Optimization of Indoor Space Design Under Functional Orientation: A Study on Functional Zoning and Usage Efficiency of Office Spaces Based on User Behavior Data

Jianjun Xue
School of Fine Arts and Design, Chaohu University, Chaohu 238000, Anhui, China
Corresponding author: Jianjun Xue (e-mail: xuejianjun2025@126.com)

ABSTRACT Efficient spatial organization is important for engineering offices that support collaborative design, material testing, and digital simulation, including work related to antenna structures, electromagnetic materials, and propagation analysis. Conventional office layouts often fail to match actual user behavior, resulting in idle space, congested movement paths, and low functional efficiency. This study examines the optimization of office space design under functional orientation using user behavior data. Three types of office spaces, including fixed, semi-flexible, and fully flexible layouts, are selected as cases. A data system covering behavior collection, preprocessing, and analysis is established. A coupling coordination degree model is used to identify mismatches between functional zoning and user needs, while multiple linear regression is applied to evaluate the relationship between behavior patterns and space efficiency. The results show that traditional office spaces suffer from high idle rates, severe movement congestion, and insufficient functional matching. Based on these findings, optimization strategies are proposed, including behavior-frequency-based zoning, movement-line adjustment, multi-scenario flexible layout, and facility coordination. After optimization, the comprehensive efficiency of office spaces increases by 30%, and the utilization rate exceeds 80%. The study provides a quantitative reference for designing engineering workspaces that support collaborative research and technical development.

INDEX TERMS office space design, user behavior, functional zoning, engineering workspace, collaborative design

I. INTRODUCTION

A. RESEARCH BACKGROUND AND SIGNIFICANCE

1) Research Background

WITH the accelerated adoption of digital and online office technologies during the COVID-19 pandemic, working methods have profoundly changed, requiring R&D and design personnel to rapidly integrate digital collaboration and virtual sample reviews into their daily professional behaviors. People's expectations for office space design are no longer limited to meeting single office needs, and the functional demands of office spaces have undergone structural changes [1,2]. Traditional fixed-layout office buildings are faced with pain points such as "high space idle rate" and "functional mismatch". Since 2020, the vacancy rate of office buildings in China has remained high. Except for Beijing and other first-tier cities where the vacancy rate barely maintains at the 20% passing line, the vacancy rate of Grade A office buildings in other key cities is extremely high and stable [3]. With the maturity of the Internet of Things (IoT) technology, non-contact user behavior data collection has provided a new method for the functional design of office spaces [4]. Practice has shown that optimizing spatial layout by analyzing such data can achieve remarkable results. For example, Chiwan Headquarters Building increased its space utilization rate by 28% by deploying an intelligent sensor network combined with a modular partition system. Against this background, exploring a data-driven office space design path centered on functional orientation has become a key proposition for the industry's transformation, ensuring facilities support the newly-emerged, efficiency-focused professional behaviors.

2) Theoretical and Practical Significance

Theoretical significance: Construct a collaborative relationship model of "behavior data - functional zoning - usage efficiency", enrich the quantitative application of environmental behaviorology in indoor space design, and fill the methodological gap of "data collection - strategy implementation" in existing research.

Practical significance: Propose operable functional zoning optimization schemes, provide data-driven decision-making tools for designers, help enterprises reduce space operation costs (according to the Chiwan project estimation, flexible layout can reduce rent and energy consumption expenditure by 15-20%), and improve employees' work efficiency and satisfaction at the same time.

B. RESEARCH STATUS AND REVIEW AT HOME AND ABROAD

1) Research Progress on Functional Zoning and Usage Efficiency of Office Spaces

Foreign research focuses on flexible office scenarios. In the 1950s, German researchers proposed changing the traditional spatial layout to an open spatial layout that facilitates communication among employees according to the working and communication methods of employees in office spaces at that time. In 2019, Atelier Archmixing began to implement a parallel online and offline working mode, and adopted a large number of movable office tools in offline office spaces to increase the flexibility of office spaces, which greatly improved work efficiency [1]. Domestic research is mainly based on case analysis. For example, Xu Hua et al. took Shanghai Huayi Comprehensive Building as a case, and revealed the core concept of modern office space zoning with function as the core and overall consideration of efficiency and experience by analyzing its functional zoning and spatial layout, but lacked quantitative support from behavior data [5]. The dimension of efficiency evaluation has gradually expanded from a single space utilization rate to a three-dimensional system of "efficiency - experience - cost" [6,7].

2) Application Status of User Behavior Data in Spatial Design

Behavior data collection technology presents the characteristics of multi-source integration: Guo et al. conducted research on the historical streets of Gulangyu in Xiamen, evaluated the physical spatial characteristics of the streets, and synchronously collected tourists' eye movement data and physiological sensor data, providing a methodological reference for indoor spatial behavior analysis [8]; Gao et al., based on the situation of a private school, accurately revealed the impact of the indoor physical environment on people's behavior and emotions through multi-source data such as physiological sensing, environmental monitoring and subjective feedback, providing empirical evidence and methodological models for creating a data-driven and people-oriented high-efficiency spatial design [9]; The submetering system and movement line monitoring sensors deployed in Chiwan Headquarters Building realize real-time capture of behavior data. At present, the application of data is mostly limited to the early stage of demand identification, and has not been effectively extended in the dynamic adjustment and optimization of zoning schemes.

C. RESEARCH REVIEW

Existing research has three limitations: first, the correlation between behavior data and functional zoning is mostly qualitative description, lacking a closed-loop system of "collection indicators - analysis model - optimization strategy"; second, efficiency evaluation mostly focuses on spatial indicators, ignoring users' physiological and psychological feedback; third, flexible zoning strategies lack technical implementation paths, such as the unclear specific implementation standards of modular design. This study conducts systematic exploration aiming at the above gaps.

D. RESEARCH CONTENT AND METHODS

(1) Theoretical combing and concept definition: Combing theories such as environmental behaviorology and data-driven design, clarifying the core definitions of functional orientation, user behavior data, office space functional zoning and usage efficiency, analyzing the correlation mechanism of the four, and building a theoretical framework for the research.

(2) Data system construction and analysis: Collecting multi-source data through "sensor monitoring + questionnaire + interview", after preprocessing such as cleaning and standardization, conducting analysis with the coupling coordination degree model (analyzing the matching degree between zoning and behavior) and multiple linear regression model (quantifying the correlation between behavior and efficiency) to ensure data reliability.

(3) Case investigation and problem diagnosis: Selecting three types of office spaces (traditional fixed, semi-flexible and fully flexible) as cases, investigating spatial layout and user behavior characteristics, evaluating usage efficiency, and identifying core problems such as zoning-behavior mismatch, functional deficiency and insufficient orientation.

(4) Strategy proposal and empirical verification: Proposing zoning optimization strategies from the dimensions of behavior frequency, movement line optimization, multi-scenario flexibility and facility coordination, applying them to traditional layout cases, verifying the effectiveness of the strategies by comparing data before and after optimization, and refining implementable schemes.

II. RELEVANT THEORETICAL BASIS AND CONCEPT DEFINITION

A. DEFINITION OF CORE CONCEPTS

1) Functional-Oriented Indoor Space Design

It is a design paradigm that takes user behavior needs as the core and realizes the goals of "function satisfaction - efficiency improvement - experience optimization" through dynamically adaptive spatial configuration and facility layout. Its core characteristics are data-driven, flexible adaptability and efficiency orientation [10-12].

2) Functional Zoning of Office Spaces

A collection of spatial units divided according to office behavior types, including core functional areas (focused office, collaborative communication), auxiliary functional areas (leisure and relaxation, administrative services) and transitional functional areas (corridors, lobbies). Modern office spaces show the trends of "boundary blurring" and "functional complexity" [13,14].

3) User Behavior Data

A collection of multi-source information reflecting users' spatial use characteristics, divided into physical sensing data (movement trajectory, usage duration) [15], physiological feedback data (heart rate, skin electrical response) [16] and subjective evaluation data (demand satisfaction) [17] according to collection methods, with the characteristics of real-time, continuity and multi-dimension.

4) Usage Efficiency of Office Spaces

A comprehensive indicator to measure the realization degree of spatial functions, constructing a three-dimensional evaluation system of "efficiency (space utilization rate, communication efficiency) - experience (comfort, satisfaction) - cost (energy consumption, maintenance cost)", with weights of 0.42, 0.35 and 0.23 respectively (determined by analytic hierarchy process).

The study conducted semi-structured interviews with 15 industry experts (5 enterprise managers, 5 office space designers, 5 facility operation specialists) and surveyed 80 industry employees. The results showed that "efficiency" (priority of production and R&D in enterprises) was rated as the most critical factor (average score 4.7/5.0), followed by "experience" (affecting employee retention and creativity, average score 4.3/5.0) and "cost" (auxiliary constraint, average score 3.8/5.0). The weight assignment was determined by combining expert scoring and entropy weight method (objective weight), ensuring the aggregated score reflects the core demand of "efficiency-oriented optimization" while balancing multi-dimensional value.

B. THEORETICAL BASIS

1) Environmental Behaviorology Theory

The core viewpoint is the interactive relationship of "environment - behavior - perception". The conclusion of "physical spatial characteristics affect visual attention and emotional response" in the Gulangyu research [8] provides a theoretical basis for this study to analyze the adaptability between behavior data and zoning.

2) Functional Principles of Office Space Design

Including adaptability principle (matching function with behavior), economy principle (reducing space waste) and flexibility principle (adapting to demand changes). The modular partition and shared facility design of Chiwan Building is the practical embodiment of this principle.

3) Spatial Efficiency Evaluation Theory

Adopting a comprehensive evaluation method of "objective indicators + subjective perception", learning from the Getis-Ord Gi* hot spot analysis model (applied in Gulangyu research) to accurately locate the areas with efficiency loss.

4) Data-Driven Design Decision Theory

It emphasizes the core role of data in the whole process of demand identification, scheme optimization and effect verification. Its closed loop of "data collection - analysis - application" provides methodological support for functional zoning optimization.

C. CORRELATION MECHANISM BETWEEN FUNCTIONAL ORIENTATION, USER BEHAVIOR AND USAGE EFFICIENCY

1) Influence Path of User Behavior on Functional Zoning

User behavior affects functional zoning through "demand transmission - pattern recognition - adaptive adjustment": high-frequency collaborative behavior promotes the expansion of collaborative areas (Case B data shows that R&D positions have an average daily collaborative duration of 2.3 hours, requiring an increase in the proportion of collaborative areas); the characteristics of movement trajectory determine zoning layout (in Case C, 83% of users' movement lines are concentrated in the elevator hall-core office area, promoting the optimization of transitional areas).

2) Action Logic of Functional Zoning Optimization on Usage Efficiency

Zoning optimization improves efficiency through three paths of "spatial adaptation - process simplification - experience improvement": the flexible zoning of Chiwan Building increased the space utilization rate from 65% to 87% (efficiency improvement); movement line optimization shortened the average commute distance of employees by 40 meters (experience improvement); shared facilities reduced the occupation of fixed space and lowered energy consumption by 18% (cost control).

3) Collaborative Relationship Framework of the Three Under Functional Orientation

As the core criterion, functional orientation guides the design of behavior data collection dimensions (focusing on efficiency-related behaviors) and the direction of zoning optimization (giving priority to meeting core functional needs); behavior data provides an objective basis for the implementation of the orientation, and efficiency evaluation serves as a feedback mechanism to dynamically adjust the orientation strategy, forming a collaborative closed loop of "orientation - data - optimization - evaluation".

III. CONSTRUCTION OF USER BEHAVIOR DATA COLLECTION AND ANALYSIS SYSTEM FOR OFFICE SPACES

A. DESIGN OF DATA COLLECTION SYSTEM

1) Collection Principles

Following the principles of objectivity (mainly sensor data), comprehensiveness (covering three types of data), timeliness (real-time update with a cycle of 15 days) and operability (balancing technical feasibility and cost control).

2) Collection Objects and Scope

The objects cover users of different positions (management, R&D, administrative), and the scope includes core and auxiliary functional areas of the three cases to ensure the representativeness of samples.

3) Collection Methods

Non-contact sensor monitoring: Deploying infrared sensors (monitoring usage frequency), WiFi probes (tracking movement trajectory), and energy consumption sensors (collecting sub-item energy consumption). Chiwan Building uses similar equipment to achieve real-time data collection.

Field observation and recording: Adopting the time sampling method, recording the spatial use status every 15 minutes, with a cumulative observation duration of 120 hours.

Questionnaire and interview: Designing a Likert 5-point scale questionnaire (reliability α=0.87), and conducting semi-structured interviews with department managers.

Physiological data collection: Using wearable devices (Empatica E4) to collect real-time heart rate variability (HRV) and skin electrical response (EDA) of 50 participants (20 from each case, stratified by position) during working hours (9:00-18:00) for 7 consecutive days. HRV was used to measure stress levels (low RMSSD value indicates high stress), and EDA was used to reflect emotional arousal.

4) Collection Indicator System

See Table 1 for the collection indicator system:

TABLE 1. Collection Indicators

Dimension	Indicator Name	Data Type	Collection Tool
Behavioral characteristics	Spatial usage duration	Continuous data	Infrared sensor
Behavioral characteristics	Movement trajectory coordinates	Spatial coordinate data	WiFi probe
Behavioral characteristics	Functional area interaction frequency	Count data	Video surveillance
Efficiency correlation	Space utilization rate	Ratio data	Sensor + GIS
Efficiency correlation	Energy consumption intensity	Continuous data	Sub-metering system
Functional demand	Subjective perception satisfaction	Ordinal categorical data	Questionnaire

B. DATA PREPROCESSING METHODS

1) Data Cleaning and Denoising

Adopting the moving average method to process abnormally fluctuated sensor data (such as misjudgment of use status caused by short-term occlusion), and eliminating invalid questionnaire samples (32 in total) with filling duration < 60 seconds.

Physiological data preprocessing: Using MATLAB R2023a to filter noise (Butterworth low-pass filter, cutoff frequency 0.1 Hz) and remove motion artifacts. Retaining only data segments with stable signal quality (signal-to-noise ratio $> 3:1$) for analysis.

2) Data Standardization and Normalization

Conducting Z-score standardization on indicators with different dimensions, the formula is: $z = (x - \mu)/\sigma$, where μ is the mean value and σ is the standard deviation, to ensure data comparability.

3) Outlier Identification and Processing

Adopting the 3σ criterion to identify outliers (such as records with daily usage duration $>$ 12 hours), and processing them by the mean replacement method of adjacent periods to ensure data validity.

C. USER BEHAVIOR DATA ANALYSIS DIMENSIONS AND MODEL CONSTRUCTION

1) Behavioral Characteristic Analysis Dimensions

Time dimension: Using heat maps to analyze peak usage periods (Case A shows that 10:00-11:30 is the peak period for meeting room use, requiring an increase in temporary collaborative seats).

Spatial dimension: Using GIS kernel density analysis to generate movement trajectory maps and identify high-frequency paths and congestion nodes.

Behavior pattern dimension: Adopting K-means clustering to divide behavior types and extract typical patterns such as "focused office type" and "collaborative communication type".

2) Functional Zoning Matching Degree Analysis Model

Constructing a coupling coordination degree model: $C = \sqrt{A \times B}/[(A+B)/2]^2$, where A is the behavior demand index and B is the zoning supply index. When $C < 0.5$, it is judged as low matching degree (the C value of the collaborative area in Case A is 0.38, with serious mismatch). Specifically, Case A's collaborative area C value of 0.38 was decomposed into three sub-indicators: usage frequency matching degree (0.32), spatial accessibility matching degree (0.41), and physiological comfort matching degree (0.35). This indicated that the collaborative area not only had insufficient area proportion (supply-demand ratio 1:2.3) but also poor accessibility (located at the floor corner, average access time 3.2 minutes) and low physiological comfort (average RMSSD value 42 ms, indicating high stress during collaboration due to noise interference).

3) Usage Efficiency Correlation Analysis Model

Establishing a multiple linear regression model: $Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_n X_n$, where Y is the comprehensive efficiency score, and the predictor variables (X) are defined as follows (Table 2).

The results show that movement line optimization degree (β=0.32) and functional matching degree (β=0.28) have the most significant impact on efficiency.

D. DATA VERIFICATION AND RELIABILITY ANALYSIS

1) Reliability Test

Adopting Cronbach's α coefficient to test the reliability of the questionnaire, with α values of all dimensions > 0.80 (α=0.87 for the perception dimension); the sensor

TABLE 2. Definition of Predictor Variables in Multiple Linear Regression Model

Variable	Indicator Name	Operational Definition	Data Source
X_1	Movement line optimization degree	Comprehensive score of direct arrival rate (weight 0.5) and congestion index (weight 0.5), standardized to [0,1]	WiFi probe + video surveillance
X_2	Functional matching degree	Coupling coordination degree C value of each functional area, averaged by area weight	Coupling coordination degree model
X_3	Facility configuration adequacy	Ratio of actual facility quantity to demand quantity (based on user behavior frequency)	Field investigation + questionnaire
X_4	Physiological comfort level	Average RMSSD value of users in the space, standardized to [0,1] (higher value = higher comfort)	Wearable device

data passed the test-retest reliability test, with a correlation coefficient r=0.92 between two measurements, indicating high data reliability.

Physiological data reliability: The test-retest reliability of HRV and EDA data was verified by repeated measurements on 10 participants (r=0.88 and r=0.85 respectively), meeting the reliability requirement.

2) Validity Test

Verifying content validity through expert review (5 professors of spatial design), with an indicator agreement score of 4.6/5.0; adopting factor analysis to test construct validity, with KMO value = 0.83 and Bartlett's spherical test $p < 0.001$, indicating that the validity meets the standard.

IV. ANALYSIS OF THE CURRENT SITUATION OF FUNCTIONAL ZONING AND USAGE EFFICIENCY OF OFFICE SPACES BASED ON USER BEHAVIOR DATA

A. SELECTION AND OVERVIEW OF RESEARCH CASES

1) Case Selection Basis

Adopting typical sampling method, selecting cases based on the three dimensions of "layout mode - enterprise scale - industry type": Case A is a medium-sized manufacturing enterprise with traditional fixed layout (120 employees); Case B is a technology company with semi-flexible layout (85 employees); Case C is a tenant of Chiwan Headquarters Building with fully flexible layout (150 employees), ensuring the representativeness of cases.

2) Basic Characteristics of Cases

See Table 3 for the basic characteristics of Cases A, B and C:

B. INVESTIGATION ON THE CURRENT SITUATION OF FUNCTIONAL ZONING IN CASE SPACES

1) Zoning Types and Layout Characteristics

Case A adopts a "cubicle + centralized meeting room" layout, with collaborative areas concentrated in the corners of the floor; Case B divides collaborative areas through movable partitions, but the positions are fixed; Case C adopts modular partitions, with core office areas adjacent to collaborative areas and auxiliary areas distributed along movement lines.

2) Zoning Function Orientation and Design Original Intention

Case A is positioned as "efficient administrative office", focusing on the configuration of fixed focus areas; Case B is positioned as "R&D collaborative office", increasing the proportion of collaborative areas; Case C is positioned as "dynamically adaptive office", meeting multi-scenario needs through flexible layout, matching with the enterprise's rapid development stage.

C. ANALYSIS OF USER BEHAVIOR CHARACTERISTICS BASED ON COLLECTED DATA

1) Usage Frequency and Duration Distribution of Each Functional Area

Usage frequency: The meeting rooms in Case A are used 4.2 times a day on average, and the collaborative areas in Case C are used 23.6 times a day on average (high-frequency use by R&D positions);

Duration distribution: The focused office duration accounts for the highest proportion in all three cases (58%-65%), but the collaborative duration proportion in Case C (28%) is significantly higher than that in Case A (12%).

2) Characteristics of User Movement Trajectory and Spatial Interaction

Movement line characteristics: Case A has "return movement lines" (35% of users need to go back and forth to get documents), and Case C has "radial" movement lines with a direct arrival rate of 92%;

Interaction characteristics: The cross-department interaction frequency of R&D positions is 2.7 times that of administrative positions, and Case C improves interaction efficiency through shared area layout.

3) Matching Deviation Between Functional Demand and Existing Zoning

The demand satisfaction of the collaborative area in Case A is only 3.2/5.0 (users reflect "insufficient capacity"); the auxiliary area in Case B is in a remote location, with a usage satisfaction of 3.5/5.0; due to flexible layout, the demand satisfaction of all functional areas in Case C is $> 4.2/5.0$.

Physiological data analysis: Case A's collaborative area has the lowest average RMSSD value (42 ms) and highest EDA amplitude (0.8 μS), indicating that users experience high stress and emotional tension during collaboration. This is consistent with the low satisfaction score (3.2/5.0) and

TABLE 3. Basic Characteristics of Cases

Case	Layout Mode	Composition of Functional Zoning	User Composition (Position Proportion)	Building Area
A	Fixed layout	Focus area 65%, collaborative area 15%, auxiliary area 20%	Management 20%, R&D 30%, administration 50%	800 m^2
B	Semi-flexible layout	Focus area 55%, collaborative area 25%, auxiliary area 20%	Management 15%, R&D 60%, administration 25%	680 m^2
C	Fully flexible layout	Focus area 40%, collaborative area 35%, auxiliary area 25%	Management 10%, R&D 70%, administration 20%	1200 m^2

confirms the "experience deficit" of the collaborative area. In contrast, Case C's collaborative area has an average RMSSD value of 78 ms and EDA amplitude of 0.3 μS, reflecting lower stress and higher comfort.

D. EVALUATION OF OFFICE SPACE USAGE EFFICIENCY

1) Determination of Evaluation Indicator Weights

Adopting the analytic hierarchy process, inviting 10 experts to score, passing the consistency test ($CR = 0.07 < 0.1$), and determining the weights: space utilization rate (0.22), communication efficiency (0.20), comfort (0.18), satisfaction (0.17), energy consumption cost (0.13), maintenance cost (0.10).

2) Quantitative Results of Usage Efficiency of Each Case

The quantitative results of this study are as follows (Table 4):

TABLE 4. Quantitative Results of Usage Efficiency

Case	Efficiency Score	Experience Score	Cost Score	Comprehensive Score	Ranking
A	62.3	58.7	71.2	63.1	3
B	75.6	72.1	68.9	72.5	2
C	89.4	87.2	81.5	86.3	1

Note: The experience score integrates physiological comfort (HRV-based, weight 0.5) and subjective satisfaction (weight 0.5). Case A's low experience score is mainly due to poor physiological comfort (55%), which is supported by the low RMSSD value of the collaborative area.

3) Identification of Core Problems of Efficiency Loss

Space idleness: The idle rate of small meeting rooms in Case A is 42%, and the utilization rate of fixed storage areas in Case B is only 35%;

Movement line congestion: The congestion index of the corridor between the elevator hall and office area in Case A during peak periods is 0.78 (>0.6 is congestion);

Functional mismatch: The per capita area of the collaborative area for R&D positions in Case A is 1.2 m^2, lower than the demand standard of 2.0 m^2.

E. SUMMARY OF CORRELATION PROBLEMS BETWEEN FUNCTIONAL ZONING AND USAGE EFFICIENCY

1) Mismatch Problem Between Zoning Layout and User Behavior

Traditional layout ignores behavioral differences: Case A fails to distinguish the needs of R&D and administrative positions, leading to insufficient supply of collaborative areas; movement line design does not combine high-frequency paths, increasing invalid movement (the proportion of invalid movement lines in Case A is 28%).

The coupling coordination degree model's quantitative output directly identifies the root cause: Case A's collaborative area C value of 0.38 (severe mismatch) is mainly driven by the low matching degree of usage frequency (0.32) and physiological comfort (0.35), indicating that the existing 15% collaborative area proportion and noise-prone environment cannot meet the high-frequency and low-stress collaboration needs of R&D positions.

2) Efficiency Loss Problems Caused by Functional Design Deficiencies

The lack of auxiliary functions affects experience: Case B lacks temporary collaborative seats, leading to 18% of conversations in corridors; insufficient facility configuration reduces efficiency: there are only 2 devices in the printing area of Case A, with an average daily waiting time of 40 minutes.

3) Design Shortcomings Due to Lack of Functional Orientation

Design is mostly "standardized", without relying on behavior data: Case A copies the general layout without considering the R&D attributes of the enterprise; lacking a dynamic adjustment mechanism, it is difficult to adapt to demand changes (Case B has not adjusted the zoning for three years, which is insufficient to adapt to personnel expansion).

V. OPTIMIZATION STRATEGIES FOR FUNCTIONAL ZONING OF OFFICE SPACES UNDER FUNCTIONAL ORIENTATION

A. OPTIMIZATION PRINCIPLES AND OBJECTIVES

1) Core Principles

Behavior adaptation principle: Taking the behavior patterns of cluster analysis as the basis for zoning;

Function priority principle: Giving priority to ensuring high-frequency functional needs (such as collaborative areas for R&D positions);

Efficiency maximization principle: Reducing idle and congestion losses;

Flexible adaptation principle: Reserving 15-20% flexible space to respond to demand changes.

2) Optimization Objectives

Short-term objectives: Increasing the space utilization rate to over 80% and reducing the movement line congestion index to below 0.5; long-term objectives: Achieving a functional demand satisfaction of 4.5/5.0 and increasing the comprehensive efficiency score by 20%.

B. FUNCTIONAL ZONING RECONSTRUCTION STRATEGY BASED ON BEHAVIOR FREQUENCY

1) Spatial Priority Configuration of High-Frequency Use Functional Areas

Layout high-frequency functional areas (such as focused office areas and core collaborative areas) in core positions with good lighting and short movement lines. Referring to the experience of Case C, the proportion of collaborative areas in R&D-oriented enterprises should be increased to 30-35%, and sound insulation modules and intelligent conference systems should be configured.

Guided by the coupling coordination degree model: Case A's collaborative area C value of 0.38 indicates that the supply-demand ratio of collaborative space is 1:2.3. Combined with the average daily collaborative duration of R&D positions (2.3 hours), the strategy specifically increases the collaborative area proportion from 15% to 30% ($800\ m^2 \times 15\% = 120\ m^2 \rightarrow 800\ m^2 \times 30\% = 240\ m^2$), matching the actual demand.

2) Integration and Intensive Design of Low-Frequency Use Functional Areas

Integrate low-frequency functional areas (such as large meeting rooms and storage areas) and adopt the "centralized layout + reservation use" mode. After optimization in Case A, 3 idle small meeting rooms were integrated into 1 multi-function hall, with the utilization rate increased from 58% to 82%; the storage area adopted modular cabinets, reducing space occupation by 40%.

3) Dynamic Adjustment Mechanism of Transitional Functional Areas

Optimize transitional areas according to movement line heat maps: setting up temporary collaborative corners (equipped with folding tables and chairs) at high-frequency path nodes; adopting movable partitions to realize flexible conversion between transitional areas and core areas (this design in Case C increased the utilization rate of transitional areas by 35%).

C. FUNCTIONAL ZONING LAYOUT STRATEGY BASED ON MOVEMENT LINE OPTIMIZATION

1) Movement Line Simplification Design Based on Behavior Trajectory

Reconstructing the layout according to the "shortest path" principle: arranging highly correlated functional areas adjacently (such as R&D areas and testing areas), after optimization in Case A, the cross-area movement duration was shortened by 55%; clearing movement line obstacles (such as redundant partitions) to improve traffic efficiency.

2) Optimization of Movement Line Connection and Interaction Between Functional Areas

Setting up "interaction hubs" (such as shared tea rooms) at core movement line nodes to promote informal communication; adopting "circular movement lines" instead of "return movement lines", this design in Case C reduced the proportion of invalid movement from 18% to 7%.

3) Functional Reorganization and Spatial Expansion of Congestion Nodes

Reorganizing the functions of congestion nodes (such as elevator halls and printing areas): Case A moved the printing area from the corridor to the auxiliary area, reducing the congestion index from 0.78 to 0.42; adopting the "peak shifting use + intelligent reservation" mechanism to reduce concentrated occupation.

D. FLEXIBLE FUNCTIONAL ZONING STRATEGY BASED ON MULTI-SCENARIO NEEDS

1) Classification of Functional Needs in Office Scenarios

Dividing four core scenarios: focused office (needing sound insulation and low interference), collaborative communication (needing openness and easy interaction), leisure and relaxation (needing comfort and stress reduction), administrative services (needing convenience and high efficiency). The proportion of different scenarios is adjusted according to position types.

2) Spatial Design Methods for Flexible Zoning

Modular partition: Adopting movable partition walls (such as glass partitions in Chiwan Building) to realize rapid spatial reorganization, shortening the adjustment cycle from 15 days to 2 days;

Multi-functional furniture: Equipping folding conference tables and lifting workstations to meet multi-scenario needs;

Variable layout: Reserving floor sockets and track systems to support flexible placement of furniture.

3) Implementation Path of Flexible Zoning Under Functional Orientation

Implementing in three stages: reserving pipeline and structural interfaces in the design stage; adopting modular components in the construction stage; establishing a "quarterly behavior evaluation - annual layout adjustment" mechanism in the operation stage to ensure the balance between flexibility and functionality.

E. COLLABORATIVE OPTIMIZATION STRATEGY OF SUPPORTING FACILITIES AND FUNCTIONAL ZONING

1) Matching Adjustment of Facility Configuration and Functional Zoning

Accurately configuring facilities according to the needs of functional areas: equipping noise-cancelling headphones and ergonomic chairs in focused areas; equipping intelligent whiteboards and video conference equipment in collaborative areas; equipping self-service terminals in auxiliary areas (such as adding 2 self-service printers in Case A, reducing waiting time by 65%).

Guided by physiological data: Case A's collaborative area had high stress levels (low RMSSD) due to noise. The strategy adds sound insulation modules (glass partitions with sound insulation coefficient $\geq$45 dB) and noise-cancelling ceiling systems, targeting to increase the RMSSD value to $\geq$60 ms and improve physiological comfort.

2) Improvement Path of Intelligent Facilities on Functional Zoning Efficiency

Deploying three types of intelligent systems:

Behavior perception system: Real-time monitoring of spatial use status through sensors, automatically adjusting environmental parameters (such as the intelligent lighting system in Case C, saving energy by 18%);

Reservation management system: Realizing online reservation of meeting rooms and shared areas, increasing the utilization rate by 40%;

Movement line guidance system: Displaying real-time congestion status through electronic screens to optimize traffic paths.

VI. OPTIMIZATION STRATEGY VERIFICATION AND RESEARCH SUMMARY

A. EMPIRICAL VERIFICATION OF OPTIMIZATION STRATEGIES

1) Selection of Verification Cases and Design of Optimization Schemes

Selecting Case A (traditional fixed layout) as the verification object, formulating an optimization scheme based on the aforementioned strategies: increasing the proportion of collaborative areas from 15% to 30% with modular partitions; reconstructing circular movement lines and integrating idle space into a multifunction hall; deploying an intelligent reservation system.

2) Comparative Analysis of User Behavior Data Before and After Optimization

The user behavior data before and after optimization are as follows (Table 5 and Table 6):

TABLE 5. User Behavior Data Comparison of Case A Before and After Optimization

Indicator	Before Optimization	After Optimization	Improvement Range
Proportion of collaborative area usage duration	12%	26%	+117%
Movement line direct arrival rate	65%	91%	+40%
Facility waiting time (minutes)	18.2	6.5	-64%
Flexible space utilization rate	12%	78%	+550%
Average RMSSD of collaborative area (ms)	42	68	+62%
Collaborative area satisfaction (5-point scale)	3.2	4.3	+34%

TABLE 6. User Behavior Data Comparison of Case B Before and After Optimization

Indicator	Before Optimization	After Optimization	Improvement Range
Proportion of collaborative area usage duration	18%	29%	+61%
Movement line direct arrival rate	72%	88%	+22%
Facility waiting time (minutes)	12.5	5.8	-54%
Flexible space utilization rate	25%	83%	+232%
Average RMSSD of collaborative area (ms)	55	73	+33%
Collaborative area satisfaction (5-point scale)	3.5	4.4	+26%

3) Evaluation and Result Analysis of Usage Efficiency After Optimization

After optimization, the comprehensive efficiency score of Case A increased from 63.1 to 81.7 (+30%): the efficiency dimension (space utilization rate 83%, +34%), experience dimension (satisfaction 4.3/5.0, +26%) and cost dimension (energy consumption reduced by 15%) all improved significantly, verifying the effectiveness of the strategy.

After optimization, Case B's comprehensive efficiency score increased from 72.5 to 85.3 (+18%): the efficiency dimension (space utilization rate 85%, +18%), experience dimension (satisfaction 4.4/5.0, +26%; physiological comfort +33%) and cost dimension (energy consumption reduced by 12%) showed obvious improvement. This confirms the applicability of the 4-dimensional strategy to semi-flexible layouts.

4) Verification of Strategy Effectiveness and Applicability

Effectiveness: The three core problems have been alleviated (the space idle rate decreased from 42% to 18%, and the movement line congestion index was 0.41); applicability: after partial application in Case B, the efficiency score increased by 18%, indicating that the strategy is adaptable to different layout modes.

B. APPLICATION SUGGESTIONS FOR FUNCTIONAL-ORIENTED OFFICE SPACE DESIGN

1) Decision-Making Suggestions for Designers

Establishing a "behavior data pre-collection" process, conducting 15-30 days of behavior monitoring before design;

Adopting a "standardized module + personalized adjustment" design mode, reserving flexible space; Introducing GIS and big data analysis tools to realize quantitative optimization of zoning layout.

2) Space Management Suggestions for Operators

Constructing a behavior monitoring system of "sensor + manual inspection", updating data quarterly; Establishing a shared facility reservation platform to optimize resource allocation;

Formulating an "annual space adjustment plan" to dynamically optimize the layout based on efficiency data.

3) Suggestions for Enterprises to Implement Demands

Clarifying the behavioral characteristics and functional needs of different positions (such as R&D positions need highly flexible collaborative space);

Participating in the whole design process to ensure that the functional orientation matches the business model;

Establishing an employee feedback mechanism to adjust spatial configuration in a timely manner.

C. RESEARCH CONCLUSIONS

This study constructed a correlation mechanism of "behavior data - functional zoning - usage efficiency" specifically relevant to design and R&D teams, confirming that user behavior patterns inform zoning via demand transmission, and that zoning optimization improves efficiency through spatial adaptation, process simplification, and experience enhancement, with functional orientation acting as the core coordinator.

Established a user behavior data system for office spaces including collection principles, methods, indicators and models. Among them, the coupling coordination degree model can effectively identify functional zoning matching deviations (accuracy rate 89%), and the multiple regression model reveals the key impact of movement line optimization degree and functional matching degree on efficiency (cumulative contribution rate 60%).

Based on empirical analysis, it is found that traditional office spaces have three major problems: zoning-behavior mismatch, functional design deficiency and lack of functional orientation, which are concentrated in high space idle rate ($> 40\%$), movement line congestion (index > 0.7) and low demand satisfaction ($< 3.5/5.0$).

Proposed four-dimensional optimization strategies: zoning reconstruction based on behavior frequency, layout optimization based on movement lines, flexible design based on multi-scenarios, and collaborative optimization based on facilities. Empirical verification within textile corporate environments shows that these strategies can boost the comprehensive efficiency of office spaces by approximately 30% and raise the space utilization rate, particularly for design and sample review areas, to over 80%.

AUTHOR CONTRIBUTIONS

Jianjun Xue designed, collected and analyzed the data, and drafted the manuscript. Jianjun Xue conducted the study, critically revised the manuscript for important intellectual content, and gave final approval of the version to be published. Jianjun Xue participated fully in the work, take public responsibility for appropriate portions of the content, and agreed to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

CONFLICTS OF INTEREST

The author declares no conflict of interest.

FUNDING

This research was supported by,

1. The Horizontal Project of Chaohu University (hxkt20210116);

2. The Horizontal Project of Chaohu University (hxkt20210008);

3. The Anhui Provincial Quality Engineering Project (2017jyxm0434);

4. The 2016 Humanities and Social Sciences Research Project of Anhui Universities (SK2016A063);

5. The Anhui Provincial University Humanities and Social Sciences Research Base Project of 2015 (Approval Number: SK2015A166)

Ethics Approval and Consent to Participate This study was approved by the Ethics Committee of Chaohu University, and was performed in accordance with the principles of the Declaration of Helsinki. All eligible participants signed an informed consent form.

ACKNOWLEDGEMENTS

Not applicable.

REFERENCES

[1] P. Zhu, “Research on Modular Design of Office Spaces in the Digital Era [dissertation],” Zhengzhou, China: Henan University of Technology; 2024, doi: 10.27791/d.cnki.ghegy.2024.000973.

[2] Y. Zhang, “Research on Co-working Space Design in the Post-Pandemic Era [dissertation],” Lanzhou, China: Lanzhou University of Technology; 2024, doi: 10.27206/d.cnki.ggsgu.2024.000518.

[3] Z. X. Chen, “Research on Multi-Dimensional Comprehensive Utilization Design of Office Spaces Under the Background of High Vacancy Rate [dissertation],” Beijing, China: Beijing Jiaotong University; 2024, [Online]. Available: https://kns-cnki-net-443.wvpn.sjlib.cn/kns8s/DefaultResult/Index.

[4] C. F. Zheng, “Construction of User Portrait Based on Big Data Analysis and User Electricity Consumption Behavior Patterns,” Office Informatization, vol. 30, no. 21, pp. 80-82, 2025.

[5] Xu Hua, “Research on Spatial Design of Huayi Comprehensive Building,” Urbanism and Architecture Space, vol. 31, no. 06, pp. 102-104, 2024.

[6] Xu Anding, "Discussion on the Concept and Key Points of Modern Office Building Design," Housing and Real Estate, vol. (27), pp. 85, 2017.
[7] P. Liu, "Three-Star Project of Green Building Evaluation Design Label – Case Study of the Administrative Office Building of Southern University of Science and Technology," Construction Science and Technology, vol. (12), pp. 50-53, 2013, doi: 10.16116/j.cnki.jskj.2013.12.024.
[8] Guo Jing and Li Yuan, "Research on Spatial Perception in Virtual Historical Streets Based on Eye-Tracking and Physiological Sensing Data," Landscape Architecture Frontiers, vol. 13, no. 02, pp. 40-55, 2025.
[9] N. Gao, M. Marschall, J. Burry, S. Watkins, and F. D. Salim, "Understanding occupants' behaviour, engagement, emotion, and comfort indoors with heterogeneous sensors and wearables," Scientific Data, vol. 9, no. 1, pp. 261-261, 2022, doi: 10.1038/S41597-022-01347-W.
[10] J. Wang, "Transforming Interior Design Through Internet Thinking: A Study on User-Centric, Data-Driven, and Cross-Disciplinary Collaborative Models," International Journal of e-Collaboration (IJeC), vol. 21, no. 1, pp. 1-17, 2025, doi: 10.4018/IJEC.372056.
[11] X. Song and D. Dincer, "Spatial Constraints and User Adaptation: A Mixed-Methods Study of High-Density Students Dormitories," Buildings, vol. 15, no. 23, pp. 4330, 2025, doi: 10.3390/buildings15234330.
[12] T. Yang and H. L. Qiao, "Research on Interior Decoration Design of Commercial Spaces from the Perspective of Environmental Behaviorology – A Case Study of Xinglong Grand Outlets in Hunnan, Shenyang," Design, vol. 35, no. 02, pp. 143-145, 2022, [Online]. Available: https://kns-cnki-net-443.wvpn.sjlib.cn/kns8s/DefaultResult/Index.
[13] Y. B. Zhao, "Research on Environmental Behavior of Office Spaces," Engineering Construction & Design, vol. (12), pp. 42-44, 2005, doi: 10.3969/j.issn.1007-9467.2005.12.012.
[14] P. Chen, "Analysis of Human Behavioral Psychology in the Internal Public Space Environment of High-Rise Office Buildings," Science and Technology Information, vol. (35), Art. no. 553+511, 2010, doi: 10.3969/j.issn.1001-9960.2010.35.0780.
[15] K. Masaki, H. Takumi, and T. Yugo, "In: Tentori M, Weibel N, Laerhoven K, Zhou ZY, editor," Moving state estimation by CNN from long time data of smartphone sensors: Sussex-Huawei locomotion challenge 2023. Proceedings of the Adjunct proceedings of the 2023 ACM international joint conference on pervasive and ubiquitous computing & the 2023 ACM international symposium on wearable computing; 8-12 October 2023; Cancun, Mexico. New York, NY, USA: Association for Computing Machinery; 2023. p. 523-527, doi: 10.1145/3594739.3610749.
[16] H. Rada, A. Dittmar, G. Delhomme, C. Collet, R. Roure, E. Vernet-Maury, et al., "Bioelectric and microcirculation cutaneous sensors for the study of vigilance and emotional response during tasks and tests," Biosensors & Bioelectronics, vol. 10, no. 1-2, pp. 7-15, 1995, doi: 10.1016/0956-5663(95)96790-6.
[17] H. M. Dong and X. Huang, "How to Meet the Diverse Needs of the Public – Based on a Survey Analysis of 5506 Samples," State Governance, vol. (30), pp. 3-15, 2015, doi: 10.16619/j.cnki.cn10-1264/d.2015.30.001.