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Using GIS technology to realise the optimal allocation of housing area functions in urban design

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Abstract Good planning of urban housing area functions can enhance the well-being of residents. Considering the configuration of external facilities and internal spatial structure of housing area functions in urban planning, the study collects the points of interest (POI) of the established study area by using GIS technology, and proposes a spatial layout optimisation method for the external area function facilities with reference to the idea of iterative method. Then set the configuration objective function of housing internal regional functions, and use the improved genetic algorithm to solve iteratively to obtain the optimal solution of housing internal regional function configuration. The results show that the entropy of the per capita enjoyment of the external regional functions configured with the 15-minute living circle for shopping facilities, education facilities, medical facilities, leisure facilities, cultural and sports facilities, elderly facilities, convenience facilities and transport facilities ranges from 0.07 to 7.96, which can create a balanced urban living space with a complete system of residence-services and facilities. In addition, ensuring that the ratio of space use efficiency, functional area ratio and space adaptability is 0.682:0.518:0.602 can complete the optimal configuration of internal area functions of housing and enhance the sense of well-being of housing.

Index Terms urban planning, housing area function, internal space structure, GIS technology, point of interest (POI)

I. Introduction

As China's social and economic development continues, the level of urbanisation is gradually increasing and the urban population will continue to grow [1], [2]. It is predicted that China's urban population will increase to 630 million in 2010. The problem of urban habitation is facing a great challenge. How to cope with this era of rapid population expansion and increasingly serious housing problems? We need to have advanced, reasonable and adaptable planning theories, urban design theories and settlement design concepts to guide us. The development history and advanced planning theories and urban design theories of western developed countries are of good reference for us [3]-[5]. Of course, this does not mean that we can copy everything, after all, the specific national conditions - economic and social environment are different, and the historical development stage is also different. We need to selectively and purposefully absorb the essence of advanced Western theories, but also to develop these advanced theories according to their own specific conditions, so that they become our own set of systematic theories [6], [7].

In order to improve the living environment, improve the comfort of living, the first basic premise should have is its planning and design to reach a certain level. In order to improve the level of planning and design of urban residential areas, first of all, it is necessary to carry out practical research on the market and the environment of construction, and on this basis, form design and planning programmes [8]. At the same time, the design and planning programme should also be discussed and repaired according to the actual situation in order to form the final programme [9]. In order to improve the implementation of the programme, it is necessary to effectively solve the problems existing in the current residential area planning, so as to continuously meet the needs of residents [10]. At present, if you want to better ensure that the urban design of residential planning and design work, so that it is more scientific, to meet the contemporary people for the quality of living and living design of the various needs, then first of all should be aimed at today's residential planning and design of the deficiencies and irrationality of the work should be analysed [11], [12].

First of all, the urban residential area in the specific planning and design work, are very important to the content of the design process and the final design effect, rather than focusing on the overall aesthetics of the building, every detail of the design is also very important to people's design aspects [13], [14]. Secondly, because people's economic gains have grown significantly in recent years, people's needs for all aspects of life are constantly improving, and the pace of people's pursuit of quality of life has been accelerating [15], [16]. However, the current stage of urban construction design work has some difficulties, in the design process of specific urban residential areas, there is a single ecological design, which is subject to a combination of factors [17], [18]. The last is that today's many residential areas in the design, just focus on a certain aspect or a few aspects of the functional development, while ignoring the actual needs of the people, such as many residential areas of the leisure place design is rough, the lack of necessary construction equipment, not enough parking spaces, etc. [19], [20].

If we want to better improve the planning and design of residential areas in urban design and make it more scientific and professional, we need to promote the continuous optimisation of the spatial layout structure of the area, and in the process of optimisation, we need to continuously satisfy the contemporary people's brand-new experience of the residence [21], [22]. Firstly, it is necessary to put the occupants' living experience in a key position, and carry out residential design and residential transformation in a timely manner according to the new requirements of people for residences in modern society, so that the overall function of residences can be brought into play to the greatest extent. Secondly, we should pay attention to the practicality of the residence, and at the same time pay more attention to the sense of design and comfort of the residence, and give play to the multi-functionality of the residence, so that it can not only be lived in, but also enable the residents to enjoy and relax in it. Finally, it is important to focus on whether the layout structure is reasonable and personalised. The overall urban residential design should follow a theme, i.e., residential area, in addition to matching with recreational area, cultural area, greening area, etc [23]-[25].

The innovation of this paper is to update the method of dividing housing areas in urban design by combining multi-source data, with the help of GIS spatial analysis platform, using internet map POI data and walking travel path planning data. The study area is selected to achieve the empirical analysis of the optimal configuration of housing area functions from the internal and external spatial configuration of housing area functions. On the one hand, according to the optimisation objective of housing external regional functions, the spatial layout optimisation method of functional facilities in the external region of the study area is proposed with reference to the idea of iterative method under the condition constraints. On the other hand, maximising the efficiency of space use, maximising the ratio of functional areas and maximising the degree of spatial adaptation are taken as the objective functions, and the improved genetic algorithm is applied to obtain the optimal internal housing spatial function configuration scheme through continuous iterative operations.

II. Spatial configuration of housing in urban design

Achieving the optimal functional configuration of housing areas in urban design takes into account both the configuration of external and internal housing spaces, as follows:

II. A. External space configuration

Good location factors can bring more convenient traffic conditions and complete public supporting facilities, and the analysis of location influencing factors is shown in Figure 1. There must be two or more public lines or underground lines within 500m (i.e. 5 minutes' walking distance) of the housing area. In addition to the transport factor, another important factor is the energy supply situation, the neighbourhood water, electricity, gas and other basic supplies must be complete. Law and order is also an important factor to consider, the surrounding environment is more stable and safe to ensure that the residents of the normal living conditions. Peripheral supporting catering, entertainment, shopping and the number of ancillary services and the scale of life is also an important factor to consider in the site selection process.

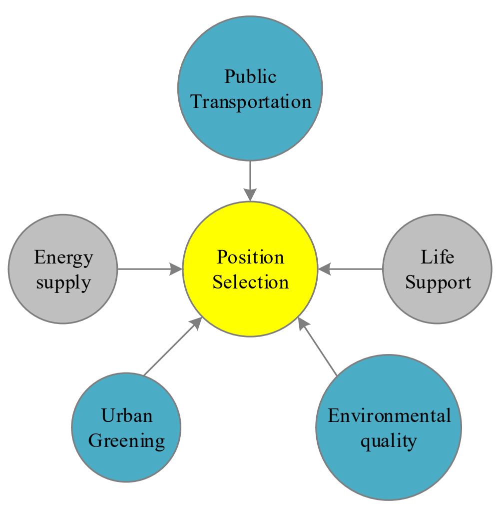


Figure 1: Location impact factor analysis

The content and form of the external space of a housing area can greatly influence community activities and the occupants' sense of belonging. Therefore, the configuration of external space is an important element in the functional design of housing areas. The external space composition of housing area can be divided into external landscape environment, parking space, and traffic space. Although the architectural image does not belong to the external material space, it is of great significance to the creation of external space as the boundary of external space, so this thesis also lists it in the part of external space configuration to be elaborated and analysed together. The specific mode of utilisation of the existing building makes the configuration of its surrounding environment with certain constraints, and it is more difficult to transform, but the transformation of the building function as a continuous process should not be limited to the interior only, but should be carried through the interior and exterior.

II. A. 1) Landscape environment space

The external landscape environment space mainly includes two aspects, activity sites and horticultural greening activity sites can be set up according to the surrounding site conditions, the art of greening the area needs to match the building as a whole, easy to take care of the lawn type garden, in view of the consideration of the economic factors of the da ying mode, the configuration of the landscape environment can be considered as a low-cost creative vegetable gardens, simple badminton courts, small equipment sites, pet leisure plaza, etc.,. Lower cost and can achieve better results. The specific size can be determined on the basis of the number of people living in the housing area and the conditions of the sites around the existing buildings.

II. A. 2) Parking space

If the area around the existing building is large, motorised and non-motorised parking can be provided as required. If there is limited space available in the surrounding area, a compact site should be set up in conjunction with the existing entrance space on one side of the building. If the site around the housing is limited and motor vehicle parking cannot be set up, other social car parks can be borrowed within 100 metres to satisfy the demand for motor vehicle parking by leasing or purchasing. When the surrounding site is limited, non-motorised parking can be combined with the indoor space of the ground floor, the basement space or the elevated space of the ground floor to be used as a parking garage.

II. A. 3) Space for transport links

In order to ensure the high demand of the living group for the sense of domain and privacy, attention should be paid to try to ensure that the traffic flow from the permanent outside to the indoor with the other property types in the neighbourhood to maintain a certain degree of independence into the site is best to set up a separate entrance and exit, and do not intersect with other properties. At the same time, attention should be paid to linking the outdoor car park with the landscaped green space.

II. B.Internal space configuration

The most basic internal space functions of housing are living unit space, public service space and traffic connection space. The relationship between the functional composition of internal space is shown in Figure 2. From the point of view of the time of use and the proportion of composition, the living unit space is the most important content of the functional composition of the internal space, which is mainly used for internal living. The public service space is the characteristic functional composition of the youth flat that distinguishes it from other building types, including auxiliary service space, public activity space and foyer space. Each functional space is organised and laid out according to the degree of public and private, and the three functional compositions within the public service space are highly public and should be arranged centrally. The living unit space belongs to the private space, which is composed of living units and is only for the use of the occupants within the units.

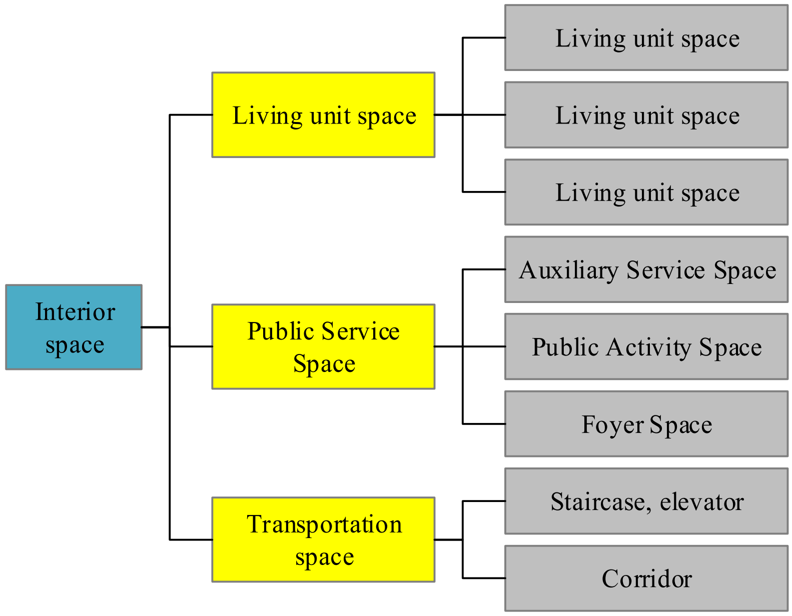


Figure 2: Internal spatial function composition relationship

II. B. 1) Bedroom configuration

Bedroom area is people's daily rest area, relative to other space is more independent and private, and need to be clearly separated from public space, can not interfere with each other. Bedroom in addition to the function of sleeping and resting, but also consider other functions, such as dressing make-up, storage, office learning, etc., these functions require absolute privacy, in the design to avoid the sight from other spaces, sound interference and activity interference, but also adequate lighting and ventilation. As people's demand for comfortable living space is getting higher and higher, or when the structure of family members is complex, the bedroom space will take on part of the living function, so it is necessary to attach other spaces, such as ironing space, storage space, dressing space, care space and office space.

II. B. 2) Living room configuration

The living room is a place where the family gathers for entertainment, and people's behaviour in the living room is basically divided into static behaviour on furniture such as sofas and dynamic indoor movement behaviour, as well as for receiving guests. The depth of the living room is determined by the ratio of the width of the living room to the width of the separate living room depth to width ratio of 5:4 to 3:2 range, while the dining room connected to the living room depth to width ratio of the general range of 3:2 to 2:1 range.

II. B. 3) Sanitary configuration

Bathroom is a functional space that people can not live without, and in recent years people's attention to the bathroom has gradually increased, the bathroom has become a space that provides a comfortable bath, make-up and wash. The arrangement of the bathroom should be closely linked with other functional rooms but there should be a certain degree of privacy, no front room bathroom door should not open directly to the living room (hall) or kitchen. Bathroom interior should have a certain storage space, in order to store the goods and other household goods separately, and should consider the space of the water heater, as well as the location of the water heater socket to ensure the safety of people in which activities.

II. B. 4) Kitchen and dining room configuration

A series of activities occurring in the kitchen is also a certain order, the kitchen plane should be configured in accordance with the operating process, while the operating table and the dining room space has a visual exchange to promote communication between people. Traditional kitchen layout can be divided into single column, double column, L-shaped, U-shaped and island. Kitchen and dining room can be divided into the form of a combination of non-compact connection, side-by-side combinations, tandem combinations, as well as dining and kitchen in one type (open).

II. B. 5) Foyer Configuration

Entrance is a public space transition to private space conversion space, so the design of the entrance should pay attention to the sense of ceremony, by setting up an independent operation space, and with the different areas between the mutual cooperation, can give a person a sense of pleasure and warmth, in and out of the door of the action sequence is people do a good job of spatial transformation process of the heart of the buffer, so the entrance should be enough space to bend or sit down to change shoes and horizontal and vertical extension of the change of clothes and other activities, with a certain storage space for the storage of shoes, hats and clothes. Activities, with a certain amount of storage space for shoes, hats and clothes. Smaller area of the entrance can use furniture such as shoe cabinets and living room dining room for soft partition, large sets of entrance can be set up independently, according to the aesthetic effect of the design, better play a transition, buffer role.

III. Optimal allocation of housing area functions using GIS technology

III. A. Data acquisition and pre-processing

III. A. 1) Points of Interest (POI)

Points of interest, or POIs for short, abstractly summarise real-life entities closely related to urban construction and development and residents' lives, such as hospitals, houses, schools, shops, banks, restaurants, stadiums, etc., into a point without volume for attribute and spatial information description, which can accurately record the spatial entity's belonging It can accurately record the information such as administrative division, name, category and latitude and longitude of the spatial entity. As POI can concisely and intuitively express the spatial layout of various types of facilities and entities within the city, it has many advantages such as real-time, precision, large volume and wide range, which can save a lot of research costs and provide a new and efficient way for the study of urban spatial functional area delineation and functional diversity, and it has an important role in the analysis of geospatial data.

In this paper, POI is used as a model carrier for urban housing settlements and various types of external functional facilities in the Arc GIS platform, so as to facilitate the study of spatial layout of housing area functions [26].

III. A. 2) Study area

The main basis for the delineation of the external function of the housing area is the behavioural activities of the residents of H. Considering different age groups, the average walking speed is 3~4km/h, the corresponding spatial scopes of 15min, 10min and 5min are 750~1000m, 500m~700m and 250m~300m, respectively.According to the ‘Standard for Planning and Design of Urban Residential Areas’, the delineation of the According to the Urban Residential Area Planning and Design Standard, the 15min living circle is 1000m, the 10min living circle is 500m, and the 5min living circle is 300m, and the neighbourhood is abstracted into point data, and the optimal configuration of the external regional functions of the housing is discussed by establishing buffer zones in the Arc GIS platform as the research scope of the living circle of the community of H city at different levels.

III. A. 3) Data sources and processing

(1) Data sources

The research data in this paper includes POI points of interest, residential neighbourhoods, administrative boundaries, and water system data. Among them, POI comes from Baidu map data crawling, and each data contains information such as uid, name, address, label, latitude and longitude coordinates, etc. The data of residential subdivisions are mainly obtained by crawling the website of Chain Home, which includes information such as name, latitude and longitude coordinates, address, the number of buildings, and the number of housing households. By vectorising the H Urban Area Planning (2016~2030), the study area line and administrative boundary line were obtained, and other line layer files including road data and water system data, etc. were obtained from the open source map open street map.

(2) Data processing

The acquired POI data are screened by research scope, industry classification, and de-emphasised according to uid (uid as the unique code of Baidu map logo, compared with other de-emphasis methods, uid de-emphasis is more accurate, so it is more widely used in the professional field), and finally, after a series of data cleaning process, we get more than 40,000 valid POIs within the research scope. The acquired vector data are all encrypted algorithms processed for Baidu coordinate system, including POI data, cell data and map data, etc. Through the process of coordinate conversion and deskewing, all vector data are finally projected to the WGS_1984_UTM_Zone_49N coordinate system. After ensuring that all the data are in a unified coordinate system, it is necessary to add attribute fields to the POI data and district data, such as classifying POI data in Baidu, setting attributes according to the community life circle and facility level, etc., adding population fields to the district data and calculating the number of population, and then establishing a spatial database under the Arc GIS platform to facilitate further screening and analysis in the subsequent stages. After the data were sorted out, a spatial database was established under the Arc GIS platform to facilitate further screening and analysis.

III. B. Optimisation of the functionality of the external area of urban housing

III. B. 1) Methods for analysing POI data distribution

The standard deviation ellipse method is an algorithm for analysing the directional layout of POI data, which results in the generation of an ellipse that can reflect the dominant direction and distribution profile of the geospatial data as a whole [27]. The method mainly analyses the spatio-temporal evolution pattern and change trend of the centre, range, shape and direction of the research object through the centre of the ellipse, the change of the area, the long and short axes, and the azimuthal angle over time. Take the research experimental area range to extract the amount of deformation rate change as weights, solve the centre, area, long and short axes, azimuth angle of the standard deviation ellipse calculation formula is as follows.

Centre of standard deviation ellipse:

$$SX = \sqrt{\frac{\sum_{i=1}^{n}\left(X_i - \bar{X}\right)}{n}} \tag{1}$$

$$SY = \sqrt{\frac{\sum_{i=1}^{n}\left(y_i - \bar{Y}\right)}{n}} \tag{2}$$

where (SX, SY) is the centre of the standard deviation ellipse, (x_i, y_i) is the coordinates of the time series point i, $(\bar{X}, \bar{Y})$ is the mean centre of all time series points, and n is the number of time series points.

Azimuth of the standard deviation ellipse:

$$\tan\theta = \frac{\left(\sum_{i=1}^{n}\tilde{x}_i^2 - \tilde{y}_i^2\right) + \sqrt{\left(\sum_{i=1}^{n}\tilde{x}_i^2 - \tilde{y}_i^2\right)^2 + 4\left(\sum_{i=1}^{n}\tilde{x}_i\tilde{y}_i\right)^2}}{2\left(\sum_{i=1}^{n}\tilde{x}_i\tilde{y}_i\right)} \tag{3}$$

where θ is the azimuth of the standard deviation ellipse, and $\tilde{x}$ and $\tilde{y}$ are the deviations of the coordinates (x_i, y_i) of all time series points from the centre $(\tilde{X}, \tilde{Y})$ of all averages.

The standard deviation of the long and short axes of the standard deviation ellipse:

$$\sigma_x = \sqrt{\frac{\sum_{i=1}^{n}\left(\tilde{x}_l\cos\theta - \tilde{y}_l\sin\theta\right)^2}{n}} \tag{4}$$

$$\sigma_y = \sqrt{\frac{\sum_{i=1}^{n}\left(\tilde{x}_l\sin\theta - \tilde{y}_l\cos\theta\right)^2}{n}} \tag{5}$$

where σ_x and σ_y are the standard deviation along the long and short axes, respectively.

III. B. 2) Configuration objectives and constraint boundaries

(1) Configuration objectives

a. Minimise the number of adjustments to functional facilities in the external areas of urban housing.

b. Improve the facility coverage of all types of urban housing external area functional facilities.

c. Improve the fairness of the spatial configuration of functional facilities in the external areas of settlements.

d. Eliminate the misalignment of external area functional facilities.

e. Reduce the service efficiency variability of external area functional facilities.

(2) Constraint boundaries

a. This study considers neighbourhoods, flats and other settlements as the starting point for residents to walk to find various types of facilities.

b. This study assumes that residents can only access the corresponding level of facility services within the scope of each level of living circle, while excluding the influence of the scale and quality of facilities on the attractiveness of different groups of people.

c. This study found that the urban road network is relatively mature, so it is not included as an optimisation target.

III. B. 3) Functional optimisation of the external area of urban housing

This study proposes an optimisation method for the spatial layout of functional facilities in the external area of the study area based on the optimisation objective and with reference to the idea of iterative method. The iterative optimisation process of the spatial layout of the functional facilities in the external area of the study area is shown in Figure 3.

In the first step, the external regional functional facilities to be adjusted are identified. In this study, the number of population covered by the service is used to characterise the service efficiency of the external regional functional facilities. External regional functional facilities with high service efficiency do not need to make adjustments due to the large number of radiated settlements and the number of resident populations served. In contrast, external area functional facilities with low service efficiency have an irrational location, radiate to fewer settlements and serve fewer residents, so this study will optimise the spatial layout by adjusting the spatial layout of such external area functional facilities. Specifically, external regional functional facilities are divided into different tiers according to their service efficiency, and spatial layout adjustments are made to the first three tiers of external regional functional facilities with low service efficiency in that order.

The second step is to adjust the spatial layout of the functional facilities in the external area and calculate the adjusted indicators. Adjustment of functional facilities in external areas is a complex issue in practice, involving issues such as facility location, building demolition and construction, building function replacement, and personnel scheduling, and covering the fields of urban planning, architectural design, and human resources. In this study, in the process of optimizing the spatial layout of external regional functional facilities, we rely on the Arc GIS platform to construct a “service circle” model of the living area of the residential area and the external regional functional facilities, and adjust the placement of facilities from the perspective of geospatial distribution, so as to achieve the synergistic goal of “fairness and efficiency” in the spatial allocation of facilities. In this process, the real situation is simulated and expressed through abstract modeling. The current spatial distribution of external area functional facilities with low service efficiency is not compatible with the distribution of residents, and the adjustment of such facilities implies the functional replacement of the original buildings and the adjustment of public service facilities with low relevance to residents' daily life services. The location of new external regional functional facilities will be determined by integrating the existing pattern of the city, the road network, and the degree of overlap of the living area of the residents, in order to achieve the goal of spatial compatibility with the residents. After the adjustment, the spatial distribution of facilities will be measured and evaluated, and the indicators of the allocation level of functional facilities and the service efficiency of health facilities in the external area of the living area of the settlement will be calculated again and compared with the situation before the adjustment and the optimization criteria.

The third step is to optimize the spatial distribution of the functional facilities in the external area with the synergy of “equity and efficiency”. The adjustment of individual external area functional facilities will have an impact on the indicators of external area functional facilities in localized settlements, but due to technical reasons, this study is not able to realize the immediate feedback of the adjustment results at this stage, and the configuration of external area functional facilities of different categories has different status, and the magnitude of the adjustment is also different, therefore, according to the high and low service efficiency of the external area functional facilities, we can gradually achieve the goal of “equity-efficiency” synergistic spatial optimization of external area functional facilities. Therefore, graded adjustment of external area functional facilities according to their service efficiency and feedback at each level can gradually realize the optimal configuration of external area functional facilities.

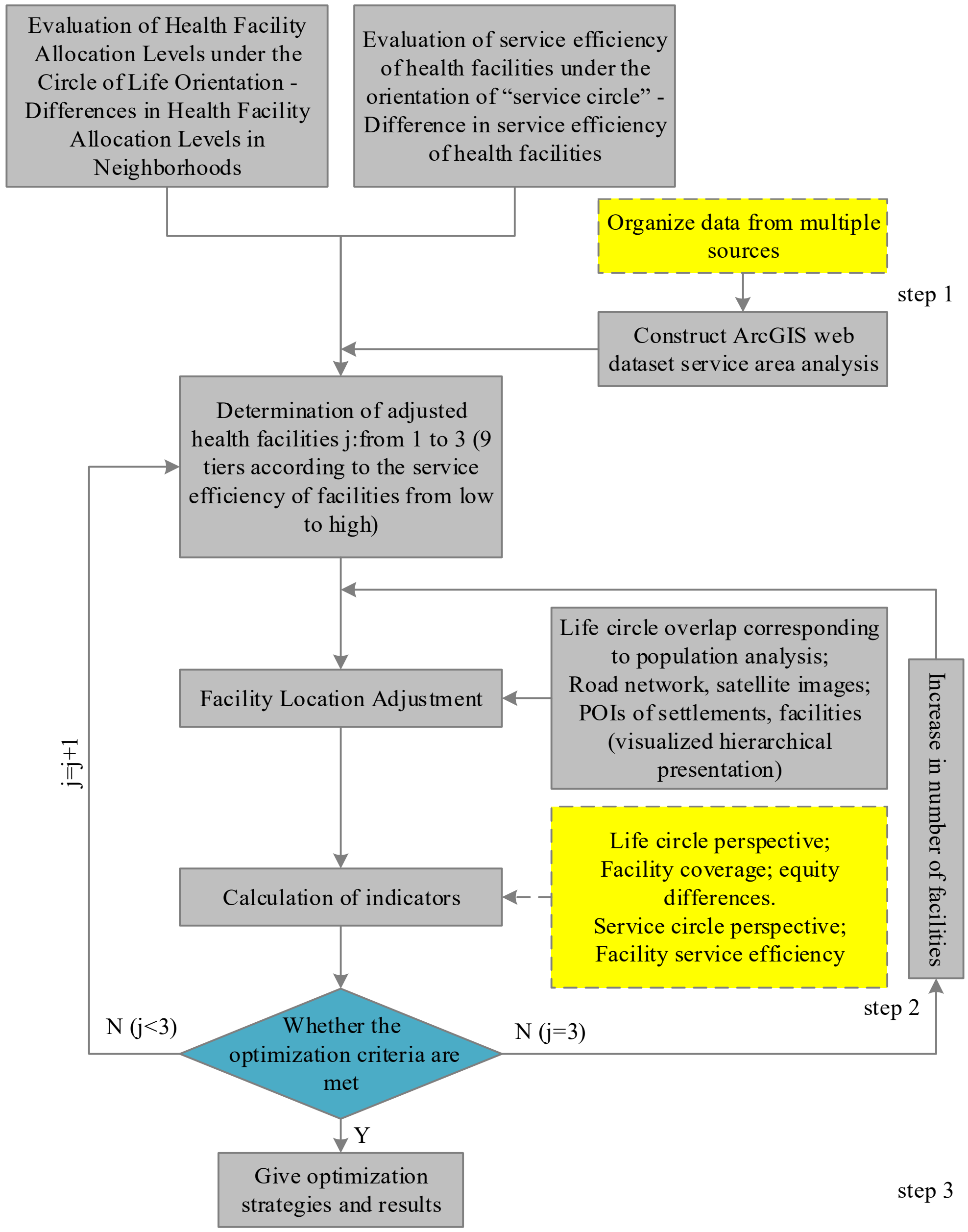


Figure 3: The spatial layout iteratively optimizes the process

III. C. Optimal allocation of regional functions within urban housing

In order to achieve the design goal of the optimal configuration of the internal housing space function, based on the BIM digital modal information, an algorithm for extracting the spatial topological relationship within the housing is designed to obtain the basic information of the internal space of the housing, which lays a solid foundation for the subsequent research to be carried out [28].

III. C. 1) Extraction of regional functional topological relationships within urban housing

The room in BIM is regarded as the basic spatial unit, which is also the node in the spatial topological connection graph, and the connectivity state between different basic spatial units is the edge in the spatial topological connection graph, and the whole set of nodes and edges is the spatial topological relationship inside the building with the expression:

$$\zeta = \{V(\zeta), E(\zeta)\} \tag{6}$$

In Eq. (6), ζ represents the topological connectivity graph of the internal regions of the housing, $V(\zeta)$ represents the set of nodes of the spatial topological connectivity graph, denoted as $V(\zeta)=\{v_1,v_2,\cdots,v_n\}$, n represents the total number of nodes, $E(\zeta)$ represents the set of edges of the spatial topological connectivity graph, denoted as $E(\zeta)=\{e_1,e_2,\cdots,e_m\}$, and m represents the total number of edges.

It is important to note that there are different definitions for both nodes and edges in the spatial topological connectivity graph. Node v_i is defined as: when v_i takes a value greater than or equal to 1, it is assumed that v_i represents a room, and when v_i takes a value less than 1, it is assumed that v_i represents an external space. Edge e_j is defined as: when e_j takes the value of 1, it is determined that e_j connects two rooms, and when e_j takes the value of 0, it is determined that e_j connects the external space to the room.

III. C. 2) Targeting of functional configuration of internal housing space

There are many factors to be considered in the design of the functional configuration of the internal housing space, such as space utilisation, space functionality, acoustic environment, privacy levels, etc. It can be seen that the internal housing space function configuration design goal is not a single, it needs to be explained in detail and determined, in order to obtain the optimal configuration design programme.

(1) Maximising space efficiency

The space use efficiency evaluates the effective use of the internal area of the housing, and the higher the value indicates that the indoor space is more fully utilised, which is calculated as follows

$$a_1 = \frac{A_u}{A_{total}} \times 100\% \tag{7}$$

In equation (7), a_1 represents the efficiency of space use, A_u represents the area of indoor space use, and A_{total} represents the total area of indoor space.

(2) Maximising the ratio of functional areas

Functional area ratio evaluates the ability of indoor space to satisfy different functional needs, and the higher the value, the stronger the functionality, is calculated by the formula:

$$a_2 = \frac{\sum A_i}{A_{total}} \times 100\% \tag{8}$$

In equation (8), a_2 represents the proportion of functional areas, and $\sum A_i$ represents the sum of the areas of each functional area.

(3) Maximising spatial adaptability

The spatial adaptability reflects the degree of adaptation of the indoor space to different functional needs, and the higher the value means the better the functionality, which is calculated by the formula:

$$a_3 = \frac{\sum_{i=1}^{N} \delta_i}{N} \tag{9}$$

In Eq. (9), a_3 represents the spatial adaptation, δ_i represents the satisfaction score of the i rd user for different spatial functional requirements, and N represents the total number of people using the internal area of the housing.

The above process completes the identification and detailing of the multi-objectives for the optimal configuration of the spatial functions of the internal housing, and provides assistance in the final realisation of the research objectives.

III. C. 3) Functional configuration programme access to internal housing space

(1) Genetic Algorithm

The idea of genetic algorithm is: firstly, the individuals of the problem studied by the algorithm are aggregated to form a population, and then the adaptive ability of each individual is calculated by the fitness function, and the individuals with stronger adaptive ability are used to create a new population by crossover and mutation operator [29].

For a population, since it is composed of individuals, it is part of the space of individuals, i.e., it is a subset of the space of individuals. This can be denoted as $\bar{x}_1 \subset S$, $\bar{x}_2 \subset S$. When using $\bar{x}_1 \subset S$, $\bar{x}_1$ is regarded as a subset, and when using $\bar{x}_2 \subset S$, it means that the non-repeating individuals in $\bar{x}_2$ are a subset in S. At this point neither $\bar{x}_1$ nor $\bar{x}_2$ are regarded as vectors. If regarded $\bar{x}$ can be expressed in matrix form as:

$$\overline{x_1} = \begin{bmatrix} 0 & 1 & 1 \\ 0 & 0 & 1 \\ 1 & 1 & 0 \\ 0 & 1 & 0 \end{bmatrix} \overline{x_2} = \begin{bmatrix} 0 & 1 & 1 \\ 0 & 0 & 1 \\ 0 & 0 & 1 \\ 0 & 1 & 1 \end{bmatrix} \tag{10}$$

For a chain length of 1 population size N can be represented as a $N \times 1$ nd order matrix:

$$\bar{x} = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1l} \\ x_{21} & x_{22} & \cdots & x_{2l} \\ \cdots & \cdots & & \cdots \\ x_{N1} & x_{N1} & \cdots & x_{Nl} \end{bmatrix} \tag{11}$$

Selection operator: selection operator i.e. selection of an individual in a population, which is a random mapping:

$$T_s : S^N \to S \tag{12}$$

In particular, according to the rules of probability:

$$P\left\{T_s^\alpha(\overline{X}) = X_i\right\} = \frac{f^x\left(X_1\right)}{\sum_{k=1}^{N} f\left(X_k\right)} \tag{13}$$

Genetic algorithms optimise individuals in a population generation by generation by repeatedly performing selection, crossover and mutation operations until a stopping condition is met. The stopping condition can be that the maximum number of iterations is reached, the fitness reaches a threshold or the population converges, etc.

(2) Acquisition step

Based on the above extracted topological relationship-space topology connection map of the housing internal area and the determined optimisation design objective of the housing internal area, the improved genetic algorithm is applied to obtain the best internal housing space function configuration scheme through continuous iterative operations.

Step 1: Load the topological relationship of the internal area of the housing - spatial topological connection diagram ζ, obtain all the digital modal information of its internal construction, and generate all the possibilities of the optimal design of the internal area of the housing with the help of computer technology, which is defined as the initial particles in the improvement of the genetic algorithm L_i, and the total number of the genetic algorithm is recorded as M.

Step 2: According to the determined optimal design objective of the internal area of the housing, construct the fitness function and add the spatial optimisation parameters, so as to improve the convergence efficiency of the genetic algorithm, which is also the key to the improvement of the genetic algorithm. The expression of the fitness function is:

$$f\left(L_i\right) = \Gamma\left(L_i\right) \times \frac{\left[a_1\left(L_i\right) + a_2\left(L_i\right) + a_3\left(L_i\right) - a_4\left(L_i\right) - a_5\left(L_i\right) - a_6\left(L_i\right)\right]}{\mu_0} \tag{14}$$

In Eq. (14), $f\left(L_i\right)$ represents the fitness value of the i nd housing internal area optimisation design solution. $\Gamma\left(L_i\right)$ represents the spatial optimisation parameter, and μ_0 represents the normalisation factor.

Step 3: Calculate the fitness values of all particles according to Eq. (14), and carry out iterative optimisation through selection, crossover and mutation operations to prevent the improved genetic algorithm from falling into local optimum.

Step 4: Determine whether the maximum number of iterations of the improved genetic algorithm has been reached, if it has not been reached, continue to carry out step 3, if it has been reached, output the optimal design scheme for the internal region of the housing corresponding to the maximum fitness value, i.e., the best optimal design scheme.

By executing the best optimal design scheme obtained above, the optimal design objective of the housing interior region can be achieved, providing a more reasonable and high-quality housing interior region environment for the user.

IV. Empirical analysis of the optimal allocation of functions in urban housing areas

IV. A. Basic characterisation of the study area

IV. A. 1) Regional distribution of urban housing

Combining Arcgis and standard deviation ellipse method to study the target housing area, Figure 4 shows the results of the standard deviation ellipse method. In the experiment, three standard deviation levels of 65%, 91% and 98% were selected to study the layout of housing areas, where 65%, 91% and 98% represent the proportion of POI data inclusion, i.e., the ratio of the number of POI data within the ellipse to the total number of POI data, respectively. The final generation of yellow, purple and white three ellipses, the centre of the three ellipses are (5.750994, 5.635299), the point is located in the middle of the two alleys, the vertical direction as the Y-axis, the top of the picture, i.e., due north for 0 degrees, the angle of the ellipses are 106.184767 degrees, the figure of the ellipses of the short semiaxis is much smaller than the long semiaxis, then the degree of dispersion of the target housing area POI data is small, and the The direction of the ellipse under the three standard deviation levels is consistent, which shows that the distribution of POI data has obvious directional characteristics, reflecting the contour characteristics and dominant direction of the spatial distribution of POI data of the residential area as a whole, and it can be seen that the direction of its development is mainly expanding to the north-west and south-east directions, and the evolution process of spatial layout can be clearly found.

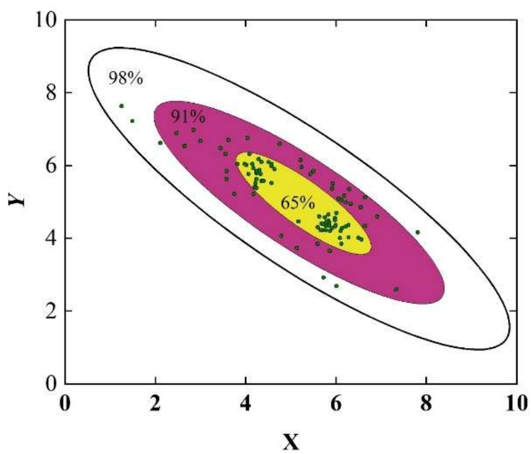


Figure 4: The results of the standard deviation elliptic method

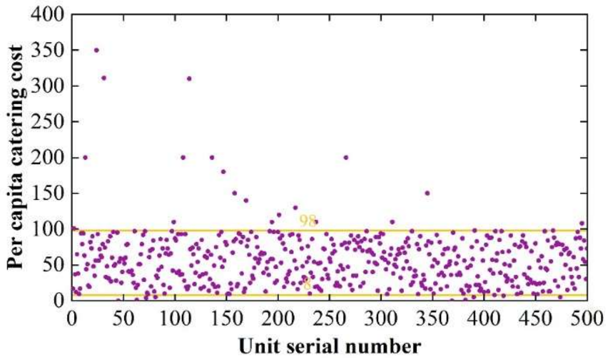
IV. A. 2) Spatial zoning of the cost of living in urban housing areas

The purpose of spatial cost-of-living zoning is to analyse the abstract income problem in a concrete spatial dimension and to provide guidance on the optimal allocation of housing areas. Firstly, we need to obtain the cost of living data and estimate the cost of living for each item and the total cost of living to be zoned, secondly, we need to carry out discrete statistics on the data in order to identify and remove the outliers in the data, and finally, we need to determine the number of grades and take the method of equivalence to estimate the cost of living value intervals at each level, and then we can use the tool of ‘Symbol System’ to visualise and present the cost of living for each item and the total cost of living using the standard of ‘Symbol System’ in the Arc GIS. As a standard, we use the ‘Symbol System’ tool in Arc GIS to visualise the cost of living, and finally obtain the spatial zoning maps of the cost of living for each item and the total cost of living. The detailed estimation process is as follows:

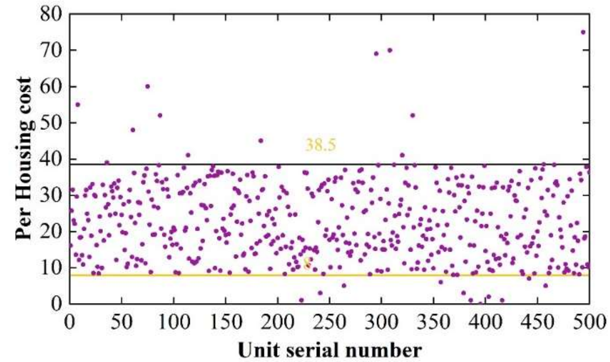
Firstly, using the cost of living estimation model to estimate the total cost of living data, discrete statistics in Excel, the cost of living of each basic unit of discrete statistics as shown in Figure 5, (a) ~ (d) are the per capita cost of food and beverage, housing costs, travelling time costs and the total cost of living, respectively. The range of value domains used for hierarchical classification is obtained by excluding the points with high degree of dispersion, in which the range of per capita catering cost is [8,98], the range of per capita housing cost is [8,38.5], the range of travelling time cost is [8,24.3], and the range of total cost of living is [0.1,0.37].

Secondly, the cost of living in urban area H is classified as high, high, medium, low, and low, based on two reasons, one is that, relative to the central urban area, the basic unit area is small and it is desirable to increase the number of class divisions to avoid the same class area range is too large for spatial feature extraction, so the number of class divisions should be increased. Secondly, the grade division is too little spatial law performance is not obvious, when the division in Arc GIS for high, medium and low three levels of medium-cost spatial range of 50% of the research scope, when the division is 5 levels of the distribution of high and low spatial distribution differences can be better highlighted.

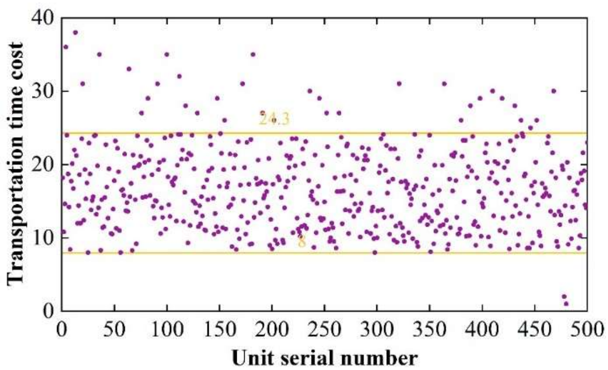
Finally, the interval value of each item and the total cost grading was estimated using the equal division method, in which the interval value of per capita food and beverage cost is 17.4, the interval value of housing rent cost is 5.95, the interval value of travelling time cost is 3, and the interval value of total cost of living is 0.58.



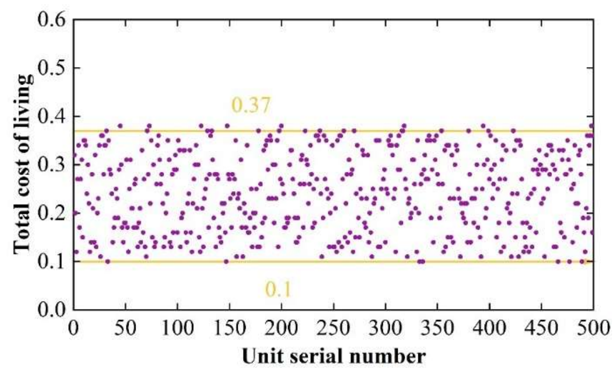
(a) Cost per capita catering



(b) Housing cost



(c) Transportation time cost



(d) Total cost of living

Figure 5: Discrete statistics of the cost of living for each basic unit

IV. A. 3) Hidden characteristics of the cost of living in urban housing areas

Based on the explicit cost of living and implicit cost of living dimensions, the cost of living space in the urban area of City H is divided into four categories: high explicit and high implicit, high explicit and low implicit, low explicit and high implicit, and low explicit and low implicit, which is operated in the following way: the normalised per capita cost of food and beverage, housing costs are weighted and summed to get the average of the explicit cost of living, and then with the normalised cost of transport time in GraphPad Prism8 to generate a two-dimensional scatterplot. The explicit and implicit cost of living characteristics are shown in Figure 6. The median of the explicit and implicit cost of living values was selected as the high and low judgement value to obtain the distribution of the four types of explicit and implicit cost of living, and the intersection point of the explicit and implicit cost of living classification was (0.285, 0.095), which was analysed and found to be:

(1) The types of cost of living in the urban area of City H are mainly high explicit and low implicit and low explicit and high implicit, while low explicit and low implicit and high explicit and high implicit are fewer.

(2) Comparison shows that the high hidden cost of living is distributed in the city centre, while the low hidden cost of living is distributed in the periphery of the city centre, which indicates that the spatial layout of the residential area in the city centre of H is not enough to consider the hidden cost of living.

(3) Analysing the distribution characteristics of the scatter points in the figure, it is found that they are mainly distributed vertically along the hidden cost of living axis, indicating that the hidden cost of living in downtown H has a greater impact on the total cost of living than the explicit cost of living, which is mainly due to the unbalanced distribution of the public transport facilities and the destinations for low-income people in downtown H.

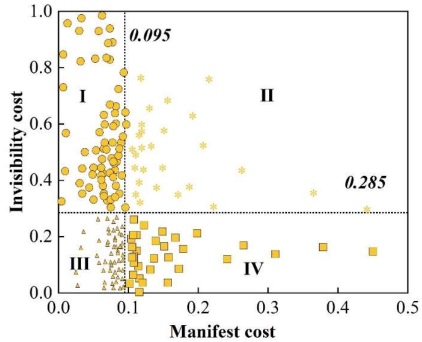


Figure 6: Explicit hidden living cost characteristics

A comprehensive study of the basic characteristics of housing areas and the cost of living to provide a data base for the optimal allocation of housing area functions.

IV. B. Results and analyses of the optimal configuration of external regional functions

IV. B. 1) Determination of the total configuration of functional facilities in external areas

Taking the living circle as a spatial carrier, optimizing the allocation indexes of various public service facilities requires not only defining the service radius and walkable time of each level of facilities, but also putting forward construction control requirements for its land and population, which is conducive to the intensive allocation of facilities on the basis of the equal layout of ancillary facilities. The study integrates the cost of living of residents and urban norms and standards, and provides reasonable guidance on the number of project configurations of functional living facilities in the delineated housing areas, and the project configurations of functional living facilities in the housing areas are shown in Table 1. It should be noted that the study's projection of the number of facilities is mainly based on the following assumptions: the facilities are homogeneously distributed in the living circle, and the service radius is brought in, so as to obtain the lower limit value of the number of facilities under the ideal distribution of homogenisation. Currently, there are many kinds of business models such as small convenience stores, vegetable markets, fresh food supermarkets, large supermarkets and shopping centres coexisting around urban residential areas. Small supermarkets, convenience stores, tobacco and liquor stores and other facilities belong to the category of basic needs of life, mainly providing the function of daily necessities sales, the service radius is not greater than 300m, the number should be 6~9. For the configuration requirements of express service points, their floor area is 15~40m2, within a service radius of 1000m, and 1~4 should be configured in a land-scale living circle.

Table 1: Project configuration of functional living facilities in the housing area

Facility category		Specific items	Number of facilities, quantity	Building area/m^2	Land area/m^2	Radius of service/m
Shopping facility	I	Small supermarkets, convenience stores, tobacco and alcohol shops	6~9	100~500	—	≤300
		Vegetable market	2~5	800~1500	—	≤500
	II	(Fresh, comprehensive) supermarket	2~3	2000~2500	—	≤500
		Shopping center	1	1800~5500	—	≤1500
Education facilities	I	Nursery school	6~9	3100~4600	5500~7550	≤300
		Primary school	3~6	40000~55000	7200~12000	≤500
	II	Middle school	1~3	11000~18500	20500~35000	≤1000
Medical facilities	I	Drugstore	6~9	100~500	—	≤1500
		Clinic, community hospitals	1~3	200~2500	1450~2800	≤500
	II	Comprehensive and specialized hospitals	1	42000	57500	≤1000
Leisure facilities	I	Park	2~5	—	1350~5500	≤1500
		Square	2~5	—	1350~5500	≤300
	II	Cinema	1	2500~4500	4000~5500	≤500
Sports and sports facilities	I	Fitness points, children's amusement facilities	6~9	—	200~1350	≤1000
		Cultural activity station	2~5	280~1250	—	≤1000
	II	Cultural activity center	1	3000~5500	3500~12500	≤300

		Sports venues and multi-functional sports venues	1	2500~5000	1250~15000	≤500
Pension facilities	I	Community pension center	6~9	400~800	—	≤1000
		House for the elderly	2~5	3500~17500	1800~22000	≤1000
	II	Beadhouse	1~3	7500~17500	3200~22000	≤1000
Convenience facilities	I	Express point	1~4	15~40	—	≤1000
	II	Sanitation service station	7~9	20~40	150~250	≤1000
		Property Service Center	1~3	750~1500	650~1350	≤1000
Transportation facilities	I	Bus stop	2~5	—	—	≤500
	II	Subway station	1~3	—	—	≤800

IV. B. 2) Results of the optimal configuration of functional facilities in external areas

Comprehensive consideration of the cost of living of residents end up getting and residents travelling under the principle of proximity and construction cost minimisation two elements of shopping, education, medical care, culture and sports, and other eight categories of facilities under the quantitative indicators of differentiation guidelines and recommendations. The optimal configuration of functional facilities in the external area of housing is shown in Table 2. As a spatial carrier for the configuration of grassroots public service facilities, and taking into account the matching between the configuration of facilities and the population and land scale, the per capita entropy of functional facilities in the external area ranges from 0.07 to 7.96, which can create a balanced urban living space with balanced housing-services and a complete facility system.

Table 2: Optimal configuration of functional facilities in the external area of the housing

Facility category	Total facilities	Dot density	Spatial coverage	Mean proximity distance(m)	Per capita enjoyment	Location entropy
Shopping facility	10	5.1	80	480	1.35×E-4	0.09
Education facilities	14	8.2	80	480	1.72×E-4	1.05
Medical facilities	12	6.9	80	480	1.11×E-4	0.07
Leisure facilities	6	1.3	80	480	0.58×E-4	1.51
Sports and sports facilities	13	5.8	80	480	1.44×E-4	1.65
Pension facilities	10	4.1	80	480	1.35×E-4	7.96
Convenience facilities	14	4.1	80	480	1.28×E-4	0.48
Transportation facilities	5	1.7	80	480	0.77×E-4	0.07

IV. B. 3) Achievement of full coverage of facilities within 15 minutes' walking distance

Under the definition of the 15-minute living circle, residents' community travelling is more inclined to walk, and the optimal allocation scale will affect the travel efficiency of residents if it cannot adapt to their changing travelling habits. In addition, different types of urban road structures generate different forms of commercial space. Generally speaking, community facilities are laid out along or around urban municipal roads. If the road density is low, the coverage of community facilities will be reduced. This results in too much residential land area, the sense of neighbourhood atmosphere in the community is missing, and the community commercial facilities cannot do the role of community catalyst. If the road density is higher, the coverage of community commercial facilities increases, which can enhance the community commercial atmosphere and neighbourhood atmosphere. Table 3 shows the proposed reachable range for the layout of community facilities. It can be divided into three types subdivided into 15 minutes (600-1000m), 10 minutes (300-600m), and 5min (0-300m), and re-adjusted for facilities beyond the walkable distance.

Table 3: Proposal table for accessibility of community commercial facility layout

Life circle type	Population scale	Walk up to distance
15 minutes of life	50,000	600~1000m
10 minutes of life	15,000	300~600m
5 minutes of life	5000~10000	0~300m

Therefore, relying on the high-density and humanised street network, to improve the articulation of the walking activity network in the living circle, the community planning configuration should be based on the actual situation of the community, to meet the consumption needs of different residents according to local conditions.The spatial layout of the facilities inside the community of the 15-minute living circle is shown in Figure 7. It is possible to form a living circle community with a good walking experience and a strong community atmosphere by stringing together the space on the ground floor of the community in the form of an arrangement on the first floor inside the community. At the same time, it is desirable to spread the layout over a large area to ensure full coverage within the living circle within 15 minutes' walking distance. Facilities that are used more frequently by residents should be arranged centrally to achieve the optimal allocation of functions in the external areas of urban housing.

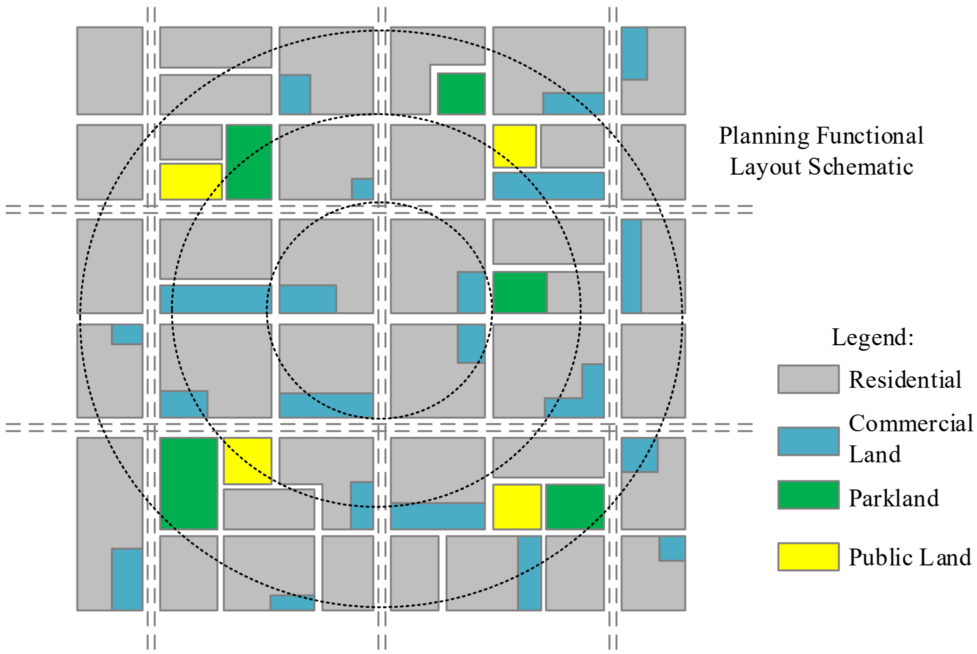


Figure 7: Space layout of the facilities within the living circle community

IV. C. Results and analyses of the optimal allocation of internal regional functions

IV. C. 1) Comparative analysis of twin targets

The result of multi-objective optimisation is not single, but provides a series of trade-off solutions, i.e. Pareto optimal solutions. Through the comparative analysis of two-by-two combinations of the three objectives of maximising space use efficiency, maximising functional area ratio and maximising spatial adaptability, the optimisation search results of space use efficiency-functional area ratio, space use efficiency-spatial adaptability, and functional area ratio-spatial adaptability can be obtained. The optimisation results of the optimal allocation combinations of regional functions within housing are shown in Fig. 8, and (a) to (c) are the optimisation results of the objectives of space-use efficiency-functional region ratio, space-use efficiency-spatial adaptability, and functional region ratio-spatial adaptability, respectively. These combinations reflect the multiple possibilities of seeking the optimal balance between different objectives.

It can be seen that there is a Pareto distribution between both objective functions of space use efficiency-functional area ratio and space use efficiency-space adaptation, with positive results. As the space use efficiency increases, the functional area ratio tends to increase, because the change of decision variables is directly related to the functional configuration of the housing area. Whereas the inverse Pareto distribution was observed between the functional area proportion - spatial adaptability objective function, an increase in the functional area proportion affects spatial adaptability, resulting in making spatial discomfort occur.

IV. C. 2) Analysis of three-objective optimisation results

In order to achieve the objectives of maximising the efficiency of space usage, maximising the ratio of functional areas and maximising the spatial adaptability, a multi-objective optimisation containing three maximisation objective functions is carried out. The optimisation results are shown in Fig. 9, where the Pareto front is transformed from the original curve to a surface due to the inclusion of the third objective function. On this surface, the optimal solutions screened all reflect the optimal balance between different objectives, and the optimal configuration of housing area functions is the space use efficiency (0.682), the ratio of functional areas (0.518) and the spatial adaptability (0.602). The optimal functional configuration of the housing internal area with the established objectives was accomplished to give the occupants the best living comfort.

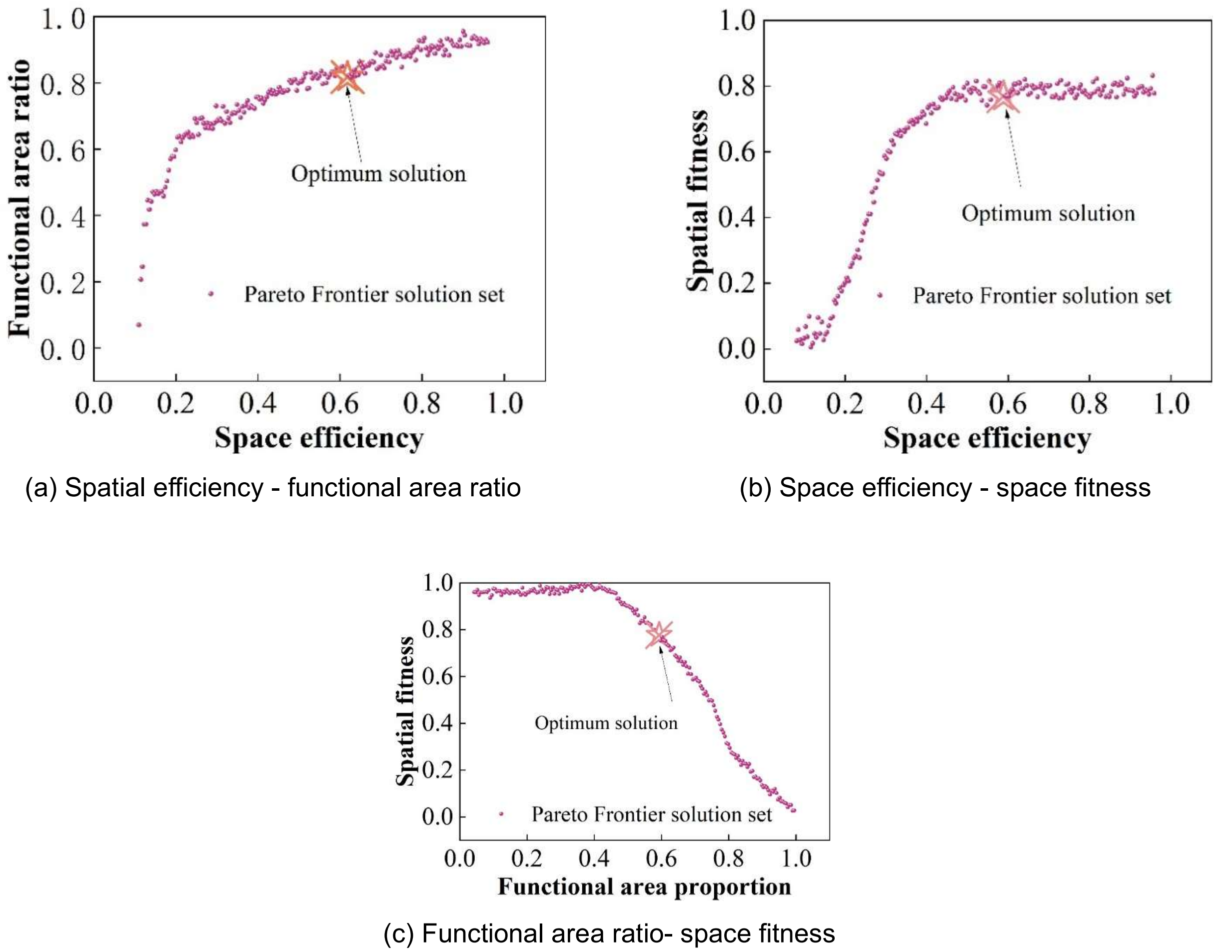


Figure 8: Optimal configuration optimization results of internal housing functions

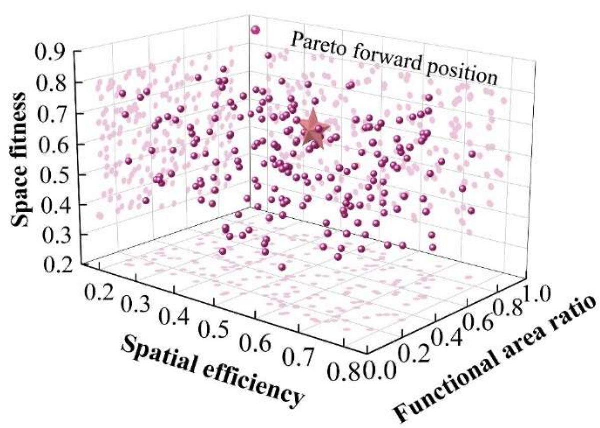


Figure 9: Multi-objective optimization results

V. Conclusion

Using GIS technology, the study empirically explores the optimal configuration of internal and external functions of housing areas in urban design, which is dedicated to enhancing the well-being of the occupants. The results of the study show that it is possible to combine the 15-minute living circle to form a living circle community with a good walking experience and a strong community atmosphere. At the same time, the layout is dispersed over a large area to ensure full coverage of the 15-minute walk within the living circle, and the facilities that are more frequently used by residents are arranged in a centralised manner to achieve the optimal configuration of the functions of the external area of urban housing. In addition, the values of 0.682, 0.518 and 0.602 for space use efficiency, functional area ratio and spatial adaptability are guaranteed to achieve the optimal allocation of functions in the internal area of the housing with the set objectives and to give the residents the best sense of living comfort. This study takes into account the impact of the cost of living on the configuration, and in the future, the impact of factors such as differences in the needs of residents of various age groups on the functional configuration of housing areas can also be considered.

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