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CORRELATIONS OF URBAN SPRAWL WITH TRANSPORT PATTERNS AND SOCIOECONOMICS OF UNIVERSITY STUDENTS IN CRACOW, POLAND

Summary. Urban sprawl is considered as a western urban development pattern, which is common in different cities around the world. Although, a large number of studies have focused on urban sprawl, modelling urban sprawl has been less emphasised, especially in various geographical contexts. This study aims to investigate urban sprawl and its determinants in a post-socialist country and model urban sprawl based on disaggregated data. In addition, the correlations of urban sprawl with travel patterns were examined, along with the socioeconomic characteristics of university students in Cracow, Poland by applying the Weighted Least Square (WLS) regression model. The WLS regression model was fitted based on the data from 1,288 online questionnaires targeting university students. Furthermore, urban sprawl around the home and the university for each student who indicated the nearest intersection to their home and university were separately estimated by employing the Shannon entropy. Based on the findings,

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urban sprawl around homes was correlated with 14 transport patterns and socioeconomic features such as gender, age, driving license, financial dependency status, gross monthly income, number of commute trips, mode of transportation for commuting, number of trips for shopping or entertainment, daily shopping area, mode choice for shopping and entertainment trips inside and outside the neighbourhoods, frequency of public transport use, the attractiveness of shops inside the neighbourhoods, and the length of time living in the current home. Additionally, urban sprawl around the university was significantly correlated with age, car ownership, number of commute trips, and a sense of belonging to neighbourhoods, entertainment place, and residential location choice. Finally, a positive correlation was reported between urban sprawl with higher income, elderly student, financial dependent students, and car dependency trips, while urban sprawl was negatively related to the use of public transit.

Keywords: urban sprawl, socioeconomics factors, travel pattern

1. INTRODUCTION

Urban sprawl is considered as a specific urban form which is characterised as a low-density, single land use, car-dependent, discontinues or leapfrog new development, or uneven pattern of growth between urban population and urban areas [14, 18, 26, 45]. Although urban sprawl is well-known as an American urban form, it is regarded as a controversial topic among urban planners and decision-makers in different parts of the world, which has been discussed as a global problem. Urban sprawl is related to environmental, social, and economic issues. For instance, urban sprawl can influence the environment by increasing CO₂ emission in more long-distance commuting trips or using natural resources as a new development area [16, 26, 49].

More distances are driven by car, less use of walking and public transport, long-distance between home and workplaces, lack of sense of place, low density and single land-use area are highly related to different social, economic, cultural, and geo-demographic circumstances, which should be considered in urban planning. Although, some studies focused on the relationship between urban form and travel behaviour [6, 16, 17, 19, 20, 26, 30, 38-40, 43, 49], more should be conducted to evaluate urban sprawl as an urban form which is correlated with various socio-economic indicators and travel patterns based on different geographical contexts. The correlation among urban sprawl, individual socio-economic variables, and travel behaviour clarify a better understanding of modelling urban sprawl and provide more practical policies for urban planners. Urban sprawl has been a matter of concern not only in developed countries but also in developing parts and emerging economies. Although, there is no agreement in definition and its quantification, the characteristics of urban sprawl were discussed by urban researchers [4, 10, 14]. However, less attention has been paid to the mechanisms, processes, patterns, and factors related to urban sprawl in different parts of the world. On the other hand, urban form plays an important role in travel literature [11, 16, 19, 47]. Hence, urban sprawl as a specific urban form associated with socioeconomic determinants and travel behaviours based on economic, governmental, and geographical context. Although, urban sprawl was studied in post-socialist cities [8, 21, 31, 35, 42], most paid more attention to the differences between socialist and post-socialist cities and impact of transformation on urbanisation in these cities. However, the socioeconomic determinants, travel patterns, and their association with urban sprawl were not considered in the literature.

Inhabitants living in sprawled neighbourhoods suffer more from traffic congestion, air pollution, long-distance commuting, lack of efficient public transport, lack of social interactions than those who live in compact urban forms. Based on sustainable development, studying the correlations between urban sprawl and its different factors including individual, household and, socio-economic characteristics, self-selection of the home place, mobility, urban form and perceptions in the Polish city can provide a better understanding of urban sprawl and its determinants in the post-socialist city. Urban sprawl is observed across the continent, although, European urban areas are more compact than Western cities in the United States. Recently, Urban sprawl has been developed in the post-socialist context. However, no study has been conducted based on reliable and disaggregated data.

Thus, this study aims to evaluate the interrelations between urban sprawl, mobility choices, socioeconomics, and perceptions of university students in Cracow, which represents Polish's larger city, as well as considering context-specificity of these factors by conducting a descriptive comparison between the results of this paper and determinants of urban sprawl in a different context. In addition, there is a shortcoming in modelling effective factors on urban sprawl based on disaggregated data in Eastern-European countries compared to the western countries. Therefore, urban sprawl and urban form features were measured for each participant individually in this study, and the features of urban sprawl were simulated.

The remainder of this paper is as follows; Section 2 reviews the determinants of urban sprawl in the sprawl literature, as well as in the context of emerging economies and post-socialist cities, and an overview of urban sprawl in Polish cities. Section 3 describes the brief explanation of the methodology. Section 4 presents the main findings of the results. While, section 5 demonstrates urban sprawl and its determinants contextually and discusses the findings in Poland and international literature, as well as the implications of urban sprawl in Poland. Finally, the conclusion is presented in Section 6.

2. THE RELATION BETWEEN URBAN SPRAWL AND SOCIETAL PHENOMENA

There is no unique definition of urban sprawl. The term "urban sprawl" describes low-density, single land use, inefficient, suburban development around the edge of cities, leapfrog and discontinues urban forms distinct from those identified in the United States. Urban sprawl is defined as low-density, leapfrog development in a relatively pristine setting [4]. Galster et al. (2001) argued that urban sprawl is a pattern in an urban area which has a relatively low level of eight dimensions including density, continuity, concentration, clustering, centrality, mixed uses, and proximity [14]. Urban sprawl as a type of urban form, which is related to socioeconomic and travel pattern, has attracted a lot of attention during recent decades. In addition, metropolitan expansion, low density, diversity of land use as three dimensions of urban sprawl were evaluated along with their relation to flow network, mode-choice, and commuting time in the metropolitan area of Madrid [15]. Further, the correlation between socio-demographic features of households, the individual, urban structure at both home and workplace with the travel pattern in Beijing, China was considered. The results indicated a significant correlation between tour-travel decision and socioeconomic attributes [24]. However, Zhao (2010) considered the sprawl pattern of expansion and the increase in distance trip and car-dependent travel in Beijing as a megacity [49]. Additionally, the differences between socioeconomic causes of urban sprawl in China and western urban sprawl were investigated to determine the drivers of urban sprawl in China. Thus, urban population density, gross domestic product per capita, and industrial structures in China were considered

as main determinants [26]. Hamidi et al. (2016) applied principal component analysis and cross-sectional data to operationalise sprawl/compactness in four contributors of urban sprawl including development density, land use mix, centralisation of activities, and street accessibility [19]. Ewing et al. (2016) examined the relationship between urban sprawl and upward mobility for Americans. The result indicated that upward mobility is considerably higher in compact areas than sprawling areas due to more accessibility to better job [12]. European Environment Agency (2016) measured the urban sprawl between European countries, along with urban sprawl determinants and its impact on natural resources [9]. Guerra et al. (2018) applied a multinomial model to examine the preference of commuters by different transport modes based on the role of age, income, education, and information about urban area [16]. Travisi et al. (2010) analysed the causal relationship between spatial developments, the sprawling pattern of the urban area and travel movement in seven major Italian cities using the mobility impact index, the cross-section data, and the Casual Path Analysis (CPA). The empirical results indicated the high impacts on travel behaviour of less compact and mix-used cities [44]. Shorter distance to the city centre and high-density neighbourhoods are associated with lower trip duration to work or education. Thus, the residents in compacted neighbourhoods are more willing to use active mode transport (walking and biking) than those living in sprawled neighbourhoods [32]. The socio-economic contributors of urban sprawl were modelled by employing regression model of urban sprawl metric in Switzerland. Furthermore, the increase in population and income, and the changes in social patterns such as single household and age resulted in creating sprawl [32]. In another study in Switzerland, the components of the urban sprawl metric developed by [22, 23], were applied in the cross-sectional regression model to study urban sprawl, along with its socio-demographic factors such as population, income, commuting pattern, price of agricultural land, homeowner rate, age, and single household [47]. Urbanisation in the 20th century was associated with modernisation and industrialisation as two primary socio-economic trends [42]. Thus, post-socialist cities were influenced by these two crucial trends like other parts of the world but at different speeds and time. Evaluating the cities in socialist countries indicated that the political economy is considered as a significant factor in shaping urban areas. Cities have some similarities and differences between capitalism and socialism in some aspects. In socialist cities, political and economic forces drove the built environment, land use, and patterns of allocation. However, there are some similarities in the spatial patterns of both capitalism and socialism since industrialisation and modernism. Socialist cities captured the features of capitalism context with the delay of a few years. To understand the post-socialist city better, it is necessary to study socialist cities' former Iron Curtain in East-Central Europe. Compared with the capitalist cities, especially American types, cities were denser in the socialist period. However, the industrialisation of the socialist economy led to boom industrial centres, which attracted rural migrants to the cities. Hence, socialist cities faced a fast growth in the urbanisation [21].

Socialist cities did not experience urban sprawl like the United States. Inhabitants in socialist cities were accommodated in mass-housing complexes between 1960 and 1980 in urban edges [5]. Socialist cities were governed through the top-down centralised control of regional development. Spatial public space and urban development were concentrated in target areas by land development policies of a hierarchically organised system. In addition, the construction of massive housing estates at the urban edge, a dense network of public transportation, and allocation of services in neighbourhoods, districts, and urban centres according to a hierarchically organised system characterised socialist cities [3, 42]. The urban development of larger cities in East-Central Europe has been transformed by collapsing

socialism in the 1990s. The interactions between the socialist urban structure and new ideologies, the market economy, and the democratic governments have shaped post-socialist cities. Transformation in spatial patterns of the urban area is considered as one of the dimensions of transformation, along with the changes in social, political, cultural, and economic aspects of East-Central Europe. Suburbanisation has become the most familiar process of changing the landscapes of post-socialist cities. Rapidly developing suburban sprawl and residential segregation are regarded as a consequence of uneven development and following globalisation in post-socialist cities [35, 42]. The clear edge of Eastern/Central European city was vanished by the end of socialism. Land-cover changes studies in Europe indicated a high rate of sprawling in post-socialist cities than Western Europe [9]. Urban sprawl has been enabled by transformation policies such as urban land, housing, and the properties have been revalued as economic goods due to the cancelling restrictions on private ownerships. In addition, car ownership increased in most parts of Eastern/Central Europe, which affected public transport, urban structure, especially in the urban form [21, 31]. After falling socialism in 1989, some changes occurred in spatial and social aspects of urban structures. Post-socialist suburbanisation and decentralisation of population and employment in Polish cities were considered as an urban form. Hence, Polish urban sprawl is in the early stages. Polish suburbanisation is identified by the large distances from the city centres, the extension of single-family housing, and the desire to live in the suburban zone compared to the core cities [41].

New Polish urban structures in the form of urban sprawl were driven by liberalising spatial planning, uneven growth, and socio-economic transformation [25, 27, 28]. The government policies during socialism emphasised relocation of workplaces outside the boundaries of Polish cities. Thus, the low quality of coordinated pattern of land development, the transformation of agricultural land, and degradation of natural resources are considered as the consequences of these policies. Economy transition, especially in land market, led to the escalating price of land in large Polish city centres. Hence, more agricultural lands were sold in the periphery of the cities [27]. Moreover, Polish cities faced massive growth in car ownership since 1990, which is related to the territorial development of urban areas and congestion on the roads [2]. Furthermore, privatisation and residential suburbanisation were promoted by national policies to support investment in housing during the 1990s. The lack of public facilities and infrastructure in new development areas is considered as one of the most critical issues accompanying urban sprawl in Poland because Polish local governments are obligated to pay high compensation to landowners for allocation of public facilities [29]. Mantey and Sudra (2019) studied 16 types of post-socialist suburbs in Warsaw, Poland, among which four planned the pattern of housing and high-density populated based on street grid neighbourhood. Contrarily, the other 12 categories followed leap-frogging new neighbourhood based on cul-de-sac street network, which was considered as sprawl pattern in the literature [29].

3. METHODOLOGY

3.1. Research objectives and hypotheses

This study aims to identify the determinants of urban sprawl in Cracow as an example of a large Polish city and determine whether factors such as transportation, socioeconomics, human perceptions, residential location choice, and urban form features of Cracow university

students are correlated with urban sprawl or not. In addition, it seeks to determine the differences between these correlations in the case study compared with those of high-income countries. Following, these objectives illustrate how urban sprawl and its determinants, especially the relationship between urban sprawl and travel behaviour, may be different in various social, historical, cultural, and economic contexts.

The main hypothesis is that a wide range of factors including commute and non-commute travel patterns, socioeconomics, human perceptions, residential self-selections, and urban form features are significantly correlated with urban sprawl in Cracow, Poland. Furthermore, the correlation between urban sprawl and travel behaviour and socioeconomic factors in Cracow as a post-socialist city is different from those in high-income countries like North American cities, Western Europe, and Australia. Hence, urban sprawl follows different patterns and determinants in the different parts of the world based on various complex conditions between developed and developing countries and emerging economies.

3.2. Data and variables

To test the hypotheses, 1,288 online Polish-language questionnaires were collected and validated during the winter of 2019. The questionnaires were randomly distributed among university students of Cracow, which indicated home and university places in different districts of Cracow. It included 23 questions based on individual and household socioeconomic factors, commute and non-commute travel patterns, perceptions of the urban environment, and mode choice of transportation. In addition, urban form and configuration of street network variables were extracted by using Geographical Information System (GIS) version 10.3 for both home places and university, respectively. Therefore, 24 variables were developed including 20 socioeconomic factors, travel behaviour and perception variables such as gender, age, main daily activity, driving license, car ownership, financial dependency status, gross income per month, number of commute trips per week, mode of transportation of commute trips per week, number of non-commute trips including those for shopping or recreation per week both inside and outside of the neighbourhood, daily shopping area, mode choice for shopping and recreational trips in both inside and outside of the neighbourhood, the frequency of public transport use, sense of belonging to the neighbourhood, entertainment place, the perception of the quality of social-recreational facilities of the neighbourhood, residential location choice, length of time living in the current home, and two urban form variables for each home and university according to the home and university place specified by each student. The respondents indicated the nearest intersection to their home and university, and then their address was pinned in two layers in the Google Maps as separate layers for home and university. The layers were exported in KML format to get the GIS-ready layers. Hence, each point in the layer of home and university represents each university student's home and university, respectively. Afterwards, the 600-metre catchment area based on the street network for each point was measured to compute other variables in the catchment area. The inverse of Building Coverage Ratio (BCR) was calculated around home and university. Furthermore, the free shapefiles of Cracow were downloaded from Open Street Map (OSM) in the computing Shannon entropy and inverse of building coverage ratio, and network dataset were built in ArcMap version 10.3. All variables are presented in Tab. 1.

Tab. 1

Variables

Variables	Source / Quantifications	Coding
Gender	Extracted by questionnaire	Men=1, female=2
Age	Extracted by questionnaire	-
Main daily activity	Extracted by questionnaire	Only student=1 Work and study=2
Driving license	Extracted by questionnaire	No=0 Yes=1
Car ownership	Extracted by questionnaire	Without car=0 1 car & 2 cars and more=1
Financial dependency status	Extracted by questionnaire	No=0, yes=1
Gross monthly income	Extracted by questionnaire	Below 1000 PLN=0 From 1001 to 2000 PLN=1
Number of commute trips	Extracted by questionnaire/each respondent indicated the number of trips for last week	-
Mode of transportation for commuting trips	Extracted by questionnaire	By car=1, other mode choice=0
Number of trips for shopping or entertainment	Extracted by questionnaire/each respondent indicated the number of trips for last week	-
Daily shopping area	Extracted by questionnaire	Outside=1, inside=2
Mode choice for shopping/entertainment inside the neighbourhood	Extracted by questionnaire	By car=1, other mode choice=0
Mode choice for shopping/entertainment outside the neighbourhood	Extracted by questionnaire	By car=1, other mode choice=0
Frequency of public transport use	Extracted by questionnaire	Almost never=0, rarely=0, a few times per month=0, a few times per week=1, every day=1
Sense of belonging to the neighbourhood	Extracted by questionnaire	No=0, yes=1
Attractiveness of shops	Extracted by questionnaire	No=0, yes=1
Entertainment place	Extracted by questionnaire	Far away=1, inside my neighbourhood=2
Quality of social/recreational facilities	Extracted by questionnaire	Not attractive=0, little attractive=0, acceptably attractive=1, medium=0, very attractive=1

Residential location choice	Extracted by questionnaire	The house was affordable to buy=1, the house was near my work=0, the surrounding environment is attractive=1, the house will have higher price=1, to be near my relatives=1, I live here since was born=1
Length of time living in the current home	Extracted by questionnaire	-
Urban sprawl around home	Measured by Shannon entropy/Cracow divided to 4256 grids in GIS, then computed by employing zonal extension and spatial analysis tools, home points joined to grids based on common spatial location to get their amount of disaggregated Shannon entropy	-
Inversed Building Coverage Ratio (BCR) around the home (%)	For each respondent who indicated home place, the 600-metre catchment area calculated according to the street network, thereafter the area of buildings divided by the area of the catchment area and then one divided by the amount of BCR in each catchment area.	-
Urban sprawl around university	Measured by Shannon entropy/Cracow divided to 4256 grids in GIS, then computed by employing zonal extension and spatial analysis tools, university points joined to grids based on common spatial location to get their amount of disaggregated Shannon entropy	-

Inversed Building Coverage Ratio (BCR) around the university (%)	For each respondent who indicated university place, the 600-metre catchment area calculated according to the street network, thereafter the area of buildings divided by the area of the catchment area and then one divided by the amount of BCR in each catchment area	-
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3.3. Case study

Cracow is located in the south of Poland on the Vistula River, the largest river in Poland. The city has 372 km² areas with its suburban areas and is populated by nearly one million inhabitants by considering suburban population. Cracow is the second-largest city and one of the oldest cities in Poland. In 2016, Cracow was populated by 765,300 inhabitants (Female=53%, Male=47%) [38]. It was considered as an urban centre from the 9th century. Furthermore, Cracow is one of the biggest academic centres in Poland with almost 160,000 students. There are 21 higher education institutions (Public=10, Non-public= 11) in the city, among whom the students of public universities constitute the vast majority (86%) [48]. Among the public universities, the majority of students study at Jagiellonian University, while Andrzej Frycz Modrzewski Cracow University has the biggest share among non-public universities. The highest number of variety was related to the students of technical universities, specifically about 28%. The universities have been of significant impact on the potential of Cracow as a scientific, cultural, economic, and political centre since 1985 [34]. After 1989, Cracow faced a series of transformations. The modern economic and political system increased the processes of urbanisation in the city, especially when Poland joined the European Union in 2004. Extension of the urban area in Cracow happened in the 20th century when Cracow was extended five times [38]. The rapid development in Cracow is a result of government policies on the construction of housing estates. The first spatial development took place in 1945 and the second important extension happened in 1973 in all directions [50]. Political transformation from socialism to post-socialism could affect Cracow in four aspects such as centralisation to decentralisation, industrialisation to deindustrialisation, underrated to acclaimed city, and the inclusion of large outside areas to city versus suburbanisation. The development of public transportation network, improvement of urban facilities, as well as lower price of land in the outskirts, resulted in extending peripheral areas in Cracow [38]. Ziobro (2019) referred to urban sprawl in Cracow, especially towards the north. In the northern part of the city, spatial structure transformed from villages into a pre-urban structure with scattered pattern and residential land driven by shortcoming urban planning system and uneven development [50].

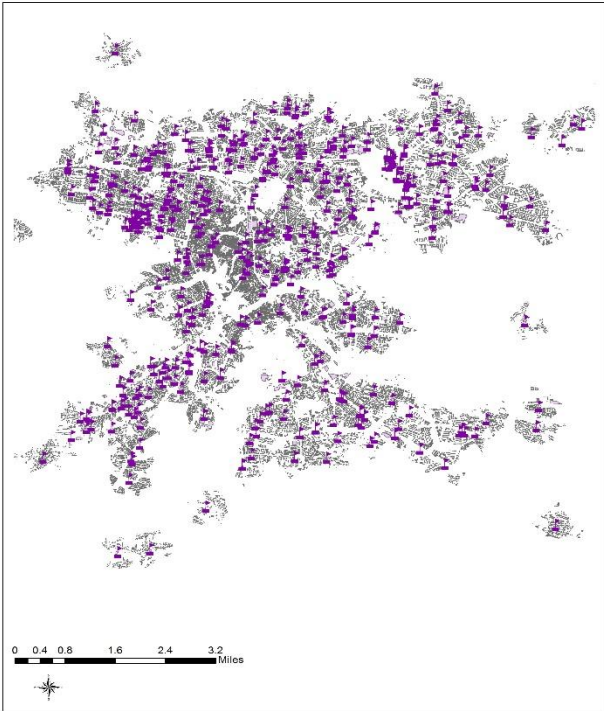


Fig. 1. The distribution of homes in Cracow

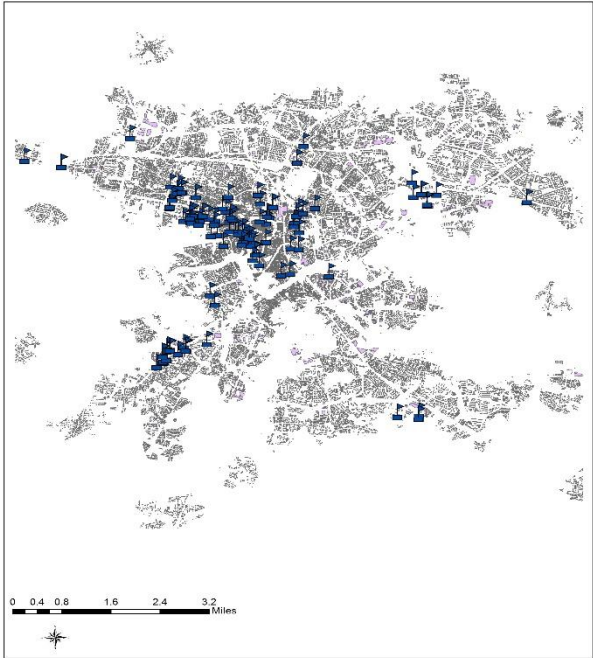


Fig. 2. The distribution of university facilities in Cracow

3.3. Case study

Cracow is located in the south of Poland on the Vistula River, the largest river in Poland. The city has 372 km² areas with its suburban areas and is populated by nearly one million inhabitants by considering suburban population. Cracow is the second-largest city and one of the oldest cities in Poland. In 2016, Cracow was populated by 765,300 inhabitants (Female=53%, Male=47%) [38]. It was considered as an urban centre from the 9th century. Furthermore, Cracow is one of the biggest academic centres in Poland with almost 160,000 students. There are 21 higher education institutions (Public=10, Non-public= 11) in the city, among whom the students of public universities constitute the vast majority (86%) [48]. Among the public universities, the majority of students study at Jagiellonian University, while Andrzej Frycz Modrzewski Cracow University has the biggest share among non-public universities. The highest number of variety was related to the students of technical universities, specifically about 28%. The universities have been of significant impact on the potential of Cracow as a scientific, cultural, economic, and political centre since 1985 [34]. After 1989, Cracow faced a series of transformations. The modern economic and political system increased the processes of urbanisation in the city, especially when Poland joined the European Union in 2004. Extension of the urban area in Cracow happened in the 20th century when Cracow was extended five times [38]. The rapid development in Cracow is a result of government policies on the construction of housing estates. The first spatial development took place in 1945 and the second important extension happened in 1973 in all directions [50]. Political transformation from socialism to post-socialism could affect Cracow in four aspects such as centralisation to decentralisation, industrialisation to deindustrialisation, underrated to acclaimed city, and the inclusion of large outside areas to city versus suburbanisation. The development of public transportation network, improvement of urban facilities, as well as lower price of land in the outskirts, resulted in extending peripheral areas in Cracow [38]. Ziobro (2019) referred to urban sprawl in Cracow, especially towards the north. In the northern part of the city, spatial structure transformed from villages into a pre-urban structure with scattered pattern and residential land driven by shortcoming urban planning system and uneven development [50].

3.4. Analysis method

The correlation of urban sprawl and 20 socioeconomics, travel patterns, and urban form variables were modelled by Weighted Least Squares (WLS) regression modelling method in IBM SPSS version 22. Urban sprawl was measured using Shannon entropy. By considering the definition of urban sprawl, there are a lot of challenges regarding the methods for measuring urban sprawl in the literature [1, 13, 22, 23, 33]. Bhatta et al. (2010) argued different methods for measuring urban sprawl and indicated that the Shannon entropy is the most reliable metric for measuring urban sprawl [1].

Yeh and Li (2001) discussed that Shannon entropy can measure the density of land development in a set of buffer zones that were drawn around the city centre. The value of entropy is always between 0 and $\log(n)$ and calculated by the following equation:

$$H_n = -\sum_{i=1}^n p_i \log_{\frac{1}{p_i}} \quad (1)$$

where p_i represents the proportion of urban area that is located in the i^{th} zone ($p_i = \frac{x_i}{\sum_{j=1}^n x_j}$), n is the number of zones, and X_i is the observed value of the phenomenon in the i^{th} zone [48]. If urban areas have a compact form, the Shannon entropy will show fewer amounts. Large value of entropy indicates urban sprawl. The amount of Shannon's entropy is represented in percent for easy interpretation in the model.

To measure disaggregated Shannon entropy for around each home and university place, the land use raster shapefile of Cracow was divided into 4256 grids to cover the whole of the city, and Shannon entropy was calculated by using Zonal extension and Spatial Analysis tools in GIS version 10.3. To model the correlation of urban sprawl with explanatory variables presented in Tab. 1, the inverse of building coverage ratio (BCR) was counted as a weighted variable in the WLS regression model with the confidence level of 95% and P-value of 0.05. The inverse of building coverage ratio was selected because building coverage ratio and Shannon entropy are inversely related. In addition, the WLS regression model was applied for the correlation of urban sprawl around home and university with 20 explanatory variables separately.

The model for home was made by 14 explanatory variables. Six variables were respectively eliminated based on the low level of significance such as the quality of social/leisure facilities in the neighbourhood, car ownership rate, residential location choice, entertainment place, sense of belonging to the neighbourhoods, and main daily activity. F-test was applied to validate the model. The results indicated a significant and marginal correlation with urban sprawl around the home perceptively.

The university model followed the abovementioned steps. In the model for urban sprawl around universities, 11 variables were successively eliminated based on the low level of significance in the model, while the number of trips for shopping or entertainment, frequency of public transport use, quality of social/leisure facilities of the neighbourhoods, attractiveness of shops, mode transport for shopping and leisure in outside trips of the neighbourhoods, financial dependency status, length time for living in the current home, gross income per month, mode choice for shopping/leisure of inside trips, driving license, gender, main daily activity, mode of transport for commuting, and daily shopping area were eliminated and the model was rebuilt to obtain WLS model with the high level of confidence. The constant was not included in both models irrespective of its statistical significance .

After modelling urban sprawl with socioeconomic explanatory variables, a descriptive comparison was made to study the similarities and differences between socioeconomic, and travel pattern determinants of urban sprawl in the world, especially in the context of developed and emerging economies. This is a shortcoming in modelling urban sprawl based on socioeconomic determinants and travel patterns in the literature.

4. FINDINGS

4.1. Descriptive statistics

The samples included 1,288 validated questionnaires, the participants aged 17-37, among whom 42.5% worked and studied at the same time and only 28.7% were financially independent of their families or other sources. The majority of these participants (84.1%) had driving licenses and the car ownership rate was two or more cars. Tram or trains were

the dominant transport modes used by the respondents for commute trips. Furthermore, 57.7% of respondents did their shopping and leisure activity inside their neighbourhoods by walking, while 31.4% preferred to go shopping and entertainment outside of the neighbourhoods. The most popular mode choice for outside shopping and leisure trip was tram or train (used by 43.6% respondents). In addition, the car had a share of 4.3, 10.5, and 17.9% in mode choice for commuting, that is, shopping trips inside and outside the neighbourhoods, respectively. The public transport was used by 70.9 and 21% of the respondents every day and a few times per week, respectively, while 0.9% did not use public transport .

The inverse of Building Coverage ratio (BCR) was counted as the weighted variable, which was developed for those that indicated the nearest intersection to their home. After pointing the home in Google map, 670 home pinpoints were validated from 1,288 questionnaires. The sample size for validated university pinpoints is 685. Shannon entropy around the home has a range from 0.01 to 0.32%. In addition, the minimum and maximum of Shannon entropy around the university are 0.02 and 0.25% from compacted to sprawled areas, respectively. Tab. 2 indicates the descriptive statistics for the continuous variables of the samples.

Tab. 2

Descriptive statistics of the continuous variables of the sample

Continuous variables	N	Minimum	Maximum	Mean	Std. Deviation
Age	1288	17	37	22.83	27.305
Number of commute trips	921	6	40	11.06	4.632
Number of trips for shopping or entertainment	1238	0	40	6.00	5.716
Length of time living in the current home	1288	0	28	5.87	7.480
Urban sprawl around home (%)	664	0.01	.32	0.1506	0.0503
Urban sprawl around university (%)	680	0.02	.26	0.1471	0.0518
Inverse of building coverage ratio around home	655	0.05	286.01	8.0634	22.4663
Inverse of building coverage ratio around university	674	0	1.23	.0786	0.1812

Two Weighted Least Square (WLS) models were developed for analysing the correlation of urban sprawl around home and university with the same socioeconomic and travel behaviour variables. The results of these two models are explained in the following sections and the feedbacks to international literature are described in the discussion section.

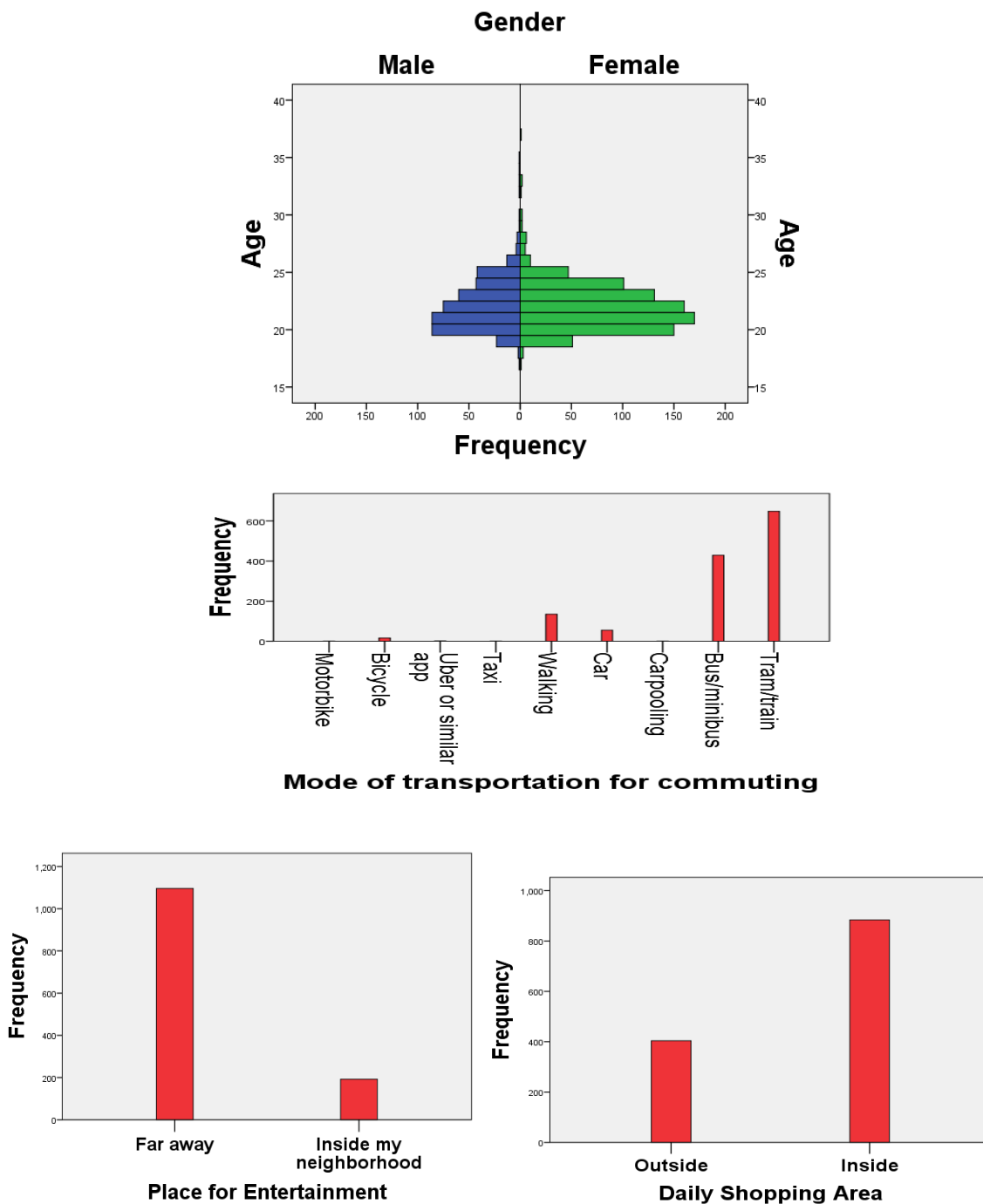


Fig. 3. Frequencies of some variables on the sample

4.2. The Weighted Least Square (WLS) model for urban sprawl around the home

The variables including gender, age, driving license, financial dependency status, gross income per month, the number of commute trips per week, mode of transport in commute trips, the number of trips for shopping or entertainment, the daily shopping area, the mode choice for shopping and entertainment activities inside and outside of the neighbourhoods,

the frequency of public transport use, the attractiveness of shops inside of the neighbourhoods, and the length time of living in the current home generated the explanatory variables of WLS model after eliminating the variables ($P > 0.10$). As shown in Tab. 3, the driving license is the weakest explanatory variable among the 14 variables, and the number of trips for shopping and entertainment and the frequency of public transport use are marginally significant, in addition to the driving license in the WLS model for urban sprawl around the home. The number of commute trips is positively correlated with urban sprawl around the home with the minimum P-value. In fact, the number of trips for commuting is the most significant prediction power in the model. In other words, those who have more commute trips per week are likely to live in sprawled areas. Daily shopping area and mode choice of transport for shopping and entertainment trips outside the neighbourhoods are negatively significant in the model. In fact, the students who do daily shopping inside their neighbourhoods may live in compacted neighbourhoods. Furthermore, those driving by car for shopping and entertainment outside their neighbourhoods may live in the sprawled areas.

Tab. 3

WLS model for urban sprawl around the home

	B	Std. Error	Beta	t	P
Gender	0.018	0.007	0.2		.008
Age	0.005	0.001	0.69	5.362	<0.001
Driving license	0.015	0.009	0.084	1.632	.103
Financial dependency status	0.035	0.007	0.184	4.887	<0.001
Gross monthly income	0.02	0.007	0.088	2.8	.005
Number of commute trips	0.003	0.001	0.255	5.582	<0.001
Mode of transportation for commuting	-0.076	0.027	-0.058	-2.807	.005
Number of trips for shopping or entertainment per week	0.001	0.001	0.056	1.868	.062
Daily shopping area	-0.038	0.007	-0.386	-5.559	<0.001
Mode choice for shopping/entertainment trips inside neighbourhood	0.079	0.013	0.161	6.182	<0.001
Mode choice for shopping/entertainment trips outside neighbourhood	-0.04	0.01	-0.121	-4.216	<0.001
Frequency of public transport use	-0.024	0.013	-0.144	-1.782	0.075
Attractiveness of shops	0.015	0.006	0.059	2.338	0.020
Length of time living in the current home	-0.001	0	-0.079	-2.238	0.026

Model Validation					
Model	Sum of Squares	df	Mean Square	F	P
Regression	91.433	14	6.531	6.531	<0.001
Residual	14.012	444	0.032	0.032	
Total	105.445	458			
Modal Summery					
R	R Square	Adjusted R Square	Std. Error of the Estimate		
1	0.931	0.867	0.863	0.17765	

4.3. The Weighted Least Square (WLS) model for urban sprawl around the university

Six highly significant variables including age, car ownership, number of commute trips, sense of belonging to the neighbourhoods, entertainment place, and residential location choice developed WLS model for urban sprawl around universities (Tab. 4). The other variables were eliminated based on the explanation in the analysis method section and there is no variable with marginal significant in the model. Car ownership and age are the most positively correlated variables. It can be formulated that urban sprawl around the university is more likely correlated with the increase of car ownership and age. In addition, the number of commute trips is negatively correlated. In fact, the students may have fewer commute trips to the universities if they are located in the sprawled areas.

Tab. 4

WLS model for urban sprawl around the university

	B	Std. Error	Beta	t	P
Age	0.003	0.001	0.512	3.451	<0.001
Car ownership	0.076	0.023	0.532	3.276	<0.001
Number of commute trips	-0.001	0.000	-0.082	-2.639	0.009
Sense of belonging to neighbourhood	-0.013	0.004	-0.065	-3.167	0.002
Entertainment place	0.014	0.006	0.112	2.217	0.027
Residential location choice	-0.014	0.005	-0.087	-3.013	0.003
Model Validation					
Model	Sum of Squares	df	Mean Square	F	P
Regression	0.670	6	0.112	828.237	< 0.001
Residual	0.064	473	0		
Total	0.734e	479			

Modal Summary					
R	R Square	Adjusted R Square	Std. Error of the Estimate		
1	.956a	.913	.912	.01161	

5. DISCUSSION

An increasing dispersed and segregated urban development is considered as a serious problem worldwide. Urban sprawl has substantial environmental, social, and economic consequences, which affects natural resources, leading to higher infrastructure cost and an increase in transport expenditure, lower social interaction, and more car dependency, and ignorance of sustainable transport demand. Although, urban sprawl progresses slower in European countries than the U.S., transforming from top-down system to the liberal in East-Central Europe, which has created a lot of problems, especially in the pattern of urban development. In addition to the economic and governmental transformed systems in post-socialist countries, a change in social structure, liberalisation, and more roles for women in societies have influenced urbanisation. This study generated a model for understanding socioeconomic determinants of urban sprawl in Cracow, as an example of a large city in Poland. In fact, it aimed to determine the correlation of urban sprawl around the home with 14 socioeconomic, travel patterns, and individual perception, as well as six significant variables for urban sprawl around universities. Urban sprawl for each participant was measured by Shannon entropy, which indicated the nearest intersection to his or her home and university. Thus, the disaggregated and weighted urban sprawl contributed to the WLS model providing more accurate and reliable results. The findings confirmed that urban sprawl is associated with socioeconomic features such as age, gender, car ownership, gross income, and the financial dependency status of university students in Cracow. Therefore, regarding the factors related to urban sprawl, the comprehensive cultural, historical, geographical, technological, political, and economic considerations are essential. Although the results are in line with urban sprawl literature in some aspects, there is a shortcoming in modelling urban sprawl based on various socioeconomic factors, travel pattern, and urban form features at the city level. This study provides a clear model to determine urban sprawl according to socioeconomic predictors and travel pattern features in Cracow.

During recent decades, urban sprawl has attracted researchers' attention. However, few studies were conducted for the determinants of urban sprawl by focusing on the socioeconomic determinants of urban sprawl at the macro level using aggregated national data. Furthermore, most of the studies in urban sprawl were conducted at the country or metropolitan level and less attention was given to its modelling, contextually. For example, in the study related to urban sprawl in Europe, 15 demographic, socioeconomic, geographical, and political variables at the country level contributed to the regression model. Each variable affected three components of urban sprawl according to the urban sprawl metric introduced by [22]. This study investigated the effects of population density, ageing index, gross domestic product per capita, employment rate, household size, car availability, fuel price, road density, rail density, net primary productivity, relief energy, irreclaimable area, fraction of coastal area, history of communism, governmental effectiveness, and natural resource protection indicator on urban sprawl index in European countries [9].

Based on the report of EEA, the higher ageing index is related to lower urban sprawl among European countries, which are inconsistent with the findings of this study. However, this index considered the ratio of the 65-aged inhabitants and older to the number of 14-aged inhabitants and younger. The present modelling represents that the older students are more likely to live and study in sprawled neighbourhoods, although, this study was done among university students with the maximum age of 37.

In addition, the results in urban sprawl around the university confirmed the positive correlation between urban sprawl and car ownership.

Weilenmann et al. (2014) developed the ordinary least squares regression model by applying cross-sectional data in municipal level of Switzerland to quantify the attributes correlated with sprawl index which was measured by [22]. The positive correlation between urban sprawl around homes and gross income and age is consistent with the result obtained, which indicated that higher-income people, outbound commuters, and elderly and single-person household are positively associated with urban sprawl, while the number of inhabitants, homeownership, and higher share of old building affected the urban sprawl index in Switzerland negatively [47].

The results indicated a positive correlation between urban sprawl and students' gross monthly income in Cracow. By considering the literature [3, 5], urban sprawl is significantly related to wealth. In higher-income cities, people are more willing to live in detached houses with private garden, and they can afford the cost of driving their own car. The results confirm the positive relationship between income and urban sprawl in France conducted by [36]. However, the findings contradict the negative correlation of urban sprawl with the income in the study, which was conducted by [7].

Furthermore, the findings in Cracow indicate that financially independent students and higher-income respondents are highly significant predictors in urban sprawl around the home. Car ownership has a positive correlation with urban sprawl around the university in Cracow. Thus, the results of this study confirm those [26] who found that higher income, number of trips to outside destinations, and car ownership are considered as positive significant predictors for urban sprawl in China. Li et al. (2019) generated a regression model and employed urban population density, gross domestic product per capita (GDP), the percentage of the added value of the secondary industry in GDP, and the percentage of the added value of the tertiary industry in GDP as independent variables in the regression model to find their relationship with urban sprawl metrics for 259 different size cities in China based on national census during 2006-2014. The findings reported for small cities demonstrated that the population density and industrial features have less impact on urban sprawl than in larger cities. Thus, urban sprawl in China differs depending on the region, urban size, and administrative hierarchy [26]. This paper analysed socioeconomic features at the micro-level by producing disaggregated data. Although, this study validated some determinants such as higher-income, outbound trips (shopping and social trips to outside the neighbourhoods), or car ownership rates, which confirms their correlation with urban sprawl such as the abovementioned studies, the level, variables, and method of analysis are different.

Automobile dependence is considered as one of the characteristics of urban sprawl [18]. They validated the sprawl and its component factors against sustainable transportation mode in large urban areas in the United States, which is consistent with the results of this study in Cracow. Thus, urban sprawl around the home is more dependent on driving by car for commuting as well as shopping and entertainment in far destination trips. Furthermore, the result on the frequency of public transport use is in line with that of Guerra et al. (2018), which found that commuters are less likely to drive in compacted neighbourhoods than

sprawled and more likely to use public transport in their commute trips [16]. An increase in the probability of public transport use is strongly correlated with urban sprawl around the home in Cracow.

5.1. Implications for urban planning in Poland

The findings in this study have substantial urban policy implications for Cracow as an example of a Polish socialist city. As shown, urban sprawl in Cracow is significantly correlated with a range of socioeconomic indicators and travel patterns. To tackle the disadvantages of urban sprawl and formulate effective preventive policies, decision-makers should consider effective determinants of urban sprawl. The results revealed the strong and weak predictors of urban sprawl. Therefore, sprawl can be controlled by effective urban planning policies in Cracow. Mixed land use of urban forms is regarded as an important factor in addressing the negative points of urban sprawl. Urban sprawl around the home in Cracow has a significant correlation with the attractiveness of shops and daily shopping area. Thus, mixed-use neighbourhoods with social and entertainment facilities are more compacted compared to those without efficient amenities. More so, it represents the quality of the urban environment as an important factor to limit urban sprawl in Cracow and the way of designing urban structures influences urban sprawl in Cracow. Investing in efficient and high-quality public transport system and designing an urban environment for fostering more walking and biking are considered as other urban policies to control car-dependent urban structures and sprawling. Based on the results, car ownership is an important predictor in commuting and non-commuting trips by university students in Cracow.

This study focused on determining socioeconomic features such as gender, age, financial dependency status, gross income, driving license and their correlations with urban sprawl. Hence, providing a clear understanding of the inhabitants' needs and behaviours is helpful for addressing urban sprawl and planning sustainable urban land use. Furthermore, contextual evaluation of urban sprawl creates a deeper understanding of its determinants irrespective of the different economic and planning systems. Finally, considering different planning systems, along with cultural, social, historical, and economic conditions in the setting for controlling urban sprawl can provide efficient tools.

6. CONCLUSION

The results of this paper shed light on the urban sprawl and its socioeconomic determinants in a post-socialist city and may be used in sustainable urban planning, which can tackle negative aspects of urban sprawl in cities. In addition, an increase in age, driving license, gross monthly income, number of commute trips, and number of trips for shopping or entertainment was correlated with the probability of increasing urban sprawl around Cracow university students' home places. However, the length of living in the current home had a negative correlation with urban sprawl around the home. Furthermore, the results indicated that students in the sprawled neighbourhoods use the automobile as a dominant mode for commuting, shopping or leisure trips to far destinations, as well as prefer to do daily shopping outside the neighbourhoods. In terms of university students in Cracow, the probability of living in sprawling neighbourhoods is higher for women than men. Urban sprawl around the university was significantly correlated with age, number of commute trips, car ownership, entertainment place, sense of belonging to the neighbourhoods, and residential location

choice. Additionally, an increase in age and car ownership led to an increase in urban sprawl around the university and the students who selected to live near the university resided in compact neighbourhoods rather than sprawled areas.

Although the socioeconomic features of the respondents were considered, they were limited for the university students. In fact, they failed to represent a large variation in some variables such as age, gross income, and main activity. In addition, students may financially rely on their families and live alone. Thus, some variables like house ownership or household size are not related to our sample. Hence, we are limited in some variables, which seem more logical.

Future studies can be conducted to evaluate socioeconomic factors and travel patterns, as well as urban form determinants of urban sprawl, contextually, according to various circumstances in developed, developing, and emerging countries to compare the results to get a better understanding of urban sprawl in the different parts of the world. Although the literature on urban sprawl is strong, these studies were limited to aggregated data by applying national statistics and limited variables. Moreover, few studies were conducted on modelling urban sprawl based on socioeconomic, travel behaviour, and urban form predictors. In addition to the descriptive findings in the geographic context, it is necessary to conduct more studies on the post-socialist cities to obtain the general modelling of urban sprawl in post-socialist cities. This is so as modelling urban sprawl based on reliable predictors and considering economic and geographic context can provide a clear framework for the urban planners and decision-makers to prevent negative impacts of urban sprawl on natural resources, economic systems, and social life. Finally, this study focused on a large city as a case study, although, urban sprawl and its determinants may happen in smaller cities in less-studied contexts. Thus, other studies for comparing urban sprawl and its determinants in different city sizes can improve the weaknesses of literature on urban sprawl.

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