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Abstract

Purpose – The purpose of this paper is to develop an approach to urban environment management through analysis of "urban emptiness" based on user-generated big data.
Design/methodology/approach – The research design is based on creating a theoretical model of urban emptiness as a multilayer phenomenon in the city space and then developing an applied approach to map its different types through user-generated and open big data from multiple online sources.
Findings – The paper provides a definition and a theoretical model of "urban emptiness" as a multilayer phenomenon integrated into the complexity of the city system and as a resource for sustainable urban development. The paper presents a methodological approach to analyse urban emptiness based on spontaneous user-generated geolocated open data emerging online. This approach is applied to the Russian city of St Petersburg with a demonstration of the data set formation based on multiple sources and an interpretation of the preliminary results.
Research limitations/implications – The paper focuses on the under-researched phenomenon of urban emptiness, which leads to a certain speculation of propositions and lack of generalisability of the results. Therefore, the researchers are encouraged to further test the proposed propositions.
Practical implications – The paper describes urban emptiness as a resource in urban development and gives recommendations on how to account for it in sustainable urban environment management, in particular, in limiting urban sprawl.
Originality/value – This paper consolidates data-driven methods to create an integrated approach to urban environment management from an original standpoint – analysis of urban emptiness.

Keywords Big-data-driven approach, Urban complex system, Urban emptiness,
Urban environment management

Paper type Research paper

1. Introduction

A wasteland where adolescents hang out preferring "dull" emptiness to established environments controlled by adults, a parking lot where subcultures socialise at night, and a roof on the housetop with a tiny urban garden perished by fans of lively atmosphere amidst concrete jungle are all examples of empty spaces in the city, which nonetheless present a space for nontrivial spontaneous urban practices, a resource to develop new urban cultures.

Some spaces and lots in the city are intentionally left blank, such as restricted or alienated areas next to highways or railways. Some of them appear as a result of improper urban planning. In particular, quite a few empty lots in the city appear due to urban sprawl process – a tendency for extensive development of the city territory. Urban sprawl leads to undesirable consequences: growth of suburbs which are devoid of local identity; monocentricity instead of polycentricity due to exceeding volume of dwelling in emerging urban infrastructure; unregulated migration of the population; and gaps in the structure of urban fabric which make it discrete and unconnected. In general the term "emptiness" has negative connotations, while it is associated with discourses of loss of meaning, social ties, material structures, or discourse of improper usage. Urban voids can be regarded as ballast, they do not possess any features of "places", such as locale, location, or sense of place. They might also be considered as non-places excluded from active urban life. Wastelands, alienated territories, and areas left out of function are placeless, disconnected materially, socially, and symbolically from the urban cloth.

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At the same time, urban emptiness is a hidden resource of the city. Void territories are less controlled and not yet established along with a certain material order. These places might become contexts for different forms of urban life; they can be settings for experimenting with urban form and design, habitation, and symbolic order. Richard Wilson, a British sculptor, wonderfully illustrates opportunities to play with architectural order by cutting circles inside empty buildings[1]. Urban voids are a reserve for diversification of the urban habitat.

Today, as urban systems expand and become more and more complex, they demand more space for further development. Urban emptiness has to be carefully estimated as a resource for this growth given principles of sustainable urban development. Void spaces might be integrated into the spatial structure of the city and rethought in terms of new functions and new scenarios of usage. At the same time, not every empty place has to be filled in; there needs to be space for emptiness and silence, otherwise there will be too many details.

In spite of the ontological need, urban emptiness is far less often considered in urban planning than urban infrastructures or functional zones. This paper provides a definition and a theoretical model of "urban emptiness" as a multilayer phenomenon integrated into the complexity of the city system and as a resource for sustainable urban development. The paper presents a methodological approach to analyse urban emptiness based on spontaneous user-generated geolocated open data emerging online. This approach is applied to the Russian city of St Petersburg with demonstration of the data set formation based on multiple sources and interpretation of the preliminary results.

2. Urban emptiness: building typology within the self-sufficient city paradigm

Urban emptiness is a multidimensional concept that embraces semantic, temporal, material, and social dimensions of the city and is an internal resource which contains high potential for sustainable urban development. To make up classification of urban emptiness, we turn to the multilayer organic model of the city proposed within the framework of the theory of the self-sufficient city developed, in particular, by the Spanish Architect Vicente Guallart. The theory criticises the extensive growth approach that prevailed in urban development throughout the industrial stage, and proposes a planning approach which focuses on high-density construction and mixed land use (Guallart, 2014). The organic metaphor of the self-sufficient city theory considers as its constituents items from natural systems as well as technical infrastructures that keep the city functioning: water, energy, matter, and mobility. The model considers distribution of public spaces, facilities, housing, and tertiary activities in the city. It shows how supply chains work on each layer of the city and how they affect social behaviours and physical composition of the city. Metabolic processes during these cycles make the city more autonomous and more efficient in terms of resource management. The self-sufficient city model is seen as a multilayer structure (Figure 1).

2.1 City as a self-sufficient system

City as a natural environment. Terrain, nature and climate form the initial conditions and options for emergence and development of the city. The human-created artificial system of the city and humans *per se* are parts of the global ecosystem. Attempts to replace nature with artificial infrastructures and to avoid any natural threats lead to a trap of creating sterile monotonous environments which exhaust our cognitive abilities. While natural threats such as wild predators, flood, frost, and hunger seem to be relevant no more, people face a more exquisite threat – a loop of events reproduced in an artificially created environment. Urban residents visit nature sights from time to time to stay far from the hustle and bustle.

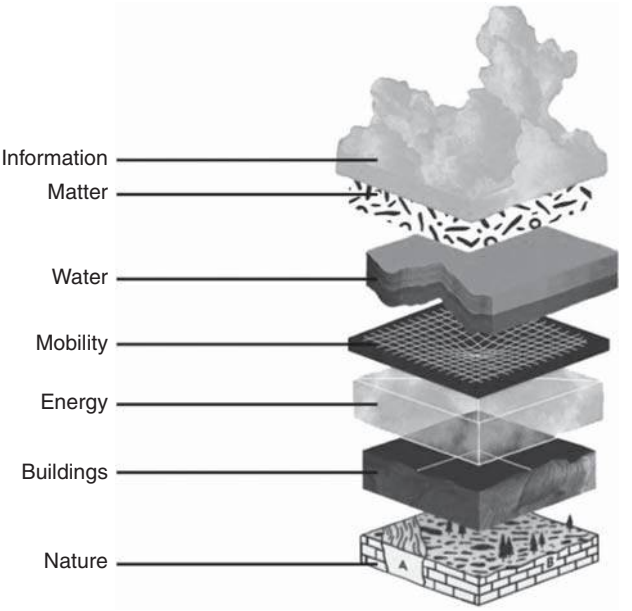

Figure 1.
The urban layers in the self-sufficient city theory

Source: IAAC (2016)

The resulting feeling of discomfort from the lack of the natural layer in the city and major ecological problems creates an urge to return the nature back into the urban cloth (Casagrande, 2010).

City as a material environment. The city has long been considered as a material conglomerate and a powerful machine (Hillier, 1999), shaping behaviours. Modernist vision has regarded the city as a landscape of skyscrapers and speedy highways, and while postmodernist approaches, in particular, STS theory, have actualised the view of the material component as a cohesive component of socio-material systems (Farias, 2010). The material environment is represented by the built and constructed material forms and comprises buildings and technical infrastructures, in particular, ones producing and circulating energy and water. Formed types of buildings, functional areas of the city, and architectural styles constitute the environment in which urban processes take place.

City as mobility. Mobility is an indisputable value of contemporary urbanised societies (Urry, 2000). Actors with low chances to move in space and time lack mobility capital. Increasing mobility goes hand in hand and new forms of social life, for example, 24 working day and hence the need for access to transportation routes and connection wires. Mobile and free citizens need to increase the "capacity" of the moment and place instead of simply expanding the spatial and temporal resources. In this context, planning of urban development takes on new challenges and a new quality: the city is perceived not as a purely spatial formation, but as a process, and the space turns from the organising element and a set of obstacles in the city into an object of dynamic, changeable demand.

City as localised identity. City also presents a more subtle layer of information related to the processes of identification with the city (Lynch, 1960). This layer acquires great topicality in the context of processes of globalisation and migration which destroy authenticity of the cities and rootedness of human experiences. Places which can urge identification processes are those which are familiar and favourite with a person, where he/she have had emotionally

intensive experience of the city. These are places where people can spend their time free from domestic worries and work processes, places enabling self-expression and giving inspiration, and places they feel responsible for. Most of the modern texts on urbanism, starting with the celestial *Death and Life of American Cities* by Jane Jacobs (1961), argue the necessity to create cities for people: lively, human scale, diverse, and inclusive. This message can be interpreted through the notion of urban emptiness. Jan Gehl (2010) in his book *Cities for People*, which is considered to be a fine example of humanistic thinking in urban planning, states that human scale is a necessity in city planning. Usually urban planners focus on physical characteristics of built environment and large distances, which cover designed areas; however, is it short distances that brings strong and meaningful sensory impressions – smell, touch, and temperature (Gehl and Gemzøe, 2004).

City as an information environment. A rapid change of the city in the global world is associated with the rise of information age and network society (Castells, 2000). Information environment has become an important dimension of human identity. In his book "Me++" W. Mitchell (2003) describes how mobile devices become an extension of the human body. Limitations are replaced with links as the main tool for managing the world, hard planning is replaced with organic growth, and sedentary lifestyle with nomadic one. "In the emerging wireless era our buildings and urban environments need fewer specialisation spaces built around sites of accumulation and resource availability and versatile, hospitable, accommodating space, that simply attract occupation and can serve diverse purposes as required. A cafe table can serve as a library reading room. A quiet place under a tree can become a design studio. A subway car can become a place for watching movies" (p. 211).

2.2 Typology of urban emptiness

To address material, semantic, natural, and temporal resources of the city, we introduce the concept of "urban emptiness" as a broad analytical concept denoting absence of content, as well as vagueness and unclearness. Emptiness depicts physical aspects of the built environment as well as idealistic features of the perceived city space. With the reference to the above-mentioned layers of the city, we build a typology of "urban emptiness" (summarised in Figure 2).

Emptiness of natural resources. This layer reveals quantity and quality of natural items in the urban space. During the urbanisation, natural environment has been deliberately destroyed and shrunk to a the form of well-controlled and decorative infrastructure. In the context of scarce "urban nature", we might want to combine consideration of initial (forests, fields, etc.) and artificially created (parks, squares, boulevards) natural environment in the city. The number of urban green spaces in the city is defined by rules of land usage and the general plan of the city. Rationing of green plantations for different territories in the city depends on its functional load (administrative centre, industrial, scientific, cultural centre, resort, etc.), the size of the territory, the built environment density, climatic conditions, existing architectural, and planning decisions. Green spaces of general use must be located in all residential areas, with concentration at public centres and sports complexes. The deficiency of greenery is usually replenished regulationonly according to minimal standards though sometimes they are not sufficient.

Emptiness of material source. Materiality of the city is not only represented by houses, streets, and highways, but has a more detailed multilevel system of space: underground-level: subway system, underground structures (bunkers, bomb shelters), parking areas, network engineering, etc.; ground-level buildings, green public spaces, etc.; and aboveground-level: bridges, roofs of buildings and built environment, overpasses, highways, etc. In current practices of sustainable urban development which fights urban

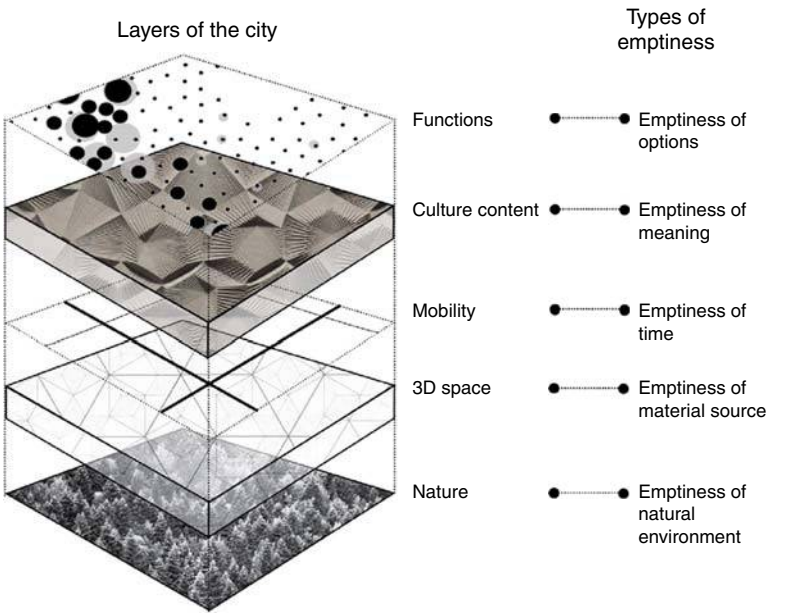

Figure 2.
Interrelation of types of emptiness and layers of the city

sprawl and monocentricity nontrivial solutions to elaborate the space not "in width" but "in depth" are searched for. Some of the best examples are High Line Park in New York built out of a derelict railway trestle[2], Lowline park in an abandoned metro station in New York[3], the pool on the roof of Marina Bay Sands hotel in Singapore (Cañizares, 2006), and Farming Kindergarten on a roof in Dong Nai, Vietnam (see footnote 3).

Emptiness of time. Space and time go hand in hand; continuous functioning of space is considered to be a parameter of a full-fledged city which gives time for everyone and everything. Emptiness of time shows intensive or low or overall or scarce usage of urban space. If the city is not equally used during the day or the year, it means loss of resources; if a city dweller cannot meet a variety of urban functions in a short time and at a short distance, it means insufficient urban planning, focused on large-scale decisions instead of human-scale ones. Emptiness of time is analysed through distribution of daily, weekly, and seasonal activities. Periodical concentration of activity in one place can reflect other macro-processes of spatial behaviour, for example, transit flow of pedestrians starting the working day creates a morning splash of activity in coffee houses, while restaurants and bars are more in demand in the evening. Popularity of public spaces is also responsive to seasonal changes: open public spaces such as beaches, parks, and embankments are rather loaded with outdoor recreation activities during the warm season, while in the cold season, they might be used less often if not equipped with comfortable infrastructure.

Emptiness of meaning. Emptiness of meaning denotes scarcity of the semantic layer of urban space, poorness of senses, images, and symbols communicated by the space. Socially active places with large flows of people, for example, huge shopping and entertainment centres, can create an illusion of high-quality place, but they often lack identity and opportunities for self-expression. Human activity is nourished by meanings expressed in the city by its different agents, these messages appeal to the citizens, guide their experience, and trigger activities. Contemporary society of mass consumption made urban life a strongly controlled routine devoid of spontaneity and deep sensitivity. Monotonous public spaces are

constructed along with the ideology of the consumer society: mediacinema halls, shopping malls fast-food chains abuse people with information about paid goods and services and making them passive speculators of this illusion of diversity.

Emptiness of functions. This kind of emptiness describes the monotony of the urban environment and lack of opportunity in a short time and at a short distance to meet the various functions of urban spaces. This type of emptiness arises in closed down spaces, such as landfills, large parking lots, garages, abandoned construction sites, unexploited industrial areas, as well as in public areas which lack comfort and safety, such as cemeteries. Quite a lot of these empty spaces have emerged during industrialisation, such as buffer zones between industrial territories and residential urban spaces formed in the 1970s. Since then, technologies of industrial enterprises have become more secure; however, restrictive regulatory norms remain the same, which prevents more meaningful usage of the territory. Defining empty lots in urban structure gives ways to redistribute functions from the overcrowded city centre to these reserves as well as redesign existing transport and engineering infrastructures in terms of better coverage and connection between the city districts.

Different kinds of urban voids are closely connected in the real urban environment; however, analytical division enables us to identify local trends and global interdependencies (Figure 2). The emptiness of the city is an ambiguous phenomenon. Is it a resource or a ballast? How do various kinds of emptiness correlate in the city space? How can urban emptiness be detected in the city space?

3. Detecting urban emptiness: spontaneous data-driven approach

Geolocated user-generated digital data increases every day: by using the web, credit and transport cards, GPS navigation, cell phones, and other data generation sources on a daily basis, people create a huge volume of information, which is an imprint of the city life, or a "digital footprint". A digital footprint emerges during interaction of an object with the digital environment. In May 2009, EMC announced the number of bits of new digital information created in 2008 – 3,892,179,868,480,350,000,000 (Farmer, 2009). Despite the economic crisis of 2008, the creation speed of digital information and its transmission via internet, telephone networks, and wireless communication lines has grown significantly. Meanwhile popularisation of information technology and its deep penetration into the life of citizens enable new approaches to emerge in the field of urban research and planning.

The term "spontaneous data" was developed within the framework of the research project Archaeology of the Periphery (2013) developed for the Moscow Urban Forum. "Spontaneity" indicates the nature of the data, rather than their size or other external criteria. The data are generated spontaneously: almost always in real time or with a slight delay, but without any planned process of production and without direct intent of the citizens. Using spontaneous data in urban studies has found its application in a number of European and US institutions: Institute for Advanced Architecture of Catalonia, Swiss Federal Institute of Technology, Centre for Advanced Spatial Analysis at the University College London, joint laboratory by the University College London, Imperial College, and Intel – ICRI, Center for Urban Science and Progress at New York University, Computer Science and Artificial Intelligence Laboratory, and SENSEable City Lab at Massachusetts Institute of Technology.

Fast-growing volumes of social media data generated by different social groups during their daily life in the city give rich data appropriate for urban analysis: information on spatially distributed social behaviours and attitudes toward space. Widely spread kind of data provided by users are geolocated posts created in Twitter, Instagram, Facebook, etc., while being in using and perceiving a certain space in the city. Such posts about urban spaces contain various layers of data: type of activity undertaken in the place, such as

celebrating, listening to music, drinking coffee, working on a laptop or meeting friends; user's attitude toward the place, expressed in likes and dislikes, emoticons, colours of photos, and emotionally loaded comments; meanings ascribed to the place expressed textually through comments as well as nonverbally through symbols. Thousands of posts created in the city every day are an unending and massive source of data on the condition of the local urban spots. Moreover, a set of data collected on the a city scale on longitudinal basis can give a picture of the city provided not by a handful of experts but by millions of people who can be divided into social groups with specific needs. Such a data set gives grounding for objectifying the urban planning process and enhancing the urban acupuncture method by designing interventions for city locations with specific profile of usage or profile of problems. This approach also minimises expenditures for urban planning, for example, for extensive sociological study of specific locations. Nowadays we have a unique opportunity to build models of urban usage with spontaneous data, which is part of the "big data" universe (Batty, 2013a). Big data is understood as a series of approaches, instruments, and methods of processing structured and unstructured volumetric and variable data, generated in the virtual space and maintained by computer networks (Batty, 2013b; Bettencourt, 2014). Every action taken on the web leaves a digital footprint – a bit of voluntarily disseminated information, for instance, photos in social media, statements on forums, likes, etc. Digital footprints are also created as a side effect of actions taken in virtual space, for example, information about the sites visited or purchases made. A set of such information allows researchers to form profiles of needs and preferences for different social groups that are invaluable for socially responsible decision making. One has to account for ethical use of social media data, which we will not consider here in detail.

Advantages of spontaneous social media data for urban planning can be summarised in the following list:

(1) Coverage: data are generated by more and more users due to the growing popularity of personal computers and smartphones, hence more and more people are represented in the data set.

(2) Availability: social media data are stored on servers and in online archives and are more available for public use unlike GPS data of mobile operators or CDR data on transportation owned by government or private companies.

(3) Details: user-generated data provide detailed account on urban behaviours on individual level, for example, it allow us for tracking of individual routes in the city, peculiarities of individual attitudes and preferences with regard to the city space as well as social and demographic details of a certain user.

(4) Richness: social media provide extensive information on different aspects of urban behaviours: mobility, space use (types of activity in the space), and attitudes toward space. The range of spaces is not limited and covers formal and informal environments, spaces for work and leisure, third spaces and transit spaces, etc. (Zhan *et al.*, 2014; Petrova *et al.*, 2016).

4. Analysing urban emptiness in St Petersburg, Russia

4.1 Case description

We trace different kinds of urban emptiness through spontaneous user-generated data analysis collected in St Petersburg, Russia. St Petersburg, former capital of the Russian Empire, is now a major federal city with a population of 5.3 million people. St Petersburg is known to be a cradle of Russian culture containing significant cultural sites: the Hermitage, the Kunstkamera, the Mariinsky Theatre, the National Library of Russia, the Russian Museum,

the Peter and Paul Fortress, the St Isaac's Cathedral, and the Nevsky Prospekt. Such a rich cultural heritage and the image of the city often called the Northern Venice annually attract tourists and create powerful migratory flows into the city from Russia and neighbouring countries. St. Petersburg is also an important scientific and educational centre and a major logistic hub for international and regional flows of people and goods. In the World City rating compiled by P. Taylor and GAWC group, St Petersburg is defined as a Gamma + city – the centre of a vast region, namely Northwestern part of Russia and the Baltic Sea region (GaWC, 2016). The population growth and dynamic development of the city poses new challenges for specialists in urban planning and city administration.

In our study, we have used different data sources: social media, Open Street Map (OSM) database[4], and data from the List of Urban Green Spaces of St Petersburg (in the most recent version introduced in July 23, 2010) – amount of green space per person. Data collection in social media was carried out through public data parsing in VKontakte, Twitter, and Instagram which were chosen as the most informative media. VKontakte is the most popular social network in Russia; data parsed from it cover more than 90 per cent of all internet users in St Petersburg. Data from Twitter and Instagram is more suitable for illustrating of the dynamic processes in the city space. Data collection was carried out for the period from January to April 2017 for the territory of St Petersburg city within a radius of 50 km from the central point of the city of St Petersburg (59.939095, 30.315868).

4.2 Data set

Data set was formed predominantly on the basis of open data from social networks such as VKontakte, Twitter, and Instagram; for particular types of urban emptiness, we used data from St Petersburg open data portals (Figure 3). Data from social networks were collected via API requests from January to April 2017. Actual amount of data is limited by the number of API requests available for downloading on each social network server for a period of one week.

Types of emptiness	Data source	Visualisation
Emptiness of options	OSM, social network (VKontakte)	Map of polygons, map of points
Emptiness of meaning	St Petersburg Portal of Open Data, Open Street Map	Heatmap with city districts graded by the number of objects, r=100 m
Emptiness of time	Social network (Instagram, VKontakte, Twitter)	Heatmap of activities in cold/ warm seasons and during the day, r=100 m
Emptiness of material source	Data from online media collected by key words	Map of points
Emptiness of the natural environment	The list of urban green spaces of St Petersburg, OSM	Map of city districts by the number of square meters per person

Figure 3.
Interrelation of types of emptiness and types of data

The VKontakte data set contains two types of geopositioned data, namely "place.search" and "places.get.checkins". Links to public photos of users attached to their posts were collected using "get.photo" function. The data set contains information about geolocation of the post, a link to the media content, time and date of the message, user ID, and the name of the place. The type of place is created either by a social media moderator or by users themselves. Every place contains a name or a description, which correlates with its function. A total of 16 types of places were detected for the data set: home, work, restaurant, park, museum, cafe, theater, swimming pool, club, hotel, cinema, shopping, education, entertainment, bar, and gym. The total amount of data is 207,000 lines. The Instagram data set contains two types of geolocated data: locations/search and locations/{location-id}/media/recent.

Using the "locations/search" function, a set of locations created by location moderators and their current users in Instagram were identified. Next, using the locations/{location-id}/media/recent method, we collected all the text messages that were written with a link to a specific location and described an action in that place or the place itself. The total amount of data is 806,100 lines and 145,643 places. The Twitter data set contains geolocation information, text of the message, date as well as the time of the message, and user ID. The total amount of data is 61,688 lines.

The obtained data were visualised in QGis, a cross-platform, free, open-source desktop geographic information system. The main tool of data visualisation is heatmaps. Heatmaps are suitable for visualization of point data clusters, identifying clusters with a high concentration of activities and analysing the location of hotspots. In this research, two types of heatmaps were used: thematic heatmaps, which reflect administrative boundaries of the city districts, each of them shaded in proportion to the level of the parameter calculated; and heatmaps of relative frequency, value, and density of analysed entities as aggregated patterns of intensity on geospatial maps or custom layout maps. The algorithm calculated the number of objects in the area within a radius of 100 metres around each point, thus calculating the heat the pixel receives.

5. Urban emptiness: resources and obstacles in St Petersburg

In this section we show the analysis of quantitative and qualitative parameters for different types of emptiness in St Petersburg.

5.1 Emptiness of the natural environment

Analysis of public greenery distribution in the territory of St Petersburg, based on data from the list of green spaces of St Petersburg and OSMs, shows that almost all city districts are experiencing a deficit of large and medium-sized parks (Figure 4). Critically low number of large and medium-sized parks is located in Vyborgsky district, Kolpinsky district lacks medium-sized parks, while, and Central and Vasileostrovsky districts experience a deficit of green public areas of all sizes. The most favourable situation is in Kurortny, Petrodvortsovy, and Pushkinsky districts of the city, which are far from the city centre and were once separate villages with massive greenery, now integrated into the agglomeration. Petrogradsky district is better equipped with greenery than other districts of the historical centre of the city.

5.2 Emptiness of material source

To describe the scope of public usage of St Petersburg material source, we focus on aboveground spaces such as roofs. Roofs are non-conventional public spaces; however, St. Petersburg has a particular myth shared by citizens and tourists about the beauty of its roofs and the value of observing the skyline from above. Besides the already existing incentive, there are favourable material conditions to develop the trend of roof usage, in particular, some of the roofs are still home for antiaircraft defensive towers which remain from the Second World War and are attractive for tourist gaze. We have processed collected

Figure 4.
Distribution of green public spaces in St Petersburg administrative districts

data from open sources by topical keywords such as "open roof", "panorama", and "above_earth", searching for the digital footprint of the public activity on the roofs. The resulting map shows that this activity is quite scarce and relevant only for the city centre, the largest number of public roofs is located in the Central district (13 roofs), while distant city districts where high-storied buildings are being intensively built have few open roofs (Figure 5). Analysis of the public usage of underground structures was conducted in the same manner and did not detect any adapted spaces for public usage, though there is a well-developed subway system as well as catacombs in St Petersburg. Thus, the formation of the multilevel material structure in St Petersburg goes on unsystematically, which contradicts the public demand and existing historical resources.

Figure 5.
St Petersburg roofs equipped for public visits

5.3 Emptiness of time

Dynamics of urban activity was analysed using daily and seasonal scales. Daily activity was calculated for four time periods: morning time 6:00 a.m. to 12:00 p.m., daytime 12:00 p.m. to 6:00 p.m., evening time 6:00 p.m. to 12:00 a.m., and night time 12:00 a.m. to 6:00 a.m. Seasonal data were divided into two main seasons: the warm season of April-September with annual average daily temperature above+10°C (+50°F) and the cold season of January-March and October-December. Heatmaps were designed to reveal dynamics of daily and seasonal activity. Hotbeds of activity are defined based on density of activity, which is expressed in an amount of text messages geolocated on the territory with a radius of 100 square metres (Figure 6).

The 6:00 a.m. to 12:00 p.m.: Morning time in St Petersburg has demonstrated the lowest activity. The number of check-ins is 50 with a maximum density of 3 per point. Epicentres of activity are not formed.

The 12:00 p.m. to 6:00 p.m.: Daytime shows the peak of activity with 13,700 geolocated messages, clusters of activities are formed and maximum density of activity is 78 tags per point.

The 6:00 p.m. to 12:00 a.m. evening time activity is slightly decreasing with 12,100 geolocated messages defined and the maximum density of activity is 72 tags per point. Some of the avenues in historical centre lose activity, but a new epicentre of activity appears at Vasilievsky Island at the Leningrad Expo exhibition centre.

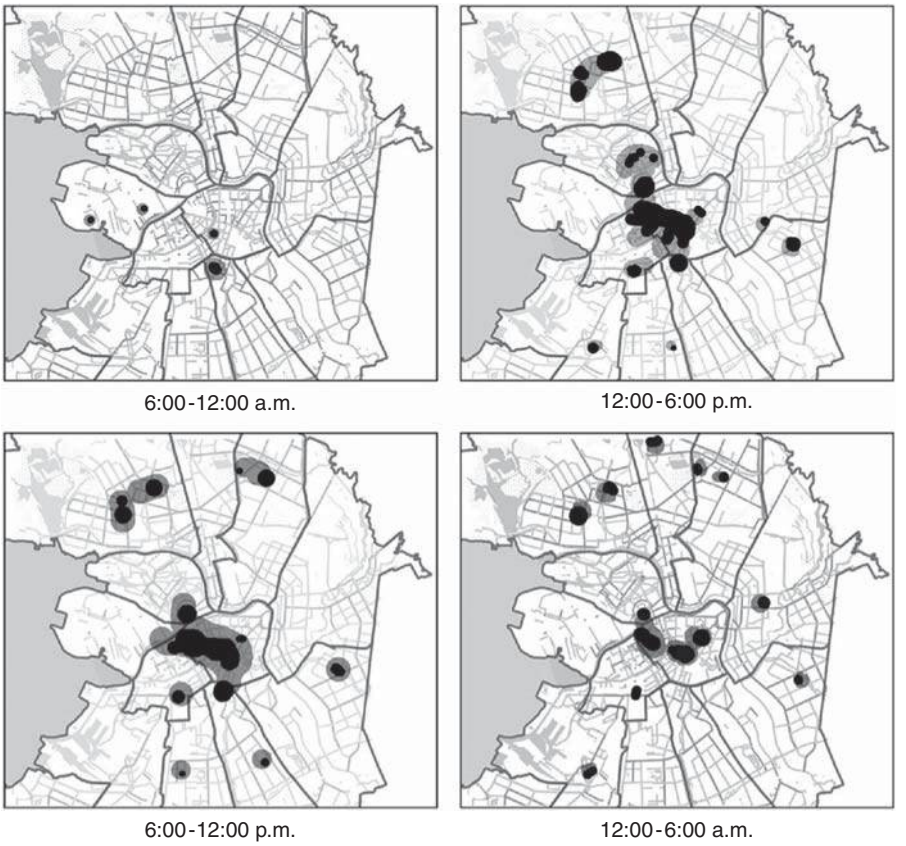

Figure 6.
Daily dynamics of activity in St Petersburg

The 12:00 a.m. to 6:00 a.m: In the night time activity declines drastically with only 3,000 geolocated messages. In the city centre, Nevsky Prospekt becomes divided into two areas: from Dvortsovaya Square to Sadovaya Street and from Liteiny Prospekt to Ligovsky Prospekt, which reflect the concentration of bars, discos, and 24 h fast food cafes visited during the night time.

Thus, continuous urban activity can be traced only in the city centre, with the most balanced dynamics in Petrogradsky, Admiralteisky, Frunzensky, Nevsky, Vyborgsky, Primorsky, and Kirovsky districts. At Vasilievsky Island, emergence of hyperactive local points is detected only in the morning period due to the large transit flow of people on their way to work having breakfast, buying coffee, and making transfer; in daytime and evening time, island activity "freezes". In remote areas of the city, such as Kalininsky, Vyborgsky, and Kirovsky, most of the daytime activity is concentrated around subway stations, and night activity is also present to a lesser extent despite the fact that subway stations are closed.

Analysis of seasonal activity husing social media shows that St Petersburg public spaces are well used both in cold and warm seasons (Figure 7). Heatmaps reveal central core and disparate local zones at peripheral areas for both seasons; however, cold season is characterised by higher concentration with large halos of activity, which can mean a tendency for people to check-in more often while being inside the buildings. Unexpectedly, embankments and sites overlooking the Gulf of Finland do not lose their relevance in cold season despite the fact that open public spaces become quite uncomfortable to be in.

5.4 Emptiness of meaning

To consider the distribution of meaning in the space of St. Petersburg, we have mapped institutions which act as of culture and knowledge generators in the city: universities, museums, libraries, theatres, cinemas, and cultural centres. The dataset collected in OSMs contains current data on cinemas (79), theaters (121), museums (307), libraries (284), cultural centres (107), and universities (462). The map shows the distribution of objects generating culture in administrative districts of the city (Figure 8). The Central district has the highest number of such objects, which create a variety of activities during any time of the year and practically at any time of the day.

Admiralteisky and Vasileostrovsky districts are in the second place by this number, while, Petrogradsky district takes the third place. As for non-central districts, Vyborgsky district contains more possibilities to get in touch with culture. Other districts are experiencing deficit of cultural facilities depriving their inhabitants of opportunities for self-development, cultural and creative diversity, and substituting these with possibilities for mass consumption in shopping malls which are speedily growing at the city periphery. However, from the point of view of the attendance and popularity of such objects, it is necessary to introduce the category of so-called unique objects.

5.5 Emptiness of functions

The variety of social activity and its expression in different types of places assumes rich functional space and choice to spend free time. The opposite picture focusing on a certain type of place generates emptiness in other forms of public spaces. A study in San Francisco shows that more than 70 per cent of social media content is generated outside the people's homes, people mostly visit restaurants, museums, and subway stations (Bendler *et al.*, 2014), while a study for Samara, a city in south-western part of Russia, shows that digital footprint of public life is located at citizens' dwellings – 60 per cent of the geolocated data on public events (Petrova *et al.*, 2016).

As for St Petersburg, restaurants turned out to be the prevailing type of public place geotagged in social networks, for example, in VKontakte 2,448 places were detected (Figure 9).

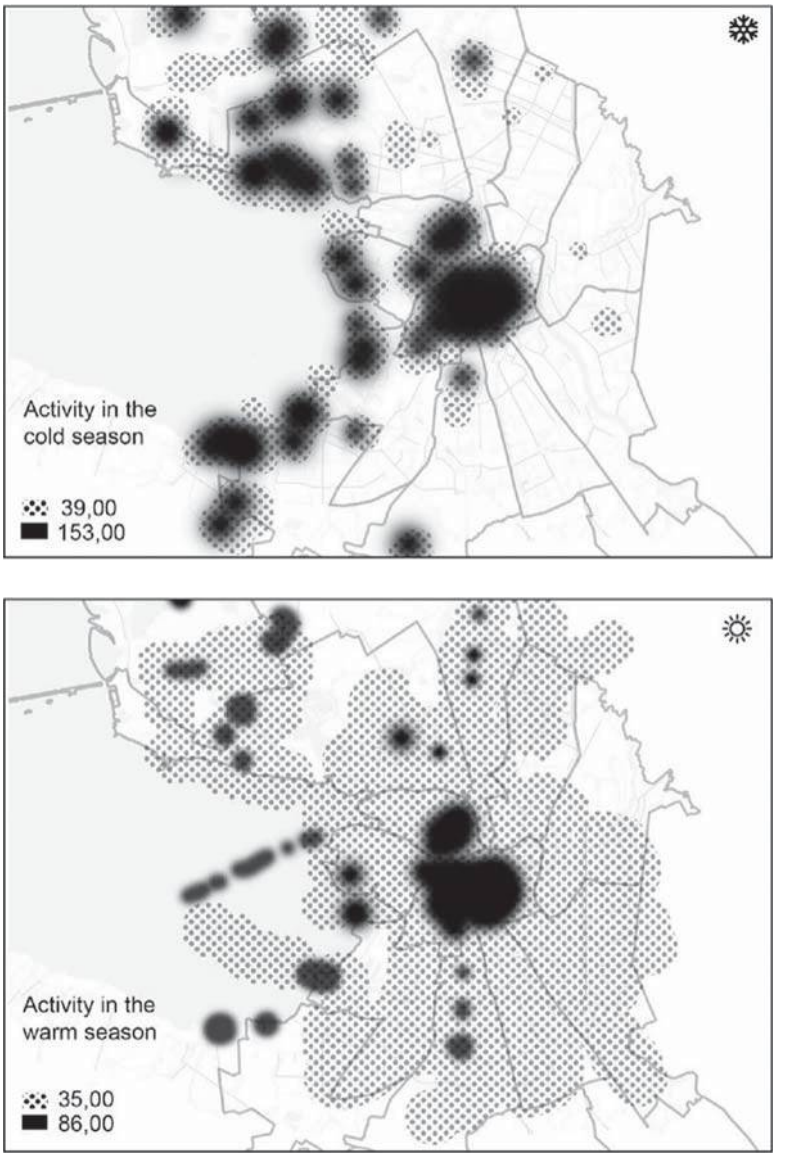

Figure 7.
Seasonal dynamics of activity in St Petersburg

In total, more than 50 per cent of digital public activity is concentrated in cafes and restaurants. At the same time, most of the activities taking place in restaurants are located in the historical centre of the city, which reflects the monocentricity of the main field of public life (Figure 10). Public eating places have become sites where friends meet, business is run, and new acquaintances are made. St Petersburg witnesses a phenomenal development of various forms of public eating and drinking places. We have also detected that the tendency for restaurants, cafes, and bars to cluster around museums, theatres, and other cultural institutions is much less than the tendency for informal forms of culture (concerts, performances, hobby-related events) to cluster around places with good food and drinks.

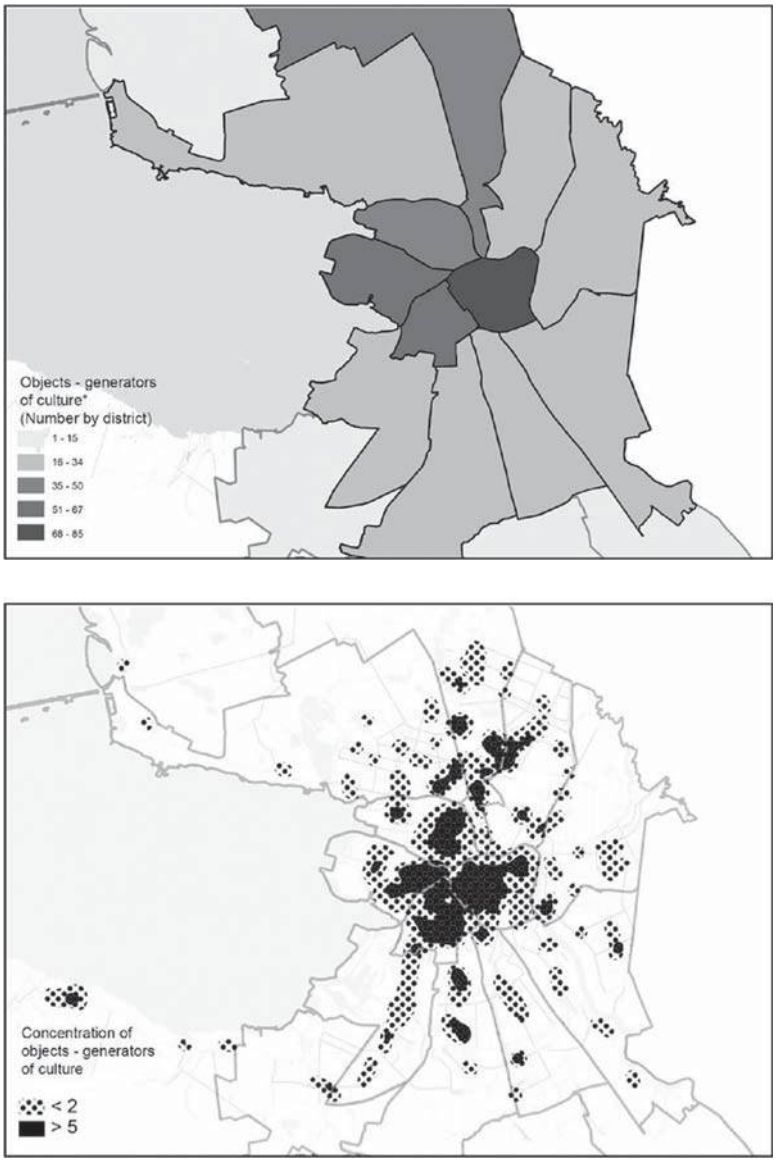

Figure 8.
Distribution of culture generators (universities, libraries, cultural centres, museums, cinemas)

Mapping functional load in the city geography shows clear clustering of spaces without any functions – the so-called industrial belt of St Petersburg (Figure 11), containing industrial territories, cemeteries, and sanitary protection zones which are still monofunctional and restricted in access. According to the Committee for Urban Planning and Architecture of St Petersburg, the territory of the industrial belt is 50,000 ha, and 5,000 ha are not used at all (CUPA, 2016). Some of these territories have a high potential for development due to good transport accessibility and presence of built heritage of the industrial era. The emptiness of functions is emerging primarily due to the urban planning policies of the city.

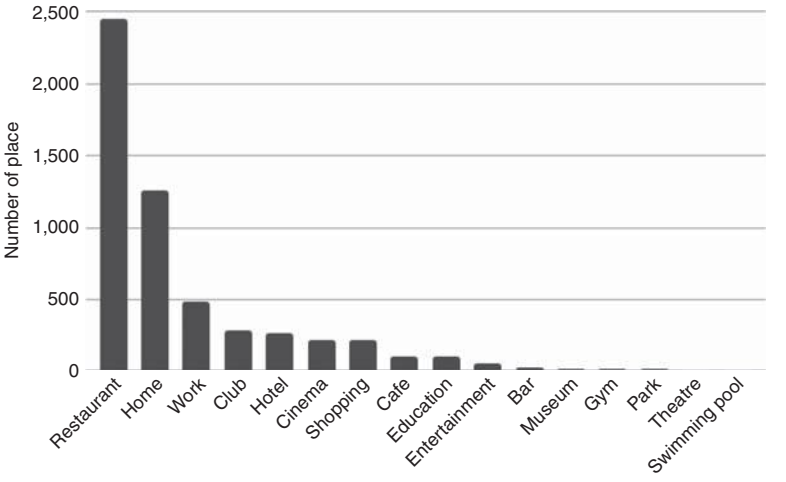

Figure 9.
Distribution of types of public places represented in the digital geography of St Petersburg

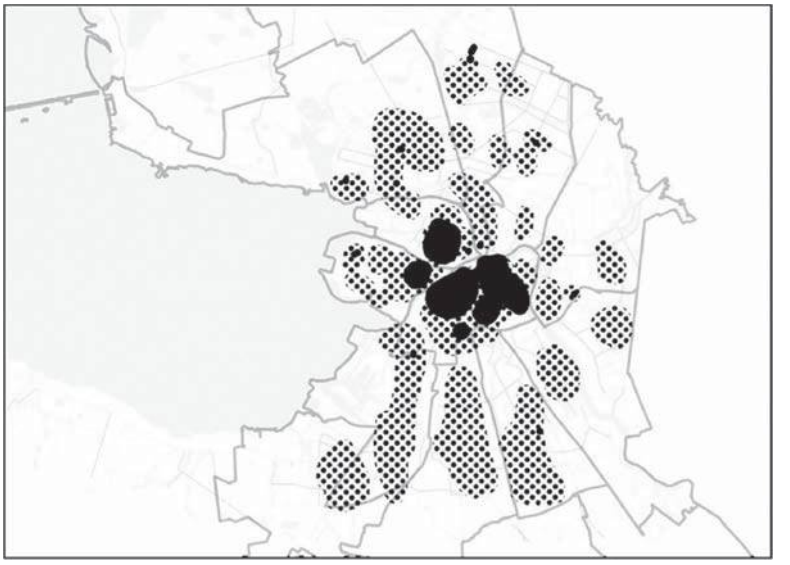

Figure 10.
Concentration of restaurants in the digital geography of St Petersburg

6. Conclusions and discussion: designing urban emptiness

Looking at the city system through the prism of urban emptiness allows us detecting the areas devoid of emptiness as well as gaps that exist in urban cloth and can be rethought as the potential for territorial development within the existing city borders. The resulting map demonstrates all data layers described above interlinked in one geographical space (Figure 12). Visualisation of activity dynamics, concentration of functions and natural environment, habitation of non-conventional built environment layers, distribution of objects generating culture, and knowledge are shown in white. Monofunctional areas and areas devoid of functions, activities, meanings, and dynamics are coloured black as planned city emptiness – the darker the area, the more types of emptiness it contains.

Figure 11.
Distribution of monofunctional territories in St Petersburg

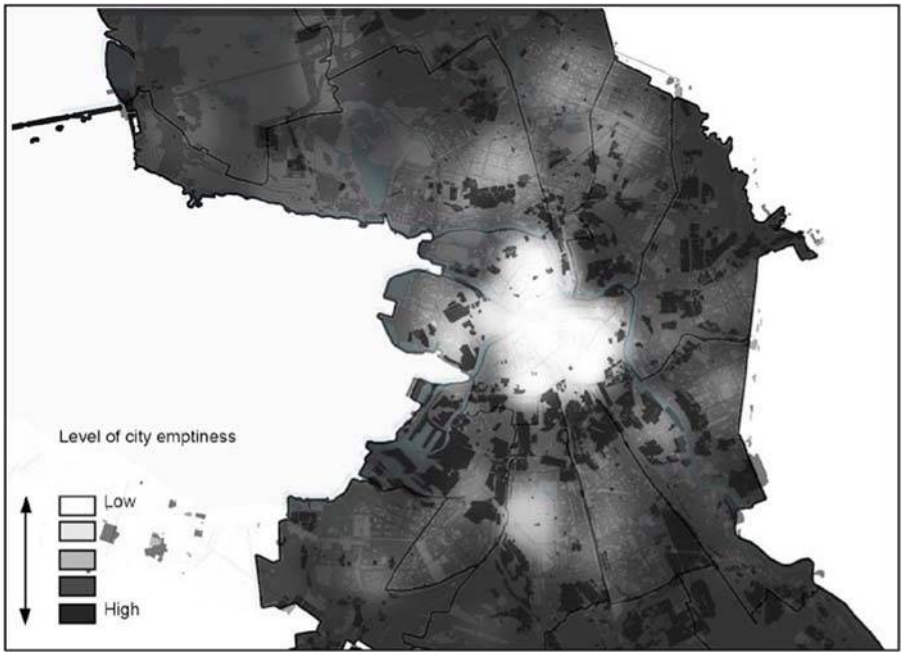

Figure 12.
Aggregated distribution of urban emptiness in St Petersburg

St Petersburg is functioning as a balanced city system with low levels of emptiness in the historical centre area, where a variety of functional objects, activities, time, and space opportunities is traced. The historical centre is restrained physically and mentally by the circle of the industrial belt around it, which is literally the territory of emptiness ruining the continuity of the urban fabric. This level of concentration shows inequality in urban development: (prevalence of the central area over the others, over-concentration of important and unique objects and practices here), and proves an urgent need for more sensible environment management, relocation, and redistribution. Contemporary development in St Petersburg due to administrative and legal issues focuses on creating alluvial territories rather than revitalising former industrial zones, which leads to growth of construction costs and negative ecological effects. Analysis of urban emptiness also shows that there are favourable conditions for creation of polycentricity and self-sufficient urban structure in non-central St Petersburg districts – Moskovsky, Nevsky, Vyborgsky, and Primorsky.

Urban emptiness presents a novel view of the city as a system and demonstrates the power of user-generated geolocated data from social networks and open sources to achieve overall vision of the city. This paper presents a theoretical and methodological model of urban emptiness and illustrations of empirical analysis. Empirical analysis should be improved further through usage of more detailed data from more sources. Future study of urban emptiness should contain measurements of interconnection between different layers of data and of correlation between data on urban activities and other contextual factors, such as transportation system.

Notes

1. www.richardwilsonsculptor.com/projects/turning_the%20_place_over.html
2. www.thehighline.org/
3. http://thelowline.org/ and www.archdaily.com/566580/farming-kindergarten-vo-trong-nghia-architects
4. http://gis-lab.info/qa/osmshp.html

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