Liquid Spaces: Understanding of Urban Spatial Networks through the Human Data

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Abstract. Today’s cities are changing faster than ever before, mainly because they have ability to produce spaces for everyone, but only when they are produced by everyone [1]. This phenomenon was even multiplied with enhanced informatisation and digitalisation. It would be wrong to perceive Smart City only as plain product of technological innovations. New markets are rising and new types of behaviour are emerging hand in hand with technological innovations [2]. Therefore technological innovations, mainly than enhanced communication and digitalisation change the habits of analogue civilisation towards more liquid spaces. Cities are forced to adapt to those changes in order to stay competitive. Therefore it seems that traditional planning reaches its limits and can’t fully address challenges produced by such change, which makes it unsustainable approach on the long term perspective. Project aims to develop set of tools and approaches towards creation of more liveable and resilient cities of 21. century by combining modern technologies, and humanocentric approach. Focus should be put on the research of relationship between the technological innovations (namely digitalisation and enhanced communication) and societal changes that transforms into material (urbanised) environment [3]. Understanding of urban spatial structures via gathering and analysing a new type of information about the city – the data – plays a key role in the research. As such, focus will be put on the analysis of urban structures through the online and offline participatory platform (Emotional maps), spatial footprint of the city (Master plan and field research), and segment analysis of the city’s structure (Space Syntax).

1. Introduction
City has become the unlimited construct of human interactions in the human made environment. With the beginning of the “antropocene” [4] cities has gained even more relevance and urbanisation was enhanced. And this is mainly caused, because cities accelerate time by compressing space, and let us do more with less of both [5]. Smart City became basic unit of today’s urbanisation. Smart City - the global city can be than referred to the process, rather than to a place [6]. Therefore it would be wrong to perceive it as a simple product of technological innovations, rather than continuous development through the enhanced communication and data collection. It is apparent, that due to the changes in the field of communication and digitalisation new behavioural patterns are emerging. These changes of socio-economic structure influence city’s spatial configuration. Traditional understanding of city, as a limited spatial structure is being blurred. This results from massive environmental changes, new types of immigration, transport, and cybernetics. Such perspective let us rethink the overall approach towards urban planning and design.
Today’s planning processes are based mainly on empirical knowledge. Moreover the big part of the process is influenced by architects own perception of the space and the ability to recognize and implement certain point of view. But with the ever growing demand for new spaces, amenities, markets and behavioural patterns, this process seems to reach its limits. A key role in this new approach plays new type of information about the city, its processes, and its inhabitants – the data. As such, data are already being used mainly by private companies and tech giants in order to optimize web interfaces and apps, or for the purpose of targeted marketing. But its use in urban planning and design is still new and developing approach. The biggest challenge appears to be within the analysis of the data itself, as well as its subsequent clearer implementation into the planning practice. Therefore process of acquisition, integration, and analysis of heterogeneous cross-sector data poses crucial challenge for subsequent implementation. Urban computing [7] therefore proposes possibilities to connect sensing technologies, data management and analytics, and new methods of visualisation. Process aims to improve planning and maintenance methods towards more liveable city environment and higher human life quality within its borders.

Amount of digital data overcame for the first time in 2002 the analogue one [8]. Geometric increase of digital storing brings us more and more opportunities how to use them. All of this information generated by both technology (common stable or mobile devices) and users (population) can be referred as BigData. This information is permanently created by the technological environment connected in great network and collected in huge data repositories. Internet of Things (IoT) becomes the main producer of BigData assets. My Data on the other hand plays an important role in humanocentric approach towards data management and analytics. These principles and technologies gives people control over the data that are being shared with governments, or corporations. People are therefore no longer passive targets of data mining, rather than empowered actors and active contributors in the collection and management of their personal lives both online and offline [9]. My Data principle further offers the opportunity, the right, as well as the means to manage their data and privacy. Shared infrastructure also enhances decentralized management and improves interoperability.

2. Cross-data cycling movement analysis

Paper aims to introduce three different approaches towards data collection and analysis of the space – Emotional maps, Space Syntax analysis, Spatial footprint and field research. In each it aims to find focal points, and to understand the correlation between perception of the space, its geometry and real shape and the use of the space.

2.1. Emotional maps

Emotional map, as a subgroup of mental maps, is the tool of active citizens involvement of collecting the information and opinion about the city, namely than about its public spaces [10]. As such, the idea is grounded within the GeoParticipation – by using spatial tools citizens get involved in the participatory processes [11]. Participants locate points or lines on the map of the selected city. Those represent geographically referenced answers. Moreover participants have the opportunity to comment their choice, which helps to better understand the reason of the choice. Platform therefore works on the principle of MyData, when participants are actively involved in the process [12]. Emotional map as a participatory data mining method highly depends on the good identification of topics, and subsequently on the asked questions. Huge amount of very valuable data can be collected with the use of this tool. In order to achieve such output, vast publicity (e.g. via social networks, or local media) is needed, as well as active citizen’s support. Evaluation of qualitative data itself is quite time-consuming due to the need for analysis and interpretation of the open inputs (e.g. comments).
For the purpose of mapping and data collection, two approaches are being used – online and offline mapping. Offline mapping, or face-to-face participation, helps to initiate interaction between participants. Therefore there is possibility to obtain information that is thicker. But the number of inputs is limited to the number of participants that attend the event. On the other hand, online platform doesn’t initiate interaction in such constructive way, as offline method does. But it can, and usually does, help to collect much broader variety of inputs across different demographic groups. Fusion of both offline and online approach helps to overcome major disadvantage of such tool – subjectivity of the output. Objectivity of gathered data rises with higher number of participants across various demographic and socio-economic groups. Such digital tool allows us for mapping of the image of the city [13] on the citywide scale.

2.1.1. Cycling movement analysis based on the emotional maps

Online platform that was used during the mapping in Presov was Pocitove mapy (www.pocitovemapy.sk). The online mapping began with offline participatory kick-off meeting. Attendance of around 80 people brought fruitful discussion over the map of the city. For the purpose of the cycling movement analysis, participants were asked two questions – *Where do you like to bike?* and *Where you do not like to bike?*. Participants gradually inserted lines and points on the digital map of the city. Lines inserted in *positive* section represent preferred movement trajectories, while dots represent certain point of interest (e.g. places to rest, viewpoints, etc.). Lines inserted in *negative* section represent trajectories with negative perception towards possibility of biking, while dots represent barriers or possible collision points between cyclists, pedestrians and transportation. Data are being automatically visualised on the website and they can be subsequently visually adjusted or quantified. Comments assigned to certain lines or dots allow for more precise qualitative analysis of the selected routes in both cases. Automatically visualised data are to some extend publically accessible. Since the data are geographically referenced, it is also possible to directly implement them into *Geographic information system (GIS)* of the city.

2.2. Space syntax analysis

With emerging density of cities there is increased demand for the understanding of different aspects of the selected spaces with aim to develop better places, streets and urban spaces. We have to perceive complexity of urban spaces more exact than it was up to now. When we want to evaluate space we need to better understand urban network structures. Nowadays it is almost impossible to identify whole relations of city structures based solely of the human perception. Christopher Alexander says that “there is impossible to imagine relations between only four different elements: orange, water melon, soccer ball and tennis ball. That our mind will automatically group and sort relationships between them: fruit versus sports equipment, small objects versus large one. However, it cannot imagine all these overlapping relationships at the same (real) time. How then should we understand something as complex as the present city?” [14] Therefore we need more effective method to detect structural relationships. In early 80’s, prof. Bill Hillier et al. comes with method, today known as Space Syntax. This methodological and theoretical approach, which includes several algorithmic techniques help us realize how the urban structures and shapes of public spaces, or their parts behave. These measurements are based on both, topological and geometric analyses. As such, those have been validated through the past decades. Research, which uses Space Syntax method of measuring network structures, enables us to better understand the range of integration of spatial systems and also helps us to recognize prediction of behavioural activity in urban structure. It also helps us to gain better image about structural relations in urban space, exemplary poor-end or well integrated structures. “Space Syntax analytical method can identify segregated spaces, hidden spaces and inaccessible spaces in city
structure” [15]. It reveals possible range of movement, and can further underline possible centres of social and economic activities. Paper focuses on both basic analyses Integration and Choice to recognize potential of cycle routes (motion) of given urban structure. These kind of analysis will be devised to identify to-movement and through-movement [16] potentials.

2.2.1. Cycling movement analysis based on spatial configuration analysis

Approaches used are based on topological and metric (angular) analyses, which including both Integration and Choice using metric radius 4500 meters in term of distance which means, that we focus on recognition of potential cycle routes and their final destinations. The aim is to gain the information and visualise the structure that should be preferred by users in term of cycling movement. Further analysis identifies the core structures, which are well-integrated for this kind of transportation. The spatial and also land use demand certain kind of organisation which we used to call urban hierarchy [17]. Spatial skeleton, linear-knot structure, hierarchical system of inner spaces represents another possibility of how could we analyse and classify the space. Urban accessible places, such as streets, squares, boulevards, coasts, parks etc., indicate how spaces are organised in something we call urbanity - range or value of hierarchy [18]. “The essential is a superior linear-knot system intertwining with that part of the urban - public space in which the most intense social, cultural, economic as well as operational links are manifested, and within which the most intense interaction of the public and private, and the interconnection of the spatial and material substance of towns.” [19] Use of public spaces depends on this kind of hierarchisation of city networks. To better prediction we try to recognize these corridors, which are well-integrated and most chosen by cyclists. Openstreetmaps data were used to identify the spatial network defined as highly urban (Figure 1). Subsequently, the methods of investigating the urban structure identified the wider operational relationships of the settlement (Figure 2). Through that kind of cognizance we are able to name the radial-rounded conception of city [20] in the meaning of city’s operational system. The source urban network for segment based analyses of city Presov has been generated by using OSM dataset (openstreetmaps.org) to draw the urban-structure representations. Whole network system of city has been subsequently divided into both cycle-accessible and inaccessible spaces. This way we have got a urban network divided into liveable and non-liveable structures defined by OSM.

Figure 1. Classified urban network

Figure 2. Operational transport structure of city
For analysis of the configuration there has been used whole structure of city imported in UCL DepthMapX 10.14. software for analysing spatial structures. Afterwards, whole source network has been converted into segment map (graph), which we analysed both ways: topological and metric (alternative angular) using cycle movement radii. Focus is put on analysis of integration and choice in order to recognize range of interconnection between structures (to-movement) and most chosen spaces in term of cycle motion (through-movement). For explanation measure of Integration shows us, how deep or shallow the space is in relation to other spaces. The choice we could understand as flow. “Spaces that record high global choice are located on the shortest paths from all origins to all destinations. Choice is powerful measure at forecasting pedestrian and vehicular movement potentials.” [21] As we mentioned before, we used specific radii to highlight all opportunities for shortest and well situated bike paths in city network system and also appear well integrated accessible core structures.

2.3. Spatial footprint analysis and the field research
Mapping of the spatial footprint of the city with subsequent field data collection about the quality of public spaces belongs to the key tools of the spatial understanding of the city. Public spaces of high quality offer safe, accessible and pleasant conditions for diverse activities and subsequently fulfill the needs of its users. The core principle of public spaces design is its democracy and possibility to be used by everyone. As such, the design needs to take into the consideration the needs of the most vulnerable groups (children, disabled and elderly) [22]. Human activities are essentially the very foundation of every successful city. Therefore the quality of the space is also evaluated according to the activities that are being performed by the users [23]. Moreover it appears that design, which respects context and unifies the space highly influences the overall quality and subsequent perception of the spaces [24]. Therefore the information about the quality of physical space and its observable interaction with human activities represents an valuable knowledge.

2.3.1. Cycling infrastructure in Presov
The cycling infrastructure is the part of the interconnected network of public spaces of every city. Therefore it is possible to analyse its spatial footprint by using the Presov’s masterplan and evaluate its placement according to the topography of the terrain and other natural elements (e.g. river, wood, etc.), and whether there are main nods (e.g. housing quarters and city centre) well connected. Subsequent field research aims to evaluate design at the level of human scale, as well as human activities within the selected spaces. As such, it is important to identify the pattern of the activities and overall impact of the design on them.

3. Results and discussions
In order to better understand, analyse and subsequently compare selected domains and its data sets, it is important to overcome conventional paradigm of the data fusion. For more reliable outputs it is recommended to use Cross-Domain Data Fusion [25], which allows for comparison of data across various sectors (see Figure 3). As such, knowledge extraction from every set plays a key aspect, instead of the plain overlapping of the gathered data. Output represents the fusion of the extracted knowledge. This helps to better understand problems and potentials of researched area.
3.1.1. Cycling movement analysis based on the emotional maps

During the mapping in the city Presov, 385 respondents entered 1297 inputs (see Figure 4, Figure 5, and Figure 6). The lower number of inputs in the positive section (538 inputs) can be connected to the smaller number of good examples of safe bike lanes in the city, as well as negative perception (759 inputs) of the quality of bike/pedestrian infrastructure. In regards to the positive choice there were as twice as much male respondent then female. This can be understood as that in Presov there are more male cyclists, which can be again referred to the low quality bike infrastructure (in the countries with safe infrastructure is ratio of men and women approximately equal).

The most frequently highlighted positive spaces in Presov were mostly the places with already built infrastructure, but also existing pedestrian zones, and small calm streets. The highest ratio of inputs is observable around the Torysa River on the left side of Figure 5. This is mainly due to the existing bike lane on the river bank, as well as the river itself. High concentration of inputs is observable also in the city centre, which consists mainly of the pedestrian zone. High concentration is furthermore visible on the right side of Figure 7 in the city district Sekcov and Svaby, due to the existing bike lane parallel to the Arm. gen. Svobodu Street. Subsequent connection between the city centre and city parts mentioned above via existing bike lane is also highlighted. People in general often highlighted factors such as, calm and car free streets, quality of the pavement, or presence of greenery or river. On the other hand, the most frequently highlighted negative spaces in Presov (see Figure 8) were
connected mostly to the spaces with high frequency of cars and transportation. Another observable output is overlapping of negative places with positive ones. This is caused mainly due to the disconnected infrastructure and insufficient urban design solutions and overall negligence of the spaces. In the comments respondents pointed out problems such as missing bike infrastructure, ineffectively designed bike lanes and collisions with pedestrians, and dangerous crossroads. Respondents also focused on the missing strategic approaches towards the transportation and its possible reduction, mainly in the historical centre.

Figure 7. Visualisation of positive inputs

Figure 8. Visualisation of negative inputs

3.2. Cycling movement analysis based on Space syntax

Analysis of spatial configuration focuses on movement research of cyclists. First approach based on 'choice' measuring shows which spaces are most usable and approachable for cycling motion (Figure 9). They represent shortest journeys and greatest motion stream according to cycling reach and 4500 meters distance. Tangent streets of the city center appear as significant in highlighted graph (Figure 10). Red signifies huge potential for cycle rides. Analysis of integration range further shows spaces that are best interconnected and therefore best accessible in given network structure (Figure 11). Besides the city center, also particular districts seems to be interconnected, exemplary Sečkov, Sidísko Mier or Solivar, they are well integrated in term of cycling motion (represented by warm colors on a graph). Despite of great integration there is no confirmation on that these structures are also reachable. Therefore we need to get results also from choice measuring. Cycling flow in streams is mainly represent by Rusinska and Levočská street as well as Vajanského and Volgogradská street.

These methods of measuring using UCL’s DepthMapX permits correlation between measurements of Integration (X axis) and Choice (Y axis) by scatter plot. Values visualise which of spaces are bothly great integrated and enables liquid flows, and which not. At the very least, it is necessary to focus on transforming both existing corridors and building coherent urban structures, well connected to the original spatial configuration (Figure 12). Research base on Space Syntax analytical method highlights spaces that are potentially suitable for bike lanes in given hierarchical urban structure. Using the Space Syntax we can also examine and evaluate the differences in the properties of given structures.
Attached graph shows us, that not even every well integrated representation of inner urban space is also mostly chosen in term of both, bike motion and its accessibility. In order to improve the results, it would be also necessary to gain better image about real motion demand. By using Big Data and its evaluation we could gain great information on movement’s behavior and its demand in real time. Subsequently it would be comparable with emotional studies and it would help with future prediction of space configuration. Results founded in Smart city conception could recognize pros and cons of spatial and land use.
### 3.3. Cycling movement analysis based on the spatial footprint and field research

The overall conditions for biking in Presov seem to be favourable due to the relatively flat terrain across the whole city, as well as quite reasonable distances from the peripheral parts of the city to its centre. Between the main strengths of the bike infrastructure belongs its relatively good placement within the city borders (see Figure 13). The main path is placed along the Torysa river, which underlines opportunity of rivers to form the green highways (pedestrian and bicycle paths). City centre’s pedestrian zone is opened for cyclists, and therefore supports the whole infrastructure and enables people to cross the congested centre relatively easy. In both cases there is high possibility to stop and perform optional activities (e.g. on the waterfront to sit and enjoy natural environment of riverside; in the centre to shop, have a cup of coffee, or just linger and watch the other people). The other major bike lanes are placed along the Arm. gen. Svobodu street and Rusinska street. Both streets are under heavy pressure of the traffic. Moreover those places offer a little possibility for optional activities and therefore they serve mostly for the necessary activities. Urban design doesn’t provide any means to reduce noise level, and doesn’t address the overall quality of the spaces towards more liveable places. Despite this fact, both lanes appear to be heavily used. This is mainly due to the fact that first lane connects two large residential zones, while second lane that crosses previous lane connects those zones with wider city centre a further continues to the riverside bike lane.

Between the main problems of the cycling infrastructure belongs its incoherency and problematic solutions of the crossroads, mainly then those with heavy traffic. Another problem lies within urban design. New bike lanes are often undersized, insufficiently divided from pedestrians or traffic and the route has to be often adjusted according to the already standing objects (e.g. marketing objects, lamps). Problematic seems to be also approach of pedestrians towards the cyclists. Lanes that are in the proximity of the sidewalks and are at the same level are often used by pedestrians, which knowingly enter the lanes and cause possible points of collision (see Figure 14).

### 4. Conclusions

Through the emotional mapping we have been able to identify the most significant corridors in the mental map of participants, as well as their key aspects. Analysis via Space Syntax has indicated potentially well-integrated and accessible corridors by bike according to the geometry of the city’s spatial network. Spatial footprint analysis together with field research has helped us to identify main strengths and weaknesses of existing infrastructure. Analysis has proven that most of the cycling infrastructure is according to the structural analysis well designed. We talk mainly then about the bike lanes in the eastern part of the city, which connects housing areas with the wider city centre. There is also general approval by public that this bike lane serves to its purpose. Yet, this connection is also
perceived negatively by inhabitants. Similar pattern is observable in the city centre. While first case can be mainly referred to the mistakes on the level of urban design (e.g. dangerous crossings, collisions with pedestrians, etc.), in the second case there is certain negative perception towards the public transportation crossing the city centre, namely then its pedestrian zone. Furthermore river doesn’t appear as a significant element in the Space Syntax analysis. But emotional map analysis has proven that the bike lane copying the riverside represents a most significant emotional mark in the mental map of biking person. Moreover, several streets that Space Syntax highlighted as potential corridors for bike infrastructure doesn’t contain one, mainly due to the spatial limits of the space, heavy traffic, or the combination of two. In general traffic is being perceived as a main barrier of the cycle movement, mainly in the city centre and around the main transport corridors.

In order to plan better and more effective bike lanes, the overall shift in the paradigm of transport is be necessary. But it is apparent, that the use of natural assets to improve and enhance bike transportation seems to be as positively perceived approach. It is also important to avoid mistakes on the level of urban design, which to big extend influences the perception of the selected route and as such has impact on the selection of the path we take. Therefore involvement of the public in the processes, together with data driven approach towards the creation and the maintenance of space is important in order to pursue the need for humanocentric approach. Focus is put on development of the analytical tool that can be adjusted according to local needs and will leave the space for serendipity, sociability and spontaneity – aspects which every city needs in order to preserve human scale. Aim for the future is to produce such analytical outputs, which will be feasible for the prediction and subsequent simulation of the processes with the use of the advanced computing and machine learning. Therefore analysis further aims to overlap its results with another possible data sets (e.g. analysis of functions, housing prices, real-time movement data, etc.) in order to understand and predict preferences of the users. Such developed approach towards more flexible urban planning methods should guarantee more sustainable planning of 21. century’s city, and ensure that no one will be left behind [26] in proposed planning processes and subsequent right to the city.

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