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A model for integrated use of fitness facilities and public sports space in new community housing design

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Abstract In the context of the increasing popularity of the health concept, traditional community fitness facilities have problems such as low space utilization. This study focuses on the comprehensive utilization of fitness facilities and public sports space in the design of new community housing, and proposes a three-dimensional synergistic fitness space comprehensive utilization model. The model takes building information modeling (BIM) as the core support, integrates vertical three-dimensional layout, modular function combination and intelligent management system, and constructs community public sports service system. Gini coefficient, concentration index and other spatial measurement methods are introduced to construct a multi-dimensional quantitative assessment system to analyze the characteristics of the spatial distribution of facilities and the direction of optimization. The study shows that increasing the proportion of multifunctional space and the efficiency of shared facilities can improve residents' satisfaction. The Gini coefficient can effectively assess fairness, alleviate the problem of resource concentration through a high composite utilization pattern, optimize the utilization rate of shared facilities, reduce the Gini coefficient to less than 0.4, and guarantee a walkability rate of over 90%. This study provides a reference for the sustainable design of high-density urban communities, helping to equalize public services and improve the health of residents.

Index Terms community fitness facilities, housing design, public sports space, building information modeling, public services

I. Introduction

At this stage, mass movement has gradually deepened from the traditional promotion of sports activities to a systematic project of improving people's physical fitness and cultivating health care knowledge, and has evolved into a strategic cornerstone for consolidating the foundation of national health [1]. Through the implementation of the national fitness strategy, the state is committed to enhancing the physical health of individuals, actively promoting the construction of a healthy and dynamic social environment, and promoting the formation of a good health consciousness among the people. With the increasing social demand and the growing prevalence of chronic diseases and lifestyle diseases, the mission of national fitness has been expanded from traditional physical exercise to the broader field of comprehensive service for public health [2]. National fitness has not only become a tool for governments at all levels to promote healthy lifestyles, but also an important symbol of social progress and improvement of public health [3]. Based on the new community housing design concept, this study upholds the design goal of closely integrating and synergistically promoting fitness facilities and public sports space to form a systematic, long-term and effective comprehensive utilization model, so as to enhance public health.

II. BIM-based residential intelligence

II. A. Design process

Intelligent construction is a brand-new field of transforming the design and construction process of building engineering and improving the efficiency of building engineering construction by widely applying various advanced scientific and technological means, including Internet technology, software design technology, information technology, data mining technology, Internet of Things (IoT) technology and deep learning technology [4], [5]. The research object of this paper is a new type of community housing, combined with building information modeling (BIM), the intelligent residential design process is shown in Figure 1. It can be seen that the model is supported by BIM technology as the core, and the new community housing widely applies a variety of advanced scientific and technological means, including Internet technology, software design technology, information technology, data mining technology, Internet of Things (IoT) technology, and deep learning technology, to transform the design and construction process of architectural engineering and to enhance the utilization of architectural space in a completely new field.

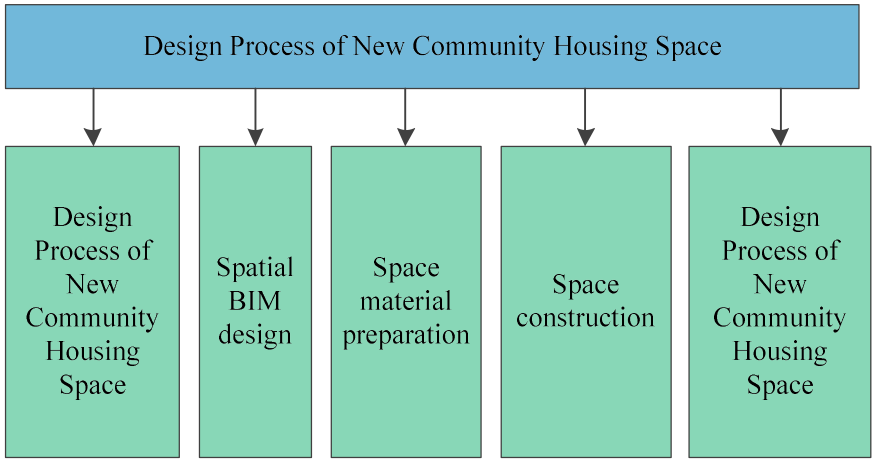

Figure 1: Intelligent housing design process

II. B.Gini index

In the design of new community housing, the assessment of the comprehensive utilization pattern of fitness facilities and public sports space can draw on the spatial measurement method in the field of economics [6]. In this paper, the Gini coefficient and the concentration index are used as the core tools to assess the degree of matching between the supply of sports facilities and the distribution of the residential population through the refined analysis of the community unit scale [7]. Specifically, the Gini coefficient divides the community into residential clusters, and quantifies the differences in per capita fitness space area, facility type abundance and other indicators in each unit, with a value range of 0-1, and values approaching 0 indicate a more balanced spatial distribution of fitness resources within the community. It is worth noting that a single dimension of balance assessment is not enough to fully guide planning practice, so it is necessary to combine with the concentration index for comprehensive analysis. The concentration index focuses on identifying the clustering effect of core sports space, and when the value is close to 1, it reflects that the public sports space has formed an intensive and efficient layout in the community. The combination of the two can scientifically diagnose the balance between equalized supply and intensive use of community sports facilities, and provide quantitative decision-making basis for the hierarchical configuration of fitness facilities and composite use of public sports space in the planning of settlements [8], [9].

In order to concretely implement the above analysis, a standardized data collection and calculation framework needs to be constructed. Several samples of new communities are selected, and the data collected are n_i, the population size of the i th community, and the area of fitness facilities of the i th community in s_i. The Gini coefficient is modeled as follows:

$$G=\sum_{i=1}^{n} Y_i P_i + 2\sum_{i=1}^{n} Y_i\left(1-V_i\right)-1 \tag{1}$$

where Y_i is the area of fitness facilities per capita in the i th community, P_i denotes the proportion of the population to the total population of the sample, and V_i is the cumulative proportion of per capita public sports space. By superimposing the population weights with the cumulative effect of resources, the system portrays the discrete degree of facility distribution. Further, the assessment of global resource concentration requires the introduction of a concentration index:

$$R=\left[1-\frac{1}{2}\sum_{i=1}^{n}\left|\frac{S_i}{\sum S_i}-\frac{n_i}{\sum n_i}\right|\right]\times 100\% \tag{2}$$

The core logic lies in comparing the match between the area share of facilities and the population share, calculating the absolute difference between the area share of facilities and the population share in each community, and summing the adjustment coefficients R close to 100%, which indicates that the facility layout is highly matched with the population density, and that if R < 80%, additional or expanded facilities are required in densely populated areas. This dynamic threshold design provides a clear optimization direction for fitness facilities and public sports space utilization [10], [11].

III. Study design and analysis of results

III. A. Equity in space utilization

Eco-Community A is planned to be ecologically sustainable with three-dimensional greening and rooftop playgrounds designed to transform inefficient spaces into fitness nodes. Intelligent Community B relies on the introduction of an intelligent management system to dynamically deploy resources, but due to the low proportion of multifunctional sports space, facilities are concentrated in a few areas. Green Community C, on the other hand, makes full use of the space under the viaduct and abandoned land parcels through a high composite utilization model with a high proportion of multifunctional sports space, combined with modular facilities and decentralized layout. Mixed-function Community D, which has a concentration of facilities and fails to effectively utilize the spatial potential of a high-density community. Youth Community E, which relies on BIM technology to optimize the design process and adopts 3D collaborative design, through the three-dimensional layout of rooftop playgrounds and elevated plazas, as well as the dense distribution of miniature sports nodes.

The comprehensive utilization rates of different communities are shown in Table 1, and the study shows that community planning parameters are closely related to resident satisfaction. Youth Community E achieved a high satisfaction score of 4.8, significantly better than other communities, by allocating 61.5% of multi-functional sports space, 89.1% of shared facility utilization rate and 97.3% of walking access rate. The study proves that the scientific allocation of fitness facilities and public sports space can not only improve residents' satisfaction, but also promote the equalization of public services, which provides a reference for the sustainable design of high-density urban communities.

Table 1: Comprehensive utilization rate of different communities

Community Name	Planned population density (person/km²)	Total fitness facility area (m²)	Proportion of multifunctional sports space (%)	Utilization rate of shared facilities (%)	Residents' walking accessibility rate (%)	Resident satisfaction rating (out of 5 points)
Ecological Community A	12000	15800	45.2	78.6	92.4	4.5
Smart Community B	14500	18200	38.7	65.3	88.9	4.2
Green Community C	9800	22500	52.1	83.4	95.1	4.7
Mixed-use community D	16200	12300	28.9	54.2	76.8	3.8
Youth Community E	13700	20100	61.5	89.1	97.3	4.8

III. B. Comparison of resource utilization rates

Enhancing the ratio of multifunctional space and the efficiency of shared facilities is the key to optimizing community sports services, and further analysis of the fairness of public sports services found that the Gini coefficient can be used as an important assessment tool.

Table 2 shows the results of resource utilization comparison, and the spatial distribution of fitness facilities in each new type of community presents differentiated and balanced characteristics. Among them, the G value of Smart Community B reflects the slightly slower accumulation of sports space in the medium-density population area of the community, and there is the phenomenon of local resource allocation lagging behind the population distribution, but the overall degree of deviation is limited, and it is still in the relative equilibrium interval, and the sports facility space is accumulated at a slower speed before the population accumulates 40%, and the space is accelerated significantly in the interval of the population accumulating 40%-70%, which indicates that the community has realized efficient agglomeration of facility resources in the densely populated areas through a high composite utilization pattern, which not only guarantees the basic balance, but also enhances the service effectiveness of the key areas. It indicates that its fitness facilities are highly concentrated in a few areas, and the supply of facilities in densely populated areas is seriously insufficient, with a prominent spatial distribution imbalance, consistent with the conclusion that the Gini coefficient is >0.45 imbalance. The rate of youth community sports space accumulation is ahead of population growth at all stages of population, especially in the interval of 60%-100% of population accumulation, where space accumulation is consistently higher than the population ratio, which, combined with its high walkability rate of 97.3%, yields a significant contribution to spatial equilibrium by the pattern of a high proportion of multifunctional space + high sharing efficiency.

It is further quantified by the concentration index to reflect the match between the area share of facilities and the population share. The R-value of the concentration index of Eco-Community A and Youth Community E exceeds 85%, and the absolute difference between the ratio of facility area and population ratio is small, indicating that the resource layout is highly compatible with the population density, and the balance between "equalization of supply" and "intensive utilization" is achieved, which is related to the high walkability rate. The balance between "equalized supply" and "intensive utilization" is achieved, which is directly correlated with the high walkability rate and high satisfaction of residents. The R-values of Smart Community B and Green Community C are 78% and 82% respectively, close to but not reaching the 80% threshold. It is necessary to further optimize the allocation of facilities in areas of high population density, and to narrow the gap between the supply of resources and the demand of the population through the addition of small fitness nodes or the enhancement of the composite functions of existing facilities. The R-value of mixed-function community D is only 65%, far below the 80% threshold, and there is a serious mismatch between the proportion of facility area and the proportion of population, especially in the high-density residential area that accounts for 50% of the total population of the community, the cumulative area of the facility is less than 30%, which directly leads to the low walking accessibility and satisfaction of the residents of the area, and it is necessary to prioritize the construction or expansion of additional fitness facilities in the imbalance area, and to reduce the Gini coefficient to less than 0.4.

Table 2: Comparison results of resource utilization

Community Type	Gini coefficient (G value)	Walking accessibility (%)	Concentration Index (R value)
Ecological Community A	0.33	92.7	88%
Smart Community B	0.46	85.2	78%
Green Community C	0.42	83.5	82%
Mixed-use community D	0.51	74.3	65%
Youth Community E	0.31	97.3	87%

IV. Strategies for optimizing the spatial layout of public sports services

IV. A. Creating miniature motion nodes

In the community planning stage, fragmented spaces such as street corners and building gaps are transformed into pocket parks and miniature fitness nodes through refined design [12]. Long or triangular remaining plots are utilized to implant fitness trails, green rest areas and simple sports facilities, and are connected to the community slow-moving system. Such spaces not only meet residents' daily fitness needs, but also serve as social nodes to promote community vitality. Expanding the exercise space through a three-dimensional strategy, connecting the roofs of low-rise residential buildings to create an aerial fitness platform that combines a rooftop playground with greenery, arranging jogging paths, yoga zones and children's activities, and setting up a semi-open fitness plaza on the elevated floors of the building [13]. This type of design not only relieves the pressure on ground space, but also enhances the microclimate environment of the community through three-dimensional greening.

IV. B. Sustainable Design Orientation and Intelligent Management

Adopt modular facilities and variable space design to adapt to the dynamic development needs of the community. At the same time, an intelligent management system is introduced to optimize resource allocation. Through green building materials, rainwater recycling and other technologies, construction and operation and maintenance costs can be reduced to ensure the ecological sustainability of public sports space. In view of the mismatch between the public sports service space and the population distribution, the new community housing design needs to optimize the facility layout strategy based on the principles of dynamic balance and intensive efficiency. For areas where the distribution of residential areas is dispersed, new sports venues with a larger service scope can be added through neighboring residential areas to enhance the resource coverage, while in densely populated but spatially restricted areas, potential resources such as space under elevated bridges and inefficient abandoned plots of land in the community need to be fully utilized to build multifunctional sports facilities in a decentralized layout mode.

To sum up, the new community housing design should be based on the principle of efficient space utilization and healthy life orientation, and through the multi-dimensional integration of fitness facilities and public space, to build an all-age friendly and functionally composite community sports network, and to provide residents with a convenient and sustainable fitness experience.

V. Discussion

Based on the results of this paper, an all-age friendly should be oriented to build a hierarchical movement network, and future research can further explore the application of artificial intelligence and big data technology in the dynamic deployment of resources to realize the transition from static planning to intelligent and adaptive design. The feasibility of synergistic promotion of equalized supply and intensive utilization is verified, providing a scientific paradigm for the design of healthy living environments in high-density urban communities. Through the in-depth integration of efficient use of space, intelligent management and ecologically sustainable technologies, the new community is expected to achieve a double enhancement of the fairness of the public sports services and the health and well-being of the residents, and to inject sustained momentum into the design of housing for the healthy new community [14], [15].

In the future, the planning of new communities needs to be further combined with the dynamic monitoring mechanism of the Gini coefficient and the concentration index. At the same time, by improving the proportion of multifunctional fitness facilities, the utilization rate of shared facilities, and the walking accessibility rate, we can build an all-age friendly and hierarchical public sports space. In the end, the efficient utilization of space and the integration of intelligent management and eco-sustainable technologies will realize the double improvement of the equity of public sports services and the health and well-being of the residents, and provide a paradigm to support the design of a healthy living environment in high-density urban communities.

VI. Conclusion

Aiming at the problem of tight public sports space and uneven population distribution in the community, this study proposes an intelligent development strategy based on BIM technology for fitness facilities and public sports space in the design of housing in new districts, which requires the establishment of a dynamic monitoring mechanism of the Gini coefficient and the concentration index, combined with the resource utilization rate to assess the balance of the distribution of facilities. By introducing the Gini coefficient and concentration index, a dynamic assessment framework for the distribution of community sports facilities is constructed. The Gini coefficient reveals the degree of matching between facility supply and population distribution, while the concentration index quantifies the core sports space agglomeration effect, and the two are mutually able to systematically diagnose the equilibrium state of equalized supply and intensive utilization. Through the optimization of the high Gini coefficient and the improvement of the concentration index, Youth Community E achieves a walking access rate of 97.3% and a resident satisfaction score of 4.8, which is significantly better than other communities. This demonstrates that scientific quantitative tools provide dynamic thresholds and clear optimization directions for planning decisions, and that the proportion of multifunctional sports space and the utilization rate of shared facilities have a significant positive impact on residents' satisfaction.

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