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How to measure peripherality at the city scale. A model proposal

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Abstract. The phenomenon of peripherality is increasingly applied to urban space. At the same time, there is no scientific consensus on how to analyse and measure peripherality. This article presents a tool for analysing peripherality at the urban scale – the Opportunity Potential Model (OPM) – based on the intervening opportunity mechanism. The article describes how the model works and presents an example of its use: an analysis of the peripherality of the Jagodno neighbourhood in Wrocław (Poland). The model takes into account three dimensions of peripherality (geographical, material and social) to create a comprehensive analysis. The case study shows not only the degree of peripherality of the study area but, above all, the possibilities of the model – its advantages and disadvantages in the process of peripherality analysis and possible further uses.

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1. Introduction

Cities have always been very contrasting places; people of different social statuses have lived together in densely populated areas. Even today, processes of gentrification, marginalisation or exclusion are taking place in cities. It is also increasingly pointed out that the phenomenon of peripherality (which had until recently been applied almost exclusively to the regional scale) is also becoming apparent at the urban scale. There are many definitions of peripherality: the literature also raises more and more aspects to which peripherality is related. Copus (2001) and Hershell (2011) point out that with the increasing importance of ICT networks, geographical distance from the centre is not as important in defining peripherality. On the other hand, Kühn (2014) believes that, despite the development of technology, geographical proximity still plays an important role in the peripheralisation process. Descriptions of peripherality highlight social factors (Bernt & Colini 2013, Kühn, 2014; Caldeira, 2017) or accessibility to services (de Falco, 2019; Ortega-Reig et al., 2023) as very important. In the absence of consensus on the definition of the concept, it was decided to adopt a universal description, according to which peripherality is a marginal position in a network of connections leading to a degradation of connections in other networks and that can lead to a reduction in development opportunities and quality of life for the inhabitants of an area (Grosel, 2023). The challenge remains how to measure such peripherality; there are a lot of methods for studying peripherality based on sociological methods involving interviewing or observation (e.g., Sawyer et al., 2021). However, these methods are difficult to replicate. This article aims to present a way to analyse peripherality using a quantitative method that is reproducible and applicable to larger areas. This article presents an opportunity potential model as a tool for evaluating peripherality as defined. Using the example of a selected neighbourhood in Wrocław (Poland), the suitability of the model for measuring peripherality is tested. The first part of the article describes the principles of the intervening opportunity mechanism and the opportunity potential model based on it, the second part presents the analysed neighbourhood and the assumptions and criteria adopted in the model, while the third part describes the results and presents conclusions concerning both the case study and the model used.

2. Materials and methods

2.1. Intervening opportunity mechanism and Opportunity Potential Model

One of the first models describing relocation to meet civilisational needs was the gravitational model. It referred to the assumption that socio-spatial relationships are similar to the physical relationships described in Newton's Law of Gravity. Hence, the strength of the contact source-target relationship was described as the product of the size of the two centres divided by the distance (or time or cost) function between them. Over time, it has been recognised that it is not distance in the geographical sense (or even time or cost) that is the determining factor in human behaviour. Instead, the measure that better reflects the distance between the origin and the destination is the number of targets located closer than the target under analysis. This relationship was first noted by Stouffer (1940: 846): "the number of persons going a given distance is directly proportional to the number of opportunities at that distance and inversely proportional to the number of intervening opportunities". Later, this idea was further developed in the report of the Chicago Area Transportation Study (1960) and eventually expressed by the formula:

$$T_{ij} = O_i[e^{-sa_{ij}} - e^{-s(a_{ij}+D_j)}]$$

O_i – origin
D_j – destination
T_{ij} – strength of relationship between O_i and zone a_j
a_{ij} – number of destinations located between O_i and zone a_j
a_j – number of destinations located in zone a_j
s – selectivity

The formula takes into account the analysis of relationships in multiple distance zones and the selectivity parameter, which allows the model to reflect the varying characteristics of different contacts (depending on the type of destination and origin of the relationship). Selectivity expresses the willingness to satisfy a need in the immediate area (it is the opposite of pickiness); the lower the selectivity, the larger the area required to satisfy the need will be. The higher the specialisation of the service underlying the contact, the lower the selectivity. For instance, an individual seeking employment in an unskilled occupation is likely to secure it in

their immediate vicinity, whereas an extensively specialised worker will not be content with just any job opportunity, thus exhibiting reduced selectivity and requiring a wider geographic job search. The contact selectivity parameter is determined by the formula (Zipser, 1990: 62):

$$s = \frac{\ln \frac{1}{R}}{a}$$

s – selectivity
R – fraction of unsatisfied trips in the study area
a – number of destinations located in the study area

Analogous to the gravitational and intervening opportunities models, potential models (originally referring to the concept of gravitational field potential derived from physics) were created, defining potential as "a measure of the relationship in a given area, depending on the forms of development and their mutual location" (Litwnińska, 1987: 6). The gravitational field potential is defined by the formula:

$$\sum_i V_j = \frac{m_i}{r_{ij}}$$

V_j – potential of region j
m_i – mass of region i (quantitative characteristics of region, e.g. population, number of jobs, etc.)
r_{ij} – distance between region i and region j

Gravitational potential is a widely described tool (e.g., Isard, 1960; Warntz, 1964; Talen & Anselin, 1998; Pacione, 1989; Chojnicki et al., 2011; Nijkamp & Ratajczak, 2021) used at urban, regional scale and international scales alike. In contrast, the idea of potential based on the mechanism of intervening opportunities has not yet been popularised. It was described by Litwińska in her doctoral thesis written at the Faculty of Architecture of the Wrocław University of Science and Technology (op. cit.). Litwińska proposed two versions of the OPM: before and after. The before version takes into account only destinations located in zones closer to the origin, while the after version takes into account both destinations located closer to the origin and destinations located in the same zone as the analysed destination. The before potential is described by the formula:

$$V_1(k) = \sum_i M_i \, e^{-sa_{i,j}}$$

and the *after* potential by the formula:

$$V_2(k) = \sum_i M_i \, e^{-sa_{i,j+1}}$$

The use of OPM to analyse peripheralisation can be described as the spread of potential from origin points (the larger the origin, the more potential it can "send" to the network) and the "consumption" of that potential in individual distance zones – the value of potential in a given zone is the same for any given point in that zone and depends on the sum of the target masses located in that zone. It should be noted, however, that the model considers all source and destination points of an activity at the same time, and this means that the distance zones derived from individual source points may overlap and a given destination point may receive the potential sent by several source points. The higher the potential, the better the position in the network of connections, which refers directly, to the definition of peripherality adopted.

As Litwinska (op. cit.: 34) notes: "opportunity potential takes into account, in addition to the masses generating the potential, the distribution of already existing development in space and the way in which the set of opportunities is penetrated, determined by the selectivity of the traveller; it is therefore defined in socio-economic space. In contrast, the value of the gravitational potential is not affected by the distribution of destinations." Due to the fact that opportunity potential shows the relationship not only with the origin of the contact but also in relation to the other destinations, referring to the adopted definition of peripherality, opportunity potential was considered as a tool that could help in determining the degree of peripherality. An important aspect is the often emphasised relativity of peripherality (e.g. Demaniuk & Szymańska 2016; Kühn & Bernt 2013) – defining peripherality requires reference to some kind of centre, so opportunity potential (being by definition a relative measure) fits into this assumption. Taking the entirety of the definition adopted, an area is considered peripheral if a low potential of a given activity is diagnosed and a subsequent decline in the potential of other activities is observed. (These conditions must occur together.)

In the case of the analysis of peripherality, it was decided to use the after version of the model, because residents located in the same zone of distance from the origin as the analysed case are also

competitors for the activity generating the potential. If one were to study a selected activity (take schools as an example) using the before potential, it would not matter how many students live in the zone under analysis – what would matter is how many students live in zones closer to the school from the zone under analysis. Although it seems intuitive, the number of students "competing" for access to the school (or other potential customers of any other service) living in the analysed zone is also influenced by the convenience of the service.

2.2. Own modifications to the model

Potential is used as a measure of network position. In order to make the research process correspond to the adopted definition of peripherality, it was decided to compare the values of potential for the study area from the two time ranges. This was done with the aim of examining whether there was an increase or decrease in potential and whether any decrease in potential could be linked to the original poor position of the study area in the networks. Litwińska's model required specific modifications for the purpose of peripherality analysis. Litwińska examined potentials at the scale of the whole country separately by considering different potentials. There are therefore two main differences: scale and complexity. This article considers a much smaller area, but on the other hand examines many potentials simultaneously, which together are intended to form a synthetic indicator used to indicate peripheral areas. Another difference is the retrospective comparison of potentials in different time periods. In view of this, the following changes have been made to the model (1):

1. Introduce weights to allow potentials relating to different activities to be added together. If potentials are to be added together, their magnitudes must first be adjusted by how the individual activities are relevant to determining peripherality. Due to the design of the model, activities with larger origin weights will, by default, generate more potential. In practice, however, a more common service (with more origin points) is not necessarily more relevant than a less common service that will be used less often. For example, trade services are used relatively frequently (even several times a day) and there are relatively many service points themselves, while healthcare services are used much less frequently, and hence there are far fewer clinics than trade points. However, this does not prove that proximity to trade services is clearly more important than proximity to a doctor.
2. Introducing a critical contact range: it was necessary to define a critical contact range (i.e., the maximum distance of potential impact) to better reflect the detailed relationships taking place at the scale of the settlement.
3. Distinguishing between the study area and the area of analysis. When analysing potential on a national scale, Litwińska restricted the location of source points to the borders of Poland only. This was justified due to the restriction on the movement of people, goods and services between countries. However, when analysing the potential at the scale of the settlement, the interaction with neighbouring areas should be taken into account, both in terms of the supply of potential (source points from outside Jagodno send potential to Jagodno) and the consumption of potential (target points located in the surroundings of Jagodno are reached by potential sent by source points located in Jagodno).
4. The distance zones: the impact space at the scale of the settlement was considered to be homogeneous, and equal distance zones (50-m-wide) were introduced. It was decided to keep the values as small as possible to reflect the relationships on the estate as accurately as possible.

3. Case study

The Jagodno housing estate in Wrocław was chosen as an example to test the model. This housing estate is characterised by a very significant increase in housing stock over the last 20 years, while, at the same time, it is widely regarded by the city's inhabitants as a housing estate with poor access to services, on which people settle mainly because of its relatively low property prices. Taking this into account, several potential causes of peripherality have been diagnosed:

1. The dynamic growth of residential development and potentially unmatched development of services (including public services): preliminary analyses (2) have shown that Jagodno, on a city-wide scale, is characterised by poor access.
2. A very large group of new residents who are not connected to their place of residence.
3. Conflicts between new and existing residents of the settlement.

In view of this, Jagodno was considered to be a potentially peripheral settlement, which is an appropriate case study for exploring the capabilities of the OPM. But, on the other hand, Jagodno is not a stereotypical peripheral settlement; it is not located far from the city centre and is characterised by mixed development (single-family, multi-family, commercial), so it is not a typical suburban bedroom community.

The boundaries of the study area were drawn on the basis of the Jagodno urban unit as defined in the *Study of Land Use Conditions and Directions of Wrocław* (2018). Areas that are outside the urban unit (sometimes even outside the city limits) but functionally connected with the Jagodno housing estate were added to the area defined in the study. A wider area of analysis than the study area was also adopted; the settlements and villages neighbouring Jagodno were included, because so too were service points from outside Jagodno's "send" potential to the households located in Jagodno. The boundaries of the analysis area were set so that the study area is surrounded on all sides by approximately the same area of the analysis area (similar to the area of the study area itself). The size of the analysis zone was adjusted to the natural boundaries (main roads and railway lines) and land use. The south-eastern fragment (between the villages of Żerniki Wrocławskie and Iwiny), which is only used for agricultural purposes, was excluded as it would not affect the simulations.

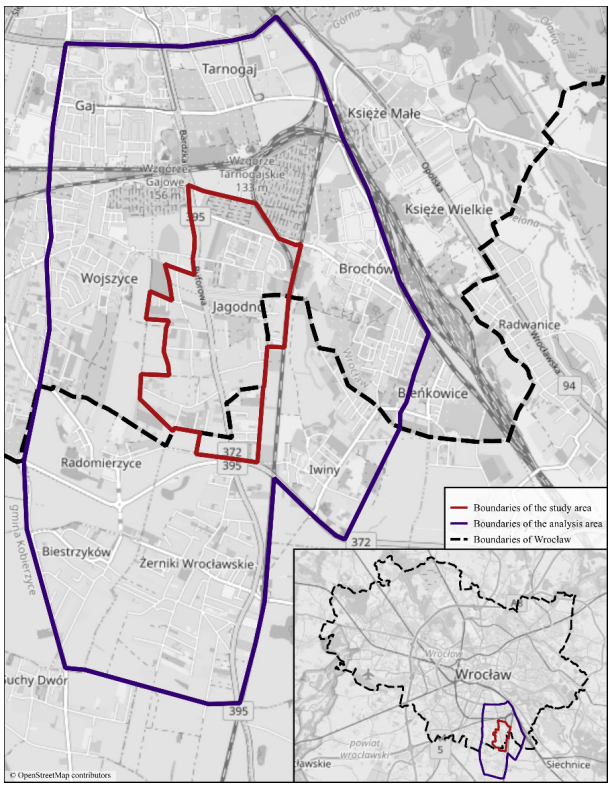

Fig. 1. Boundaries of the study area and the analysis area
Source: Own author's draft

3.1. Model indicators

For a thus-defined study area, it is necessary to choose the network along which the potential is "distributed", the list of analysed activities and the parameters of the model: distance zones, selectivity and weights of individual activities.

The pedestrian network (i.e., all streets, pavements and paths) was selected as the network, as it was considered that, on the scale of the housing estate, pedestrian, cycling and car transport all function, and the pedestrian network takes into account all these modes of transport. Due to the settlement scale of the analyses, it was decided to select distance zones of 50 metres, so as to reflect the studied phenomena as precisely as possible.

The work of de Falco et al. (2019) was used as a basis for the selection of activities, where, in describing peripherality at the urban scale, three dimensions were identified:

1. Geographic (spatial) urban peripherality: distance from the centre;
2. Hard (material) urban peripherality: access to public services and other civic facilities;
3. Soft (social) urban peripherality: social capital, diffusion of knowledge and innovation, share of vulnerable groups in the population.

Eight activities were considered in the modelling. They were selected to best relate to the quoted peripherality dimensions. Table 1 describes how the individual elements of the model (analysed activities and network) relate to the listed peripherality dimensions (3). It should be noted that many of the aspects listed affect more dimensions than indicated in the table, where only the main relationships are highlighted.

The activities described were analysed using data from 2018 and 2023 so that the resulting potential scores could be compared and it could be seen whether the potential of individual households is increasing or decreasing (and therefore whether their position in the network of relationships is improving or deteriorating).

When analysing peripherality at the scale of the settlement, only those activities were selected that reflect the needs of residents realised within the settlement, abandoning the analysis of needs

Table 1. Relationship between model elements and peripherality dimensions

Model Element	Dimensions of urban peripherality		
	Geographic	Hard	Soft
Public transport stops	X		
Primary schools		X	X
Kindergartens		X	X
Primary care clinic		X	
Basic services (commerce, small services, crafts, catering)		X	X
Green areas		X	
Public spaces			X
Semi-public spaces			X
Network	X	X	

Source: Author's own study

met at the scale of the whole city (hence, access to specialised services was not analysed). The catalogue of activities analysed emphasises public services (access to them as a criterion of peripherality, in addition to de Falco (op. cit.), was indicated by Copus et al. (2017) and Mahzouni (2013). Issues of social relations are represented in the model by the activity of public and semi-public spaces (based on the assumption that the existence of spaces that integrate residents positively influences their neighbourhood relations and sense of identity – the same function is also performed by education or basic services, though to a lesser extent).

The origin points are the individual service points (in the case of public transport, the bus stops, and in the case of green spaces, public and semi-public spaces, the centroids representing the individual areas), and the target points where the potential was measured are the address points of the residential buildings.

For source activities, the mass-creating potential was expressed by the maximum number of customers that could be served at a given service point in three hours, and an approximate number of residents was assigned to each target point (4).

Since the origins of the contact are service points and the destinations are households, the fraction of unsatisfied trips will *de facto* be the potential generated by service points located in the study area that has not been consumed by households located in the study area. Determining selectivity is therefore a significant challenge in the OPM; potential itself is an abstract measure, so also estimating how much of it has been consumed outside the analysis area is impossible using, for example, surveys or observations of consumer behaviour. It was therefore decided to determine the fractions of unsatisfied trips using the expert method on the basis of experience with the OPM and other models based on the mechanism of intervening opportunities.

Another important parameter is the weight that has been assigned to each activity as a reflection of how relevant individual activities are in determining peripherality. Accordingly, one component of the weight is the probability rate of using a given activity in three hours. (For example, for primary schools, this probability is equal to the share of the school population.) The second component of the weight is the share of a given activity in the total of all activities; this component is intended to balance the inequalities arising from the nature of the different activities. The final weight is the multiplication of both indicators. The values of the potentials of the individual activities are added up after they have been multiplied by the weight.

3.2. Data collection

A major challenge in using the opportunity model is the data collection process. In the model, the data relating to the maximum capacity of service points must be accurate (as to address point). To obtain such accurate and specific data, it was decided to use several complementary data origins.

The network for the modelling was drawn from Database of Topographical Objects (BDOT) data, which was updated in both 2018 and 2023; the network was also verified using the 2018 orthophoto and field inventory. The location of source and target points was based on BDOT and verified using open data resources (OpenStreetMap, Google Street View, Google Maps). The origin of data on the amount of activity at each point varied by activity:

1. Housing: the number of inhabitants was estimated based on the area of housing as detemined using BDOT (no reliance was placed on official datasets as high data accuracy [as to address point] not provided by official datasets was required).
2. Public transport: frequency and capacity of public transport vehicles were estimated based on data obtained from MPK Wrocław (Municipal Transport Company).
3. Primary schools and kindergartens: the capacity of education facilities was determined based on data obtained from the local authorities running these facilities.
4. Basic healthcare – data obtained from the National Health Fund.
5. Basic services, public, semi-public spaces and green spaces – volume estimate based on field inventory and behavioural observations.

4. Results and discussion

A comparison of the potential results for the 2018 and 2023 data shows a definite increase in potential at each address point analysed. It should also be mentioned that not only did the sum of the potentials of all activities increase, but each value of the potential of a single activity at a single point also increased.

It should be noted that Figure 2 shows the spatial distribution of potential, whereas, in the context of defining peripherality, the focus should be on how potential has changed relative to population: since population density is heterogeneous, spatial distribution is not synonymous with per capita distribution. A statistical summary of the potential data shows that the average per capita potential increased by 62%. It is worth noting that 22.7% of Jagodno's population in 2018 had a lower potential than the lowest score in 2023, while on the other hand, as much as 81.2% of the population in 2023 had a higher potential than the highest score in 2018 (Fig. 3.)

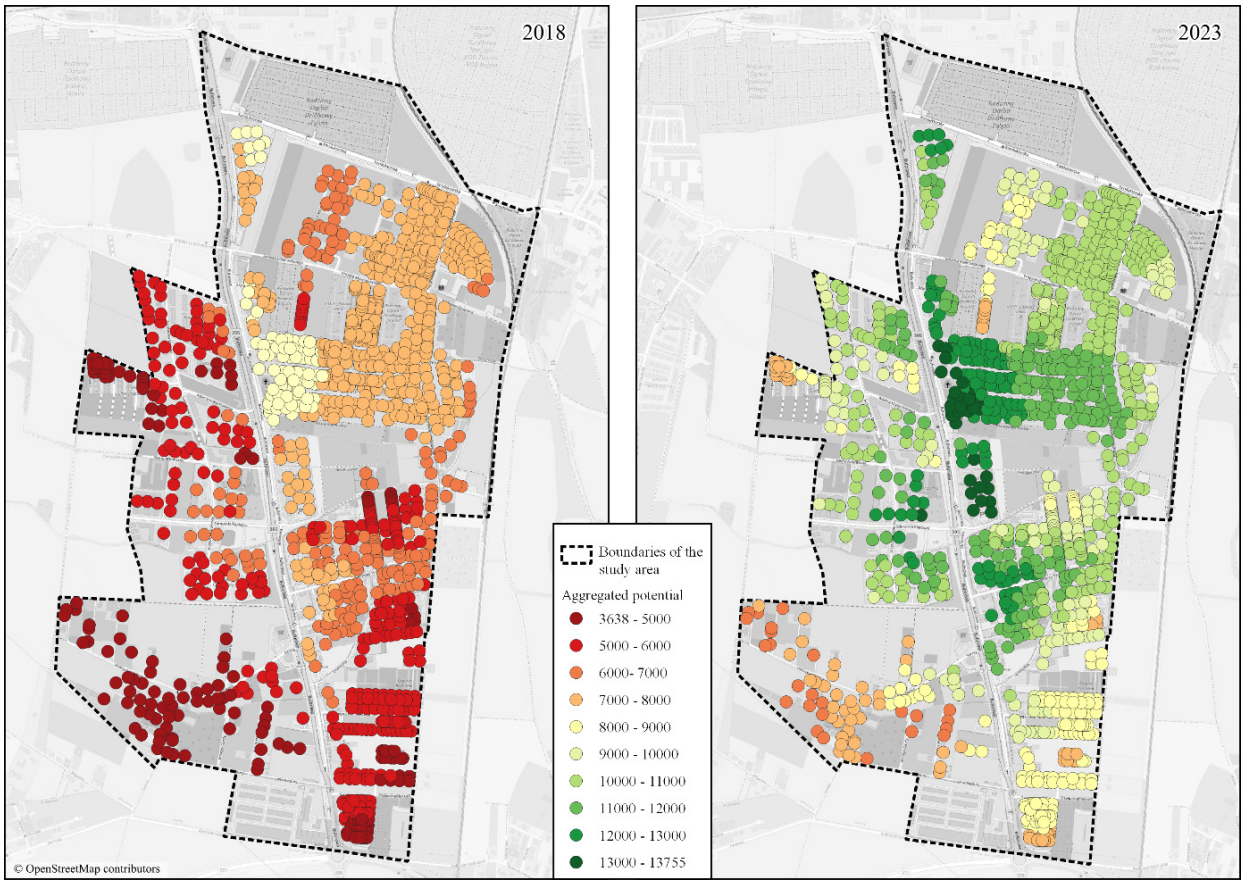

Fig. 2. Aggregated household potential of Jagodno
Source: Author's own draft

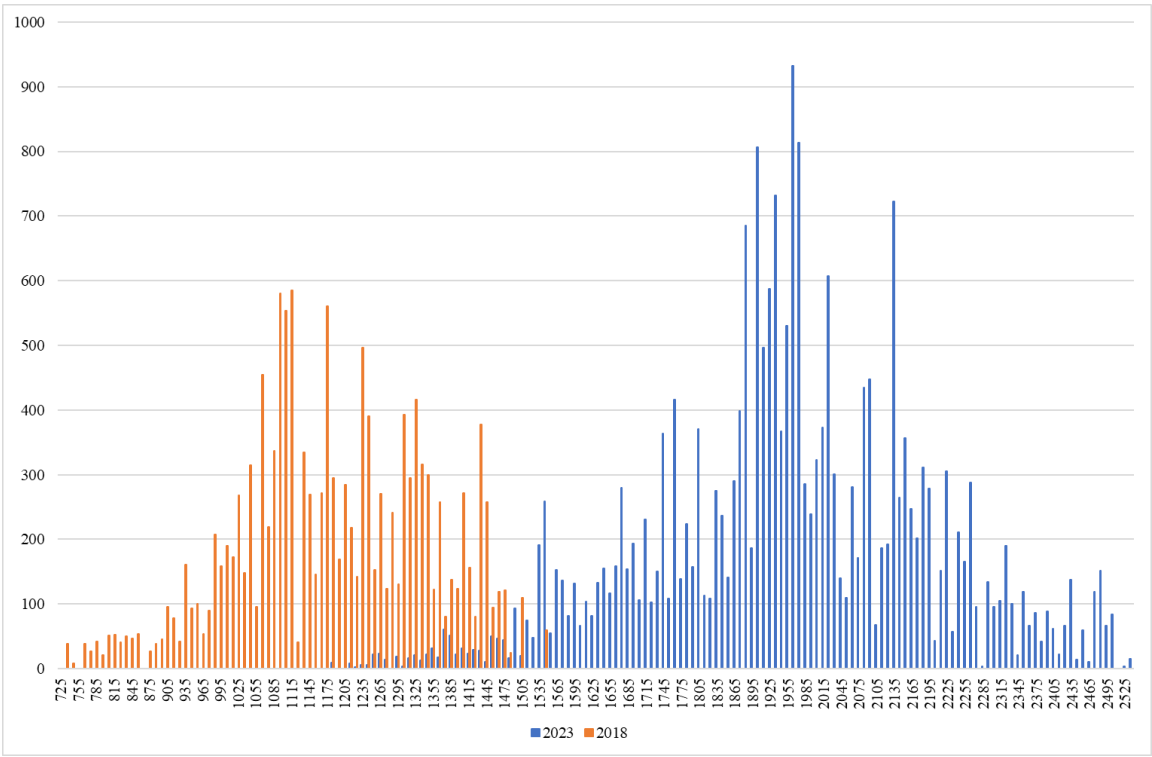

Fig. 3. Histogram comparing *per capita* potential in 2018

Taking into account both the spatial distribution of potential and the distribution of potential *per capita*, and juxtaposing them with the adopted definition of peripherality, the studied settlement cannot be considered a pheripheral area. Since an increase in potential was recorded at each analysed point, the position in the network of connections of the whole system is better in 2023 than in 2018. Thus, it can be seen that, despite the sizable increase in population between 2018 and 2023 (an increase of about 30%), the rate of growth of the analysed activities was even higher. This therefore indicates that, although Jagodno (due to the dynamic development of housing) may have been temporarily under-served, there was no permanent peripheralisation causing a degeneration of the situation in the settlement. Rather, one can point to the fact that the service offer was adjusted (by both public service providers and the free market) and upgraded to meet the demands of the population. Ultimately, therefore, neither of the two conditions necessary for an area to be considered peripheral is met.

The analysis of potential also makes it possible to indicate inequalities in the distribution of potential within the entire system studied. A comparative analysis of the normalised data shows that the values of potential are much more diverse in 2023 than in 2018. The differences are evident even if (for comparing values with the same geographical dispersion) address points that were not inhabited in 2018 are also taken into account. The increased variation in potential may be indicative of uneven development of the settlement. Although, as shown earlier, all households increased potential compared to 2018 (their position in the network improved relative to their position in 2018), there are households whose position relative to the household with the highest potential deteriorated between 2018 and 2023.

Some conclusions can also be drawn from the location of the points with the lowest potential. On the one hand, these are the points located at the border of the city and the settlement. On the other hand, these are single-family houses, which are naturally (due to their lower population density) characterised by poorer access to services and, due to the characteristics of their landscaping (private backyard gardens), poorer access to public and semi-public spaces. It is also worth mentioning households which, although located relatively centrally within the settlement, received some of the lowest potential values. This is due to the sub-optimal road network, which forces residents of some properties to take excessively circuitous routes. This state of affairs can be caused by a faulty design

of the network, its non-completion, or its emergence being organically related to the construction of further housing developments.

The phenomena observed in Jagodno are reminiscent of the form of Multilayered Patchwork Urbanisation (Mulapa) described by Schmidt et al. (2018); it is not strictly a peripheral area, but an incoherent area that extends from the city limits into the suburban area. Among the characteristics that the authors attribute to Mulapa, which can also be attributed to Jagodno at the same time, are the overlapping of different compositional layers, the interpenetration of functions, the lack of clear boundaries of the individual complexes, the visible relics of agricultural and industrial development, and the existence of service centres that nonetheless do not fully serve the needs of the inhabitants. On the other hand, Howe (2022) describes the phenomenon of aspirational urbanism, i.e. the process of suburbs expanding and being populated by residents who accept inferior access to services and a considerable distance from the centre, but can thus realise their middle-class aspirations. Interestingly, according to Howe, the structures so described are peripheral, while Jagodno cannot be described as such. Of course, the typologies proposed by both authors come from contexts different than Jagodno, but the processes occurring in the border zone of large cities can be considered to some extent universal. The concept of the inner–outer city proposed by Millington (2011) also seems to fit Jagodno, according to which the suburbs, with their development (and simultaneous gentrification of the centre), are gradually taking over the role of traditional inner cities while retaining a suburban form. Thus, if a transitional form between the centre and the periphery is being dealt with and, at the same time, one that does not aspire to be the traditionally perceived centre, the study of peripherality becomes only part of the investigation into the true nature of the area under study.

5. Conclusion

The proposed model can be used to analyse peripherality on a city scale, it can indicate the change in network position over time and the spatial variation in the distribution of opportunity at the scale of the settlement under study. Analysis using opportunity potential gives a more complete picture of the degree of service provision than a simple service availability analysis. This is because not only the distances between the target and source points are taken into account, but also the capacity of the service points, the number of potential customers and their choiceness. OPM is therefore a valuable research tool.

Using the presented model also creates some challenges associated with determining the degree of peripherality, such as the need to establish the maximum capacity of activity sources during data compilation and the abstraction of values, like quantifying unutilised potential within the study area during indicator determination. The model also exhibits limited capabilities in analysing social phenomena. In the case under examination, social phenomena were approximated through the operation of infrastructure that facilitates social relations, though this approximation is not entirely precise. On the other hand, OPM can also be a valuable support for qualitative research; e.g., the model can be used in determining potential problem areas qualifying for more detailed social studies.

In this specific case, peripherality was not observed. However, a comprehensive assessment of negative phenomena would require the analysis of data over a broader time range at shorter intervals to reveal associations between the low potential of one activity and the declining potential of other activities.

To date, OPM has remained a more widely unknown tool. Further analysis and research using this tool will help to recognise the full usability of opportunity potential and eliminate the drawbacks faced in the case study.

6. Notes

1. This software is maintained as a Python library and is available in official PyPi repositories as well as publicly on the GitHub platform (GitHub 2023a); the source code for the research simulations is available at GitHub(2023b).
2. Preliminary analyses investigated the availability of selected services throughout Wrocław using Network Analyst tools.
3. The activities used in the article are only a sample set to demonstrate the performance of the model. The set of activities examined should be selected individually for each study area.
4. All the activities analysed in the model must be based on the same units, which in this case is the inhabitants. It would be a mistake to compare, for example, the sales area or the number of service points with the number of inhabitants.

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