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Designing residential areas using geospatial modelling

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Abstract

The subject of the paper is design using modelling methods of geographic information system (GIS). The authors propose using GIS modelling as a method to solve the actual problem of designing housing estates in a big city. The purpose of the paper is to design a model of a residential area with a complete infrastructure and all necessary elements. In the paper, the following tasks are solved: 1) developing design of a digital geoinformation model of a projected residential area; 2) formalization of the process of designing residential areas by developing a design algorithm; 3) creation of a visual two-dimensional model of a residential area. The method used in the paper is geoinformation modelling of real estate objects using two-dimensional models in a geodatabase, and software implementation using the *ArcMap* application. As a result of the research, the authors obtained the following results: a centric approach to planning a semi-autonomous region was chosen as the most rational and effective for urban planning. To solve the problem, the geographic information system *ArcGIS* was used, and a geodatabase was created to analyse the existing territory of the city of Kharkiv and select a construction site. The developed geographic information system *ArcGIS* and the created geodatabase help in solving the issues of further designing the location of buildings and infrastructure elements of the area. Namely, “buffer zones” were used for further accommodation of schools, kindergartens, and shops. The use of “buffer zones” made it possible to optimally place these establishments depending on the number of potential visitors. The authors chose blocks for the division and development of the projected area, considering the historical aspects of the city of Kharkiv. This enabled to develop a GIS in which each block would have its urban ecosystem. The authors have also developed an algorithm for performing design tasks of residential areas. The algorithm can be applied when creating projects for residential areas not only in Kharkiv, but also in other cities of Ukraine and the world. Results of the research made it possible to use the capabilities of geoinformation systems in designing new types of residential areas with a highly developed social and transport infrastructure, harmonious development, as well as attractive features for stakeholders and future residents. Thus, the developed GIS visualization will enable a visual representation on the map of all spatial objects, which are necessary for analysis, and to reflect spatial patterns of the placement of all necessary infrastructure facilities.

Keywords: classification; urban planning analysis; social infrastructure; residential area; geographical information system; satellite town; semi-autonomous suburban area; zoning of the territory.

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Problem statement

Modern trends in urban planning are increasingly reduced to housing construction purely as a commodity. Traditionally, developers do not account for equipping residential complexes in Ukrainian cities, notably Kharkiv, with social infrastructure. Therefore, the load on the social infrastructure of neighbouring regions is increasing. The construction of large housing estates without schools, kindergartens and other infrastructure has resulted in the formation of semi-criminal areas in many countries, where even the police do not go. A rather big problem of modern development is the lack of transport infrastructure, which should play an important role, due to modern trends to have at least one vehicle (car) in the family, so it should be well established within the residential area and with other areas of the city using highways, electric transport and bus routes. In addition to the lack of social infrastructure, the yard of new residential complexes is often a continuous car parks. Another main aspect in designing residential areas is the foresight of various social infrastructure facilities, such as shops, schools, kindergartens, different types of playgrounds, squares, parks, laundries, garages, and car parks. The districts often lack green spaces. This deprives residents of the opportunity to spend their leisure time without leaving the residential area, forcing them to get to distant parks and squares or spend their leisure time inappropriately. Furthermore, modern buildings are chaotic. Newly constructed housing estates are not subject to any general plan, but practice has shown that some of the most comfortable cities to live in were carefully designed considering all needs of the population from scratch.

The goal of the paper is to develop a visual model of optimal housing estate with all necessary elements of infrastructure and transport communications by developing an algorithm for such design involving geographic information systems. The purpose of the paper is to develop a digital geoinformation model of a projected residential area using geoinformation technology.

Analysis of recent research and publications

Modern urban planning trends suggest the creation either of so-called satellite towns, or "sleeping" areas, located on the outskirts of big cities [1]. Generally, such cities are located near big ones, often a capital, at no more than 30 kilometres. In addition, a satellite town is usually built near industrial areas or huge factories or enterprises (Harlow and Crowley in England, Energodar in Ukraine). From general history of urban planning, it is known that a city often cannot meet all the needs of residents because there are many problems that are not actually easy to solve even in the advanced countries of the world. Satellite towns, as a result of being designed from scratch, have the opportunity to foresee various nuances that arise during living.

Satellite towns do not violate the historical part of an old city, they have well-thought-out infrastructure, are rich in parks, squares, and sports grounds. Moreover, for such towns, already at the stage of developing a master plan, it is known an approximate number of residents and the number of schools and kindergartens to meet all possible needs. This issue has been studied and analysed by such researchers as E. Ryabkova, D. Sherstneva and A. Kalabin [2–4].

Since many growing cities tend not to comply with all sanitary and hygienic standards in addition to increasing population and a chaotic, even spontaneous nature of development and heavy traffic, living conditions have significantly deteriorated. The former enterprises located outside the city are now connected with it. Due to the concentric growth of the urban area, the city's communications became heavily congested. The construction of satellite towns to solve this issue is expensive and impractical. Therefore, it is wiser to create suburban (semi-autonomous) districts that will be located no more than 10–15 kilometres from the city centre. Such areas will reduce the load on the central parts of the city by relocating some industrial or other urban capacities to this area. Although it is assumed that in semi-autonomous suburban areas, there will be only part-time jobs available (30–50% of locally employed people), all other people will have the opportunity to quickly get to other parts of the city and work there using urban transport links. This is all possible due to closer location of such areas to communication transport stations. To increase the capacity of such areas, the underground line is duplicated with the motorway lines and supplemented with tram lines and bus routes. Another main point is the creation of clear zoning of the territory in such areas, which implies a more concentrated development within the district (medium and high number of floors) and sparse on the outskirts of the district (low-rise and mansion type). The internal communications system will provide a high level of communication between the areas of the district [5, 6].

From an ecological point of view, suburban areas look quite attractive, as they have many lands allocated for parks, squares, and various types of playgrounds for outdoor recreation. So, the design of residential areas based on semi-autonomous suburban areas is the best option for providing people with high-quality housing, various social facilities and to reduce the chaotic development of the central historical and cultural parts of the city. To free the city from the influx of a huge number of people and to reduce the load on the urban infrastructure, ensuring high optimization and rationalization in the city, there should not only be housing or work places in suburban areas, but also number of catering establishments should be transferred to the same suburban areas.

The practice of other countries, using the examples of such regions as Agenskalnsky pines in Riga, Troparevo and Veshnyaki-Vladichin in Moscow, has proved that it is the combined development that is more flexible than others, considers many aspects and can adapt to different conditions and meet various needs. Therefore, when designing a residential area, it is necessary to give preference to a combined development, due to its versatility and the opportunity to account for different aspects when building a residential area [7–9].

World practice shows that in the modern world it is better to approach the solution of various problems, and in particular the construction of residential areas, through clear planning considering even small aspects. Means and tools of GIS systems have great potential for solving similar problems – problems of planning residential areas [10–13].

The reliability and plausibility of results of geoinformation modelling depend on the plausibility and accuracy of the input data. Spatial data, which can be obtained using space and/or aerial photography and high-precision GPS observations, form the basis of GIS information support.

Outline of the basic material

The aim of the research was to design a housing estate based on a semi-autonomous area. At the same time, the existing historical trends in urban planning were analysed. The existing pros and cons of different design approaches were also highlighted. This type of analysis helped to choose the best option. World practice has shown that semi-autonomous suburban areas are a cutting-edge achievement in rational and efficient urban planning. Therefore, such areas should become the base for constructing a residential area. It is this approach that will provide the most appropriate layout and efficiency at the same time reducing the load on the central parts of the city.

The Scandinavian countries share a similar climatic and geographical situation with Ukraine. When deciding on the number of floors in buildings, first, the previous experience should be considered, which has shown that when creating a residential area it is rational to design eight-, nine-, ten- and eleven-floor buildings. These houses should be in the centre of the city or close to the main transport hubs of the area as much as possible. Low-rise houses should be closer to the periphery of such residential areas because it is the centric approach to planning that is the most effective.

Another main aspect in the design of a residential area is the design of various social infrastructure facilities such as shops, schools, kindergartens, various types of playgrounds, squares, parks, laundries, garages, car parks, etc. Transport infrastructure also plays an important role, so it must be well established within the residential area and other areas of the city using highways, electric transport, and buses.

To select the location of the residential area, the existing territory of the city of Kharkiv and its outskirts was analysed, considering the following requirements:

Relief. It should be even, without large differences in height, so that less money was spent on levelling it.

Vicinity to major roads. This requirement assumes that the residential area should be close enough to the roads for fast transport links with other parts of the city.

Availability of park zones in the selected area. When choosing a territory, it can be in someone else's possession and be built up with some types of structures.

First, when choosing the location of a future semi-autonomous region, it is necessary to rely on the fact that the built-up area should be as small as possible. Based on the analysed territory of the city of Kharkiv, the most suitable territory for modelling of a residential area is the northeaster part of the city (Fig. 1) since this territory does not go beyond the Kharkiv belt road and is close to it, which provides fast transport links to any part of the city. In addition, this territory is located relatively close to the "Studentska" and "Heroiv Pratsi" underground stations, and thanks to the trolleybus and tram service leading from the underground people are quickly taken to any point of the city.

Based on historical aspects and some of already existing buildings in the city of Kharkiv, blocks of buildings are the best choice. This type of development is the best because each block has its own urban ecosystem. People do not need to travel long distances to meet their needs because in a small block, there are already all the necessary social infrastructure facilities, or at least in neighbouring blocks. Another advantage is the highways that envelop the block, allowing people to quickly get out of the residential area in just a few minutes.

After choosing the division of the residential area, buildings were created in the middle of each block. The buildings themselves are placed on the principle of centricity, that is, high buildings (eleven floors) are closer to the main objects of transport and social

Fig. 1. The territory selected for modelling of a residential area

infrastructure. A little farther from the central transport hubs and various establishments are mid-rise buildings (five floors). Low-rise buildings are located a little farther from eleven-floor buildings than middle-rise ones. The last buildings located on the outskirts of the residential area are cottages. In this case, all cottages are one floor high.

To speed up the work on the optimal placement of infrastructure facilities, a file geodatabase and a basic set of classes of spatial objects were created, where, in turn, eleven classes were located, namely residential buildings, educational institutions, green areas, shops, roads, car parks, underground stations, transport stops, recreational areas, residential area and other objects. All this became possible thanks to the use of the ESRI *ArcGIS* software product, where the *ArcCatalog* module was used to build the classes. To create links and interdependencies between the classes of spatial objects in compliance with all laws of normalization, the MS Access database management system was used. To convert the classes to map layers, the *ArcMap* module of the selected geographic information system was used [14, 15].

The next stage is modelling of buildings in the chosen place against each other, where the world practice of constructing residential areas acts as the basis. Therefore, the placement of car parks, playgrounds and sports grounds, parks, squares, and green spaces in yards was considered, including all types of transport infrastructure facilities, as well as existing infrastructure facilities, such as underground stations or existing roads and transport routes. In addition, the division of the residential area into zones for further planning should be developed. Based on the so-called "buffer zones", it is necessary to locate schools, kindergartens, shops and determine their number based on theoretical estimates of the total number of people who can live in a residential area. Using certain formulas and knowing the number of residents, the theoretical number of children, who are the starting point when choosing the number of kindergartens and schools, can be calculated.

Article 47 of the Housing Code of Ukraine provides a sanitary standard, which is 21 m^2 for one person and an additional 10 m^2 of living space for a family. The average number of people in a family in Ukraine is 2.39 people. Based on these data and sanitary standards, the living space that an average family occupies can be calculated as follows:

$$S_{family} = n * S + 10, \tag{1}$$

where n is the number of people in an average family, n = 2.39 people;

S is the envisaged sanitary norm of the living space per person, S = 21 m^2.

The number of residents per house is calculated using the following formula:

$$N = \frac{N_{floor} * S}{S_{family}} * n, \tag{2}$$

where N is the number of dwellers in the residential area;

N_{floor} is the number of floors in the building;

S is the area of one floor of the building;

S_{family} is the area designed for an average family, S_{family} = 60.19 m^2;

n is the number of people in an average family, n = 2.39 people.

According to the statistics, children under 17 make up 13.7% of the population of Ukraine. This indicator was used to calculate the approximate number of children per building using the formula:

$$N_{children} = N * k, \tag{3}$$

where N is the number of dwellers in the residential area;

k is a coefficient that determines the proportion of children in the entire population, k = 0.137.

With the help of the layer "*Transport stops*" of the created geodatabase, it became possible to map the existing trolleybus, tram, and bus stops, as well as create new ones that would improve the existing transport links with other areas of the city. Before the modelling of new stops, the residential area had about eight trolleybus and bus stops, as well as several more tram stops within a radius of 700 m.

So, based on all the information about the location of underground stations, a beltway, tram, bus and trolleybus stop, it can be concluded that the designed residential area has attractive transport links with other districts and residential areas. Despite the fact that the underground stations are far from this area, other transport stops, and the beltway are close. Moreover, new created stops are added to the existing transport infrastructure. All this, in turn, makes it possible to talk about a developed transport infrastructure.

The last layer created and analysed is "*Car parks*". These objects were placed considering the type of building in the blocks. So, for example, the largest car park will be in blocks with eleven-floor buildings, where there are more people than in other blocks. It should also be borne in mind that in blocks with eleven-floor buildings, there will be underground car parks under the buildings (S_{under}), information about which is contained in the attribute table of feature classes.

Formula (4) can be used to calculate the approximate number of parking spaces in a residential area:

$$N_{place} = \frac{(S_{under} + S_{above})}{S_{place}}, \tag{4}$$

where N_{place} is the number of parking spaces;

S_{under} is the area of underground parking, S_{under} = =38549.44 m^2;

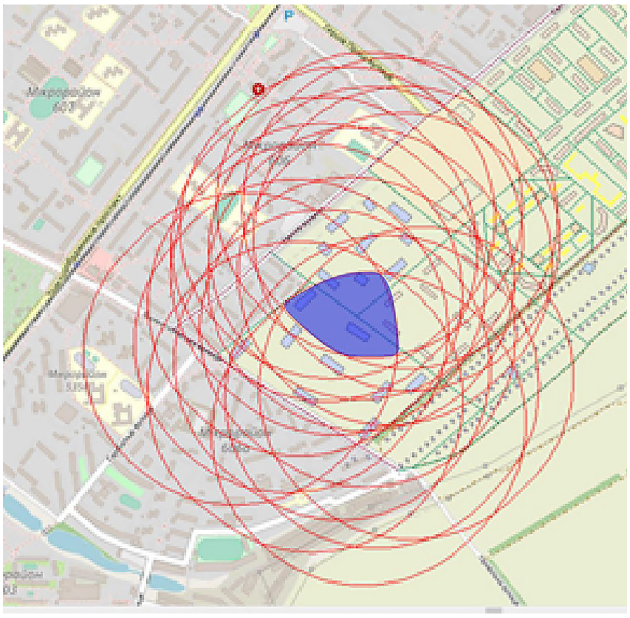

Fig. 2. View of the constructed buffer zones

S_{above} is an open-air parking area, $S_{above} = 48518.14$ m^2;

S_{place} is the area of a standard parking space, $S_{place} = 13.25$ m^2.

So, many visual models have been designed based on different feature classes. Some of them were used for further calculation of the number and location of other objects.

The *ArcMap* module of the *ArcGIS* software product provides a visual display that enables geospatial analysis and the use of the VBA programming language. With the help of VBA, the "Buffer Zone" form was created, with the help of which buffer zones around the selected objects on the map can be built.

The work of the created form can be illustrated by the example of choosing a place for building a school. If the school were in one block, it would be logical to locate it in the middle of this block, but when choosing a place where there is more than one block, the program coped with the task and showed the best place to locate the school. The type of buffer zones, which was used to determine the optimal location of a school in the projected neighbourhoods, is shown in Fig. 2.

In Fig. 2, the area highlighted in blue is the area where the location of the school will be most appropriate. All buffer zones intersect in this place, so residents who will live in the above-mentioned tentative neighbourhoods will be able to quickly get to school without additional transport. This example is only necessary for a clear demonstration that the program can fully meet the goal of the task. In a similar way, it is possible to build buffer zones for other spatial objects that represent objects of social infrastructure. And, based on different conditions and tasks, these buffer zones can be built larger or smaller, that is, they can be adjusted if necessary.

When designing different subtypes of classes of spatial objects and layers, the average distance between buildings with different numbers of floors was considered on the map, for example, eleven-floor buildings are on average 115 meters apart, five-floor houses – 80 meters, buildings with four floors – 50–60 meters (Fig. 3).

This approach provides great variability for the creation of other social infrastructure facilities in a residential area. For example, it becomes possible to place car parks, many green spaces, play and sports grounds, shops and other facilities. Such a large space between buildings is provided with the help of combined development, which in its main part

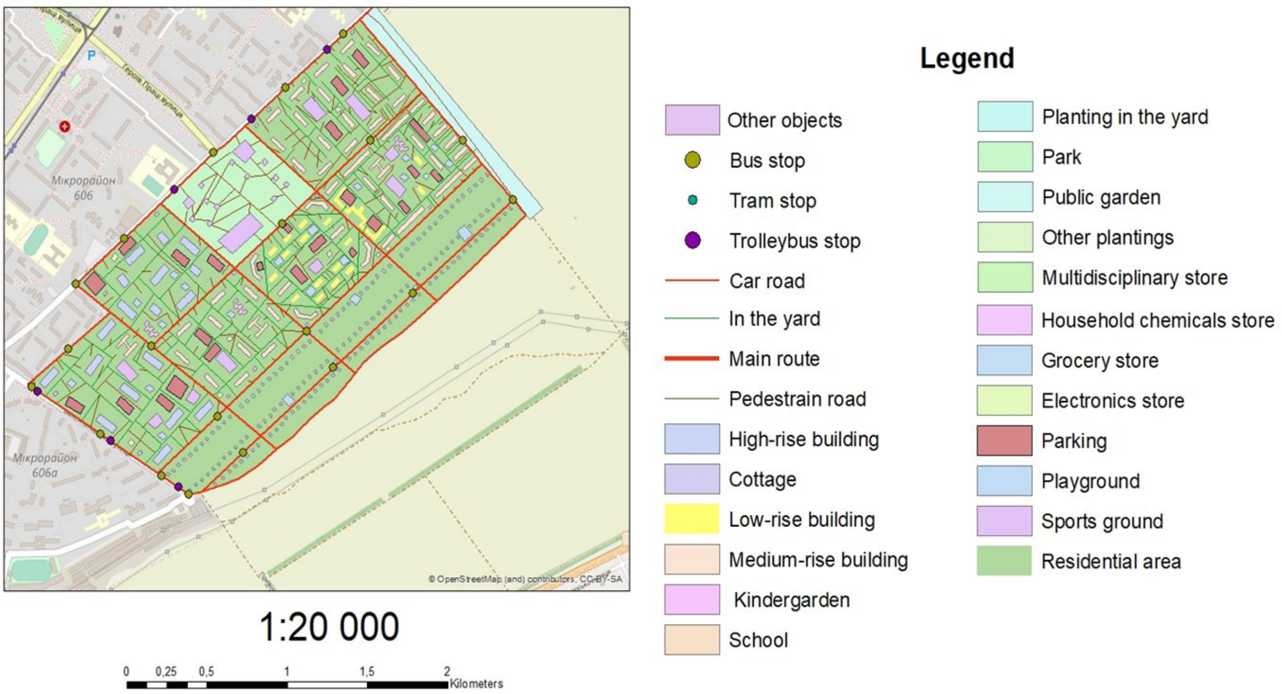

Fig. 3. Residential area model

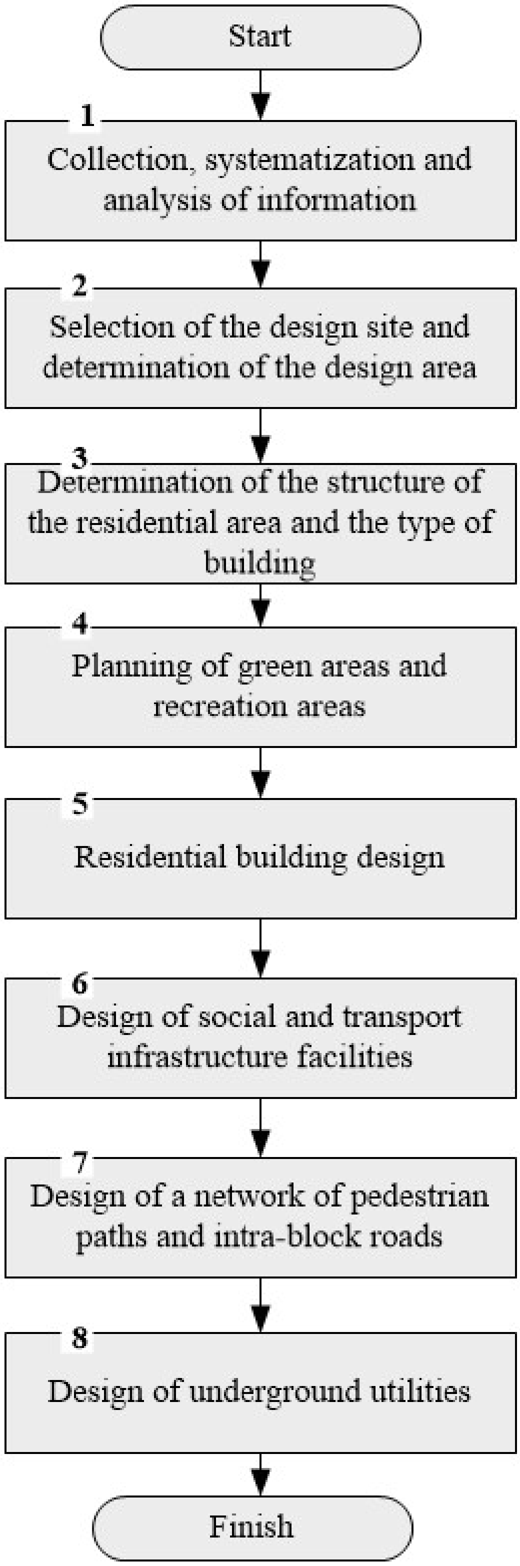

Fig. 4. Algorithm for designing residential areas

is represented by perimeter non-enclosed and high-priority residential buildings.

Furthermore, if this approach is applied to the placement of residential buildings, high-quality ventilation a high level of insolation will be ensured, which will have a beneficial effect on residents.

It is necessary to separately highlight how the cottage development was implemented. Cottage is a line building because it provides the best transport links with the main transport routes.

With this approach, there are opportunities for creating a park, so the park is in a quite advantageous position, since it concerns almost all blocks and neighbouring existing micro-districts that do not have such recreation areas nearby. In addition, in the north-east there is a public garden, which is aimed at improving the environmental situation in the residential area.

In the course of the work, a method for the design of housing estates was developed, which can be conditionally divided into certain stages (Fig. 4). This algorithm can be applied not only to the city of Kharkiv, but also to other cities of Ukraine and the world.

The first stage of design includes the collection, systematization, and analysis of information about the place where the residential area will be designed. In particular, this stages envisages conducting an analysis of the city development, identification of trends as concerns the number of floors and types of buildings, and other building characteristics. This stage will immediately allow setting a framework for the type of residential area so that it harmoniously interacts with the urban environment. Moreover, at this stage, the analysis of the transport and communal infrastructure of the city is carried out to determine the best option for the location of the residential area in the future.

The second stage is the choice of the location for the design of a residential area based on the previous stage. At the same stage, the design area of the residential area is determined. The third stage of the design is to determine the structure of a residential area and the type of development. At this stage, the network of the main streets of the residential area is designed and its constituent parts – blocks or micro districts – are determined. Based on the structure of the residential area, the type of development is chosen.

The fourth stage is to determine the need for large green areas based on the location and structure of the projected residential area. If there are no large parks and squares nearby, it would be appropriate to design significant areas of green spaces. Having own places for leisure will allow residents not to waste time on using transport to spend their leisure time away from home.

The fifth stage is the design of residential buildings. This process should be based on structure, type of development and other previously provided steps.

The sixth stage is the design of social and transport infrastructure facilities based on previously designed residential buildings. So, based on the data on the designed buildings, it is possible to determine the optimal location, size, and number of schools and kindergartens, car parks, and other facilities.

The seventh design phase is the development of a network of pedestrian paths and carriageways within the courtyard. After the buildings and objects of social and transport infrastructure have been designed, the main directions of movement of future residents can be foreseen.

The eighth stage is the design of underground utilities of a residential area.

Consequently, the design of residential areas includes eight mandatory stages, from the analysis of the design site to the complete design of all components of the residential area. Compliance with these stages and consistent implementation of the tasks of each of them will allow designing a residential area with a highly developed social and transport infrastructure, harmonious development, as well as attractive for stakeholders and future residents.

Results

1. A digital geoinformation model has been developed for a projected residential area in the north-eastern part of the city of Kharkiv with the introduction of a significant amount of attributive data.

2. A method for designing residential areas has been developed.

3. A procedure in the VBA language has been developed, which allows building buffer zones around the selected objects according to a given diameter. For the ease of use, a form has been created with which the required size of the zone can be entered and build it around the selected object can be built around it.

4. An optimal visual model of a residential area has been developed.

Conclusions

Having analysed the world experience in designing satellite towns and semi-autonomous residential areas, an approach to design new micro-districts and residential areas was proposed. With the help of geoinformation technologies on the selected undeveloped territory of the city of Kharkiv, a residential micro district was designed, including residential buildings, shops, schools, and other social infrastructure facilities. It is with the help of geoinformation technologies that a schematic diagram of the design of housing estates can be created.

In the research, a visual model of a residential area was developed using the *ArcGIS* software package. The proposed sequence of actions for the use of geoinformation technologies for modelling of such tasks will allow, with minimal time expenditures, to complete the entire cycle of work on the design of a residential area in any territory.

Удосконалення соціальної інфраструктури житлових масивів засобами ГІС

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Анотація

У статті розглядається актуальна проблема проєктування житлових масивів. Грамотно запроєктовані житлові об’єкти та об’єкти інфраструктури вирішили б не лише проблему перенаселення, а й усі пов’язані з цим проблеми, зокрема паркування особистих автомобілів, працевлаштування мешканців, достатню кількість місць для дітей у школах та садочках. Тобто такі житлові масиви були б комфортними для проживання та мали б усю необхідну інфраструктуру. Аналіз світових тенденцій проєктування показує, що ці проблеми вирішуються при проєктуванні міст-супутників або напівавтономних приміських районів. Проаналізовано існуючі плюси та мінуси різних підходів до проєктування. Було обрано центричний підхід до планування напівавтономного району як найбільш раціональний та ефективний у містобудуванні. Для розв’язання завдання було використано геоінформаційну систему ArcGIS та створену базу геоданих для аналізу існуючої території Харкова та вибору місця будівництва й подальшого проєктування місць розташування будівель та елементів інфраструктури. Зокрема, для подальшого розміщення шкіл, дитсадків та магазинів використовувалися “буферні зони”. Використання “буферних зон” дозволило оптимально розташувати ці заклади залежно від кількості потенційних відвідувачів. Зважаючи на історичні аспекти міста Харкова, для проєктованої території було обрано квартальний поділ та квартальну забудову, у зв’язку з тим, що кожен квартал матиме власну міську екосистему. Було розроблено алгоритм виконання завдань з проєктування житлових масивів. Запропонований алгоритм можна застосувати при створенні проєктів житлових масивів не тільки в Харкові, а й в інших містах України та світу. У статті продемонстровано можливості геоінформаційних систем у проєктуванні нових типів житлових територій з високорозвиненою соціальною та транспортною інфраструктурою, гармонійною забудовою, а також привабливими рисами для зацікавлених сторін та майбутніх мешканців.

Ключові слова: класифікація; містобудівний аналіз; соціальна інфраструктура; житлова площа; геоінформаційна система; місто-супутник; напівавтономна приміська зона; зонування території.

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