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The Design of Sustainable Retrofitting Strategies and Energy-efficiency Optimization for Residential Buildings

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Abstract. There is a huge stock of existing residential buildings in China, with high energy consumption but low comfort, so it is of great significance to retrofit the residential buildings in order to enhance energy-efficiency of the buildings. In this paper, residential buildings, built between 1980 and 2000 in typical cities of the Northeast China, are defined as the research objects. This project tries to systematically put forward an applicable design method and an overall retrofitting plan of residential buildings. Dealing with the issues of the existing research on practical retrofitting of residential buildings in China, such as short of basic data and statistics, neglect of preliminary design planning and lack of guidance evaluation criteria, this project, based on the classification of residential building envelope system, builds a façade system information modelling database of residential buildings in typical cities of the Northeast China and abstracts a design prototype. Relying on the design prototype, Matrix method is used to organize, discover and edit the retrofit design strategies. BIM - EnergyPlus integrated technique is also introduced to evaluate and optimize the design strategies suitable for reference methods for realizing the sustainable retrofitting and energy efficiency optimization. The findings of this research will extend and improve the role and scientificity of architectural design in the retrofitting of residential buildings.

Keywords: Residential Buildings；Sustainable Retrofitting；Energy-efficiency Optimizations；Design Strategies；Facade Refurbishment

1. Research Background and the Issue

Since the reform and opening up, China's urban housing construction has developed rapidly and achieved tremendous success especially the construction of residential buildings. However, cities in china have a huge housing stock which accounts for more than half of China's existing building area. However, its building performance lags behind the needs. On the one hand, it is of great significance to improve the energy efficiency of existing homes because of the low design standards for energy efficiency in buildings especially in the Northeast. On the other hand, the designed life is far from the useful life when the functional have expired. So, it is imperative to renovate existing housing, which is the focus of China's construction industry in the new era.

Building energy efficiency is an important part of the national energy conservation and emission reduction work. And the energy-saving renovation of existing buildings is an important part of building energy conservation. However, there are still problems in the retrofitting of existing residential buildings. In the scope of architectural design, the following are mainly reflected in: lack of basic information data; ignoring the previous design planning; and lack of effective design evaluation.

Above problems have led to a single retrofitting method, extensive operation processes, and unclear energy-saving effects. It is difficult to achieve the best comprehensive optimization.

2. Research Definition

There is a lack of research on the collection and arrangement of basic data and the specific application guidance of the design strategy in the actual retrofitting projects of existing residences in China. Therefore, this study proposes that it is necessary to establish a design strategy system which is applicable for complex existing residential situations. And it should be the focus of exploration. Based on the idea of hierarchical and partial reform, this study proposes should focus on the weak links of thermal performance in the various components of the existing residential enclosure structure. It is also important to advance the quantitative evaluation of the existing residential renovation performance to the design phase. This requires the integration of optimization technology methods to optimize the energy efficiency of the building renovation design.

This study takes the retrofitting performance of the existing residential buildings in the Northeast China as an example, selecting the typical urban residences in the northeastern region which constructed between 1980 and 2000 as the research object to explore the selection and optimization methods of green residential design strategies for existing residences. Green retrofitting is the source of design strategies in this topic and is also the goal of energy efficiency optimization.

The ultimate goal of this project is to select green building retrofit design strategies and energy efficiency optimization methods for existing dwellings to provide effective design guidance and reference for designers and related practitioners.

3. Research content

3.1 Construct an information model database for the facade system of old cities in typical cities in Northeast China and establish a design prototype:

- Sort out the constituent elements (walls, windows and balconies) and facade system information (architectural form, shape factor, orientation of each facade, and ratio of window to wall) of the old residential facade system. The corresponding materials, structural forms, structural characteristics (heat preservation measures and thermal performance, presence or absence of special structural nodes, etc.) and degradation degree of the elements of the old residential facade system should be recorded and arranged. The BIM information data is constructed as Carrier of northeastern region typical old house facade system information model database;
- Based on the facade system information model database, some typical old residential design prototypes in Northeast China were established through type selection.

3.2 Reorganization, editing and integration of existing housing renovation design strategies:

- Collect and sort out existing home renovation design strategies.
- Based on the design prototypes of typical old residential buildings in the northeastern region, it carried out exploration and integration of retrofitting design strategies, including: solar direct and thermal collectors (winter), natural lighting (winter, summer), natural ventilation and passive cooling (summer), and other low-cost passive design integration methods (ventilation form module design, double Layers of windows and walls integrated technology applications, etc.).

The retrofitting and design strategy of collation and integration applies BIM information data as a form of expression in the editing process, establishing the corresponding relationship between the retrofitting design strategy and the components of the facade system of the research object.

3.3 The selection, evaluation and optimization of green retrofitting design strategies for old houses in typical cities in Northeast China:

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- According to the corresponding relationship between the various components of the facade system and editing design strategies, taking a comprehensive analysis of different factors are required to select green retrofitting design strategy;
- According to the current normative standards or set up energy efficiency promotion goals, use the BIM-EnergyPlus integrated technology optimization platform to form green retrofitting design strategies which are targeted and operational.

4. Research method

To achieve research goals, specific research methods include:

4.1 Field survey and data collection methods based on element sorting and type processing:

The important foundations of this topic are field research and data collection work. The field survey of the existing residential facade system form and status sorts current existing residences (each component of the facade system and the architectural form, shape coefficient, the orientation of each facade and the ratio of window to wall) and type of treatment (materials, structural forms, thermal insulation properties, structural characteristics, and degradation levels) and data collection work. The results of field research and data will be edited by Autodesk Revit Architecture based on BIM information data to form the existing housing renovation information model library material. This provides the basis for further deepening integration and research.

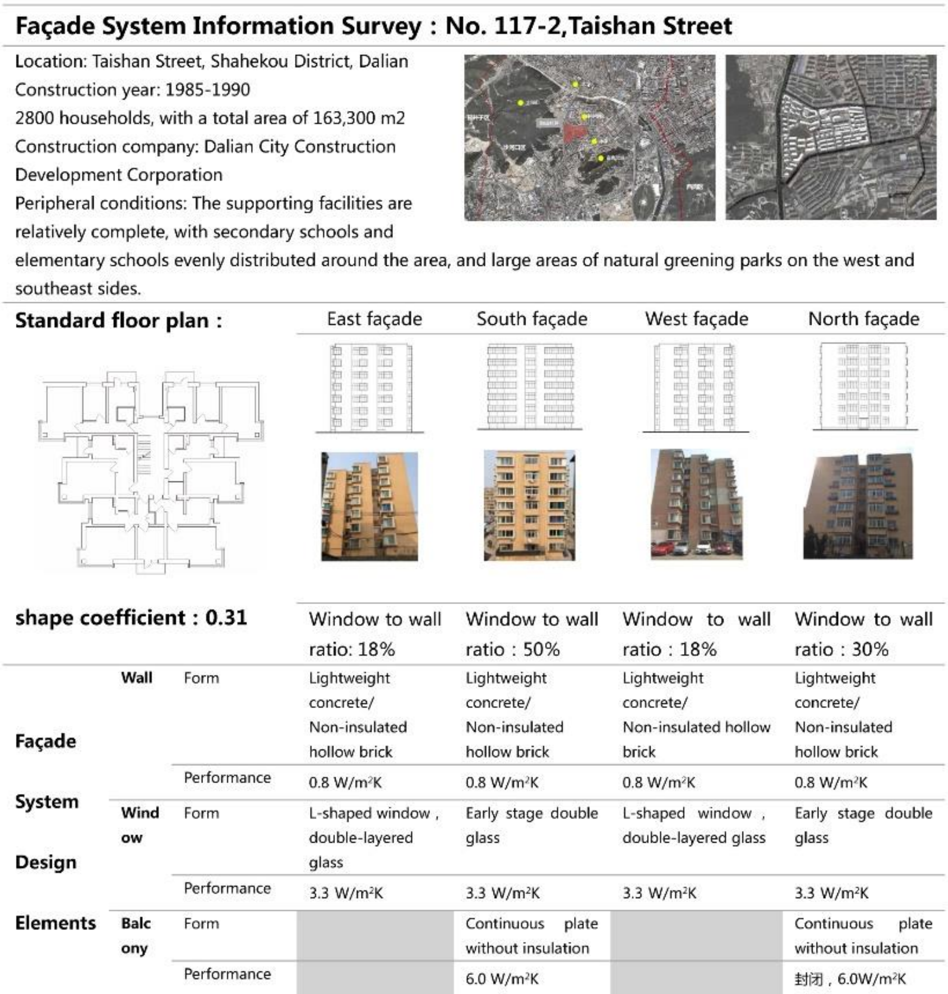

Figure 1. Façade system information survey (taking No.117-2, Taishan Street, Dalian as an example)

4.2 The hierarchical matrix editing method applied to the consolidation and integration of green retrofitting design strategies:

The research focuses of this project are selecting and designing a suitable retrofitting strategy for the retrofitting site of the facade system and the design integration method between the various components of the facade system. Therefore, this project uses the hierarchical matrix editing methods to organize design strategies, emphasis the progressiveness of retrofitting design, and formulate a hierarchical retrofitting method that transforms the individual elements of the facade system elements into facades.

Measure	Description	Strategy	Material	Functions,	Limitations	Variations
Upgrade window	Double glazing applied on existing window frame	Add-in	Glazing	Heat protection Solar gains Increase thermal resistance of window pane	Additional weight and width of glazing Air tightness not improved	Different types of glass and frames
Secondary single glazing	Secondary single glazing window in the inside	Add-in	Glazing, window frames, sealant	Heat protection buffer zone, External appearance unchanged Acoustic performance improves	Adequate ventilation needed in the cavity, Secondary glazing draught-stripped, while the existing widows left without seals.	Different types of glazing and frame
Secondary double glazing	Secondary insulated window pane in the inside	Add-in				
Replaced windows with double glazing	Replace the existing glazing and frame with double-insulated glazing windows	replace		Heat protection Solar gains Increase thermal resistance and ait-tightness. Solves thermal bridging in window frame	Thermal break in fame needed. Correct site installation includes sealing round window and door frames. Improves infiltration, ventilation consideration needed	
Replaced windows with triple glazing	Replace the existing glazing and frame with triple glazed windows	replace				
Shading fixed	Shading devices placed outside the window pane, in form of overhang, fixed louvers, etc.	Wrap-it	Shading devices, Aluminum, plastic, timber, etc.	Solar protection	Consider orientation for the type of shading	Different types of shading devices
Shade adjustable	Shading devices placed in or outside the window pane, in form of movable louvers, venetian blinds etc.	Wrap-it				
Enlarged windows	Existing window and parapet removed and replaced with enlarged, improved window pane	replace	Glass, window frames, sealing material	Insulation, lighting, absorption of higher solar heat, greater transparency, creating new indoor and outdoor relationships	Thermal break in fame needed. Correct site installation includes sealing round window and door frames. Improves infiltration, ventilation consideration needed	Different types of glazing and frames

Façade system retrofitting design			
	Wall	**Window**	**Balcony**
Original structure	Brick-concrete structure, hollow wall without insulation	single glazing	Non-insulated continuous floor
	Lightweight concrete structure, hollow brick without heat insulation	Early double glazing	No or very few insulation boards
	Poor thermal insulation material		
Retrofit measures	Increase air space as insulation buffer	Upgrade window	Balcony floor insulation
	Insulation	Secondary single glazing	Demolition of the balcony
	External insulation and veneer integration	Secondary double glazing	Balcony closed - single glazing
	Wooden frame thermal insulation wall	Replaced windows with double glazing	Balcony Closed - double glazing
	Ventilated facade	Replaced windows with triple glazing	
	Second facade, single glass	Shading fixed	
	Second facade, double glass	Shade adjustable	
Space intervention	Increase the space and integrate the second façade	Enlarged windows	Balcony integration
Green building design strategy	Direct Solar Heating and Passive Heat Harvesting Strategies (Winter)		
	Natural lighting related design strategies (winter, summer)		
	Natural Ventilation and Passive Cooling Related Design Strategies (Summer)		

Figure 2. Matrix method (taking window retrofitting as an example-left, and its position in the façade renovation system-right)

4.3. Building energy efficiency design optimization method based on BIM-EnergyPlus integrated optimization technology platform:

The important part of the research purpose of this project is the performance evaluation and optimization of the remodeling design strategy by using BIM-EnergyPlus. Based on the data convertibility between the BIM information model file IFC and the EnergyPlus model data file IDF, the BIM information model can be integrated with the EnergyPlus energy consumption simulation to form an integrated technology. At the same time, a genetic algorithm batch generation file can be introduced, which can efficiently promote design interaction between architectural design and performance quantification, the specific process is:

- Adopt the Autodesk Revit Architecture to integrate retrofitting design strategies of existing home prototypes to form a BIM information database, and use the IFC conversion function of Revit to generate an IFC data exchange file of the BIM information model;
- Create IDF files with geometric information through IFC and IDF files. It is necessary to embed a material thermal parameter database and establish the correspondence between the material name and the parameter. This can search the corresponding parameter according to the material name in the conversion process, and integrate energy-related information into the IDF file with geometric information for EnergyPlus energy consumption simulation;
- Track specific retrofitting sites through genetic algorithms, change geometry and material design parameters in batches within a certain range, generate a variety of design options, and conduct energy evaluation by EnergyPlus to perform verification and verification. Plans that meet the design criteria will go to the next step;
- Transfer the IDF file that meets the requirements of the design standard to the IFCViewer graphical interface through the VRML/DXF format, and then fed back to the Revit Architecture in the IFC/CAD format to be reflected in the building information model to complete the energy efficiency optimization process.

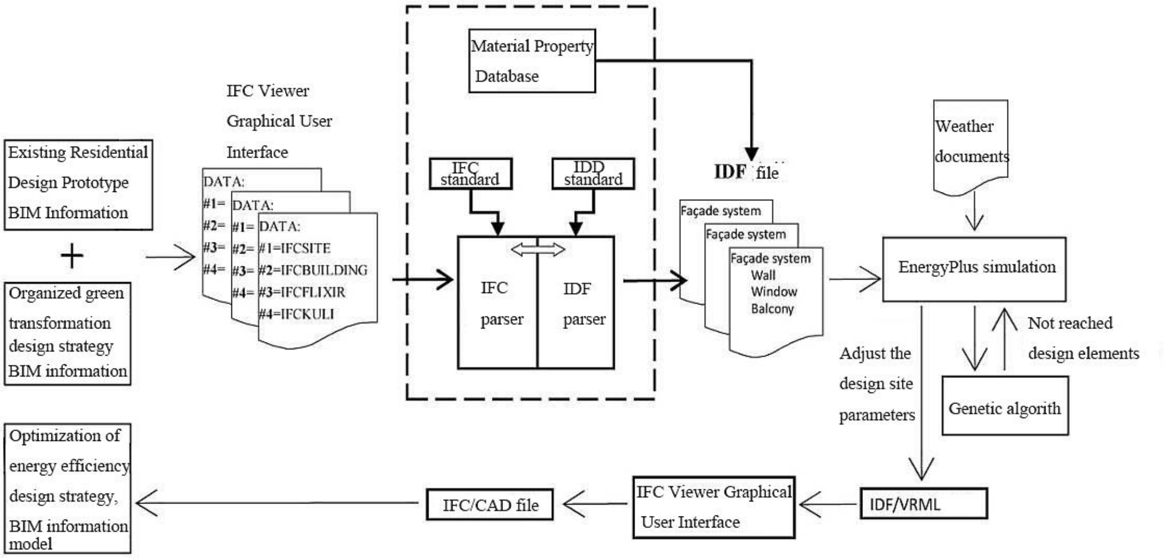

Figure 3. energy efficiency design optimization process based on BIM-EnergyPlus integrated optimization technology

5. The Technical Framework

Combining the research contents and research methods, the technical framework of this project is shown as follows:

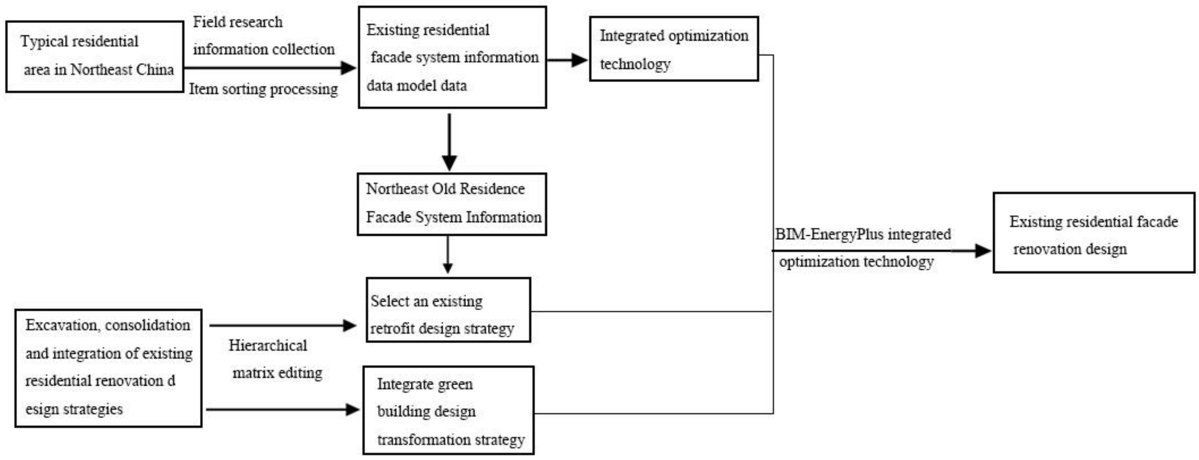

Figure 4. the technical framework showing the research procedure

6. Summary and Discussions

This research study attempts to explore a design approach to improve energy efficiency in existing residential buildings by utilizing passive design strategies. The study takes existing residential buildings built between 1980 and 2000 in Northern China heating areas as research objects. This study can provide integrated passive design strategies that quantify the impact of residential building facade components refurbishment, as well as decision-making information towards energy-efficiency upgrade for designers and related groups, such as contractors and home owners.

The research methods involve case studies and energy performance calculation. Existing residential buildings in different cities of Northern China heating areas are investigated. And based on the case studies, the early stage of this study has laid a solid foundation for energy performance calculation. The key methods of energy performance calculation rely on computer simulations and physical model testing. These approaches are relatively reliable and repeatable. However, the feasibility of this method has not been fully verified due to time limits. A comprehensive consideration of inspection process is needed in the future research plan.

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Acknowledgments

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