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GIS-based Estimation of Function Mix in Urban Environment at Neighbourhood Scale

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Abstract. Urban consumption is growing with every year and the studies of urban form, density, transportation, and infrastructure are becoming more popular research topics. Mixed-use development is widely recognized and discussed subject of urban sustainability. It helps to cope with energy and transportation related problems in urban environment, forms walking-friendly, economically and socially vital communities. Although mixed land use is the key planning principle of sustainable development and this term frequently appears in the urban planning strategies and literature, it is rarely elaborated upon with substantive and empirical support. Furthermore – the standard mathematical models and methods for quantifying this parameter in most cases are meant for macro-scale, e.g. comparison between cities, districts. This approach miss the human scale – the scale of walkable neighbourhood, and is not suitable to support local planning decisions and detailed measures. This study performs functional mix analysis of Klaipėda City (Lithuania) with emphasis on neighbourhood scale. The demonstrated model proves the importance of scale factor and adds another dimension to existing methods providing background for micro-scale studies of urban form.

Keywords: urban sustainability, mixed land use, mixed use development, spatial metrics, work-housing balance.

Conference topic: sustainable urban development.

Urban explosion and energy issues

Urbanisation is now becoming the most powerful and dangerous process which is changing the surface of the Earth to such an extent that it can lead to ecological and economic catastrophe. More than half of world's population, which is by now around 7.5 billion, live in the cities, and the urbanization is becoming progressively faster with every year.

The built environment is responsible for significant use of final energy (62%) and is a major source of greenhouse gas emissions (55%). If current trends in urban expansion continue, urban energy use will increase more than threefold, from 240 EJ in 2005 to 730 EJ in 2050 (Seto *et al.* 2015). Urban planning and transport policies can limit the future increase in urban energy use to 540 EJ in 2050 and contribute to mitigating climate change (Creutzig *et al.* 2015).

Achieving environmental goals, including climate change mitigation, requires comprehensive methodologies to accurately assess and minimize the impacts from this sector. At the urban scale, urban form, density, transportation, infrastructure, consumption, and analysis methods are the main research focuses now (Anderson *et al.* 2015).

Functional zoning policy and misuse of land

During the last century the need to separate land uses was stressed a lot. It started with first industrial towns and advanced during the modernist era. Influenced by the principles of functionalism, zoning had been firmly entrenched since the 1920s in the European and North American cities as a strategy to increase efficiency and safety by separating incompatible land uses. Zoning had played an important role in the reconstruction and recovery efforts after World War I.

Till now in traditional or exclusive zoning systems, it is deemed paramount that residential uses, especially single-family residences, must be protected from commercial and industrial uses. From this perspective, commercial facilities are considered nuisances, luring crowds, producing noise pollution, and creating congestion. Zoning, the core practice of land use controls, has chiefly been utilized to mitigate negative externalities that stem from nearby offending land uses and protect property rights by promoting segregation (Yang *et al.* 2016). Driven by separate function principles, built environment in Western countries in general went throw different expansion waves: dispersed growth in the 1970s, moderate re-polarization and discontinuous expansion in the 1990s and sprawl in the 2000s (Zitti *et al.* 2015).

However, like many other well-intended urban policies and planning initiatives, functional zoning, which was repeated mechanically, created many of its own problems such as congestion, pollution, urban sprawl, workplace-residence separation and the loss of urban vitality (Jacobs 1993).

The ineffectiveness of urban sprawl, excessive land consumption in the past decades has led the governments to formulate political strategies focused on the pattern of urbanization. Only recently the paradigm has changed and the concept of mixed-use development was proposed against the functional division which so strongly influenced urban design and planning in Western cities in the 20th century. Mixed use planning in urban environment helps to use energy for infrastructure and transportation more efficiently, forms the compact, walking-friendly, economically and socially vibrant communities by fusing together different functions such as residential, commercial, and recreational (Yue *et al.* 2016; Fina 2016).

Current urban research trends and mixed use development

Support for mixed-use development has increased in the literature and by interdisciplinary researchers around the world (Mirzaei *et al.* 2015; Robbins 2013). It is now proved by great number of studies that urban system efficiency is linked with the dispersion of urban functions. The resource and energy use increases drastically if urban functions are dispersed and disconnected (Oueslati *et al.* 2015; Burgalassi, Luzzati 2015). Within the research community there is a wide agreement that compact developments with a high mix of land use functions are preferable over low density or mono-functional development (Wakamatsu 2015). In economically developed regions – United States, Canada, Japan, European countries, where urbanization level is high, and also in a great number of developing countries – China, Korea, mixed-use development is recognized as a key element in both modern urban theories and planning practice (Kong *et al.* 2015). The functional configuration and dislocation of land uses within the city environments has become widely discussed topic of concern (Fina 2016).

Some commercial uses, such as retail and dining, are no longer considered inherently in conflict with residential uses. In line with New Urbanism and Smart growth, balance between residential and commercial land use is regarded as mutually beneficial: commercial owners have potential workers and consumers nearby, while individuals living in the area have easy access to retail shops and restaurants.

Past studies have revealed that mixed land use in a neighbourhood is linked to creating sustainable environment, resulting in less automobile use, gas consumption, and air pollution as well as lower transportation costs (Yang *et al.* 2016). The pioneers in this field – Handy and Niemeier (1997) first explored major mixed-use factors affecting sustainability such as neighbourhood type, travel times, and the presence of business establishments (Handy, Niemeier 1997). Krizek used neighbourhood accessibility to study land-use travel and regional behaviour (Krizek 2003). Cervero and Kockelman's work (Cervero, Kockelman 1997) has become well known for conceptualizing the three principles that comprise travel demand and pedestrian accessibility: density, design, and diversity. These authors provided empirical evidence that greater mixture of land use is related to fewer vehicle miles traveled.

Mixed land use can promote street activities, support local businesses, and create a sense of community (Song, Knaap 2004). Neighborhoods that contain a mix of retail, dining, and other commercial spaces can be attractive to residents interested in having healthy lifestyles with lower car dependency (Yang *et al.* 2016). In mixed use environment the possibility to find all the objects of daily needs in close neighbourhood increases and therefore it reduces private car use, travel distances, travel time and save the resources associated with these activities (Creutzig *et al.* 2015). Naturally land value increases when there is proper mix of uses. Case study of Seoul show that a higher spatial concentration of commercial land use in a neighborhood initially results in increased residential land values, but drops off beyond a threshold level by excessive noise or crowding (Yang *et al.* 2016). The study of Athens land use intensity illustrates a multidimensional analysis of indicators of urban land use efficiency. Researchers conclude that typical urban functions – mixed land uses, multiple-use buildings, vertical profile, are the variables most associated with high efficiency in the use of land (Zitti *et al.* 2015).

Integrating transport and land-use mix is one of the goals of planning policies around the world (Houston *et al.* 2015; Parkin 2016). Many studies mention the benefits of mixed land-use development towards creating sustainable transportation system (Marquet, Miralles-Guasch 2015; Giles-Corti *et al.* 2015; Sallis *et al.* 2016a; Newman *et al.* 2016). The attempts to assess the sustainability of the neighbourhoods with mixed land-use reveal that neighbourhoods with high and moderate land-use mix and proper work–housing balance are sustainable with travel behaviour (Piatkowski *et al.* 2015; Zondag *et al.* 2015; Forsyth, Oakes 2015; Gao *et al.* 2016). Some studies even advocate the proportion of mix in land-use planning decisions to save energy on transportation, i.e. make transportation most efficient by mixing different existing functions (Bahadure, Kotharkar 2015).

The health issue is also addressed with land-use changes (Zander *et al.* 2015). The compact cities with diverse land-use decrease distances to public transport and produce low motorised mobility, namely a modal shift from private motor vehicles to walking, cycling, and public transport. The modelled compact city scenarios result in health gains (for diabetes, cardiovascular disease, and respiratory disease) with overall health gains of 420–826 disability-adjusted life-years (DALYs) per 100 000 population (Sallis *et al.* 2016b).

Smart Growth and similar sustainable urban development policies had become evident concepts in public policy debates. While these concepts had widely been touted to promote an urban development pattern characterized by compact and mixed-use development, walkable and bikeable neighborhoods, not much has been written about its contribution to sustainable development. It needs a more quantitative study to be able to measure the magnitude of the contribution associated with the smart growth and similar policies (Mohammed *et al.* 2016).

Existing methods to define level of function mix

Despite growing research interest in the impacts of urban land use mix, there have been few methodological analyses of how to measure urban mixed use environments. Some methods for the estimation of land use mix level exist and are used by social geographers, social economists and statists (Song *et al.* 2013).

The concept of urban land use mix implies that nearby land uses or activities have an influence over each other across a limited spatial range. Therefore urban mixed use measures all contain two concepts: distance and quantity and reflect how the quantity and proximity of one type of land use influences another.

Most of the recent research studies in this subject come from geographical and social science background. These studies deal with the sum of each land use, most commonly the percentage of each urban land cover type and are usually based on crude estimations (Abdullahi *et al.* 2015; Rau *et al.* 2015; Govindu 2016; Cen *et al.* 2015). In the existing literature, several types of variables have been suggested and applied to measure the neighborhood-scale characteristics of urban environments as these relate to non-residential land use. The simplest way to evaluate neighborhood land use attributes is to calculate the distance from an individual residential parcel to the nearest non-residential property. Nearest-distance variables only consider proximity to a primary location designated for non-residential use and do not reflect its intensity or concentration (Yang *et al.* 2016).

In regard to quantifying mixed land use, the entropy index has been often utilized. However, since it is based on the assumption that residents prefer the availability of various facilities and balanced activities in their neighborhoods, this index does not provide estimation of the individual effects of spatial concentration of commercial activities on residential land values. Thus, we utilize the number of nearby commercial employees around each residential parcel with a quadratic formation in order to identify the trade-off relationship between the proximity effect and the disamenity effect (Yang *et al.* 2016)

Case study

This study is performed for Klaipėda city, Lithuania. This is demonstrational study with the methods developed by Urban Planning Institute of Vilnius Gediminas Technical University. The methods were used in town planning when working on general plans of smaller Lithuanian towns and other urban projects. The results helped planners to find suitable locations, and functional uses for city blocks.

Klaipėda city covers 110 km2 and at has around 157 000 inhabitants, from which 78 000 are working people. The city has a sea port in Baltic sea and is at a great degree industrial city. It is administratively divided into 4 districts and 12 smaller divisions which can be called neighbourhoods according to modern urban terminology (see Table 1).

Table 1. The names of districts and neighbourhoods of Klaipėda city

District name	Neighbourhood name	Area, ha	Population, approx.
Marių	Žardės	1267.57	950
	Smeltės	603.48	51 400
	Lypkių	821.03	60
Baltijos	Gedminų	464.49	45 100
	Rumpiškės	453.74	18 620
Pajūrio	Centro	514.51	17 060
	Melnragės	708.05	1 220
	Smiltynės	774.72	80
Danės	Sendvario	569.66	4 160
	Luizės	492.28	10 060
	Tauralaukio	806.97	2 720
	Labrenciškių	1356.66	5 980

Preparing the dataset

To create the readily available vectorial data GDB25000 was used. This data contains layers with buildings, street lines and other objects without attribute information. Vectorial data was extended by adding x any centroid coordinates and specific data values to vector entity of each building. To prepare the database and manage this data GIS was used.

In this case study there was a need to collect more precise information about the use of the buildings. Land cover images didn't give this kind of information, they only provide information about dominating function of area or land plot. Collecting the information about the use of the buildings was more time-consuming than getting readily available information from satellite images or CORINE land cover data, but it is still the most practical way for analysis on neighbourhood scale. Only such a data can give useful results at smaller scale.

Three constant and clear functions (land-uses) used by transportation planners were declared. These are:

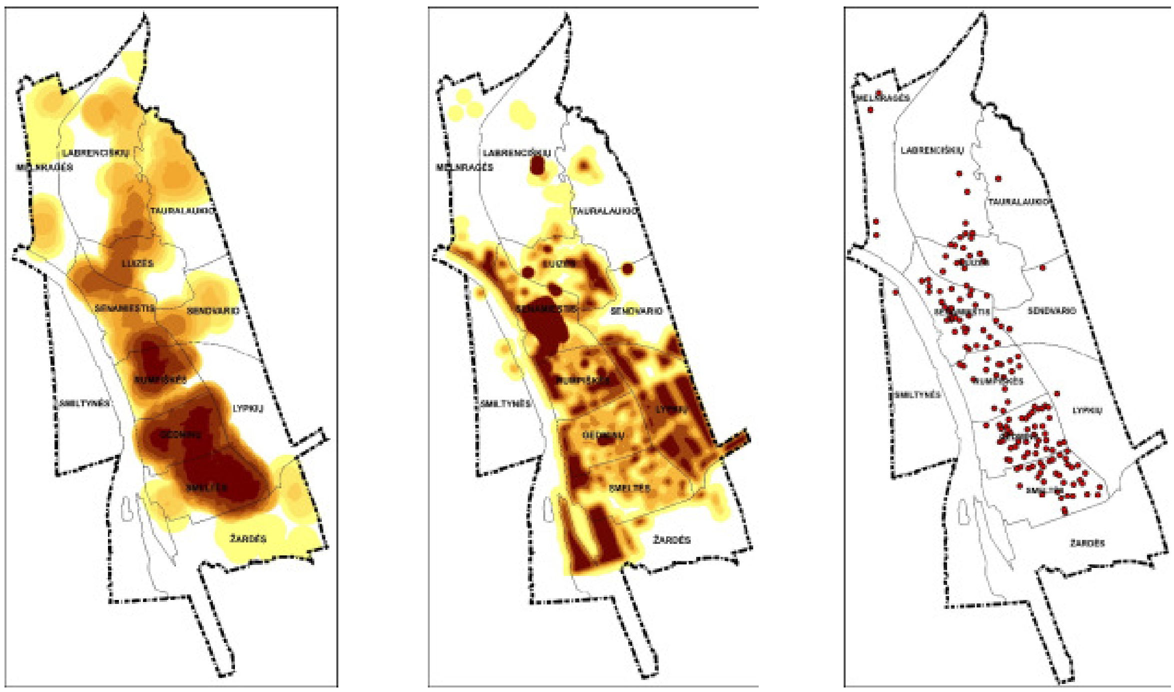
- Living places (each building was given a number of people living in it);
- Working places (each building was given a number of people working in it);
- Places of public attraction (each building was assigned a number of people visiting it in their daily activities different from going home and going to work).

To define the location and number of living places all individual houses were assigned the mean value of inhabitants per single family house derived from Lithuanian National Department of Statistics. For multifamily houses the number of flats was calculated and multiplied by the value of mean person per dwelling obtained from the same official sources.

To collect data of working places register of companies was used, but the data had to be corrected by the people working at home (around 7% of working people) and other means to get the actual 78 000 working places.

The most challenging task was to collect the number of visitors in the objects of public attraction. This data is very dynamic and there are innumerable attractions inside the city, so the most significant objects like retail centres, public buildings, other known places which attract more than 100 people per day were taken into account. It was done by survey data and analogies. This part of database was still incomplete and can be filled and updated with smaller objects to make more precise calculations.

The prepared GIS database contains 17 680 objects. The most significant part of living places (around 55%) are concentrated in multifamily neighbourhoods (Gedminų, Smeltės). The biggest part of working places are located in city centre, in the sea port area and business zone in eastern part of the city. The places that attract public are concentrated in the city centre and in Gedminų neighbourhood with the biggest population density (see Fig.1). It is worth to notice that some single family housing districts (Tauralaukio, Sendvario, Labrenciškių) have very few objects of public attraction.



A B C

Fig. 1. The diagrams showing Klaipėda city GIS model data prepared for evaluation (A – population density, B – density of working places, C – most significant objects of public attraction)

Computational algorithms

The most common GIS software for developers (QGIS) and PYTHON scripting language was used to process the data.

The Balance Index was used to express the ratio values.

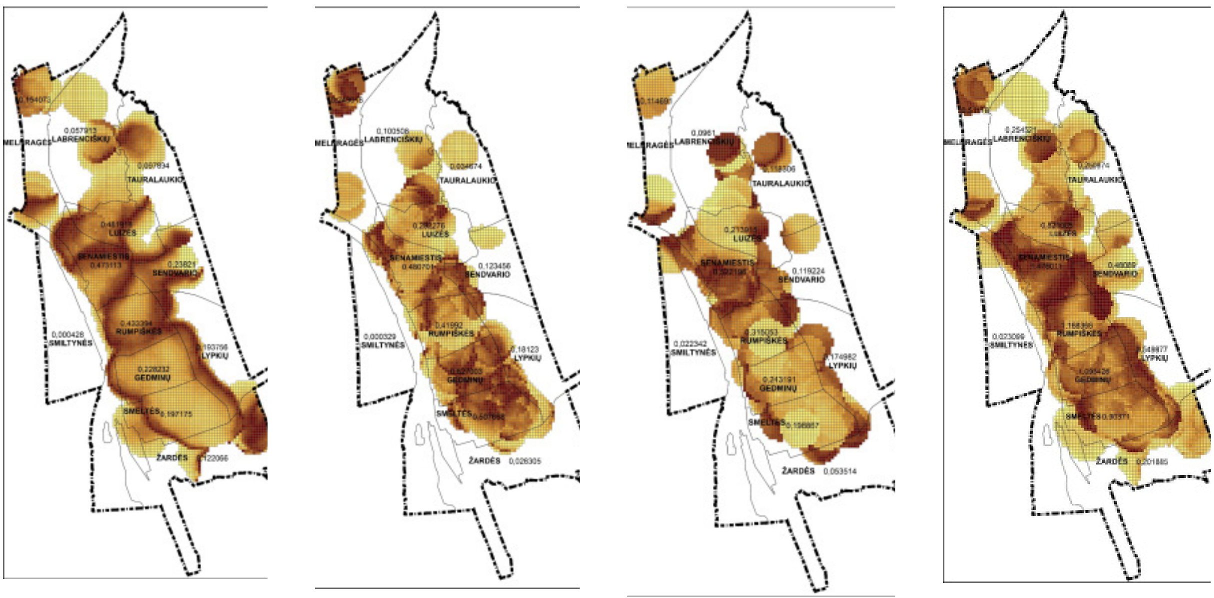
To start with computation few standard functions are necessary. Here the function written in PYTHON to define mixed use level at the specific standing point is presented. The level of function mix varies depending on location and to get the visual scheme all the analysed territory must be divided into cells and each cell with centroid coordinates then assigned the mixed use values.

Arguments passed to the function are cell centroid coordinates (x, y) and “list_of_objects” – for it here stands global array of all city objects. The script has many “if” statements to avoid division by zero and to find symmetrical ratio between two numbers.

```
def MIX_LEVEL(living,working,attraction):
#####calculate living-working ratio
if (living==0) or (object.working==0):
        i_mix_LW=0
elif living<working*0.45:
        i_mix_LW=living/working*0.45
else:
        i_mix_LW=working*0.45/living
#####calculate living-attraction ratio
        if (living==0) or (attraction==0):
            i_mix_LA=0
        elif living<attraction:
            i_mix_LA=living/attraction
        else:
            i_mix_LA=attraction/living
#####calculate working-attraction ratio
        if (working==0) or (attraction==0):
            i_mix_WA=0
        elif working<attraction:
            i_mix_WA=working/attraction
        else:
            i_mix_LA=attraction/working
mix_SUM=mix_LW+mix_LA+mix_WA
return mix_SUM, mix_LW, mix_LA, mix_WA
```

To create the schemes representing the mixed use level value across the area the cycle must be lauched and cells must be assigned the calculated attributes:

```
for i in Cells:
    sum_array = OBJECT_SUM(i.coord,
                                        list_of_objects)
    attributes = MIX_LEVEL(sum_array[0],
                                          sum_array[1],
                                          sum_array[2])
```



A B C D

Fig. 2. The diagram of mixed-use level index between: A – living places and working places, B – living places – places of public attraction, C – working places – places of public attraction, D – overall degree of function mix.

Results of performed estimation

Calculated values were passed to attribute table of GIS objects. The diagrams were created (Fig. 2) to show the most and least mixed areas between three different pairs of functions. Examination of such diagrams gives clear insight of sustainability and object location problems to the planner.

From diagram A comes conclusion that the mix of living-working places is the best on the edges of mono-functional multifamily living districts. However it is the worst inside these districts.

Mix between living-attraction objects is the best in historical town centre, new centre and in Smiltės and Gedminų neighborhoods. It is very low in single family housing areas with low population densities.

Mix between working-attraction objects is the best in historical town center. In other territories it is quite low.

Table 2. The degree of mixing the uses for the neighbourhoods of Klaipėda city

Name	Rating	LW	LA	WA	SUM
Žardės	11	0.12	0.02	0.05	0.20
Smeltės	4	0.19	0.50	0.19	0.90
Lypkių	6	0.19	0.18	0.17	0.54
Gedminų	3	0.22	0.62	0.24	1.09
Rumpiškės	2	0.43	0.41	0.31	1.16
Centro	1	0.47	0.48	0.52	1.47
Melnragės	7	0.15	0.24	0.11	0.51
Smiltynės	12	0	0	0.02	0.02
Sendvario	8	0.23	0.12	0.11	0.48
Luizės	5	0.48	0.28	0.21	0.82
Tauralaukio	9	0.09	0.03	0.11	0.25
Labrenciškių	10	0.05	0.10	0.11	0.25

Overall level of mixed uses (Fig. 2) depicts the most problematic mono-functional areas and these are, not surprisingly, areas of multi-family living districts built in modernist era and areas of recently developed suburban single family housing. It also shows that only the central district has the proper mix of all three functions.

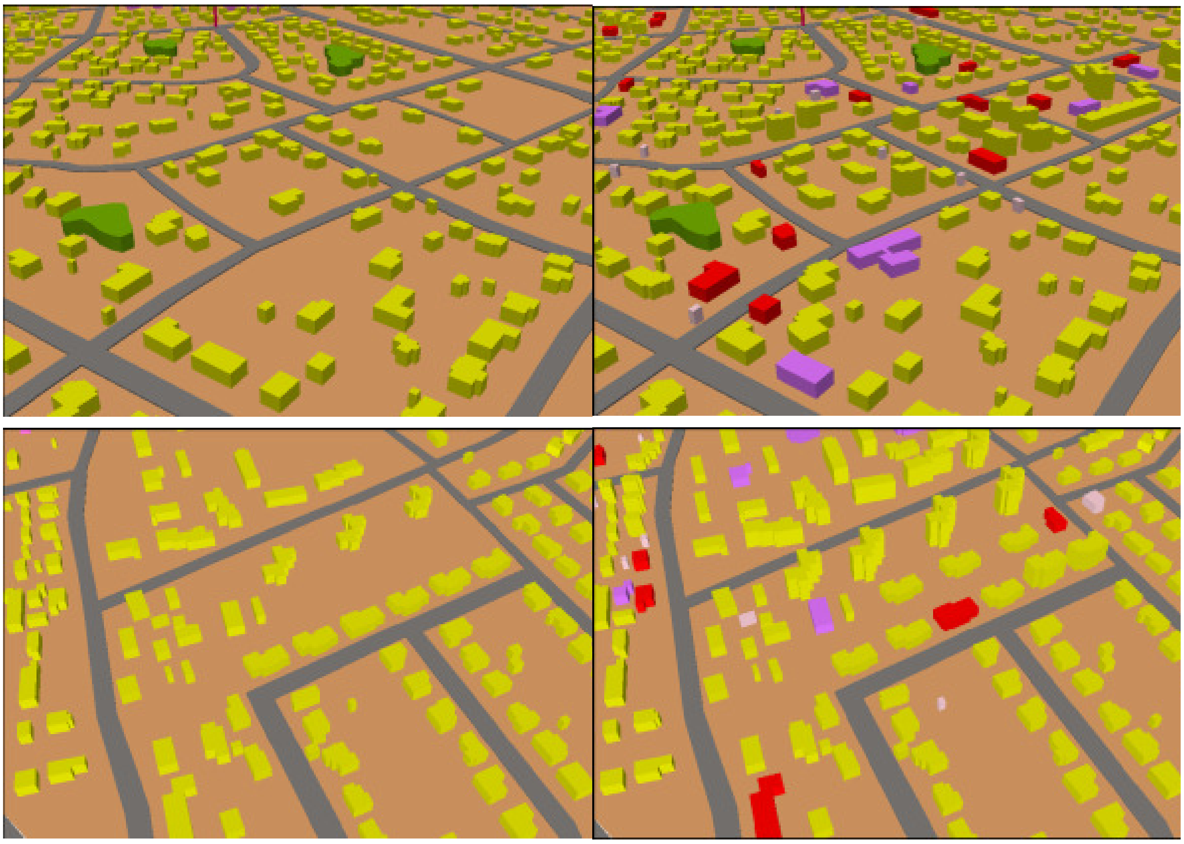
Knowing the "white spots" of the worst areas the planner and decision maker can find the best places and functions for new development.

The overall mean values for the different neighborhoods are shown in Table 2.

One of the worst neighborhoods in terms of mix of function (Tauralaukio) was examined more closely. Since this neighborhood is built up mostly by sungle family houses and 2 storey buildings the proposals for micro-insertions of small buildings with missing functions were given (see Fig. 3). The proposals were given to add blocked family houses, small multi-family houses, locate few small business enterprises, small daily market. It was observed that there is no kindergarden in district which has more than 2000 inhabitants, so the proposal was given to add this small object that contributes greatly to the mix of uses. As a result the neighborhood can become more compact, sustainable and walkable. After adding new objects the calculation was performed again and Table 3 shows significant improve of mixing levels.

Table 3. The degree of mixing the uses for the Tauralaukio neighbourhood before and after supposed measures

	LW	**LA**	**WA**	**SUM**
Before	0.09	0.03	0.11	0.25
After	0.13	0.12	0.14	0.38



A B

Fig. 3. The solutions to improve the level of mixed use in Tauralaukio district of Klaipėda city
(A – existing situation; B – proposals for micro-insertions)

Conclusions

Mixed-use development is one of the most important issues of urban sustainability. Although it is the key principle for sustainable development and is frequently mentioned in urban literature, it is rarely elaborated upon with substantive and empirical support.

Recent research is often based on inaccurate datasets taken from readily available sources such as satellite images or land cover data. These studies are meant mostly for statistical comparison on macro level. The standard mathematical models and methods for quantifying mix parameter come from social geography sphere and miss the planning goals and human scale. To add human scale researchers must be very sensitive with the distance factor.

The term "land use mix" is incorrect by itself because actual interaction is between people living, working and fulfilling other daily activities in the city. To measure the possibilities of these interactions more precisely the data must be based on smaller scale objects – the buildings.

The demonstrated mathematical model works with precise data and adds human dimension when considering possible interactions between objects. The presented schemes show the walkability of the analysed area and prove the importance of scale factor.

The presented algorithms can be easily adopted to work with other types and subcategories of data. It can be extended by implementing more complex indexing between functions. The distance function can be changed to function that calculates actual paths of travel and returns real urban distances from the objects. There are many ways to improve the method, but scientific novelty and key points of it lies in:

- Clear definition of functions and relations between different types of functions.
- Consideration of human scale distances – the point which is missing in most other case studies.

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