International Journal for Housing Science and Its Applications
Publish August 10, 2025. Volume 46, Issue 4 Pages 7034-7045

https://doi.org/10.70517/ijhsa464607

Research on Interdisciplinary Collaboration Mechanism Based on 3D Engineering Design Collaboration Platform in Residential Building Design

Yanshuo Hou[1] and Cheng Zhong[1,*]
[1] PowerChina Chengdu Engineering Corporation Limited, Chengdu, Sichuan, 611130, China
Corresponding authors: (e-mail: 18628287086@163.com).

Abstract Traditional residential building design relies on designers to manually build models of each floor and finally assemble them, which requires tedious operations such as delineating the axial network, defining the cross-section, and arranging the components, and the workload grows exponentially once the floors become complex. Modern architectural design faces challenges such as difficult interdisciplinary collaboration, poor information transfer, and frequent design changes, and there is an urgent need for more efficient design methods to improve work efficiency and design quality, and to ensure the coordination and unity among various specialties. In this study, we constructed an interdisciplinary collaboration mechanism based on the 3D engineering design collaboration platform of BIM technology, used Autodesk Revit to establish a residential building model, applied Ecotect Analysis software to perform performance simulation analysis, and evaluated the building thermal environment through PMV-PPD thermal comfort evaluation index. The research object is a four-story residential building with a floor area of 4,251 square meters and a height of 22.8 meters, with a reinforced concrete frame structure. The results show that after the BIM interdisciplinary 3D collaborative design renovation, the indoor PMV value was reduced from 1.41 to 0.62 in summer, and improved from -1.69 to -0.65 in winter, the total energy consumption of the building was 11.69*107 Wh, and the payback period of the exterior window optimization scheme was 7.2 years. The collaborative mechanism effectively enhances the efficiency of residential building design, improves indoor thermal comfort, significantly reduces building energy consumption, and provides a scientific basis and technical support for residential building design.

Index Terms BIM technology, 3D co-design, interdisciplinary collaboration, thermal comfort evaluation, building energy consumption, payback period

I. Introduction

Residential architecture occupies an important position in construction and has special significance for human survival [1]. Especially today, it has become an important factor affecting whether the national economy can develop sustainably and social stability [2]. And residential building design plays an important role in improving the comfort and happiness of living [3], [4]. At present, residential building design has entered the era of competition and comparison of a hundred flowers blossoming and a hundred schools of thought, in order to realize the applicability, safety, economy, aesthetics and personalization of residential building design, residential design technology occupies an ever-increasing position in construction enterprises, and has a very important role in the competition between enterprises in the construction industry [5]-[8].

As an important technology in the field of construction, the 3D engineering design-based collaboration platform is widely used in residential design [9]. The platform takes Building Information Modeling (BIM) as the core technology, and BIM is a comprehensive tool based on digital technology, which promotes the collaborative work of the construction engineering industry by creating, managing, and sharing the information related to the construction project, which makes the 3D engineering design collaboration platform equipped with the functions of 3D model sharing, building construction analysis, etc., and is able to reduce the disagreement of the management personnel and reduce the cost of building construction [10]-[13]. In the process of residential design, interdisciplinary collaboration has also become more and more important, and BIM engineers play a key role in assisting the various professions to work together, which can ensure the efficient advancement of residential projects [14]-[16].

Building information modeling (BIM) technology, as the core driving force of digital transformation in the construction industry, is reshaping the traditional building design model and providing a new technical path to solve the collaboration challenges in complex building projects. In the current residential building design process, there is a lack of effective information sharing mechanism among various specialties, frequent design changes lead to high rework rate, and the traditional two-dimensional design method is difficult to accurately express complex spatial relationships, which affects the design quality and project progress. By establishing a unified data environment, the 3D collaborative design platform realizes the information integration of multiple disciplines, such as architecture, structure, and electromechanics, and provides a visual design interactive interface, enabling the design team to collaborate in real time and synchronously update the design scheme. This technology not only improves the design efficiency, but also provides a scientific basis for building energy-saving design and comfort optimization through the performance simulation and analysis function, which promotes the development of residential building design in the direction of intelligence and refinement.

Based on the above background, this study constructs a complete BIM 3D collaborative design workflow, firstly establishing the project role authority system and clarifying the responsibility interface of each participant, then formulating the collaborative work planning scheme, standardizing the information communication and change management procedures, and finally ensuring the data quality and project results through digital delivery standards. The research adopts the method of combining theoretical analysis and example verification, takes a city residential building project as the research object, establishes a 3D model using Revit software, performs performance simulation using Ecotect Analysis, analyzes thermal comfort through the PMV-PPD evaluation system and carries out the economic benefit assessment to validate the practicability and effectiveness of the BIM cross-disciplinary collaborative design mode.

II. Collaborative three-dimensional engineering design incorporating BIM technology

The traditional way of designing residential buildings is that the designer manually builds up the models of each floor and finally assembles them to obtain them. During the whole process, the designer needs to divide the axis network, define the cross section, arrange the components, arrange the loads and arrange the constraints and other operations by himself. If the buildings on each floor are similar, the problem can be solved by duplicating the layers with a few modifications, but once the floors are complex, the workload needs to be doubled. Based on this, exploring more efficient residential building design methods is an effective way to further improve the efficiency of residential building design, and the 3D engineering design collaboration platform combined with BIM technology provides effective support for this.

II. A.3D Collaborative Design and Platform

II. A. 1) Advantages of 3D co-design

(1) Advantages of three-dimensional collaborative design image

The application of three-dimensional collaborative design technology in residential building design can generate a virtual three-dimensional model, and based on the virtual model for the simulation of the specific construction process of the residential building project, which can better understand the problems that may occur in the actual construction and construction, as well as the parameter calculation errors that may occur. After clarifying the problems, then according to these problems for design correction, can achieve the effect of comprehensive optimization of design work. Since the 3D collaborative design based on BIM technology can realize image simulation, the specific engineering design can be directly presented to the review unit and organizational leaders for review, which can enhance the accuracy of the 3D collaborative design review and evaluation of residential construction projects [17].

(2) Three-dimensional collaborative design space advantage

In residential construction engineering design practice, the use of BIM technology and three-dimensional collaborative design concept has significant spatial advantages. The spatial advantage mainly refers to the spatial modeling that can be realized through 3D collaborative design, on the basis of which the spatial layout defects that could not be solved by the previous plane design can be studied, so as to make the spatial layout of the residential construction project more reasonable and intuitive. At the same time, it can also better solve some problems in residential construction projects, enhance the scientific nature of space layout, and significantly improve the overall design quality of residential construction projects.

(3) Advantages of 3D collaborative design management checking

In the construction phase of the project, there are cross positions in the field and various monoliths, with the help of BIM technology's outstanding spatial simulation and visibility, it can mark out the cross operations in the spatial virtual model in an image, which can effectively avoid losses and inconvenience due to the cross-collision operations, so it can be seen that the application of BIM technology is an effective way to optimize the design scheme.

II. A. 2) Three-dimensional collaborative design platform

The platformization strategy of Autodesk's products requires the establishment of a set of basic business software platforms, rather than the establishment of an operating system or database platform, based on a careful analysis of the functions, features, and software technologies used in existing products [18]. The system architecture diagram is shown in Figure 1. From the software architecture point of view, the work of Autodesk software platformization can be divided into the basic service layer, the general function layer and the cloud computing function layer from the bottom function to the advanced function.

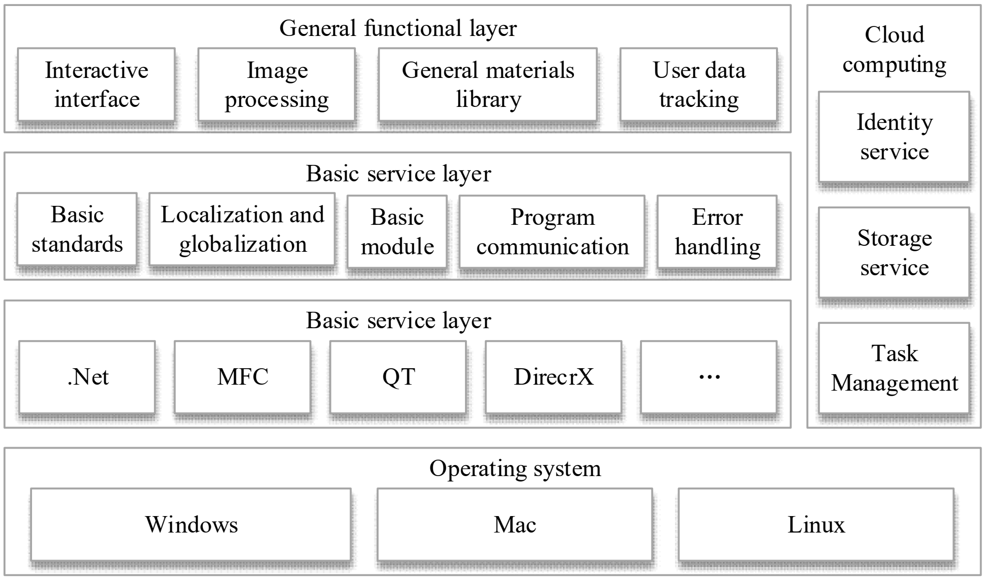


Figure 1: Overall Architecture

(1) Basic service layer. This layer mainly includes basic and core software components. The main modules are basic modules: string processing, encapsulation and improvement of string processing, this component will encapsulate and improve string operations on the needs of all Autodesk products. Smart pointer encapsulation, through the definition of smart pointer encapsulation class, easy and effective management of various pointers, minimize memory leakage, etc., define the software installation, deployment strategy.

(2) General function layer. This layer mainly builds the basic functions and business logic components required for software operation. It will include user interface, rendering engine, file format, user data tracking and other modules. The purpose of this layer is to achieve uniformity while maintaining the need for differentiated customization of individual software, which is the main part of Autodesk's software platform.

(3) Cloud Computing. This layer mainly builds the most core and basic functions required for cloud computing. The main modules are identity service, storage service, and task management service.

II. B.BIM 3D collaborative design mode

II. B. 1) Characteristics of BIM technology

BIM technology has the characteristics of visualization, analyzable, manageable and shareable [19]. Specifically as follows:

(1) Visualization. The use of computers can visualize the BIM, to achieve the “what you see is what you get effect”, without the need to go through the complexity of the mind to imagine.

(2) Can be analyzed. Based on the same model, the use of computers can arbitrarily extract a layer of BIM or a class of information for analysis and calculation. For example, based on the model volume of the volume of statistical summary, based on the component construction progress analysis, based on the volume and price information investment analysis, model-based mechanics, sunshine analysis.

(3) Manageable. It is extremely convenient to manage and maintain the model and information. BIM establishes the correlation between the geometric model and the information of the whole process of construction, and it becomes simple and efficient to find and browse any model or information. At the same time, any changes to the model or information will cause changes to the associated information.

(4) Sharable: The application of BIM is based on open architecture and data standards, which allows different professions to share and collaborate with each other, as well as effectively supporting data exchange between various application systems in the construction industry and data management of the whole process of construction.

II. B. 2) BIM 3D collaborative design

For the interdisciplinary collaboration mechanism of residential building design, this paper takes Autodesk 3D design as an example, and the BIM 3D collaborative design on this platform consists of a collaborative management platform and a design platform, whose specific model is shown in Figure 2. The 3D collaborative management platform is responsible for the collaborative design process organization, role allocation, rights management, model and document management and maintenance, data security and other aspects of collaboration and management, 3D design platform consists of software clients to meet the needs of each professional 3D design. Civil 3D is responsible for three-dimensional geological modeling, earthwork design, etc., Inentor is responsible for complex model design such as hydraulics, electromechanical gold, etc., Revit is responsible for architectural, structural and pipeline design, NavisWorks is responsible for model integration, browsing, calibration, collision detection, construction simulation, animation production, Infraworks is responsible for early planning and design, scheme comparison, large scene model visualization. Infraworks is responsible for early planning and design, scheme comparison, and large scene model visualization. The collaborative design system based on the unified platform architecture simplifies the interdisciplinary collaborative process, reduces data entry, effectively avoids errors and duplication of efforts, and improves the efficiency of residential building design.

The BIM-based interdisciplinary 3D collaborative design platform should establish a complete and mature 3D collaborative workflow. First of all, based on the project division of roles, authority, behavior, relationships and nodes, to clarify the various parties involved and their mutual relationships. Secondly, carry out the general planning of the collaborative work of all parties, and make clear the work interface, information communication, construction phase, special application and other specific work of all parties. Once again, coordinate the organizational relationship between the parties, work strictly according to the parties' cooperative work planning, strengthen the information management of documents and engineering changes, and standardize the change procedures. Finally, based on the planning stage of the project, the project digital delivery regulations were formulated to carry out data organization, document archiving and data delivery.

Residential building engineering design generally goes through several stages of scientific research design, preliminary design, and construction design, and during these processes, changes in the information data proposed by external related specialties are inevitable. Under the traditional CAD drawing conditions, such data changes may require rearranging and drawing the structure-related drawings, but under the conditions of interdisciplinary three-dimensional collaborative design, no matter how the data parameters of external specialties change, as long as the relevant parameters are reset, the three-dimensional model can be automatically updated, and the relevant two-dimensional drawings are also automatically updated, which greatly improves the work efficiency.

III. Residential building BIM model simulation and evaluation methodology

Energy-saving retrofitting of residential buildings is an important measure to reduce building energy consumption and achieve energy-saving and emission reduction goals. However, energy-saving retrofit projects have the implementation difficulties of large initial investment and long payback period, and clarifying their benefits is conducive to the large-scale development of retrofit work. Under the current situation of mandatory building energy-saving retrofit work, scientific evaluation of the benefits of residential building energy-saving retrofit projects can identify existing problems in energy-saving retrofit, guide the decision-making and implementation of subsequent building energy-saving retrofit projects, and further promote energy-saving retrofit work in residential building design.

III. A. Residential Building BIM Modeling and Performance Simulation

III. A. 1) Residential building BIM modeling

In this paper, the feasibility of interdisciplinary 3D collaborative design mode based on BIM technology in the analysis of residential building environment is investigated by taking a residential building project in a city as an example. The project has a building area of 4,251m2, a building height of 22.8m, four building floors (partially six floors), and a structural form of reinforced concrete frame structure. The application of BIM technology to some of the problems faced in the construction and use of residential buildings is investigated, focusing on the application of BIM interdisciplinary 3D co-design to solve the performance of residential buildings in the design process, thus improving the efficiency and quality of the project, as well as the goal of reducing errors and risks.

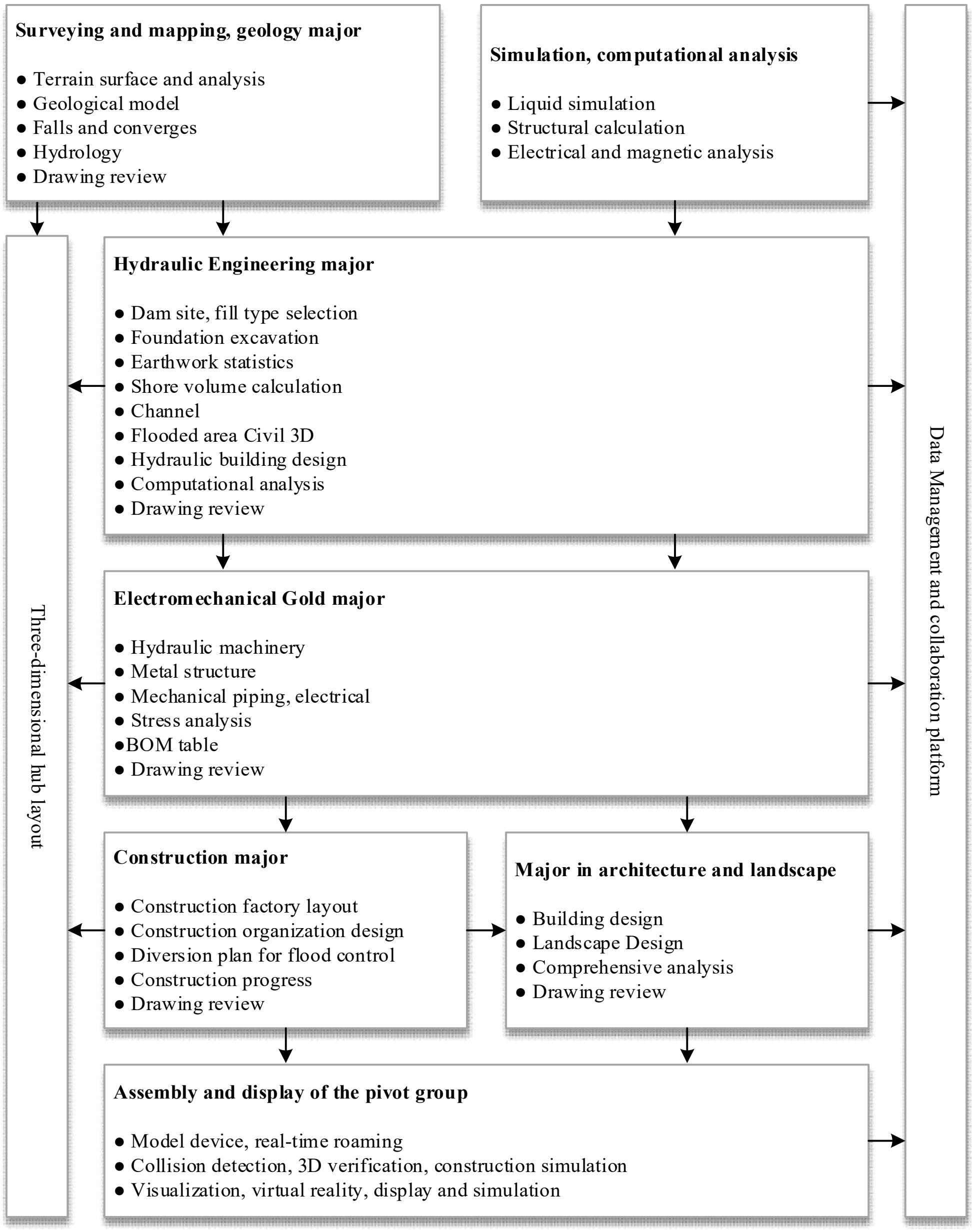


Figure 2: BIM 3D collaborative design mode

In this paper, Autodesk Ecotect Analysis software is used to analyze the environment of the building. The software can be interfaced with Autodesk Revit software, which has a powerful sustainability analysis function, and can simulate the performance of the conceptual design and detailed design stage of the building, such as energy efficiency, carbon emissions, lighting, ventilation, etc. and feedback the results of the analysis in the form of reports or visualization views. By simulating and analyzing the environmental performance of a building in the schematic design phase, the results provide a rough prediction of the building's environmental performance and provide a basis for architects to design.

In the process of modeling this paper using Revit software, the building information model is created by adding building object tuples and modifying their parameters, and these tuples are interrelated and interactive. For the BIM model of the building of this project, the main implementation steps of its modeling are as follows:

(1) Open Revit Architecture software, create a new project file and set the elevation and axis network of the model according to the drawing information.

(2) According to the drawing information, input the relevant parameters of the components to build the model and set the wall material.

(3) Create 3D models of walls, columns, doors, windows and other components according to the drawings in the plan view.

(4) Adjust the color of the building appearance, the appearance of the filling style and view the model effect in the 3D view.

Through the above steps, the building model based on BIM interdisciplinary 3D collaborative design is obtained and used for the simulation analysis later.

III. A. 2) Residential building performance simulation process

Traditional performance analysis, due to its specialization and complexity, is generally operated by specialized technical staff of the design unit, which is less involved in the program decision-making of the designers because the stage of development is after the completion of the construction drawings, while the developers and owners are even more seldom involved in the performance analysis process. It is an interactive performance simulation method that conforms to the designers' working mode, synchronizes with the design, and focuses on the architects and the design process. Therefore, designers from all parties involved can use the BIM technology platform for real-time performance simulation to understand the energy consumption difference of design solutions. And the calculation report presents the simulation results clearly and directly through charts and color diagrams, reducing the obscure and difficult-to-understand professional barriers, and truly enabling all relevant designers to participate, communicate efficiently, and collaborate to promote the project process.

Figure 3 shows the performance simulation and analysis process based on BIM interdisciplinary 3D collaborative design platform. The design and performance simulation interfaces can be freely switched to directly recognize the attribute information given in the design process, without the need to re-establish the model, not to mention the need to re-enter the space, materials and other information, while the model is modified, the associated technical indicators are synchronously updated in real time. It ensures the integrity and consistency of the simulated building information, avoids the error of manual setting, greatly saves the workload of model creation and model conversion, and the accuracy of the calculation model is greatly improved, which makes the comparison of multiple scenarios easier.

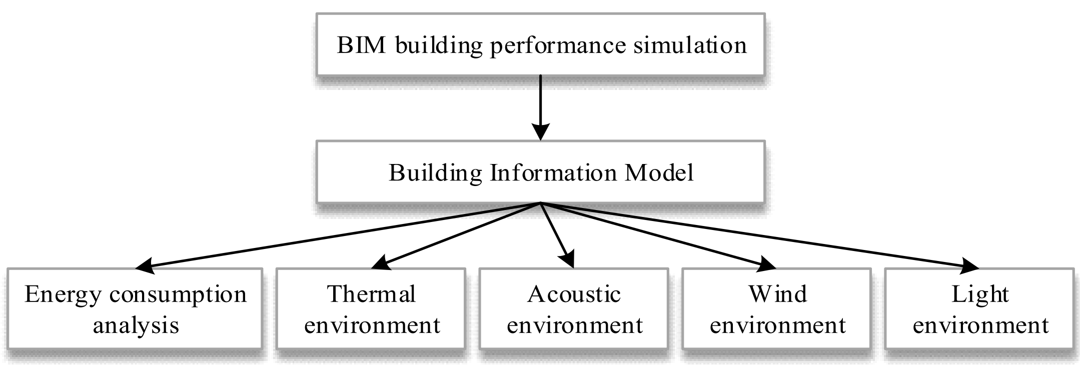


Figure 3: Simulation process of residential building performance

III. B. Thermal comfort evaluation methods for residential buildings

III. B. 1) Heat balance and thermal comfort equations

In nature, the transfer and conversion of energy is a universal phenomenon, and all interactions between objects involve this process. The human body, for example, is a large, open and complex system that is constantly engaged in a variety of cumbersome heat exchange processes with its surroundings. In order to maintain a normal body temperature, the body needs to dynamically balance the relationship between heat production and heat emission. As a result, a specific and detailed heat balance equation that describes the thermal interaction between the human body and the thermal environment has been developed as:

$$S = M - W - C - R - E \tag{1}$$

where S is the rate of heat storage in the body, M is the rate of metabolism in the body, which depends on the size of the individual's level of physical activity, W is the mechanical work done by the body, C is the heat emitted in the form of convection, R is the heat emitted in the form of radiation, and E is the evaporative and respiratory heat loss of the body.

When the value of S is positive, it means that heat is accumulating in the human body, which may be caused by factors such as a hot external environment or heat generated by metabolism in the human body. When the value of S is negative, it means that the body continues to lose heat, possibly due to a cold external environment or the regulation of body temperature through heat dissipation mechanisms. When the value of S is zero, it means that the body gains and loses heat to reach a balanced state, indicating that it is in the stage of thermal equilibrium. From the perspective of dynamic equilibrium, the state necessary to maintain normal physiological function is to keep the body within a temperature range that can self-regulate and remain stable.

When the body is in a thermally neutral state, i.e., at $S = 0$, the body's heat production is:

$$H = M - W \tag{2}$$

The body's heat dissipation mainly includes the heat generated by respiration, evaporation of heat from the skin, and the heat released by evaporation of sweat for:

$$E = L + E_{res} + E_d + E_{sw} \tag{3}$$

Thus, in the absence of heat storage, the heat balance equation for the human body can be expressed as:

$$H - L - E_{nc} - E_d - E_{sw} - R - C = 0 \tag{4}$$

where H is the body heat production, L is the respiratory sensible heat loss, E_{rez} is the respiratory latent heat loss, E_d is the skin diffusion evaporation loss, and E_{sw} is the evaporative heat loss caused by sweating on the skin surface.

According to the existing research results, when the human body is close to thermal neutrality, t_s and E_{sw} are only affected by the individual metabolic rate and external work, and the two show a linear correlation. Then:

$$E_{sw} = 0.42 \times (M - W - 58.15) \tag{5}$$

$$t_s = 35.7 - 0.028 \times (M - W) \tag{6}$$

The thermal comfort equation is derived by bringing all the variables as the body approaches neutrality into the following equation. To wit:

$$\begin{aligned} M - W = {} & f_{cl} h_c (t_{cl} - t_a) + 3.96 \times 10^{-8} f_{cl} \left[(t_{cl} + 273)^4 - (t_r + 273)^4 \right] \\ & + 3.05 \times \left[5.733 - 0.007(M - W) - P_a \right] + 0.42(M - W - 58.2) \\ & + 0.0173 M (5.867 - p_a) + 0.0014 M (34 - t_a) \end{aligned} \tag{7}$$

where M is the metabolic rate of the human body, W is the mechanical work done by the human body, f_{cl} is the area coefficient of the garment, h_c is the convective heat transfer coefficient, t_{cl} is the temperature of the outer surface of the garment, t_r is the average radiant temperature of the room, p_a is the partial pressure of the ambient water vapor, and t_a is the temperature of the indoor air.

III. B. 2) Thermal comfort evaluation indicators

PMV-PPD refers to Predicted Mean Thermal Sensation Voting and Predicted Unsatisfactory Thermal Sensation Voting, which can be used to predict the level of thermal comfort of the human body in a standardized environment of steady state [20]. Thermal comfort evaluation is a subjective sensory characteristic of the human body, which is related to the state of the thermal environment in which it is surrounded and the human body's own thermal balance. The PMV steady-state model is a human thermal comfort equation derived by Prof. Fanger based on the human thermal balance equation, which is combined with the experimental data of the test. In the course of the study, two indicators frequently used in subsequent studies, namely PMV and PPD, were proposed: PMV refers to the evaluation index of human thermal response, which represents the average value of human thermal sensation under the same environment, and PPD is the satisfaction level of the current thermal environment, which indicates the percentage of the human body that is dissatisfied with the thermal environment in the room; PPD is the quantitative index of the human body's comfort level, which is one of the important parameters in the study of thermal comfort. comfort and is one of the important parameters in the study of thermal comfort.

The PMV is calculated by the formula:

$$PMV = (0.303e^{(-0.036M)} + 0.028)(M - W) - 3.05\times10^{(-3)} \times (5733 - 6.99 \\ (M - W) - P_a) - 0.42\times\{(M - W) - 58.15 - 1.73\times10^{(-5)} M(5876 - P_a) \\ -0.0014M(34 - t_a) - 3.96\times10^{(-8)} f_c l(t_c l + 273)^4 - (t_r + 273)^4 - f_c l h_c (t_c l - t_a) \tag{8}$$

where M is the energy metabolic rate of the human body, W is the mechanical work done by human activity, Pa is the partial pressure of water vapor, f_{cl} is the area coefficient of the garment, h_c is the coefficient of convective heat transfer, t_{cl} is the temperature of the outer surface of the garment, t_a is the temperature of the air around the human body, and t_r is the average radiant temperature of the environment.

PMV is used as a reference for the evaluation of thermal comfort, and after the value is determined it is possible to predict the percentage of thermal and cold dissatisfaction with the environment, i.e., to predict the dissatisfaction vote value PPD. where the relationship between PMV and PPD can be expressed by the equation, i.e.:

$$PPD = 100 - 95e^{(-(0.03353PMV^4)+0.2179PMV^2)} \tag{9}$$

ISO7730 standard for acceptable thermal environment and comfortable thermal environment has a corresponding explanation, 75% of the personnel feel satisfied with the thermal environment for acceptable thermal environment, 85% of the personnel feel satisfied with the thermal environment is called comfortable thermal environment, corresponding to the PMV take the value of the range between -0.6 ~ 0.6.

IV. Simulation analysis of BIM models of residential buildings

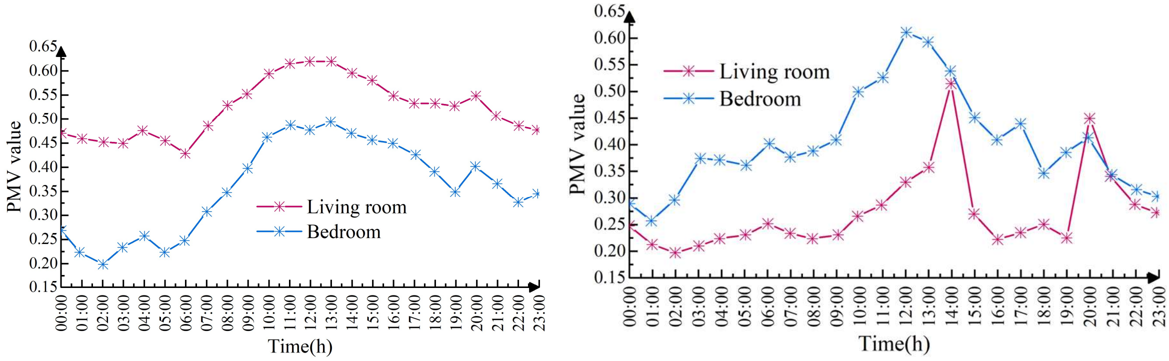
Based on the BIM interdisciplinary 3D collaborative design mode to assist in the realization of residential building design, the building model can be better optimized to improve the feasibility and accuracy of the design of residential buildings. On this basis, the residential building model constructed by BIM interdisciplinary 3D collaborative design mode is used to carry out performance simulation analysis, which provides a design basis for better improving the comfort and reducing the energy consumption of residential buildings.

IV. A. Simulation of indoor thermal comfort and energy consumption

IV. A. 1) Indoor thermal comfort

In order to test the energy efficiency of the housing building project designed in this paper, the thermal environment of the BIM model of the designed housing building was tested. When the air temperature is around 26℃, the air humidity level has no effect on the physiological response and thermal sensory reflection, and the change of relative humidity between 35% and 80% is almost imperceptible. Only when the air is close to the saturation state type can obviously feel the skin sticky and humid. Therefore, the humidity condition in the residence in summer is still relatively satisfactory.PMV and PPD are important indicators for evaluating the thermal environment of the indoor habitat. Through the temperature, humidity and other data obtained from the test, according to the thermal comfort equation of the human body's energy balance under steady state conditions given in the previous section, that is, the PMV equation of the predicted thermal index, the PMV and PPD values are calculated through the equation to evaluate the indoor thermal environment indexes of the residential building under test. Fig. 4 Variation of PMV values in residential interiors, where Fig. 4(a)~(b) shows the variation of PMV values in residential interiors for 24 hours in simulated summer and winter, respectively.

Based on the historical data of this housing building, its historical PMV values in summer and winter can be calculated as 1.41/1.08, -1.69/-1.54, respectively.In the housing building designed using the BIM interdisciplinary 3D collaborative model given in this paper, the average PMV values of its indoor thermal comfort tests in summer and motivation are 0.62/0.39, -0.65/-0.61, respectively. Based on the previous standard definition of PMV values for thermal comfort, it can be seen that PMV values between -0.6 and +0.6 are more comfortable regions. Thermal comfort values less than -0.6 indicate a cooler room. Thermal comfort value greater than +0.6 indicates that the room is hot. After the transformation of BIM interdisciplinary 3D collaborative design, the indoor thermal comfort of the residential building is basically in the more comfortable region, which indicates that the indoor thermal environment has been well improved and the energy saving effect is obvious.



(a) Summer PMV value (b) Winter PMV value

Figure 4: Indoor thermal comfort

IV. A. 2) Building energy simulation

The energy consumption simulation analysis of the building mainly examines the heat preservation and insulation performance of the envelope. Poor heat preservation and insulation of the enclosure structure makes the energy consumption of the building high, and vice versa, the energy consumption is low. Before analyzing the energy consumption, it is necessary to set up the basic information of the project, load the required meteorological data, and fill in the corresponding geographic location information of the building. After that, set the material of the building model in the "material library", and then set the parameters of the personnel and thermal environment attributes of each room, and then analyze the "month-by-month energy consumption/uncomfort" after the settings are completed. Figure 5 shows the results of the analysis of energy consumption of residential buildings, in which the red graph is the heating energy consumption and the light blue is the air conditioning and cooling energy consumption, as can be seen from the figure, the heating energy consumption of the building is relatively higher than the cooling energy consumption.

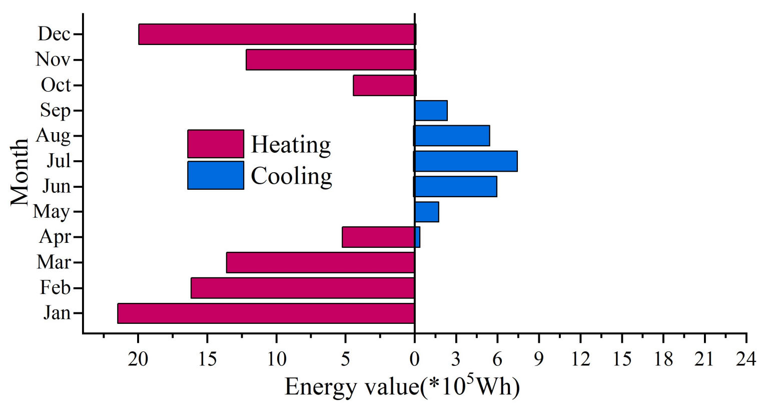


Figure 5: Energy consumption analysis results of residential buildings

As shown in the figure, the energy consumption of heating and air-conditioning cooling of the housing building is $9.32*10^7$Wh and $2.37*10^7$Wh respectively, and the total energy consumption is $11.69*10^7$Wh. In addition to the bar charts, the analysis results can be exported in the form of Excel tables, which is more intuitive to analyze the energy consumption of the building. The exported Excel data also contains the energy consumption of each month and the average monthly energy consumption, which can help designers better understand the energy consumption level of housing buildings and accurately evaluate the housing building design program.

IV. B. Economic Benefit Analysis of Residential Buildings

IV. B. 1) Economics of the building before and after optimization

For the economic benefits of the housing building model constructed by the BIM interdisciplinary 3D co-design mode proposed in this paper, the original building design scheme of the selected research object is used as a comparison in this paper to explore the economic benefits of the housing building design under the BIM interdisciplinary 3D co-design mode. For the economic benefits of housing buildings, this paper mainly simulates from four dimensions:

existing building (BIM1), facade optimization (BIM2), roof optimization (BIM3) and exterior window optimization (BIM4), and Table 1 shows the results of the economic analysis of the residential buildings before and after optimization. In the table, EC, ECC, ECR, ECCR, RR, and IIC are energy consumption, energy cost, energy consumption reduction, energy cost reduction, reduction rate, and initial investment cost, respectively.

As can be seen from the data in the table, the initial investment cost of the 25mm thick expanded polystyrene board adopting the external wall insulation scheme is approximately 64,216.51 yuan, the annual electricity consumption cost saved is 5,114.99 yuan, and the simple payback period of the initial investment cost is 11.82 years. By adopting the external insulation scheme for the roof, the initial investment cost of 30mm thick expanded polystyrene board is approximately 33,716.68 yuan, and the annual electricity consumption cost saved is 1,151.12 yuan. The simple payback period for the initial investment cost is 189.7 years. Applying heat insulation film on the original glass, the total initial investment cost is 90,102.25 yuan, the annual electricity consumption cost saved is 11,914.67 yuan, and the simple payback period of the initial investment cost is 7.2 years. Overall, when using the BIM cross-disciplinary 3D collaborative design model to design different schemes, it can to a certain extent reduce the investment cost of housing construction, effectively lower the corresponding economic expenditure, and is more in line with the high economic income requirements of housing construction compared to the original housing design scheme.

Table 1: Optimize the economy of residential buildings before and after

	BIM1	BIM2	BIM3	BIM4
EC/kWh	118245.57	110763.58	116957.38	100476.38
ECC/yuan	91427.63	86312.64	90276.51	79512.96
ECR/kWh	-	7481.99	1288.19	17769.19
ECCR/yuan	-	5114.99	1151.12	11914.67
RR/%	-	5.96	1.25	14.20
IIC/yuan	-	64216.51	33716.68	90102.25

IV. B. 2) Economic comparison of different design options

Construction project economic evaluation that is, in the comprehensive analysis of different programs on the study, from the perspective of engineering economy on the various factors affecting the study, to project benefit evaluation as a means to select the optimal program. Profitability is an important indicator of the creditor to recover the principal and interest, is the ability of the creditor to maximize the profit, the greater the profit, the stronger the profitability, so the analysis of profitability can be said to be the key link in the economic evaluation of the project. In this paper, the main choice of financial net present value (NPV) and discount rate as an evaluation index, NPV is the project life cycle of the net cash flow that occurs in each year, according to the given discount rate discounted to the beginning of the period of calculation of the present value of the project, and then subtracted from the algebraic sum of the initial investment. The social return on investment is then taken as the discount rate for the calculation. The housing building models based on DeST (Scenario B) and Quanta (Scenario C) are selected as a comparison for the BIM interdisciplinary 3D co-design model (Scenario A) in this paper.

In this paper, the dynamic payback period is used as an indicator to select among the three envelope retrofit programs mentioned above. First of all, determine the annual net cash flow, the initial investment is the beginning of the first year, the end of the first year began to have a return, the return is the savings of energy consumption into electricity and then converted to the price of electricity. According to the discount rate of 6.5% and different years of electricity savings for the annual return, listed in the cash flow of Scheme A as shown in Table 2. In the table, NCF, CNCF, DC, PVNCF, PVCNCF represent net cash flow, cumulative net cash flow, discount factor, present value of net cash flow, present value of cumulative net cash flow, respectively.

As can be seen from the table, the dynamic payback period of the housing building design scheme based on BIM interdisciplinary 3D co-design is around 9.82 years, and the same method can be used to find out that the dynamic payback periods of scheme B and scheme C are around 12.73 years and 12.51 years, respectively. Taking the payback period as the evaluation index, option A should be selected, and if the rising energy and electricity costs are taken into account, the payback period of option A will be shorter. However, if the owner's indicator is the investment cost, if the payback period of the three options is not much different, option C should be the preferred option. Similarly, when the owner's evaluation index is energy savings, Option B should be selected.

Therefore, if the difference in the dynamic payback period is not large, if the focus is on the payback period, option A should be selected, if the focus is on the energy savings, option B should be selected, and if the focus is on the investment cost, option C should be selected.Therefore, the use of BIM interdisciplinary three-dimensional collaborative design mode can effectively enhance the economic efficiency of housing building design, and provide reliable support for improving the economic recovery ability of housing building design.

Table 2: Cash flow statement of retrofit scheme A

Year	NCF	CNCF	DC	PVNCF	PVCNCF
0	-252763.48	-252763.48	-	-252763.5	-252763.48
1	35763.91	-216999.57	0.9437	33749.59	-219013.89
2	35763.91	-181235.66	0.9166	32780.34	-186233.55
3	35763.91	-145471.75	0.8791	31441.11	-154792.44
4	35763.91	-109707.84	0.8610	30791.29	-124001.15
5	35763.91	-73943.93	0.7873	28157.53	-95843.62
6	35763.91	-38180.02	0.7111	25432.17	-70411.45
7	35763.91	-2416.11	0.5637	20161.44	-50250.01
8	35763.91	33347.8	0.5392	19282.52	-30967.49
9	35763.91	69111.71	0.5187	18549.23	-12418.26
10	35763.91	104875.62	0.4690	16772.13	4353.87

V. Conclusion

Through the application of BIM interdisciplinary 3D collaborative design platform, the efficiency and quality of residential building design are significantly improved. The thermal comfort analysis shows that the indoor thermal environment of the building is significantly improved after the BIM co-design mode is adopted, and the PMV values in summer and winter are controlled within the range of the more comfortable area, which effectively solves the problem of inaccurate control of the thermal environment in the traditional design. The results of energy consumption analysis show that the heating energy consumption of the residential building is 9.32*107Wh and the air-conditioning cooling energy consumption is 2.37*107Wh, and the effective control of the building energy consumption is realized through the optimization of the envelope structure and the rationalization of equipment configuration. The economic benefit assessment shows that the exterior window optimization scheme has optimal economy, verifying the advantages of BIM collaborative design in cost control. The collaborative mechanism establishes unified data standards and workflows, realizes seamless docking of architectural, structural, electromechanical and other disciplines, eliminates the problem of information silos in traditional design, and provides feasible technical solutions and implementation paths for the digital transformation of the residential building industry.

References

[1] Rauf, A. (2022). Reducing life cycle embodied energy of residential buildings: importance of building and material service life. Buildings, 12(11), 1821.

[2] Memari, A. M., Huelman, P. H., Iulo, L. D., Laquatra, J., Martin, C., McCoy, A., ... & Williamson, T. (2014). Residential building construction: State-of-the-art review. Journal of Architectural Engineering, 20(4), B4014005.

[3] Van Steenwinkel, I., de Casterlé, B. D., & Heylighen, A. (2017). How architectural design affords experiences of freedom in residential care for older people. Journal of aging studies, 41, 84-92.

[4] Malik, S., & Hassan, K. A. K. (2019). An investigation of house designs in Lahore: Transformation of residential architecture from traditional to modern. Journal of Design and Built Environment, 19(1), 49-59.

[5] Almaganbetovna, T. A., Daniyarovna, T. A., Ogly, M. S. E., Papin, H. E., Nikolayevna, K. Y., & Alua, A. (2023). Development of the Architecture of Residential Buildings from the Beginning of XX to XXI Century (By the Example of Astana). Civil Engineering and Architecture, 11(3), 1220-1233.

[6] Shatwan, A. P. D. A. (2022). Cultural changes and flexibility in residential architectural design. J Art Arch Hum, 7(31), 58-69.

[7] Lu, Y. A., & Shi, L. (2021). BIM architecture design from the perspective of smart city and its application in traditional residential design. Journal of Intelligent & Fuzzy Systems, 40(2), 3127-3136.

[8] Mukkavaara, J., & Sandberg, M. (2020). Architectural design exploration using generative design: framework development and case study of a residential block. Buildings, 10(11), 201.

[9] Saorín, J. L., de la Torre-Cantero, J., Melián Díaz, D., & López-Chao, V. (2019). Cloud-based collaborative 3D modeling to train engineers for the industry 4.0. Applied Sciences, 9(21), 4559.

[10] Jin, R., Yang, T., Piroozfar, P., Kang, B. G., Wanatowski, D., Hancock, C. M., & Tang, L. (2018). Project-based pedagogy in interdisciplinary building design adopting BIM. Engineering, Construction and Architectural Management, 25(10), 1376-1397.

[11] Liang, N., & Yu, M. (2021). Research on design optimization of prefabricated residential houses based on BIM technology. Scientific Programming, 2021(1), 1422680.

[12] Ciribini, A. L. C., Ventura, S. M., & Paneroni, M. (2016). Implementation of an interoperable process to optimise design and construction phases of a residential building: A BIM Pilot Project. Automation in construction, 71, 62-73.

[13] Jununkar, S. M., Aswar, P. D. S., & Mittapalli, P. D. L. (2017). Application of BIM and construction process simulation using 5D BIM for residential building project. International Research Journal of Engineering and Technology, 4(7), 1063-1067.

[14] Wei, T., & Chen, Y. (2020). Green building design based on BIM and value engineering. Journal of Ambient Intelligence and Humanized Computing, 11, 3699-3706.

[15] Zhao, X. G., & Gao, C. P. (2022). Research on Energy-Saving Design Method of Green Building Based on BIM Technology. Scientific Programming, 2022(1), 2108781.

[16] Li, S., & Yu, Y. (2019, October). Application of BIM Technology in Calculation of a Residential Building. In IOP Conference Series: Earth and Environmental Science (Vol. 330, No. 2, p. 022071). IOP Publishing.

[17] Kai Ding,Detlef Gerhard & Liuqun Fan. (2025). AML-Based Multi-Dimensional Co-Evolution Approach Supported by Blockchain: Architecture Design and Case Study on Intelligent Production Lines for Industry 4.0. Information,16(3),243-243.

[18] Carvalho José Pedro,Bragança Luís & Mateus Ricardo. (2021). Sustainable building design: Analysing the feasibility of BIM platforms to support practical building sustainability assessment. Computers in Industry,127.

[19] Chengyong Chen,Wenming Su,Wenqiang Dou,Yongquan Dong & Ben Zhang. (2025). Construction control of cable-stayed bridge top push method based on BIM technology. Discover Applied Sciences,7(4),346-346.

[20] Ahmed Kaihoul,Efisio Pitzalis,Leila Sriti,Silvia Di Turi & Khaoula Amraoui. (2024). Enhancing thermal comfort assessment: A sensitivity study of PMV-PPD and adaptive models in an Algerian reference hotel across different climate zones. Indoor and Built Environment,33(9),1680-1704.