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COMPUTATIONAL ANALYSIS OF EFFICIENT ENVIRONMENTAL STRATEGIES FOR SMART CITIES DEVELOPMENT

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ABSTRACT

The existing housing stock offers a large potential for the future. The housing stock of the mass construction is located mainly near downtowns or at their outskirts. Internet network, road network, urban mass transportation, social and cultural services, civic amenities, sports grounds, rest and relaxation zones are established in these residential districts, housing estates. All social strata of residents reside in city districts. The trend during the last 20 years shows that people move from cities to their suburbs. We cope with problems related to civic amenities, transportation, sewerage and water supply networks or internet connection in suburbs. Residents of suburbs work in cities, so they must commute to cities for work, and spent many hours in means of transport, there are no sufficient parking places for them, they produce excessive quantity of CO_2 emissions, which is not smart. On the basis of the aforementioned factors, a residential district with the existing housing stock and its renovation in comparison with the individual housing construction at suburb was selected for subject of the case study. In this case study, we focused on obtaining the information and solution of three components creating a smart city, namely: smart energy, smart mobility, and smart economy. These three components were verified in the study by comparison of two areas in the SR. One area is located in the downtown, existing city district in the City of Kosice. The second area is located 11 km from downtown, and it is the suburb. These two areas were compared taking into account energy, environmental and economic demandingness. Primary energy and CO_2 emissions were solved in energy assessment. The quantity of primary energy and CO_2 emissions was calculated as the total quantity and specific quantity related to the measure unit. In order to take into account the number of residents residing in areas of interest, a new coefficient has been introduced, namely the population number coefficient (KPO). From results of multi-criteria analysis it follows that the residential district achieves the potential of 91.2% to 96.2%. The suburb achieves the potential of 30.2% to 45.7%. It has been demonstrated that the renovation of the existing housing stock is more advantageous from the point of view of energy, environment and economy than the construction of the new housing stock.

Keywords: *Smart city, City district, Suburb, Renovation, Energy*

1. INTRODUCTION

The smart city includes technologies, innovations and planning that respond to social, economic and political challenges in city districts. Stress is put on demographic changes, solution of pollution of the environment, city life sustainability, utilization of brownfields vs. greenfields, transportation, energy effectiveness and others. General requirements for smart cities exist, but they must be solved specifically for respective cities or countries, because each country has different problems and different requirements [1].

Figure 1: Smart city scheme [2]

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In the Slovak Republic (SR), housing capacities are expanded in the form of individual housing construction in suburbs that is not smart approach taking into account expansion of capacities. Sufficient capacities exist in cities either in the form of the existing apartment dwelling houses, or unused areas intended for the construction or brownfields. Suburbanization is most frequently related to migration of inhabitants of cities to countryside background, where they look for more pleasant and healthier environment for life [3], [4], [5]. This phenomenon is seen not only in the SR, but also in Central and Eastern Europe during last decades [5], [6]. Problems originate, for example in relation to transportation, because capacity of road connection with cities is not sufficient for increasing traffic intensity resulting in the origin of traffic congestions. Whereby the network of urban mass transportation has been established in cities that can save time, money, reduce loads caused by transportation and protects the environment, because the lower quantity of CO_2 emissions is produced. Approximately 25% of worldwide CO_2 emissions can be ascribed to transportation. Although cars and trucks produce substantial portion of emissions (approximately 75% worldwide). Because consumption of energy in transportation could probably double by 2050, associated CO_2 emissions, as an integral part of general strategy of CO_2 emissions reduction, must be dramatically reduced by 50% [7]. The Commission of the European Union states in the Green Paper on the Urban Environment 1990: The development of the suburbs is perceived as a threat to functioning cities and peaceful life [8].

Buildings are among the largest consumers of energy [9]. As cities are host to the majority of the world's population and building stock, they are responsible for approximately 60% of global energy use and over 75% of energy related CO_2 emissions [10], [11]. The European Union states in its strategies for the period of 2020 – 2050 the necessity of renovation of the existing buildings with stress put on energy saving, protection of the environment and natural resources [12], [13], [14], [15], [16]. Cities are recognized as pivotal players for the development of a smart, sustainable, and low-carbon economy [17]. One side of the coin identifies cities as key elements of social and economic innovation, as milieus where consumers, workers, and businesses are concentrated, delivering about 67% of EU's gross domestic product (GDP) [18]. The other side points out how poverty, segregation, energy consumption, and pollutant emissions often manifest themselves there [19], [20]. There is necessity for a rapid transition toward more efficient and sustainable urban settlements [21]. Smart cities, when properly implemented, represent the current way of creating more livable areas, which are both sustainable and energy efficient [22].

New buildings represent the increase of 1% to the existing housing stock [23]. In the Slovak Republic, 48% of apartments are located in apartment dwelling houses [24]. The demographic curve has been stabilized in the Slovak Republic during the last 10 years. The total increase of inhabitants has even the decreased nature [24]. Up to 95% of inhabitants living in the Slovak Republic can be categorized to the lower and middle classes [24], [25]. Less than average monthly wage is received by 58% of inhabitants of the Slovak Republic [26], [27]. Demand for housing is a temperamental problem of each class of inhabitants. The existing housing stock, mainly in the form of the panel construction in the period 1970 – 1990 offers a great potential in the solution of the housing question for dominant group of inhabitants of the Slovak Republic. In spite of this fact, the housing construction takes place now that is oriented towards minority groups of inhabitants. The design and implementation of buildings energy retrofit strategies is a complex process involving a large number of decision variables and actors, especially when public housing is concerned [28], [29], [30]. Okamura [31] states that it is necessary to examine, solve and pay attention how to use better things that already exist without necessity of further useless expansion. It is always necessary to look for reserves. It is necessary to look for real economic, social and ecological improvements of functioning using reasonable planning. He states that well-considered town planning is missing. It is necessary to define rules for individual entities implementing their partial investment plans on the territory.

On the basis of these facts the city district of the existing housing stock and its renovation as smart city in comparison to the individual housing construction at suburb was selected for subject of the case study. In this case study, we focused on obtaining the information and solution of three components creating a smart city, namely: smart energy, smart mobility, and smart economy. These three components were verified in the study by comparison of two areas in the SR. One area is located in the downtown, existing city district in the City of Kosice. The second area is located 11 km from downtown of the City of Kosice, and it is the suburb. These two areas were compared taking into account energy, environmental and economic demandingness. In the literature mentioned so far, neither the similar areas nor the established or concluded conclusions are assessed. Little attention is dedicated in literature how efficient, smart and scientifically can an existing residential stock be renovated. Most are dedicated to structural renovation of the residential buildings.

2. METHODS

2.1 Description of the area of interest

Climate of the SR is determined by its position in the North Temperature Zone, where 4 seasons of the year alternate. The lowest average annual temperature is -3.7°C at highest altitudes. Lowlands with the average annual temperature of 10.3°C are the warmest areas in the Slovak Republic. January is the coolest month in lowlands and February in highest altitudes. The average temperature of the warmest month (July) ranges from 15°C to 18.5°C, and temperature the coolest month ranges from -3°C to -6°C [32].

2.1.1 City district

The overall surface of the area of interest is 147,550 m^2. The area of interest is inhabited by 1,724 residents. They are residents with the permanent address in this area [33]. The area belonging to apartment dwelling houses is 55,228 m^2. The term “area belonging to apartment dwelling houses” means the built-up area and surface of near surroundings including side-walks, front gardens, green areas, garages and parking places. This is the area belonging to apartment dwelling houses. Panel and brick systems of apartment dwelling houses are present in the area of interest with the average heat transfer coefficient U = 1.12 W·m^{-2}·K^{-1}. The apartment dwelling houses are connected to the centralized heat supply system. Heat and hot water are produced in the city heating plant.

2.1.2 Suburb

The area of interest is located approx. 11 km from the downtown. Single storey and two-storey family houses are present in this area. The size of the area of interest is 55,800 m^2. Sizes of parcels of land ranges from 660 to 810 m^2 with the total number 70. The average size of the parcel of land located in the area of interest is 720 m^2. Floor areas of family houses range from 130 m^2 to 155 m^2. The average floor area of family houses is 140 m^2. The number of persons living in a family house was 3 in average, 210 persons in total. The overall floor area of family houses A_b is 9,800 m^2.

A population number coefficient (KPO) has been introduced allowing comparison of two areas with identical size from the point of view of different load, where a number of housing units are located and a number of people live. If apartment dwelling houses are located on one territory and family house on another territory, their absolute values, for example energy demand, will be different with the same technical design depending only on the building volume. On the contrary, mutual comparison will lead to the same results when assessing the gauging surface (most frequently m^2). But it is not possible to say in either case, which load they cause on the area, where they are built. The introduction of this coefficient allows the quantification of the solution from the point of view of different areas.

KPO = Number of inhabitants living in area of interest / Size of the area adjacent to houses [inhab·m^{-2}] (1)

2.2 Energy assessment

Four energy alternatives of the apartment dwelling house were considered in the city district. Alternative A1 considered specific energy used for heating of 141 kWh·m^{-2}·a^{-1} and specific energy used for domestic hot water production of 22 kWh·m^{-2}·a^{-1}. These values represent actual measured values of specific consumption of energy in the Slovak Republic [34]. This alternative represents the original state. Alternative A2 considered specific energy used for heating of 52 kWh·m^{-2}·a^{-1} and specific energy used for domestic hot water production of 22 kWh·m^{-2}·a^{-1}. This alternative represents the current partial standard of renovation. Alternative A3 considered specific energy used for heating of 30 kWh·m^{-2}·a^{-1} and specific energy used for domestic hot water production of 16 kWh·m^{-2}·a^{-1}. This alternative represents the current comprehensive standard of renovation. And the last, fourth alternative A4 considered specific energy used for heating of 15 kWh·m^{-2}·a^{-1} and specific energy used for domestic hot water of 8 kWh·m^{-2}·a^{-1}. This alternative represents the construction standard in the future. The overall floor area of apartment dwelling houses A_b is 70,239 m^2. The primary energy factor for the urban heating system was considered f_p is 0.70 [-] and CO_2 emission coefficient K is 0.22 [-].

Two energy alternatives were considered for family houses in the suburb. Alternative B1 considered specific energy used for heating of 42 kWh·m^{-2}·a^{-1} and specific energy used for domestic hot water production of 12 kWh·m^{-2}·a^{-1}. This alternative represents the current construction standard. Alternative B2 considered specific energy used for heating of 15 $kWh \cdot m^{-2} \cdot a^{-1}$ and specific energy used for domestic hot water production of 8 $kWh \cdot m^{-2} \cdot a^{-1}$. This alternative represents the construction standard in the future. Natural gas, electric energy and solid fuels are mainly used as a heat source in family houses in the SR. Therefore, these three media were considered in the calculation. The percentage distribution was considered equal, namely 33.3% for each medium. The primary energy factor f_p is 1.10 for natural gas; 2.20 for electric energy and 0.15 for solid fuel. The CO_2 emissions coefficient K is 0.22 for natural gas; 0.167 for electric energy and 0.02 for solid fuel. The average primary energy factor f_p is 1.15 and the CO_2 average emissions coefficient K is 0.14.

2.3 Environmental assessment

Environmental assessment is understood as assessment of areas of interest in relation to transportation, i.e. to CO_2 emissions. In the first step, percentage distribution of transportation was determined for 38 variations (V1 – V38). This number of variations is based on the transportation distribution as follows: Urban mass transportation/bus transportation from 0% to 100%, cars from 0% to 100% and pedestrians or passengers from 0% to 30% and their mutual combinations. The average production of CO_2 emissions by a car is 160.4 $g \cdot km^{-1}$. The average production of CO_2 emissions by urban mass transportation is 98.5 $g.km^{-1}$ [35]. Individual distributions of transportation are arranged from the lowest to the highest average value of CO_2 emissions, from 69.0 $g \cdot km^{-1}$ to 160.4 $g \cdot km^{-1}$.

In the second step, the number of perimeters was determined that are stated in Fig. 2. Their number was determined for two perimeters of the city district and two perimeters of the suburb. For the city district: perimeter No. 1 with a radius of 2.5 km and perimeter No. 2 with a radius of 5.0 km. For the suburb district: perimeter No. 1 with a radius of 7.5 km and perimeter No. 2 with a radius of 12.0 km. The selected perimeters represent theoretical (air) distances that must be moved by people for work, entertainment, shopping and other duties. In reality, these values were increased using the conversion factor of 1.4 to real number of km for individual perimeters. They were modified to 3.5 km for the perimeter No. 1 and to 7.0 km for the perimeter No. 2 of the city district. In the case of the suburb, the number of km was modified to 10.5 km for the perimeter No. 1, and to 16.8 km for the perimeter No. 2. The conversion factor serves for achieving the real numbers of kilometres moved. The value of the conversion factor 1.4 was derived from real distances obtained from public available GPS navigations (Sygic, Waze, Google maps). The values of perimeters are based in internal survey and from available distance to the downtime in the case of smaller perimeter, and a wider surroundings in the case of larger perimeter.

In the next step, the number of routes was determined in individual perimeters. The number of routes was determined to 2, 4 and 6. The minimum number of routes was determined to 2 ones. This means that residents travel to work and back from work home. The maximum number of routes was 6, and it was considered as travel to work, from work, for entertainment, to interest group, shopping, transport of children, family members and the goods or other duties. In the next step, the number of residents living in areas of interest was taken into account. The number of residents considered for the city district was 1,724, and the number of residents considered for the suburb was 210. Total CO_2 emissions and CO_2 emissions per KPO were determined on the basis of these input data.

2.4 Economic assessment

2.4.1 Approaches to the renovation of apartment dwelling houses

The renovation for demands of work are understood in a broader sense as follows:

- Standard,
- Eco – friendly,
- Smart.

Sd: Standard

This approach to the renovation represents the current comprehensive renovation. The estimated price of the renovation ranges from € 100 to 130.m^{-2} (€ 115.m^{-2} in average) of the floor area. This price is based on real projects that were implemented in SR [36], [37]. The basic price of the original apartment in the area of interest is € 93,000 [38].

Ef: Eco – friendly

Smart approach to the renovation represents the higher standard of the renovation. This type of renovation is related to apartment dwelling houses and their close surroundings. The increase of useful area in housing units is considered. This means interconnection of several apartments either vertically or horizontally. Modernization of architectonic aspect of apartment dwelling houses is considered using renewable energy resources in apartment dwelling houses (the application of solar, photovoltaic system on the roof, integration of these systems directly into façade...), the application of shadowy elements,

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utilization of solar architecture, application of forced ventilation with the heat recuperation unit, application of smart control systems. Atomization or change of the source of heating and hot water preparation is considered. The estimated price of the renovation ranges from € 200 to 260.m^{-2} (€ 230.m^{-2} in average) of the floor area.

St: Smart

The system of public spaces has the principal impact on the housing quality of environment. Interventions into public parks and squares have potentially large impact not only on layout, but also on perceived image of the whole locality. This is why this type of renovation is related to apartment dwelling houses and their wider surroundings. Living, shared spaces or also private front gardens can provide natural social control of public spaces. Places with business activities and services contribute to richer functional content of environment. At the same time, but within an active parter, they create nature and importance of spaces, in which they are opened. Roof surfaces of apartment dwelling houses and annexes can also be used as private terraces, or shared terraces and gardens. So-called "double it solutions" are also considered, such as: playground and front garden on the roof of underground parking place, underground litter baskets connected to the centre (waste management), smart lighting of apartment dwelling houses and parks with monitoring (public safety). The estimated price of the renovation ranges from € 400 to € 520.m^{-2} (€ 460.m^{-2} in average) of the floor area.

Table 1: Monthly payments based on renewal category according to buying an apartment and renovating a housing stock

Category	Price of three-room apartment	Mortgage payment	Cost of an apartment	Fund repairs	Fund repairs average	Total costs	Total payment (mortgage payment)
	[€]	[€·month^{-1}]	[€·month^{-1}]	[€·month^{-1}]	[€·month^{-1}]	[€·month^{-1}]	[€·month^{-1}]
Sd	93 000	285	145	25 – 35	30	175	460
Ef				50 – 70	60	205	490
St				100 – 140	120	265	550

The difference between total payments in purchase of apartment and renovation for renovation categories Sd and Ef stated in Tab. 1 is € 30 that represents 6.1%. If we compare total payments for renovation categories Sd and St, the difference is € 90 that represents 16.4%. If we compare total payments for renovation categories Ef and St, the difference is € 60 that represents 10.9%.

Table 2: Monthly payments based on renewal category according to renovating a housing stock

Category	Price of three-room apartment	Mortgage payment	Cost of an apartment	Fund repairs	Fund repairs average	Total costs	Total payment
	[€]	[€·month^{-1}]	[€·month^{-1}]	[€·month^{-1}]	[€·month^{-1}]	[€·month^{-1}]	[€·month^{-1}]
Sd	93 000	0	145	25 – 35	30	175	175
Ef				50 – 70	60	205	205
St				100 – 140	120	265	265

The difference between total payments for renovation categories Sd and Ef stated in Tab. 2 is € 30 that represents 14.6%. If we compare total payments for renovation categories Sd and St, the difference is € 90 that represents 34.0%. If we compare total payments for renovation categories Ef and St, the difference is € 60 that represents 22.6%.

2.4.2 Construction of family houses

The prices of family houses with parcel of land are very difficult to estimate, because they depend on locality, floor area of the house, house facilities. But in general we can consider the price ranging from € 1,300 to € 2,400 .m^{-2} [39]. The completion of houses is not included in the price, this means that it is considered in the form of a bare house.

Table 3: Monthly payments based on the category of family houses construction

Category	Price of the family house	Mortgage payment	Costs of a family house	Fund repairs	Fund repairs average	Total costs	Total payments (mortgage payment)
	[€]	[€·month^{-1}]	[€·month^{-1}]	[€·month^{-1}]	[€·month^{-1}]	[€·month^{-1}]	[€·month^{-1}]
Sd	182 000	570	70	25 – 35	30	100	670

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Ef	259 000	855	70	50 – 70	60	130	985
St	336 000	1 140	70	100 – 140	120	190	1 330

The difference between total payments for construction categories Sd and Ef stated in Tab. 3 is € 315 that represents 32.0%. If we compare total payments for construction categories Sd and St, the difference is € 660 that represents 49.6%. The difference between total payments for construction categories Ef and St is € 345 that represents 25.9%.

2.4.3 Mutual comparison and summary

The following two tables (Tab. 4, Tab. 5) compare total payments between the city district and suburb. In Tab. 4 an apartment in the city district is compared with a family house at the suburb in relation to the total monthly payment. In this chase, purchase of an apartment and renovation of housing stock is considered according to renovation category. In Tab. 5 an apartment in the city district is compared with a family house at the suburb in relation to the total monthly payment. In this case only renovation of housing stock according to the housing stock renovation category is considered, because the apartment is already in personal possession.

Table 4: Comparison of the city district and the suburbs with respect to the total monthly payments where the purchase of the apartment and the renovation of the housing stock is contemplated

Total payment for city district (with mortgage payment)	Total payment for suburb (with mortgage payment)	Difference	Difference
[€·month^{-1}]	[€·month^{-1}]	[€]	[%]
460	670	210	31.3
490	985	495	50.3
550	1 330	780	58.6

Table 5: Comparison of the city district and the suburbs with respect to the total monthly payments where the purchase of the renovation of the housing stock is contemplated

Total payment for district city	Total payment for suburb (with mortgage payment)	Difference	Difference
[€·month^{-1}]	[€·month^{-1}]	[€]	[%]
175	670	495	73.9
205	985	780	79.2
265	1 330	1 065	80.1

The difference between monthly payments ranges from 31.3% to 58.6%, if purchase of the apartment and renovation of housing stock is considered, and from 73.9% to 80.1%, if the apartment is in personal possession, and costs on the apartment and renovation according to the renovation category are paid. In both cases the renovation of the existing housing stock is more advantageous from the economic point of view than the construction of the new housing stock.

2.5 Potential and strategy of the renovation of the housing stock

Potential of the renovation of the existing housing stock was determined on the basis of multi-criteria analysis. Resulting values of energy, environmental and economic assessment were used for this analysis. Intervals for individual assessments were determined and depicted in Fig. 3. These intervals were determined on the basis of resulting minimum values obtained from the city district and resulting valued obtained from the suburb. The minimum values were selected from the city district because they were lowest ones. The maximum values were selected from the suburb because they were highest ones.

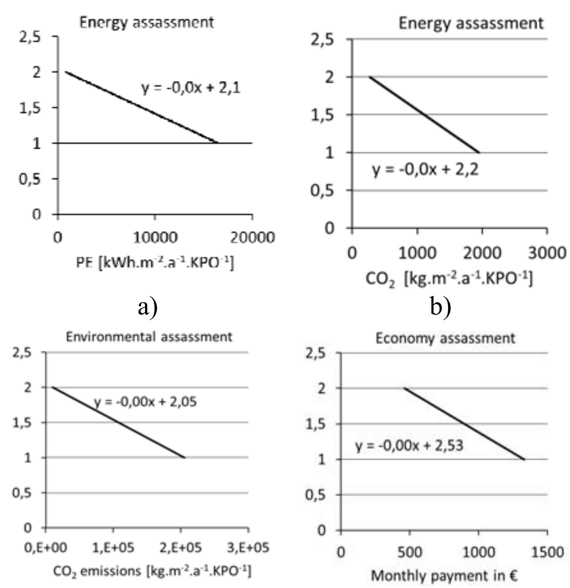

Figure 3: Determination of intervals for multi-criteria analysis, where a) Primary energy per KPO, b) CO_2 emissions per KPO from energy assessment, c) CO_2 emissions per KPO from environmental assessment, d) monthly payment from economy assessment

For primary energy per KPO, interval ranging from 861 to 16,501 was determined, where the value 2 was assigned to number 861 and the

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value 1 was assigned to number 16,501. The value 2 is understood as the best one, or as the value with the highest potential, and the value 1 is understood as the worst one, i.e. the value with the lowest potential. For CO_2 emissions per KPO, interval ranging from 271 to 1,947 was determined, where the value 2 was assigned to number 271 and the value 1 was assigned to number 1,947. For CO_2 emissions per KPO, interval ranging from 9,835 to 205,870 was determined based on environmental assessment, where the value 2 was assigned to number 9,835 and the value 1 was assigned to number 205,870. For monthly payments, interval ranging from 460 to 1,330 was determined based on economic assessment, where the value 2 was assigned to number 460 and the value 1 was assigned to number 1,330. Subsequently, combinations K1 to K4 were determined, and weights of individual criteria were assigned to them. Weights were considered in the following sequence (economic, energy and environmental assessment): K1 – 40/30/30; K2 – 33.3/33.3/33.3; K3 – 30/30/40, K4 – 30/40/30.

The K1 combination represents the current situation in the renovation of housing stock and the use of public transportation. The K2 combination represents the future renovation standard. It is considered that public transportation will be used more intensively than in the present time. If we considered that individual transportation will be used more intensively than in the present time, the potential arising from the K3 combination will be achieved. If we considered that public transportation will be used more intensively than in the present time and individual transportation will be used less, and if stress will be put on energy and economic intensity, the potential arising from the K4 combination will be achieved. Achieved potential of the areas of interest is the result arising from individual combinations. This potential ranges from 0% to 100%. 100% in this study is understood as the best area from the energy, environmental and economic point of view.

3. RESULTS

Resulting values from energy assessment are represented in following four figures. Resulting values of primary energy are represented in Fig. 4 and Fig. 5. CO_2 emissions are represented in Fig. 6 and Fig. 7.

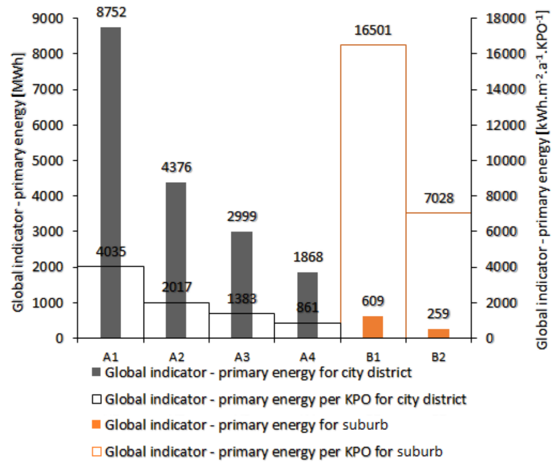

Figure 4: Primary energy for city district and suburb

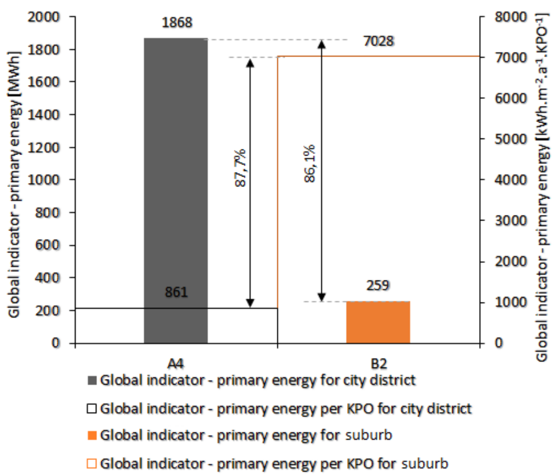

Figure 5: Primary energy for selected variants for city district and suburb

Variants A4 and B2 were mutually compared, because they have equal energy inputs. The selected variants differ in heat supply and number of residents. Difference between values A4 and B2 in the case of primary energy is 1,609 $MWh \cdot a^{-1}$ that represents 86.1%. Difference between values A4 and B2 in the case of primary energy per KPO is 6,166.8 $kWh \cdot m^{-2} \cdot a^{-1} \cdot KPO^{-1}$ that represents 87.7%. Impact of the number of residents on comparison of areas of interest has been proven taking into account primary energy per KPO.

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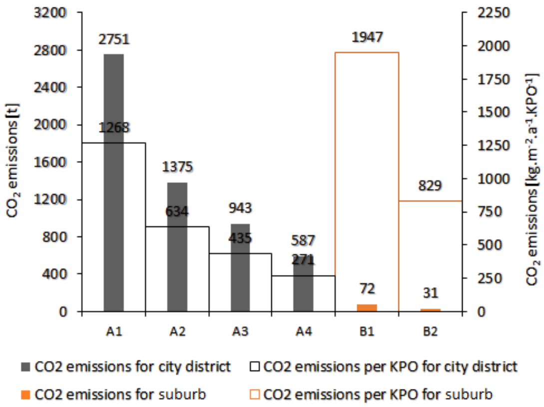

Figure 6: CO_2 emissions for city district and suburb

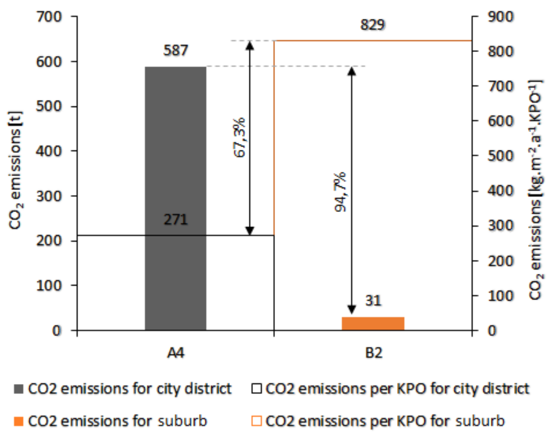

Figure 7: CO_2 emissions for selected variants for city district and suburb

Variants A4 and B2 were mutually compared, because they have equal energy inputs. The selected variants differ in heat supply and number of residents. Difference between values A4 and B2 for CO_2 emissions is 556.6 $t \cdot a^{-1}$ that represents 94.8%. When comparing the values of alternatives A4 and B2, the difference for CO_2 emissions per KPO is 558.4 $kg \cdot m^{-2} \cdot a^{-1} \cdot KPO^{-1}$ that represents 67.4%.

Impact of the number of residents on comparison of areas of interest has been proven taking into account CO_2 emissions per KPO. The quantity of primary CO_2 emissions per KPO is considerably lower for the city district than for the suburb. These results point out that the quantity of primary energy per KPO is by 87.7% lower, and CO_2 emissions per KPO are by 67.4% lower for the city district than for the suburb. The renovation of the existing housing stock is more advantageous from the energy point of view than the construction of the new housing stock.

Resulting values from environmental assessment are represented in following three figures. The resulting values of CO_2 emissions were compared in three scenarios. Scenario 1 deals with usability of public transportation. At the present time usability of urban mass transportation in cities is approx. 33% [40]. Therefore, the values from distribution of transportation for a city district were selected for comparison ranging from 20% to 40% (V6, V9, V13, V15, V19, V23, V25, V28, V31, V32, V34, V36). The values from distribution of transportation ranging from 0% to 30% (V9, V13, V17, V19, V21, V23, V26, V28, V29, V31, V33, V34, V35, V36, V37) were selected for the suburb, because not all satellite towns and suburbs are connected to the public transportation network. Urban mass transportation and bus transportation are not very frequent. This is way the residents of suburbs use cars more frequently. Comfort certainly plays its role in it. The resulting values of CO_2 emissions for the city district and suburb for the selected variations of transportation distribution and specified perimeters are represented in figure below. CO_2 emissions are represented in two columns of the figure. CO_2 emissions in $t \cdot a^{-1}$ are stated in the left primary axis (solid columns). CO_2 emissions per KPO in $t \cdot a^{-1} \cdot KPO^{-1}$ are stated in the right secondary axis (empty columns). The results point out the fact that CO_2 emissions per KPO are lower by 69.5% in the city district than in the suburb.

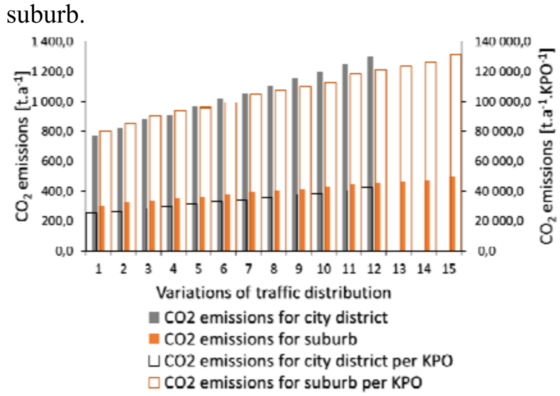

Figure 8: CO_2 emissions for city district and suburb for small perimeter and 4 routes

Extreme values are compared in scenario 2. The minimum value of CO_2 emissions per KPO for the city district is 9,835.1 $t \cdot a^{-1} \cdot KPO^{-1}$ that is valid for 3.5 km perimeter and 2 routes in the case of V1 variation of transportation distribution. The minimum value of CO_2 emissions per KPO for the suburb is 32,139.8 $t \cdot a^{-1} \cdot KPO^{-1}$ that is valid for 10.5 km perimeter and 2 routes in the case of V2 variation of transportation distribution. The difference between compared values is 22,304.7 $t \cdot a^{-1} \cdot KPO^{-1}$ that represents 69.4%. Based on the results it is obvious that CO_2 emissions per KPO are lower by 69.4% in the city district than in the suburb.

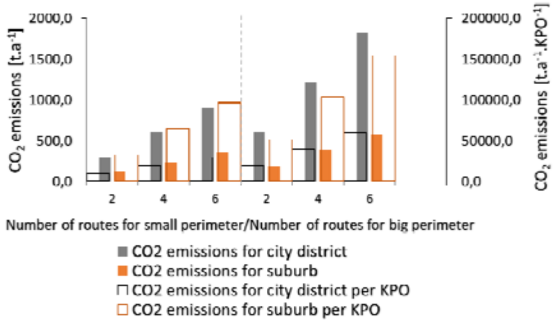

Figure 9: Comparison of minimum values of CO_2 emissions for city district and suburb

Scenario 3 considers distribution of transportation as really as possible, therefore the following variations of transportation distribution are taken into account: V6, V9, V13, V15, V17, V19, V23. The resulting values of CO_2 emissions were compared for the city district and suburb and for specified perimeters. The total number of variation combinations was considered 30. Difference between CO_2 emissions per KPO for the city district with smaller perimeter and CO_2 emissions per KPO for the suburb with smaller perimeter is 77,404.3 $t{\cdot}a^{-1}{\cdot}KPO^{-1}$ that represents 85.3%. Difference between CO_2 emissions per KPO for the city district with larger perimeter and CO_2 emissions per KPO for the suburb with larger perimeter is 77,404.3 $t{\cdot}a^{-1}{\cdot}KPO^{-1}$ that represents 81.6%. All values of CO_2 emissions per KPO for the city district are considerably lower against the values of CO_2 emissions per KPO for the suburb, namely by 81.6% to 85.3%. From the results it is obvious that CO_2 emissions per KPO are lower by 85.3% in the city district than in the suburb. On the basis of results, we can conclude that the renovation of the existing housing stock is more advantageous from the environmental point of view than the construction of the new housing stock.

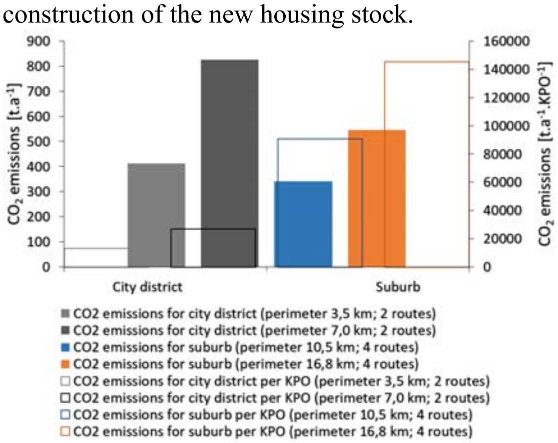

Figure 10: CO_2 emissions for combination of variation V9, 2 routes and V17, 4 routes

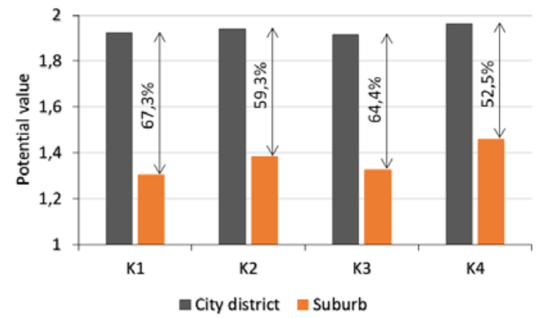

Figure 11: The results of the combinations and their comparison

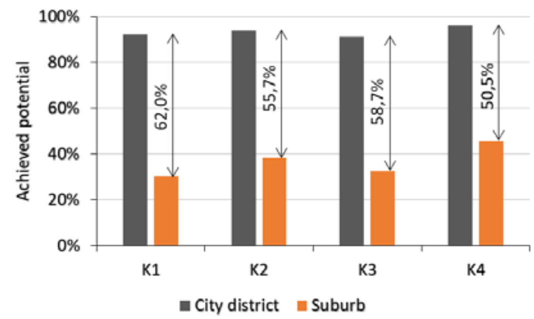

Figure 12: Achieved potential of the areas of interest

From the aforementioned results it follows that the city district achieves potential of 91.2% to 96.2%. The suburb achieves the potential of 30.2% to 45.7%. The achieved potential of suburb versus city district ranges from 32.8% to 47.5%.

4. DISCUSSION

In the Slovak Republic, housing capacities are expanded mainly in the form of the housing construction in suburbs or on greenfields at outskirts of the city. Cities are expanded uselessly, non-controllably and non-effectively. Such approaches are not smart ones. Taking into account the number of the existing apartment dwelling houses in the Slovak Republic, it is necessary to look for reserves in the existing capacities (existing construction). Occupancy of resources, additional land, construction of new roads for connection of the suburb with the city, expansion of parking places due to increased transportation is not sustainable, and it increases load of the environment. On the contrary, the existing housing stock provide almost comprehensive facilities (inevitability to complete certain types of buildings and facilities) without necessity of additional excessive expansion or occupation of additional resources. Comparison of capacities of cities was based for example on knowledge that the Swedish City of Malmö has by approximately 50 thousand residents more than Kosice [41], but it covers only

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the area of 155 km^2, while Kosice covers the area of 242 km^2. Or the Austrian City of Vienna covers doubled area than the City of Kosice, but it has 7.3 times more residents than the City of Kosice [42].

Support of functional diversity in parter of building finishing or additional buildings forming an active boundary line of streets provides higher comfort of available services for residents. This procedure also extends the active time of day, and further supports general security in the locality because it increases frequency of movement in streets. The completion of new buildings in structure of residential areas is also an opportunity how to improve physical condition of the surroundings. New buildings help to correct perceiving, strengthen diversity of the surroundings, and support its higher understandability by better definition of public spaces. Observance of following strategies, requirements and outlooks is recommended for achieving the determined potential of the existing housing stock: Proposing "double it" solutions (playgrounds on roofs of underground parking places, underground litter baskets connected to the central (waste management), monitoring parks and their surroundings (public safety), using roofs of apartment dwelling houses as terraces and small gardens; using renewable energy resources that could be integrated on the façade and on the roof; expansion of spaces by connection of apartments; expansion of spaces of balconies and loggias; perceiving city residential areas as living organisms consisting of several components.

Examination of behaviour of residents, their subjective feelings, level of interaction with the city and its facilities and other social aspects will be a principal element of further research. Cooperation with sociologists and other specialists outside technical disciplines will be necessary for this field of research. As it was mentioned above, it could be suitable to focus on optimizing further components additionally creating smart cities such as city planning, management, society, health of residents, industry and others.

5. CONCLUSION

In this case study, we focused on obtaining the information and solution of three components creating a smart city, namely: smart energy, smart mobility, and smart economy. These three components were verified in the study by comparison of two areas in the Slovak Republic. The area of city district was compared with the area of suburb of the same city taking into account energy, environmental and economic demandingness. In order to compare these different areas, it was necessary to choose an evaluating parameter that would allow this comparison. A new coefficient, namely the population number coefficient (KPO) was introduced in the study. This coefficient was introduced due to effective consideration of the number of residents living in the area of interest. The introduction of this coefficient allows the quantification of the solution from the point of view of different areas. Such approach shall be applied in the future for studies of similar type.

The subject of the energy assessment was to determined primary energy and CO_2 emissions. The quantity of primary energy and CO_2 emissions was calculated as the total quantity and specific quantity related to the measure unit per KPO. The results show that the primary energy per KPO is from 75.5% to 87.7% lower and CO_2 emissions are from 34.9% to 67.4% lower in city district than in the suburb. Environmental assessment is understood as assessment of areas of interest in relation to transportation, i.e. to CO_2 emissions. In the first step, percentage distribution of transportation was determined for 38 variations (V1 – V38). This number of variations is based on the transportation distribution as follows: Urban mass transportation/bus transportation from 0% to 100%, cars from 0% to 100% and pedestrians or passengers from 0% to 30% and their mutual combinations. In the second step, the number of perimeters was determined for two perimeters of the city district and two perimeters of the suburb. The resulting values were compared in several scenarios. Scenario 1 deals with usability of public transportation. The results show that the CO_2 emissions per KPO are lower up to 69.5% in city of district than in the suburb. Extreme values were compered in scenario 2. The results show that the CO_2 emissions per KPO are lower up to 69.4% in city of district than in the suburb. Scenario 3 considered distribution of transportation as really as possible. The results show that the CO_2 emissions per KPO are lower up to 85.4% in city of district than in the suburb.

From environmental assessment it followed that if public transportation is used more than at the present time, lower production of CO_2 would be achieved. At the same time, load rate of the transportation network that would be perceived mainly in traffic peaks, would be reduced. The study unambiguously demonstrated that load rate of the environment by transportation of residents is high in spite of availability of urban mass transportation. For science discipline, it is

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inevitable to see contribution of the study in the field of assessment of buildings in relation to the users and their activity. Sustainability is based not only on the high-quality building, but also on its interaction with all impacts including human activity.

From the aforementioned results of multi-criteria analysis, it follows, that the city district achieves potential of 91.2% to 96.2%. The suburb achieves the potential of 30.2% to 45.7%. The achieved potential of suburb versus city district ranges from 32.8% to 47.5%. It has been demonstrated that the renovation of the existing housing stock is more advantageous from the point of view of energy, environment and economy than the construction of the new housing stock.

The renovation of residential districts and cities must be solved in interaction of several aspects creating the concept of a smart city not only from the point of view of energy saving, but also from the point of view of extension of service life of apartment dwelling houses. The renovation of city districts should also be solved in interaction of science disciplines and political strategies. The modern, comfort, attractive and sustainable housing is the result. The smart city is where it is life, satisfied residents and society, transportation situation solved, sufficient energy economy, utilization of technologies and innovations.

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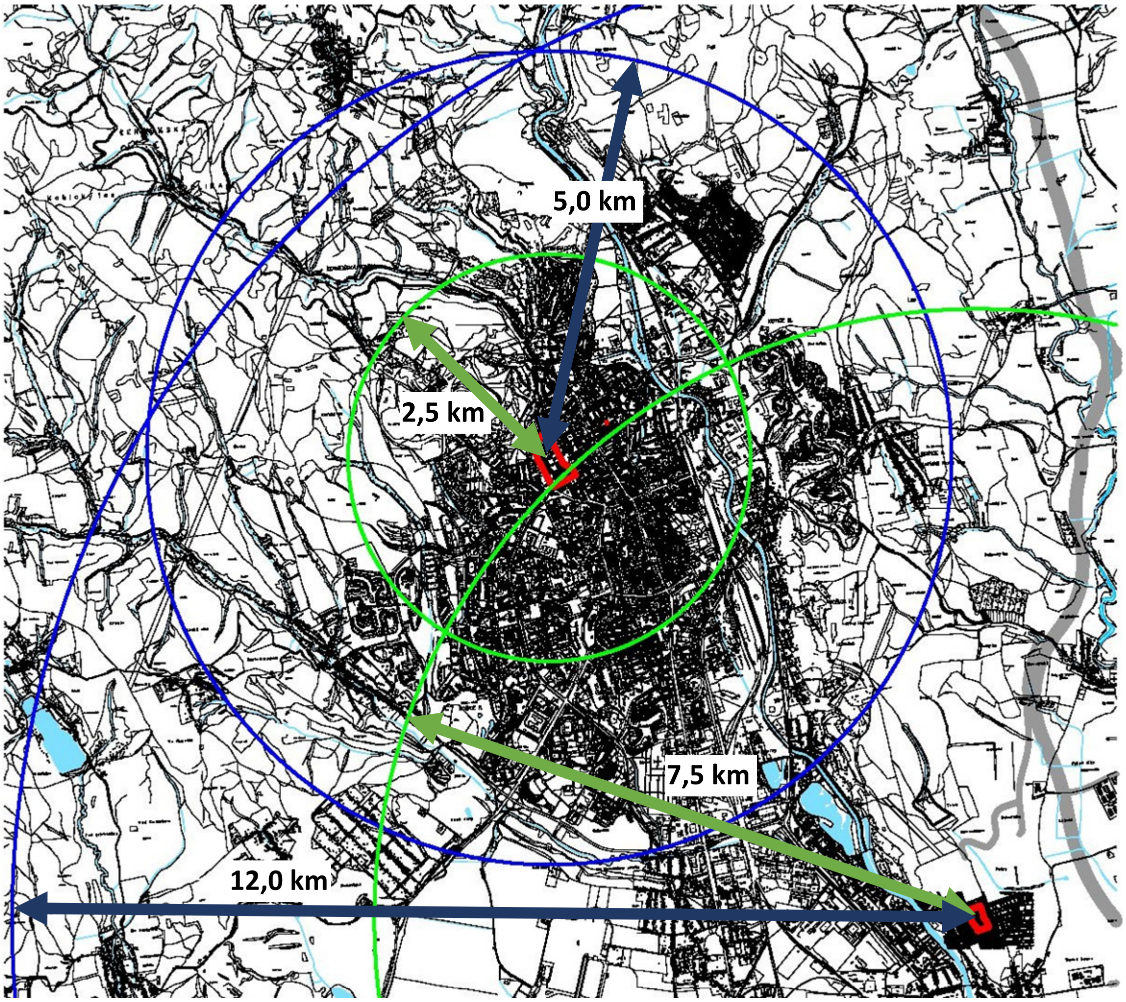

Figure 2: Scheme of the areas of interest with marked perimeters

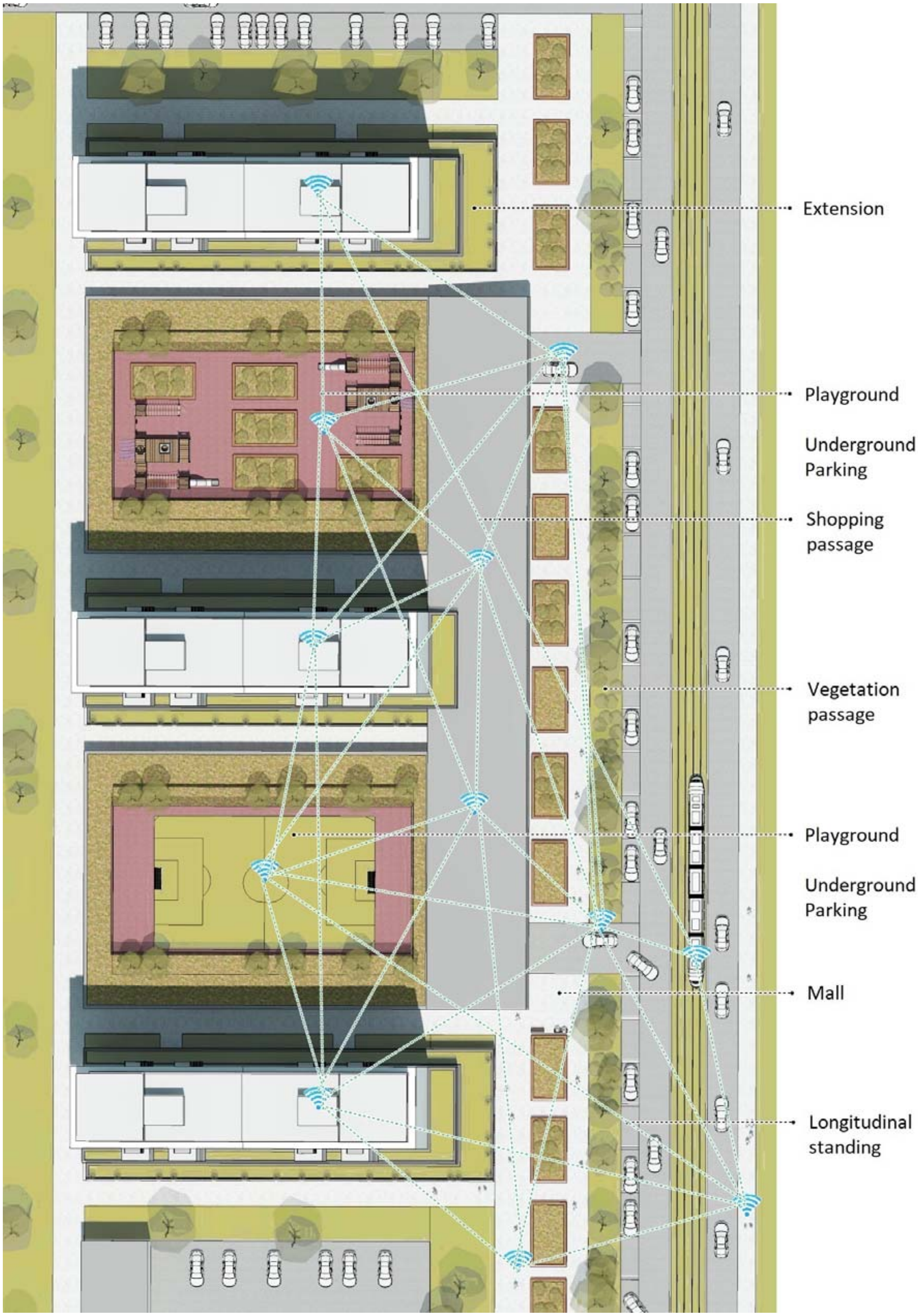

Figure 13: Area of interest of city district as a smart city

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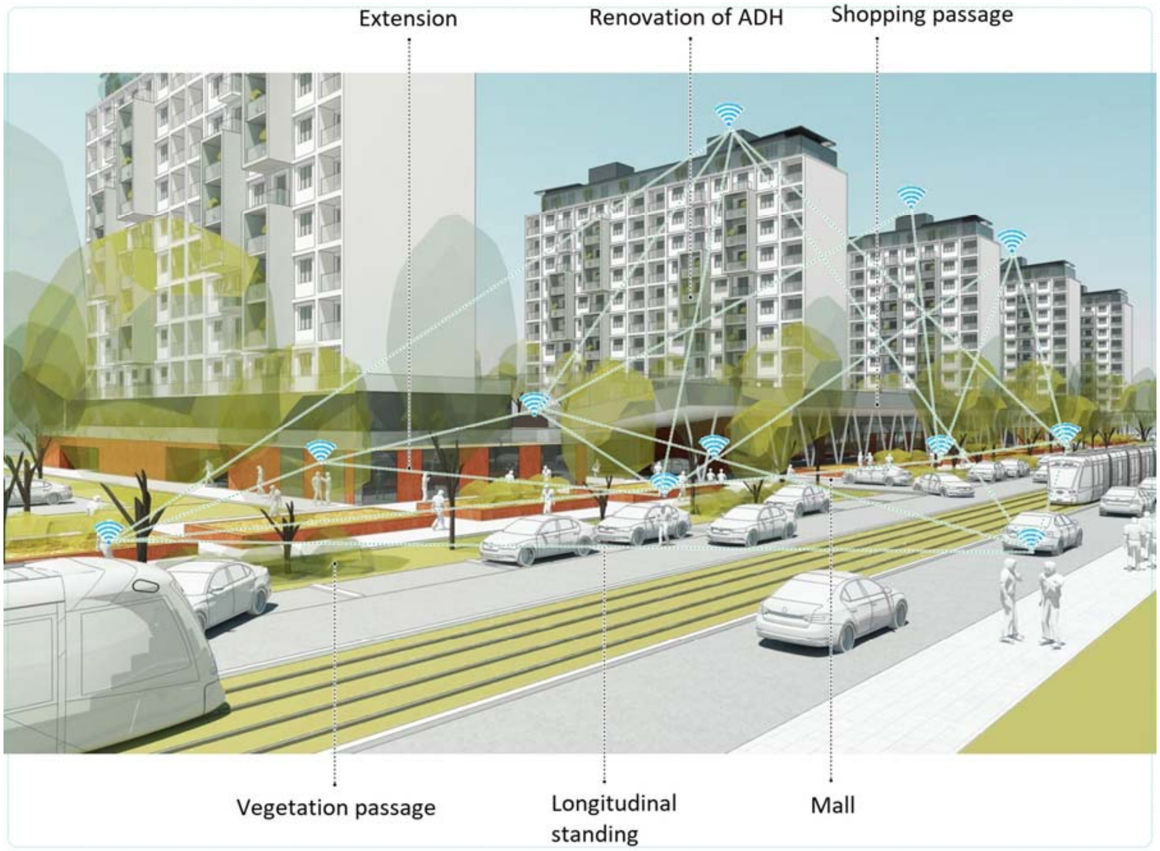

Figure 14: Area of interest of city district as a smart city