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Review

A Review of Integrated Design Process for Building Climate Responsiveness

Zhixing Li *, Mimi Tian, Xiaoqing Zhu, Shujing Xie and Xin He

School of Design and Architecture, Zhejiang University of Technology, Hangzhou 310023, China
* Correspondence: zxlee910@zjut.edu.cn

Abstract: In recent years, increasingly prominent energy and environmental problems have pushed for higher requirements for buildings' energy saving. According to the conventional energy-saving design method, the cooperative operation between architects, structural and equipment engineers and other professionals cannot run smoothly, so the energy-saving and emission reduction efficiency of the whole building cannot be improved effectively. The integrated design process (IDP) is a systematic method, which is applied in the scheme design stage and according to which the multi-level design factors of cities and buildings are considered comprehensively. It provides a concrete path of multi-specialty collaborative operation for the building's climate responsive design. In this article, the development, operation process, software platform, evaluation and decision-making methods of the IDP are reviewed in a comprehensive manner. Finally, the prospect of IDP applied to the climate responsive design of buildings is analyzed, and some suggestions for future development are put forward. The IDP framework proposed in the research can provide a reference method for architectural climate responsive design practice and help formulate the future policy of energy-saving design.

Keywords: cooperative operation; building climate responsive design; integrated design process

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1. Introduction

The construction industry significantly impacts the environment and contributes to about 30% of global greenhouse gas emissions and 40% of energy consumption [1]. In the EU countries, 40–45% of total energy consumption comes from the construction industry [2]. In China, however, by the end of 2018, the carbon emissions of buildings in the whole life cycle accounted for 51.2% of the national energy carbon emissions [3]. Faced with the risks of energy depletion, global warming and climate change, all countries urgently need to reduce the buildings' energy consumption while maintaining a comfortable indoor thermal environment.

To cope with climate change and environmental problems, great changes must be implemented in the construction industry, and thorough improvement must be made in the process of architectural design, so that the destructive impact on the environment can be effectively reversed. For traditional buildings, attention is paid to cost, schedule and quality, while for sustainable projects, environmental protection, user health, low carbon emissions and low energy consumption must be considered [4,5]. To that end, governments should encourage the use of innovative and collaborative design processes, such as IDP [6,7]. IDP, a holistic approach, can help optimize building performance through an iterative process. In this process, all members of the design team need to cooperate from the early stage, so with IDP, the designers, contractors, suppliers and users can interact with each other more frequently [8].

Currently, the concepts of IDP in climate responsive building design are focused on the practical level. Few literature works study IDP from a theoretical perspective, such as

Refs [9–13]; most of the studies focus on actual cases and field research and mainly discuss the design optimization methods and technical means, while ignoring the multidisciplinary cross-research relationship. Therefore, IDP in the field of climate responsive building design has a lack of guidance under a theoretical research framework.

In this article, the relevant literature works from the past ten years are reviewed, and the latest progress of climate responsive design of buildings and the frontier development of IDP are discussed and analyzed from different aspects, such as method framework, operation process, software platform, evaluation and decision-making methods, so that the latest progress of the current IDP in climate responsive building projects can be obtained. Then, the main advantages and disadvantages of the current IDP applied to climate responsive building projects are analyzed in detail.

The study is conducted to build a conceptual framework of IDP for building climate responsive design, evaluate the advantages of integrated design in the field of building energy-saving and climate responsive design and research, clarify the restrictive factors of IDP in the current political and social context, and provide reference for future building climate responsive design practice and policy formulation.

2. Overview of Building Climate Responsive Design

The Köppen climate classification system [14] is the most widely used climate classification system in the world. According to this system, the global climate is classified into five main types based on annual and monthly average temperature and precipitation. These types are represented by capital letters: tropical humid climate (A): the average temperature in all months is above 18 degrees Celsius; dry climate (B): there is a lack of precipitation for most of the year; mid-latitude climate (C): the climate is humid, and it is mild in winter; mid-latitude climate (D): the climate is humid, and it is cold in winter; polar climate (E): it is extremely cold in winter and extremely hot in summer. Each major type can be further subdivided into many specific climate types, as shown in Figure 1.

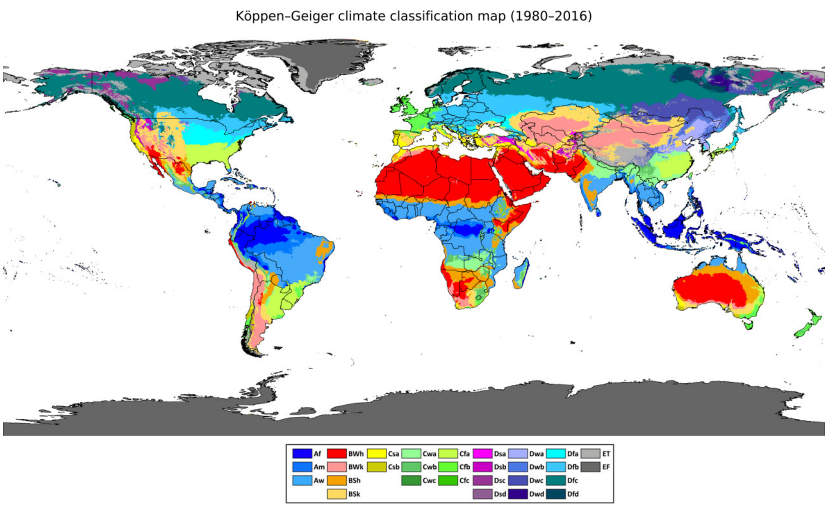

Figure 1. World climate map [15].

In 1923, Houghton et al. [16] first proposed the effective temperature (ET) index, which was used to estimate the body’s surface temperature by analyzing the comprehensive effects of air temperature and humidity and airflow velocity. Later, the important role of thermal radiation in physiological variables, such as body surface temperature, perspiration rate and metabolic rate related to human thermal comfort, was also studied. Gagge from the Pierce Laboratory of Yale University and Gagge from the ASHRAE Laboratory of Kansas State University, respectively, developed a relatively reasonable thermal comfort standard, namely the standard effective temperature (SET) index, according to human physiological conditions and heat transfer principles [17–19].

It has become the theoretical basis for ASHRAE staff to determine the environmental comfort standard. After 20 years of design research, in the 1930s, the Chicago architects Fred and William Keck designed and constructed the residential forms of south-facing windows, and they first proposed the concept of a "sun house" (Watson 1977). In 1963, V. Olgyay [20,21] proposed a systematic method of architectural design based on climatic conditions and human comfort requirements, that is, the bioclimatic design method featured in the design route of climate–biology–technology–architecture. Later, Baruch Givoni [22], by inheriting and further developing this method, formulated a new standard for the thermal comfort evaluation index of thermal stress (I.T.S.), as well as proposing the "building bioclimate map", which provides the range of thermal comfort conditions that buildings can achieve under different environmental conditions. However, the application of these theoretical studies and methods in practice is still worth exploring. As Givony said, when the actual climate conditions are different from the assumed ones, the "building bioclimatic map" is not accurate, and it can only provide a possible thermal control strategy.

In recent years, Alfano et al. [23] discussed the main criteria for thermal comfort design and evaluation to assist architects, HVAC system engineers and operators in effectively dealing with complex and diverse thermal environment evaluation criteria. Meanwhile, they also proposed adaptive strategies to improve indoor environmental quality and save energy. Currently, a number of evaluation standards for thermal comfort have been established internationally, such as EN 16798-1 and -2 [24,25], ISO 17772-1 [26], ISO 7730 [27], ASHRAE 55:2021 [28], which shows that the assessment of thermal comfort has a certain complexity. Meanwhile, their work suggests that the physical parameters and individual parameter input values recommended by the standard must be used under specific conditions because the current thermal environment assessments of existing buildings are suffering from two major problems, i.e., the lack of precision of the measuring equipment and the uncertainty of the human metabolic rate. These uncertainties will greatly affect the assessment of building thermal comfort.

Different from Alfano et al.'s research on PMV-based assessment indicators in a HVAC environment, Runming Yao et al. [29] systematically reviewed and discussed the development and evolution of thermal environment assessment methods for buildings under natural ventilation conditions. In addition, they devised three representative thermal environment assessment methods, namely the heat balance approach, the adaptive regression-based approach and the adaptive heat balance approach. The advantages and limitations of each method are analyzed.

The typical examples of bioclimatic design practice refer to the regional architecture by Correa in a dry and hot area of India, the vernacular architecture by Fathy in Egypt, as well as the "bioclimatic skyscrapers" by Kenneth King Mun YEANG in Malaysia [30]. In the former two, low technology and vernacular materials are very likely to be adopted, while in the latter one, high technology and new materials are very likely to be adopted. The regional architecture by Correa includes a number of design prototypes suitable for India's dry and hot climate, such as tubular houses, open corridors and open spaces. A series of spatial environments that meet the requirements of indoor thermal comfort and are highly localized are created through the use of cheap technology and local materials. In Fathy's architecture, more attention is paid to low-income people. He first explored local traditional building techniques and methods and then optimized and redeveloped them with the research results of aerodynamics and other related disciplines. Some climate strategies were designed. For example, wind-catching windows were developed to increase convection for heat dissipation; open corridors, vaults and domes were designed to control heat dissipation of the roof; inner courtyards were used for temperature drop. The Malaysian architect Kenneth King Mun YEANG is dedicated to applying bioclimatic design methods to high-rise buildings. Based on the traditional building form elements (terraces, arcades and ventilated roofs), as well as advanced technologies, the overall building energy efficiency was achieved. His design theory mainly involves five aspects: vertical circulation system, interior space design, vertical landscape, natural ventilation organization and skin design.

Today, many scholars have explored the relationship between the climate environment and building energy-saving design in different spaces or different time frames. In this study, "Building Climate Responsive Design" are used as keywords for visual analysis of co-occurrence diagrams. The number of related literature works is 746, as shown in Figure 2. The size of the circles in the co-occurrence diagrams represents the frequency of the keywords. The larger the circle, the higher the frequency; the lines represent the co-occurrence relationship. The denser the lines, the stronger the co-occurrence nature. It can be found that the keywords of the research on "Building Climate Responsive Design" are multi-objective optimization, circular economy and decision making, etc.

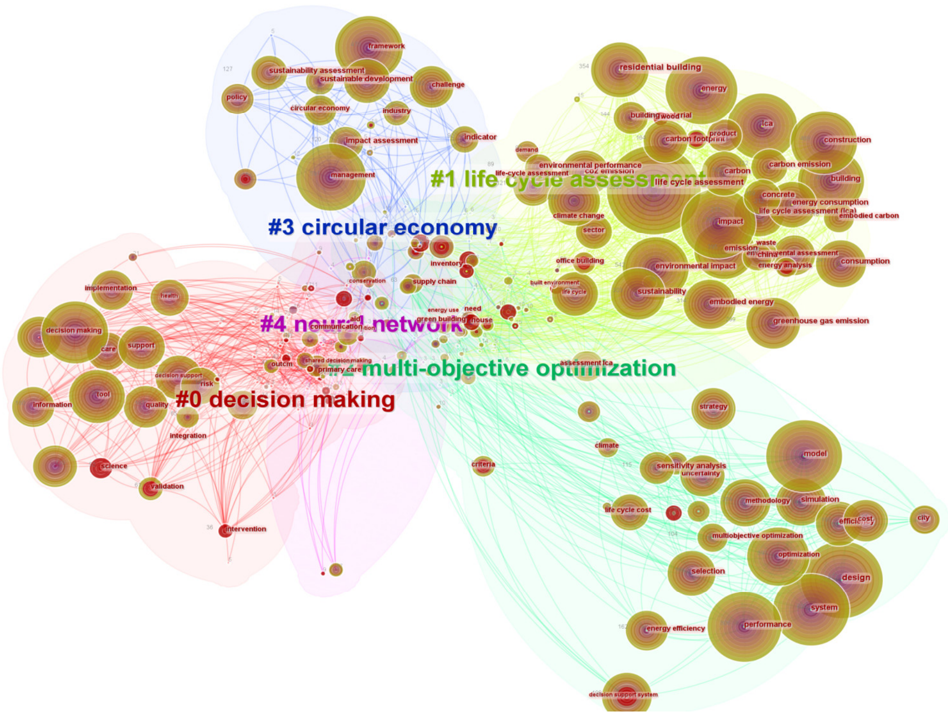

Figure 2. Co-occurrence diagram analysis of keywords related to building climate responsive design.

In the study, the mutation words of "Building Climate Responsive Design" are analyzed based on the database to understand the shift of research hotspots in the past 10 years, as shown in Table 1. The mutation characteristics of these words are presented in two aspects: the intensity and the duration. In the study, 43 mutation words with more than 3 years of popularity are extracted based on mutation intensity and popularity duration. The greater mutation intensity and longer duration indicate that such words can be seen as research hotspots that are more mature in a certain period. The greater mutation weight indicates that the mutation of such words has undergone an evolutionary process; the longer duration indicates that such words have a great impact on the field and are worthy of in-depth study. It can be seen from the mutation analysis that the research hotspots of Building Climate Responsive Design have gradually evolved from word groups (or words) such as energy use, decision support system and conservation in 2013 to word groups such as energy performance, BIM, thermal comfort and ecosystem service, and more, in recent years.

For example, Uelun-Ujin Purev et al. [31] measured the indoor and outdoor thermal environment data of Mongolian yurts in northern east Asia. It was found from the research that there were occasionally abnormal values of the indoor air temperature beyond the comfortable temperature range. The research team analyzed the indoor thermal environment of mobile tents and put forward strategies for improvement. Abdelkader Bassoud et al. [32] conducted a field study on the old adobe buildings in the Adrar arid desert area in summer. Adobe buildings made of local materials with high thermal insulation can bear local harsh conditions and can better provide a comfortable indoor thermal environment. Khawal Ravindra [33], based on the thermal environment research in the rural areas of Punjab, India, measured the relative humidity and air temperature, compared the results by using thermal comfort and household survey and analyzed the main factors affecting the comfort, so as to improve thermal comfort and reduce air pollutants. Beatriz Montalbán Pozas [34] conducted a thermal environment study on the local houses in the Hielte Valley of Central Mountain, Spain. The study was conducted in the mountainous climate of the Mediterranean continent, where it is warm and dry for half a year but cold and rainy for the other half. The potential contribution of traditional buildings to thermal comfort was explored in the study. May Zune et al. [35], in the study of passive design technology for thermal comfort of local houses in Myanmar, used the experimental design method. A simulation study was conducted to compare the effects of various passive design techniques on thermal comfort under three climates in Myanmar. Fifteen models were generated via the evaluation of measurement and analysis. ApacheSim and Macroflo programs were used to model the heat transfer process inside and outside the building and simulate the air and heat exchange, so as to test the thermal performance of houses in Myanmar throughout the year. İrem Sözen Gül and other researchers [36], based on the climatic conditions and local settlement characteristics of Mardin, Turkey, mainly studied the outdoor thermal comfort in hot and dry climate, analyzed the microclimate using ENVI-met software through the basic laws of fluid and thermodynamics, simulated the interaction between the buildings, atmosphere, soil, vegetation and water, and finally provided a general thermal comfort space form for streets and courtyards. Based on the summary of the existing literature, the types of parameters that improve the climate responsive design of buildings are shown in Table 2.

Table 1. Analysis of mutation words of building climate responsive design.

Keywords	Year	Strength	Beginning	End	2013–2022 *
intervention	2013	16.09	2013	2016	
energy use	2013	9.84	2013	2016	
quality of life	2013	9.83	2013	2016	
primary care	2013	8.55	2013	2017	
health care	2013	8.49	2013	2016	
decision support system	2013	7.75	2013	2016	
water	2013	7.52	2013	2015	
aid	2013	7.4	2013	2015	
need	2013	7.02	2013	2016	
conservation	2013	6.48	2013	2015	
guideline	2013	6.25	2013	2016	
environment	2013	5.81	2013	2015	
randomized controlled trial	2013	5.81	2013	2015	
industrial ecology	2013	5.41	2013	2015	
validation	2013	5.08	2013	2017	
preference	2013	4.91	2013	2016	
power	2013	4.76	2013	2015	
environmental impact assessment	2013	4.76	2013	2015	
support system	2013	4.02	2013	2016	
time	2013	3.97	2013	2015	

wood	2013	10.83	2014	2018
criteria	2013	8.48	2014	2017
inventory	2013	7.59	2014	2017
science	2013	7.46	2014	2019
resource	2013	7.25	2014	2017
scale	2013	6.85	2014	2017
thermal insulation	2013	6.04	2014	2017
thermal performance	2013	2.41	2014	2016
future	2013	8	2015	2017
green building	2013	3.58	2015	2017
house	2013	10.51	2016	2018
perspective	2013	8.31	2016	2018
education	2013	6.78	2016	2018
office building	2013	4.35	2016	2018
energy analysis	2013	5.36	2017	2019
energy performance	2013	4.58	2018	2022
land use	2013	4.02	2018	2020
life cycle analysis	2013	3.21	2018	2020
built environment	2013	9.86	2019	2022
footprint	2013	8.1	2019	2022
BIM	2013	7.46	2019	2022
thermal comfort	2013	6.71	2019	2022
ecosystem service	2013	2013	2019	2022

* The red color represent the hot period of each keyword during 2013–2022.

Table 2. Types of parameters impacting climate responsive design of building.

Factor		Description
Environmental factors [37]		External meteorological parameters (such as air temperature, humidity, wind speed, solar radiation intensity and effective sunshine time, etc.)
		Geographic information (such as location, orientation, altitude, etc.)
		Microclimate environment (such as buildings and vegetation around the building, building shading, ground reflection, heat island effect, etc.)
Building factors	Building enclosure structure	Geometric parameters (such as geometric size and shape of buildings [38–43], wind–wall ratio and window–ground ratio [44–46])
		Physical parameters (such as thermal performance [47–60], airtight performance [61–67], shading performance [68–72] of the materials of each part of the envelope)
		Maintenance status
	Equipment [73–84]	Type and quantity of equipment (such as HVAC equipment, lighting equipment, hot water equipment, office equipment, etc.)
		Equipment power (including nameplate power and actual efficiency)
		Energy efficiency ratio
		Maintenance status
Human factors		Setting of indoor thermal comfort (involving indoor temperature, humidity, wind speed, internal surface temperature and ventilation rate, etc.) [85–90]
		Routines, life habits, lifestyles and life attitudes, etc. [91–95]
		Frequency of use of buildings [96–100]

It is found from the literature analysis that the current building climate responsive design has the following characteristics:

(1) In recent years, scholars in relevant fields have measured and analyzed the environment of buildings in different climatic regions. Researchers have conducted in-depth research in severe cold regions, plateau regions and mountain forest regions with obvious regional characteristics. Here, the main methods were provided for research objects based on thermal environment data and analysis of building spatial layout. Thus, the strategies for improvement are provided for the research objects. The thermal comfort is comprehensively analyzed according to human thermal perception. The strategies for adaption of the regional climate are sought from the traditional construction methods in China.

(2) In the existing research works, the single physical measurement and analysis of the built environment are gradually replaced by humanistic studies in which subjective and objective data are combined. Questionnaire survey, as a common method in environmental comfort research, is widely used as a satisfaction survey, but this subjective research method is prone to deviation. At present, the measurement of physiological parameters, due to its objectivity, is also used in environmental analysis. Here, three main physiological parameters are involved: metabolic rate, skin temperature and heart rate variability. While most of these physiological parameters are studied in laboratories with controllable variables, few are applied based on actual project cases.

(3) Most of the existing studies are design-based studies conducted to realize a single environmental goal, without enough multi-objective integrated parametric analysis and practical cases of related integrated performance analysis.

(4) As the research on building climate responsive design is further conducted, attention is paid to the whole life cycle of buildings in an increasing number of documents, such as the whole life cycle cost, the carbon emission of whole life cycle, etc. The climate parameters involved are beyond the climate parameters of the typical year. Based on the climate prediction algorithm, energy consumption is simulated and calculated on the basis of climate change in the whole life cycle of the building.

3. Integrated Design Method Applied to Climate Responsive Buildings

3.1. Literature Analysis of Integrated Building Design Process

Based on the Web of Science database, the author created a co-occurrence diagram analysis of the relevant research hotspots in the past 10 years with “integrated building design process” as the keywords (as shown in Figure 3). The number of relevant documents is 5303. It is found from the co-occurrence diagram that the keywords of the research on “integrated building design process” mainly include building information modeling, public space, event-driven method, etc. Some literature works also involve keywords such as climate change, optimization, decision support system, life cycle assessment, etc.

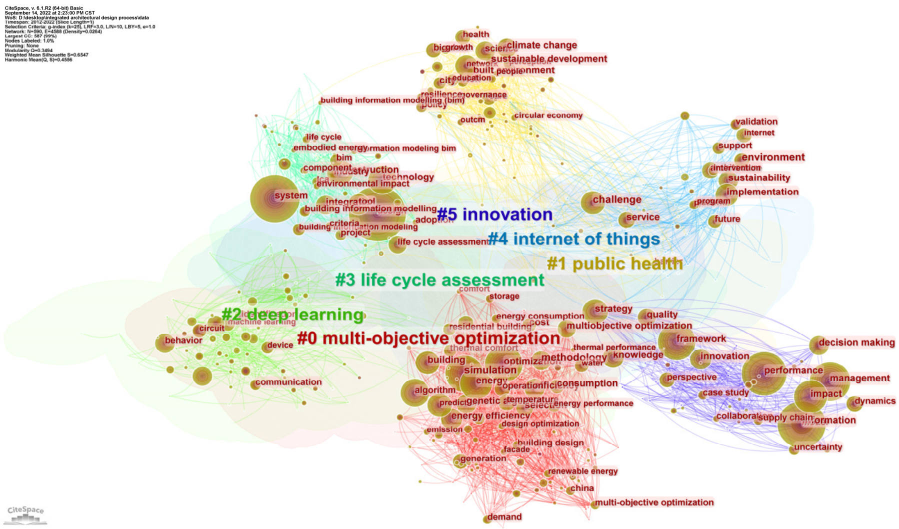

Figure 3. Analysis of keyword co-occurrence diagram of integrated building design process.

In the study, based on the database, the mutation words of "integrated building design process" are analyzed to reveal the changes in research hotspots in the past 10 years, as shown in Table 3.

Table 3. Analysis of mutation words in integrated building design process.

Keywords	Year	Strength	Beginning	End	2013–2023 *
circuit	2013	6.1	2013	2016	
program	2013	4.73	2013	2014	
decision support system	2013	4.63	2013	2016	
climate change	2013	4.31	2013	2015	
energy efficiency	2013	3.82	2013	2014	
air flow	2013	3.68	2013	2014	
design process	2013	3.53	2013	2015	
ontology	2013	4.96	2014	2017	
conservation	2013	4.96	2014	2017	
identification	2013	3.65	2014	2015	
management	2013	3.45	2014	2015	
control strategy	2013	4.16	2015	2017	
tool	2013	3.66	2015	2016	
intervention	2013	3.66	2015	2017	
firm	2013	3.59	2015	2018	
indicator	2013	4.87	2016	2019	
organization	2013	4.29	2016	2018	
resilience	2013	4.15	2017	2018	
device	2013	4.03	2017	2018	
density	2013	3.75	2017	2019	
plant	2013	3.7	2017	2018	
PCM	2013	3.58	2019	2020	
principle	2013	3.58	2019	2020	
machine learning	2013	5.57	2020	2023	
integrated circuit modeling	2013	5.23	2020	2023	
integrated circuit	2013	4.63	2020	2021	

opportunity	2013	4.47	2020	2021
mental health	2013	4.2	2020	2021
integration	2013	3.71	2020	2020
representation	2013	3.51	2020	2021
degradation	2013	3.51	2020	2021
mechanism	2013	3.51	2020	2021
digital twin	2013	6.42	2021	2023
internet of things	2013	5.15	2021	2023
computational modeling	2013	4.9	2021	2023
task analysis	2013	4.77	2021	2023
parameter	2013	4.62	2021	2021
artificial intelligence	2013	4.57	2021	2023
deep learning	2013	4.31	2021	2023
life cycle cost	2013	4.15	2021	2023
mathematical model	2013	3.94	2021	2023
predictive model	2013	3.77	2021	2023
transport	2013	3.66	2021	2021
reliability	2013	3.58	2021	2023
multi-objective optimization	2013	3.41	2021	2021

* The red color represent the hot period of each keyword during 2013–2022.

It is found from the analysis of mutation words that the research on integrated building design process has gradually shifted from the fields of decision support system, climate change and energy efficiency in 2013 to the fields of machine learning, integrated circuit modeling, life cycle cost and predictive model in recent years.

The mutation words can be divided into the following two categories based on the intensity and duration of the mutation.

The first category, with strong mutation intensity and short duration, is a sudden research hotspot in a certain period. The strong mutation indicates that the mutated words are triggered by influential realistic factors. The short duration indicates that these words are transitional hot words that will be merged or transferred to other research hotspots. It is found from the mutation analysis of "integrated building design process" that the short-term hotspots of words, such as resilience, PCM and degradation, are strong.

The second category, with strong mutation intensity and long duration, can be regarded as a mature research hotspot in a certain period. The large weight of mutation indicates that the mutation of words of this kind has experienced a certain evolution process; the long duration indicates that this kind of words have great influence in a certain field, which is worthy of further study. It is found from the mutation analysis that word groups, such as machine learning, predictive model, internet of things, life cycle cost, etc., are mature research hotspots with a long duration.

3.2. Methodology Framework of Integrated Building Climate Responsive Design

In the system for integrated building climate responsive design, scientific and rational logical thinking ability and creative activities based on ecological rules are considered. The system not only requires strict compliance with technical rules, such as codes, standards and node structures, but also emphasizes the subjective freedom of creative design behaviors, such as site selection, layout creation and form adjustment. In addition, it also advocates professional cooperation of multi-disciplinary fields, which strengthens group coordination and encourages public participation. The integration of design content, the expansion of design scope, the systematization of design procedures and the diversification of design objectives can also be reflected in the system. The design methodology itself is developed when a systematic coordination is carried out, and the overall design contradiction is handled. Therefore, from the perspective of design methodology, integrated building climate responsive design can simplify the thinking and increase the theoretical depth of integrated design. Separately, the development of integrated building climate responsive design may more or less absorb the theoretical fruits of the modern design methodology; thus, the applied research of modern design methodology can be further expanded.

The processes of integrated building climate responsive design can be summarized into target formulation, design analysis, design hypothesis, comprehensive evaluation and internal feedback.

(1) Target formulation

The design objectives are determined based on the comprehensive consideration of various constraints, including relevant national or local design standards, policies, overall planning objectives and Party A's requirements.

(2) Information classification and synthesis

Information must be collected as much as possible to be processed collectively into a standardized and unified information source. Meanwhile, the information is classified. Then, on the basis of information acquisition and classification, the knowledge rules are explored. On this basis, an information model is built for the provision of a system model in which the component attributes, static rules and dynamic rules are integrated.

(3) Design assumptions

According to the results of design analysis, one or more hypothetical schemes are put forward properly. Here, the assumed factors mainly include the architectural and environmental factors that impact energy use, such as the surrounding buildings' shading, thermal properties of building envelope, shading, behaviors for building use, etc. These factors may correspond to certain index parameters that need to be determined according to regional or national standards.

(4) Energy consumption simulation and comprehensive evaluation

Evaluation and selection of schemes. A comprehensive solution evaluation can be performed via the use of the inventory list method or the life cycle evaluation method or the evaluation method based on the simulation of building energy consumption, so that proper solutions can be selected. In addition, in terms of the energy-simulation-based evaluation method, the comparison and synthesis of multiple solutions are also useful for the identification of the interactions between the design variables, facilitating the determination of the main design variables and guiding the design optimization of the next cycle.

(5) Internal feedback and design optimization

The internal feedback is given based on the evaluation results in the comprehensive design phrase. If the evaluation results meet the design objectives, the evaluated solution is the final optimized solution; otherwise, it is necessary to revise the connection between the variables in the information model according to the evaluation results and go through the process of "design analysis–design assumptions–comprehensive evaluation" again. Then, the process will be repeatedly circulated and optimized until a satisfactory solution is obtained.

This is an open, dynamic, cyclic solution-seeking process, which requires the involvement of professionals from various disciplines in the early stages of the project. Therefore, it is different from the conventional terminal linear route of work. The openness of the design method brings more possibilities of design optimization. Therefore, the energy efficiency obtained via the use of this method for energy-efficient design is much higher than that obtained from conventional methods.

It is important to note that the conventional energy-saving design approach is applied throughout the entire engineering design process, involving schematic design, preliminary design and design of construction drawings. Meanwhile, the integrated building climate responsive design is created to integrate the advantages of each design stage, which are then applied into the schematic design stage. This is mainly because, in the schematic design stage, when the scheme is yet to be determined, there are more opportunities for design optimization. An effective energy-saving design can minimize the building's energy use on the one hand and create a favorable environment energy-saving design at a later point.

3.3. Operational Process of Integrated Building Climate Responsive Design

Due to the constraints of the research objects in different climatic regions, different design scales, different building types and different design stages, the design objectives cannot be met. In addition, considering the many disciplines involved and the complex information links between different disciplines, the contents of the integrated building climate responsive design tend to change in multiple ways. Such dynamic nature determines the variability of the specific design process organization under the method framework. Therefore, based on the methodological framework and application practice proposed above, a preliminary exploration is conducted on the operational process organization of energy-saving integration design applicable to the design of the whole building and part of the building on the basis of energy consumption.

In the research on integrated building climate responsive design of the whole building and part of the building, much attention is paid to the building's own systems (such as envelope, equipment systems and renewable energy systems) and the impact of user behavior on the building's energy use. Meanwhile, the impact on the surrounding environment must be considered. The work procedures are as follows.

(1) Objective formulation

Generally, the design objectives are determined according to the energy-saving-based codes and policies. For example, the target status can be determined according to the energy-saving design standards of similar buildings in the region. If there is no local standard, the regional standard or even the national standard can be referred to.

Integrated building climate responsive design represents the integration of performance based on physical and visual integration, as well as a systematic synthesis of space, time, energy efficiency, economic efficiency and other multi-dimensional factors under the premise of meeting the requirements for indoor thermal comfort. Literally speaking, integrated building climate responsive design is created to save energy. Meanwhile, there must be more than one design objective due to the systemic nature of integrated design [101].

Currently, many researchers who study the fields related to building optimization use genetic algorithms for the optimization of building performance scenario by integrating rhino, grasshopper (GH) plug-ins for building performance simulation (e.g., DIVA) and GH evolutionary solver, Galapagos, including optimization of energy-efficient building skin [102], optimization of high-performance building system [103,104], building orientation optimization [105], optimization of building operations [104,106–108], optimization of life cycle assessment [109–111] and optimization of alternative energy application [112–116]. However, in the GH platform, Galapagos can only optimize one objective function at a time, so the data results must be reprocessed, or other evolutionary solvers of the platform, such as Octopus, must be used when multi-objective optimization problems of buildings are addressed. The objectives of the integrated climate responsive design of existing buildings should be as shown in Table 4.

Table 4. Optimization parameters and their associated settings of previous studies.

Optimization Parameters	**Objective Function**
Heat transfer coefficients: wall, roof, floor, window frame and glazed window, heat absorption of walls, solar radiation absorption and visible light absorption, window–wall ratio, number of windows, g value of glass, transmissivity of daylight and visible light, open window area (natural ventilation), tilt angle and depth of external shading devices, type of shading, indoor and outdoor shading system, control strategy for shading devices, building shape, building shape coefficient, length–width ratio of building shape, ceiling height, building orientation, house area, airtightness/permeability, convection coefficient, and vegetation.	Economic nature: Minimization: life cycle cost (LCC), total investment cost, building operating cost and net present value (NPV). Energy: Minimization: total electrical load, lighting energy consumption and net energy deficit (NED). Environment: Minimization: impact of life cycle environment, assessment of the impact of life cycle and carbon emissions of life cycle. Comfort: Minimization: predicted mean votes (PMV), summer thermal discomfort, winter thermal discomfort, visual discomfort, long-term percentage of dissatisfied (LPD) and predicted percentage of dissatisfied (PPD). Others: Minimization: shape coefficient. Maximization: window opening ratio, heat transfer coefficient, solar radiation, space efficiency.
Constraints	Algorithm
NED ≤ 0; heating load ≤ 15 kWh/m^2; annual building energy demand ≤ 5 Mj/m^2; air exchange rate ≥ 0.6 ACH; total window width ≤ floor width. In the window areas, adequate natural lighting and ventilation must be guaranteed. Acceptable range of heat transfer coefficients of building envelope; budget constraints; constraints of design variables; maximum discomfort time fixed at 200–350 h; PMV ≤ 0.5–0.7; construction budget; life cycle cost budget.	Generalized pattern search (GPS), multivariate optimization, particle swarm optimization (PSO), non-dominated sorting genetic (NSGA-II) algorithm, genetic algorithm, life cycle assessment (LCA), artificial neural network (ANN), particle swarm optimization based on the Hook–Jeeves algorithm, sequential search (SS), tabu search algorithm (TSA), artificial bee colony (ABC).
Decision making/sensitivity analysis—uncertainty quantification	
Decision making: Weighted sum method (WSM), weighted product method (WPM), preference ranking based on ideal solutions, analytical hierarchical process (AHP), preference prioritization organization method for evaluation. Sensitivity analysis–uncertainty quantification: Energy price, discount rate, CO_2emission price, climate, utility rates, setting points of heating and cooling, sensitivity of algorithm parameters, weight of objective function, decision preference thresholds, uncertainty of distributed design variables based on probability.	

(2) Information classification and synthesis

Information must be collected as much as possible, while the information is classified and processed. The collected information should include the basic information about the site and building that is required for conventional design and the information related to energy-saving building design. Such information can be divided into two categories: information about the design conditions and technical information (e.g., Table 5). The technology application is restrained by the design conditions, while the technical information is collected mainly to prepare for the energy simulation at a later stage.

Table 5. Classification of parameters required for integrated design.

Design Conditions	
Geographic location	Latitude, longitude and time zone of the region where the project is launched.
Climate information	Typical local annual climate involves temperature, relative humidity, wind direction, wind speed, solar radiation, etc. The EnergyPlus website already provides downloadable climate data of major cities around the world; if multiple sources are available, comparative research is required, so that the one that best matches actual conditions can be selected.
Surrounding physical environment	Topography, landforms, surrounding building envelopes and more can be obtained through external environmental research.
Base conditions	Base size, shape, layout of greenery and water bodies, etc., can be obtained through field survey of the base.
Local technical and economic conditions	The performance and price of commonly used, encouraged or restricted energy-saving products and technologies can be determined based on the relevant local standards, policy documents and market prices.
Geographical culture	A survey must be conducted to gain information about local customers, lifestyle and culture. Particular attention should be paid to symbolic characteristics of the building and human use of the building.
Regional experience in energy-saving design	Research on regional architecture or interviews with experts can be conducted to obtain information about the characteristics of building forms, spatial layout features and prototypes of energy-saving components.
Technical information	
Building materials	Physical properties of commonly used materials: heat transfer coefficient, density, specific heat capacity.
Building components	Material composition and thickness of opaque components, material composition, thickness, transmission and absorption coefficients of light-transmitting components, etc., and size and dimension of prefabricated components.
Heating and cooling equipment	The output power per unit area of rooms with different functions and the corresponding working schedule.
Indoor lighting equipment	Thermal power of illumination per unit area of rooms with different functions and the corresponding working schedule.
Indoor electrical equipment	Thermal power of indoor electrical equipment per unit area of rooms with different functions and the corresponding working schedule.
Indoor personnel	The thermal power of indoor personnel per unit area of rooms with different functions and the corresponding working schedule.
Indoor ventilation	The indoor fresh air requirement per unit area of rooms with different functions and the corresponding working schedule.

(3) Design assumptions

Many design assumptions are made within the scope of the information model. This can be achieved via different combinations of design variables. In the information model, the relevant factors that impact the building energy use under the constraints and the range of their variations are basically determined. In the design assumption stage, the values of the variables corresponding to these factors and their possible combinations are assumed, that is, different energy-saving design strategies are integrated to obtain different energy-saving design solutions. The design variables involved vary by region and building type, mainly including building orientation, envelope heat transfer coefficients of building envelope, shading coefficient of the exterior window, window–

wall ratio, ventilation rate at summer nights, the COP and EER of the air conditioning system, solar photoelectric conversion efficiency, solar heat collection efficiency, etc.

(4) Energy consumption simulation and comprehensive evaluation

First, based on the complexity of the information model and the content of the design objectives, the suitable software tools need to be selected to simulate the building energy use and indoor environmental conditions. Software simulation can be divided into a simple mode and a specific mode. The information of the former is simple and general, and the software is modeled quickly, while in terms of the information of the latter, specific, accurate and complete information sources are required, and the modeling process is very complex and time consuming. The simple model is often used for qualitative comparison at the early stage of scheme design, while the specific model is usually used for quantitative evaluation at a later stage of the design. In terms of the scheme evaluation of this period, the environmental and economic benefits of energy-efficient design are required to be considered in a comprehensive manner, or the expert system is introduced, or the public are invited to participate.

(5) Internal feedback and design optimization

In the traditional architectural design process, there is no integrated system approach in the early stage of scheme generation and the later stage of scheme ending. Traditionally, architectural design is always judged based on the architect's experience, and the architect's cognition of the design determines whether the expected goals can be achieved in the project. With a large number of complex variables in the design, it is difficult to achieve the optimal goal if only the architect makes his/her own subjective judgment. As today's architectural simulation technology sees further development, the designers can be effectively assisted in decision making, so that the uncertain guesses in the design can be eliminated to a certain extent, and the design solutions can be evaluated quantitatively. However, these procedures are complex, and the data required to be input are detailed. It is difficult to obtain them in the early stages of the design, so the relevant schemes can only be evaluated in the later stages of the design. Most decisions that have a significant impact on energy consumption are made in the early design stage, making it difficult to effectively assist in the building climate responsive design only via the use of these simulation programs in the traditional design process.

In previous studies, the use of optimized search methods based on building environment simulation [117,118] is proposed. A Monte Carlo simulation framework is established based on building simulation tools to perform the uncertainty analysis and search for input parameters. The automated means are used to solve the problem of the input parameters being difficult to determine in the traditional sense. Optimization is a process in which the best combination of different solutions is sought while a given constraint condition is met. In the execution of optimization, decision variables, objective functions and constraints are needed. The following Formula (1) demonstrates the optimization process in a general mathematical sense.

$$\begin{gathered}\min_{x\in R_n} f(\mathrm{X}) \\ \mathrm{g}_i(\mathrm{X}) \le 0, i = 1,2,\ldots,m \\ \& l_j(\mathrm{X}) = 0, j = 1,2,\ldots,p\end{gathered} \tag{1}$$

Here, X represents different decision variables, and the $f(\mathrm{X})$ is the objective function. The constraint conditions are $\mathrm{g}_i(x) \le 0, i = 1,2,...,m$ and $l_j(\mathrm{X}) = 0, j = 1,2,\ldots,p$. Determining the decision variables, the objective function and the constraint conditions is the most important part of the optimization process. Different optimization algorithms can be selected according to the classification of different objective functions and constraint conditions.

Pareto optimality is the classical model for multi-objective optimization [106,107], and its core thinking is an extreme objective under the premise of minimum objective conflict. The Pareto optimal solution is a set containing solutions that are no better than any others. In other words, different solutions cannot be compared with each other. The multi-objective optimization often ends up not with a unique optimal solution but a set of Pareto optimal solutions.

If the minimization value of the objective is required, there are two feasible solutions $x_1, x_2 \in \mathrm{S}$. When Formula (2) is workable, the x_1 is called the Pareto optimal solution ($\succ$) x_2

$$F_i(x_1) \le f_i(x_2), \forall i \in \{1 \ldots k\}$$
$$F_i(x_1) < f_i(x_2), \exists i \in \{1 \ldots k\} \quad (2)$$

Formula (2) indicates that all of the objective functions corresponding to the x_1, are no greater than the value of the objective function of x_2. In $f(x_1)$, there is a value that is absolutely lower than $f(x_2)$. When the maximal solution is required in the objective function, the expression will be changed into Formula (3)

$$F_i(x_1) \ge f_i(x_2), \forall i \in \{1 \ldots k\}$$
$$F_i(x_1) > f_i(x_2), \exists i \in \{1 \ldots k\} \quad (3)$$

The integrated analysis process based on parametric simulation and optimization of building performance consists of two parts and three steps, as shown in Figure 4. The data collection step and the generation step constitute part 1: design prototype generation. The optimization step constitutes part 2: design optimization. In part 1, specific design parameters are collected, such as building form factors, window–wall ratios, etc., and default parameters contained in the design, such as the constraint parameters used to generate the design prototype. In part 2, the architectural design prototypes generated in part 1 are optimized. This process facilitates the formation of a series of optimized architectural design solutions that designers can evaluate, select and further develop. For building climate resilient design, the result is a building design solution with high thermal comfort and low energy and cost, which can be specified in the process shown in Figure 5.

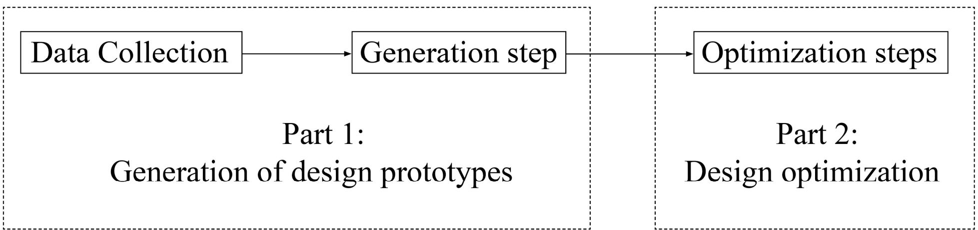

Figure 4. Basic steps of design generation and optimization.

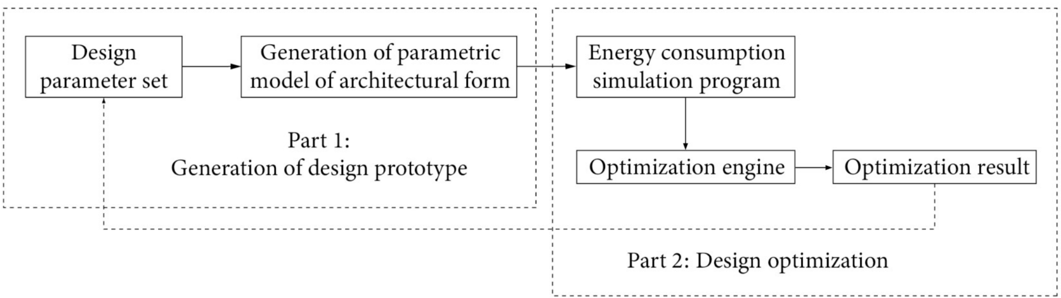

Figure 5. Simulation-based modeling process for building form generation and optimization.

It should be noted that in terms of the simulation prediction at the urban scale (urban planning and urban design), the information about the building layout, energy supply and even the surrounding physical environment of larger scope is needed; in terms of the simulation prediction at the indoor environment level, the information about room layout, interior decoration and equipment system operation is needed.

3.4. Software Platform for Integrated Building Climate Responsive Design

In addition to the basic design software, such as AutoCAD, SketchUp, 3DMAX, etc., there are four other types of digital tools for integrated building climate responsive design: the first type refers to the integrated simulation design platforms, such as design platforms based on BIM [119–121] technology; the second type involves assessment software for energy consumption and environmental impact, such as BEES, Athena, EQUER, etc. [122,123]; the third type represents simulation technologies for complete energy consumption, such as EnergyPlus, ESP-r, DOE-2, etc. [124–126]; and the fourth type is auxiliary professional analysis software, such as AirPak, Radiance, Weather Manager, ENVI-met, etc. [127–132].

The internationally recognized PHPP software is the only software approved by PHI for passive building design simulation. PHPP, developed by PHI, is used to calculate the load and energy of passive buildings. The scheme follows a built-in German passive building certification standard [133]. In China, other simulation software programs, such as DeST [134] and eQUEST [135,136], are used for the year-round energy simulation. DeST was developed at the Institute of Environment and Equipment, Tsinghua University. The state space method is adopted, and AutoCAD is used as the graphic interface to analyze building thermal characteristics and calculate the annual hourly load and building energy consumption. The simulation results of DeST are consistent with those of DOE-2 and EnergyPlus developed by the United States Department of Energy.

In addition, an increasing number of researchers based on the Rhino/Grasshopper parametric platform use environmental analysis plug-ins Ladybug and Honeybee to conduct the analysis on building environment and energy consumption modeling. The application of this workflow can be seen in Figure 6 below.

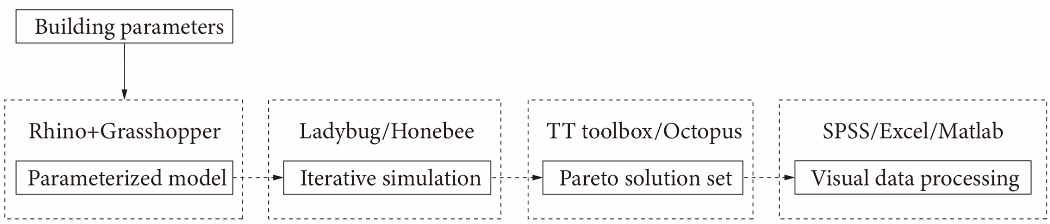

Figure 6. Parametric building optimization process.

Grasshopper is a parametric plug-in of the modeling software Rhinoceros 3D. In the Grasshopper program, one can create a program only by dragging the parameter command component into the canvas and connecting the input and output of the components in different logical orders. Grasshopper, as a graphic algorithm editor, provides a new method of expanding and controlling the 3D design and modeling process. For example, complex geometry is generated through mathematical functions. In addition, complex models are driven and quickly changed according to the environmental performance algorithms under predefined modeling logic [117,118].

Ladybug and Honeybee, the plug-ins of Grasshopper, are free computer applications that support environmental design. They connect 3D computer-aided design (CAD) interfaces to Daysim and Radiance, the light environment analysis software, and the verified simulation engine EnergyPlus. Daysim and Radiance are widely used in the analysis and evaluation of the light environment of buildings. Via the simulation of the real physical environment, the light environment can be predicted, and the impact of direct light, diffuse light and ground-reflected light on indoor natural lighting can be comprehensively calculated. They are suitable for different sky environments all year round, such as sunny sky, overcast sky and cloudy sky.

EnergyPlus is a building dynamic simulation software for energy consumption developed by the U.S. Department of Energy and Lawrence Berkeley National Laboratory on the basis of the features and functions of BLAST and DOE-2.1E. It is designed to provide integrated (load and system) simulation to achieve the accurate prediction of energy, temperature and comfort. EnergyPlus is the most widely used tool in the current building energy analysis and research. It can simulate the heating, cooling, lighting, ventilation and other energy flows and humidities of buildings. It is especially suitable for simulation of the dynamic behavior strongly influenced by thermal inertia [137,138]. The simulation process of this software is illustrated in Figure 7. EnergyPlus has irreplaceable advantages over some other simulation software (as shown in Table 6).

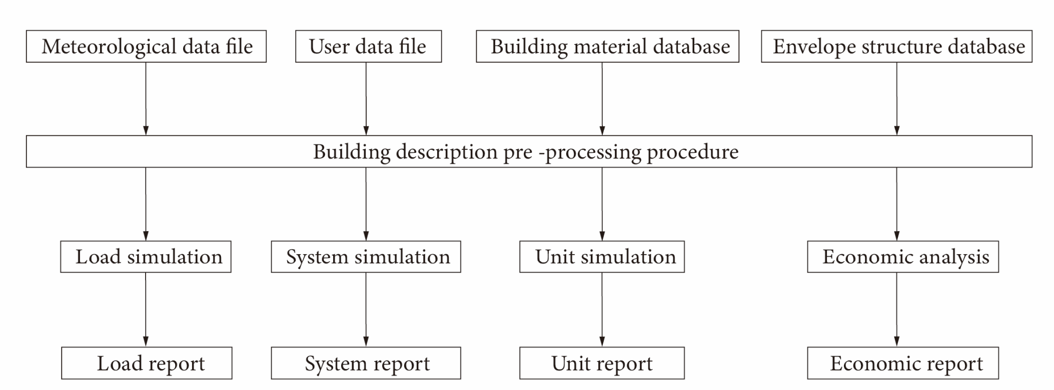

Figure 7. Operation logic of EnergyPlus simulation.

Table 6. Comparison of EnergyPlus with other software.

Comparison Contents	EnergyPlus	DOE-2	BlAST	IBLAST	DeST
Integrated simulation and iterative solutions	Yes	No	No	Yes	Yes
User's self-defined time step	Yes	No	No	Yes	No
Output interface	Yes	No	No	No	No
Self-defined output reports	Yes	No	No	No	Yes
Calculation equation of room heat balance	Yes	No	Yes	Yes	Yes
Calculation equation of building's heat balance	Yes	No	No	No	Yes
Convective heat transfer calculation of internal surfaces	Yes	No	No	Yes	Yes
Long-wave mutual radiation between inner surfaces	Yes	No	No	No	Yes
Heat transfer model of neighboring chamber	Yes	No	No	No	Yes
Humidity calculation	Yes	No	No	Yes	Yes
Thermal comfort calculation	Yes	No	No	Yes	No
Radiation model of sky background	Yes	Yes	No	No	Yes
Calculation of window model	Yes	Yes	No	No	Yes
Solar transmittance distribution model	Yes	Yes	No	No	Yes
Daylight model	Yes	Yes	No	No	No
Calculation of water cycle	Yes	No	No	No	Yes
Circulation of air supply and air return	Yes	No	No	No	Yes
User's self-defined air conditioning equipment	Yes	No	No	No	Yes
Calculation for the concentration of hazardous particulate matter	Yes	Yes	Yes	No	Yes
Interface with other software	Yes	No	No	No	Yes

EnergyPlus has a simulation kernel but has no visual interface suitable for user modeling operation. Therefore, the integrated operation logic can be realized if the OpenStudio is linked with Grasshopper's plug-ins: Ladybug and Honeybee.

On the basis of modeling and performance analysis, if Octopus—a plug-in of Grasshopper—graphical parametric modeling environment is adopted, the optimization search of building environment parameters can be easily carried out. The general optimization process is divided into three parts: parameter gene, parameter model and optimization objective, namely, input parameters, performance simulation and simulation results.

Via the operation procedures shown in Figure 6, the interactive operation and optimization integration of building model and environmental analysis can be realized. The data concerning the changes of geometric model parameters in Grasshopper will be updated in the environmental analysis software in real time. The iterative simulation of the model is driven by the optimization engine. Different geometric and environmental input parameters and corresponding output result parameters of the analysis target are recorded, thereby generating an "input–output" table.

3.5. Evaluation and Decision-Making Methods of Integrated Building Climate Responsive Design

The evaluation method of integrated building climate responsive design is mainly used to evaluate the performance optimization of buildings. The evaluation results are used to screen and optimize the design schemes and to guide the internal feedback to correct the information model.

International evaluation methods of building performance can be roughly divided into four categories, namely: the prescriptive index method, the list method, the life cycle evaluation method and the evaluation method based on building energy consumption simulation or calculation. Among them, the prescriptive index method is the method according to which the evaluation is conducted based on the prescriptive indices of key engineering parameters stipulated in the energy-saving standards and specifications, such as the heat transfer coefficient, window–wall ratio and shape coefficient of the external envelope stipulated in the building energy-saving design standards. According to the list method, the key problems are listed in the form of a list. Different problems or categories of problems will have weight values. According to the problem scores and weight values, the final score can be calculated, and then, the building rating can be provided with reference to the grading standards. According to the life cycle evaluation method, an inventory analysis of the material and energy flows of buildings is conducted based on the basic framework of life cycle evaluation. Then, a comparative evaluation is generated. The evaluation method based on building energy consumption simulation or calculation is the evaluation method based on the energy consumption value calculated via the simulation software or calculation method for building energy consumption.

In the prescriptive index method, the limits of important energy-saving parameters are specified in the form of indicators. Although these indicators are obtained through analysis on the basis of a large number of engineering practices and scientific research works, this method still greatly limits the "communication" between the parameters. Therefore, there is no possibility of integration, and the method is not suitable as an evaluation method for integrated building climate responsive design. Comparatively speaking, the latter three kinds of evaluation methods are more flexible and adaptable. They can be used as an evaluation method for integrated building climate responsive design because of the "communication" between parameters and their characteristics of integration. It should be noted that different evaluation methods have different conditions of application, evaluation contents, evaluation objectives and auxiliary tools, so attention should be paid to a reasonable selection of these methods according to the actual situation.

(1) List method

According to the list method, the most widely used environmental assessment method, questions are posed on the key issues or criteria. Based on the weight values given to these issues and criteria, the final total score can be calculated. This method is relatively straightforward and operational but requires the user to know the project well enough; in addition, it allows different questions to complement each other, i.e., if the score of one question is low, that of another will be high enough, so that the final total score will not be decreased. However, the biggest problem with the list method is how to ensure the objectivity of the weighting factor. The unified view is yet to be found. In addition, subjective factors make it difficult to reconcile the contradictions between national standards and local adaptations. Nevertheless, considering its excellent operability, it is still an effective method for constructing a building evaluation index system, as shown in Table 7 of the relevant literature.

A comprehensive evaluation system consists of several elements: evaluation purpose, evaluator (development agency), evaluation object, evaluation index, weighting coefficient, comprehensive evaluation model and evaluation result. The core elements of the evaluation system include determining the evaluation indicators, selecting the scoring methods, determining the weighting coefficients and creating a comprehensive evaluation model. A good evaluation index system should be equipped with comprehensive and integrated evaluation indices, a scientific and rational scoring method, an objective and reasonable weighting system, an operation-friendly evaluation model, and an accurate and effective evaluation result expression.

Internationally, many studies are conducted on green building evaluation systems, which have been strongly supported by the governments of various countries. The famous evaluation systems include BREEAM of the U.K., LEED of the U.S., CASBEE of Japan, GBTool of Canada, etc. China is also going to introduce a new version of green building evaluation standards. The theoretical and methodological achievements of these evaluation systems provide valuable experience for the development of evaluation systems for building energy-saving design.

Table 7. Relevant literature where the list method is applied.

Farzad et al. [139]	proposed a method of combining BIM with the Canadian green building certification system (LEED).	Based on the BIM platform, a model by which the LEED certification is automatically calculated is constructed. Meanwhile, the cost of the model can be calculated.	In this study, attention is only paid to the integration of BIM and sustainable development from the perspective of LEED. Therefore, the research results cannot go beyond LEED. The general framework of sustainable development is not produced.
Farzad et al. [140]	put forward a comprehensive framework that integrates BIM with green building certification system in the early design stage of the project.	Plug-ins for the calculation of LEED points were developed by accessing the BIM application interface (API), tools for energy analysis and lighting simulation, Google Maps and its related libraries.	The accuracy of the model was restricted by the number of projects. The information transmission from Green Building Studio (GBS) to plug-ins needed to be performed manually by users.
In the study of Liyin et al. [141],	the text-digging technology was integrated into the case-based reasoning (CBR) system to improve the decision-making efficiency of green building design.	Seven cases were randomly selected from seventy-one LEED cases as target cases to test how efficient the TM-CBR system is.	It was difficult to obtain the original data; there was a limited number of cases; there was a lack of verification of a large number of empirical data.
In the study of Walaa et al. [142],	both qualitative and quantitative methods were adopted. A comprehensive framework (IAF) for a green building rating and	In the study, a reference was provided for the development of a LEED system and different building rating and certification systems with a comprehensive	However, in the study, the dominant position of some tools and how they impact important decisions were not clearly demonstrated; there was a lack of descriptions of iterative behaviors

	certification system was proposed.	framework; and interactive decision support tools, software management applications and user-friendly system interfaces were established.	in the integration process in the proposed framework.
In the study of Yingyi Zhang [143],	the impact of parameter codes based on forms on the sustainable development of urban communities was evaluated.	In the study, the LEED-ND method was adopted to establish a code evaluation system based on parameter forms in order to guarantee the health of social environment and urban communities and the sustainable development of the communities.	The study was only conducted in Tsim Sha Tsui, Hong Kong. The findings were mainly obtained from the analysis of the Jordan Road community. In future studies, investigations of a larger scale can be conducted in different regions.
In the study of Mohamed Marzouk [144],	a mixed integer optimization model was developed to help architects and owners select building materials during the design phase. Meanwhile, the costs and risks involved in the selection process needed to be considered.	Deterministic and probabilistic cost analysis of various design alternatives can be conducted through the model developed in the study with reference to the LEED rating system based on the simulation optimization tool.	The study analysis was only conducted for office buildings in Egypt and only with reference to the LEED rating system; more building types will be considered, and more green building rating systems will be incorporated in the future.
Jin Ouk Choi [145]	developed an integrated optimization tool for LEED evaluation.	In the study, the LEED decision and review index (LDRI) tool was established based on the MS Excel platform and MS Access database format. The user can rank the LEED scores by performing the steps listed in the LDRI tool. The tool will automatically provide the corresponding reports.	Currently, no weight is assigned to each factor. In the future, the analytic hierarchy process (AHP) can be added to the model to determine the weight of factors. In addition, more factors should also be added to the tool to reflect the growing needs of owners and users.
Elena et al. [146]	proposed an integrated approach for energy and environmental analysis, specifically for historic building renovation.	An intervention strategy indicating the principal direction of historic building operations and maintenance was proposed.	A weakness of the study is the lack of applicability to all LEED protocols, precisely because the structure of the credits and categories in O+M is substantially different from that in most rating systems.
In the study of Ricardo et al. [147],	the extent to which the integrated design can effectively improve project performance and reduce environmental impacts was verified.	The study was conducted on three Canadian building projects that were certified by LEED and in which various environmental strategies were integrated. The study team first identified and evaluated building environmental impact strategies, then analyzed the decision-making process and measured the relationship between reference buildings, schematic design and construction documents using the life cycle assessment (LCA) tool and building energy simulation (BES).	The study was only conducted on projects (gold and platinum) that were certified by LEED, and no analysis was conducted on other types of green building certified projects (e.g., SbTools, Living Building Challenge, BREEAM and DGNB). The impact of full life cycle assessment metrics on integrated processes was rarely mentioned.
In the study of Emre et al. [148],	a method of obtaining the required number of credits in the LEED (v4) category of "energy and atmosphere" under the "optimized energy performance"	The LEED v4 credits were calculated automatically based on Excel macros via the use of energy simulation software (Sefaira), cost database (RSMeans) and BIM	It was assumed in the study that the building's lighting and HVAC systems had been determined by the analysts. In the future studies, changes in lighting and HVAC systems can be considered. Meanwhile, a large

	credit at the lowest cost was proposed.	software (Autodesk Revit) with an office building as example.	number of scenarios can be created to obtain the desired LEED scores.
In the study of Johnny et al. [149],	the Delphi method and case study method were adopted to explore the potential of BIM application in the project of sustainable certified residential buildings under BEAM Plus in Hong Kong.	In the study, an integrated BIM-BEAM Plus assessment framework was constructed and applied to a modular apartment model for public housing in Hong Kong. It was proved in the study that 26 BEAM Plus scores can be obtained via the integrated BIM-based assessment framework.	The validity of the framework needs to be further verified based on real case studies. The results generated by the framework need to be compared with the real BEAM Plus scores.
In the study of Bahriye et al. [150],	an integrated BIM sustainable data model framework was proposed based on integrated foundation classes (IFC) in the design stage of the whole building life cycle.	In the study, a green building assessment tool (GBAT) was established based on the IFC-BIM integrated framework. Then, it was applied to a sample project, and the accuracy of the tool was verified via the use of the BREEAM evaluation system.	In the model, only materials in the BREEAM database can be used, and the material library (GML) can only be used in ArchiCAD software. The material database in the BREEAM database cannot be updated automatically.

(2) Life Cycle Assessment

Life cycle assessment (LCA) is a method of evaluating the resource consumption and environmental impact of products, systems and services throughout their life cycle, including the inception and the ending. In 1969, the Midwest Resources Institute in the U.S. conducted a study on product packaging, marking the first step of LCA research; by the mid-1980s, research on LCA methodology gradually emerged, and LCA methodology was widely used in design, industry and marketing; by the 1990s, The Society of Environmental Toxicology and Chemistry (SETAC) explicitly introduced the concept of "life cycle assessment". Since then, the International Organization for Standardization (ISO) has developed a series of LCA standards (ISO 14140 series). According to ISO's LCA methodology, LCA should include the following steps: definition of the objectives and scope, inventory analysis and impact evaluation. The relevant literature is shown in Table 8.

Like the life process of all the other products, the life process of a "building product" includes six stages: planning, design, building, test, operation and recycling. It represents the unification of the time process and "information flow change", as well as a process of diversified information and circular flow. As a systematic information processing method, the whole life cycle evaluation method can be directly used for the economic and environmental performance assessment of buildings. Meanwhile, the energy-saving performance of buildings needs to be evaluated comprehensively based on the results of energy consumption simulation or calculation. The LCA of a building requires the creation of a detailed inventory of the inputs and outputs of building materials and resources during the building process. Then, on this basis, an evaluation of the associated environmental impacts and resource consumption is conducted. Recommendations and alternatives for improvement are proposed.

Table 8. Relevant literature where the LCA is applied.

Thais et al. [151]	developed a framework for environmental impact assessment within the design life cycle.	In the article, two different whole building environmental impact assessment (EIA) tools are analyzed, including life cycle assessments (LCA) and green building rating systems (GBRS).	A software tool or framework needs to be developed to support designers in conducting whole life cycle EIA throughout the design process.

In the study of Ahmad et al. [152],	BIM and LCA tools were integrated with a database for designing sustainable building projects.	In the study, an integrated BIM-LCA model was described to simplify the process of sustainable design, build inter-operable design and analysis tools, and assist designers in quantifying the environmental impacts of design solutions.	The main disadvantage of the model is that it cannot be applied in the detailed design stage of a building project, as only information on commonly used components is stored in the database, with the information on a large number of green building materials uninvolved. In addition, the model is not fully integrated with automation, and some steps still require manual adjustment by the user.
In the study of Mohammad et al. [153],	an evaluation model of integrating BIM and LCA was established.	Based on the ISO 14040 and 14044 guidelines in the existing database, the BIM-LCA integrated analysis framework was established with Autodesk Revit as the BIM-LCA program and applications of Green Building Studio and Tally in Revit as tools.	In the future, more parameters of building materials will be included in the study to assist in evaluating the energy consumption, carbon dioxide and environmental impact of different building materials in the whole life cycle of buildings.
Maria et al. [154]	developed a multi-objective optimization model to obtain the minimum design parameters of greenhouse gas emission and life cycle cost in building operation.	Based on DAKOTA, TRNSYS and multi-objective genetic algorithm (MOGA), the multi-objective optimal designs were compared with typical houses in four climatic regions of Greece as examples.	In the study, attention was only paid to residential buildings and only under the climatic conditions in Greece. In the future, more different types of buildings will be considered, and more architectural design parameters will be included.
In the study of Hae Jin Kang [155],	a decision support tool suitable for early design stage was constructed to evaluate the performance and cost of CO_2 emission reduction. A program with a database was developed.	In the study, a decision support tool was developed to comprehensively evaluate and compare the environmental and economic impacts in the early design stage, so as to achieve effective decision making. The tool could be used to improve the realization and popularization of nZEB, so that the evaluation results could be obtained quickly and simply, and the comprehensive performances of design alternatives could be compared.	The evaluation tools developed in the study are only suitable for the early design stage. In the future, more evaluation decision-making methods can be added to the building operation stage.
Farshid et al. [156],	by combining the multi-objective optimization method with the BIM design process, solved the trade-off decision problems in implied energy and operational energy.	The design prototype was developed with a low-energy residential building in Sweden as an example. The best design scheme for the use of LCE of the building was found through the trade-off calculation of implied energy and operational energy.	Further study needs to be conducted to reduce the time cost of calculation and expand the design framework, so that more design variables are covered, such as the geometry of the building, etc.

(3) Evaluation method based on consumption calculation or simulation of building energy.

The evaluation method based on the calculation or simulation of building energy consumption refers to the method of calculating the running energy consumption of a building via the use of a certain calculation method or energy consumption simulation software and performing an evaluation and analysis on this basis. The method can be seen in the Standard Assessment Procedure (SAP) in the United Kingdom, ENERGY STAR in the United States and the building energy passport in Germany. The related literature is shown in Table 9.

The greatest advantage of this method is that it provides a quantitative comparison and evaluation of building energy consumption, while the disadvantage is that it relies too much on a certain energy consumption model. This is because the model, whether in the form of a calculation method or simulation software, is generated based on certain assumptions, which tend to be idealized or to be only applicable to a certain region, a certain scale or a certain type of building. Therefore, the accuracy of the simulation results is questionable. In fact, many environmental factors impact the energy efficiency of buildings. The calculation method or simulation software are difficult to be considered in a comprehensive manner, so the results of quantitative calculation are not necessarily accurate. In addition, most of the current energy consumption simulation software and calculation methods tend to be specialized and complicated. They are difficult to operate, and high requirements are posed to users. Thus, the possibility of inaccurate calculation results is enhanced. Therefore, it is obviously unreasonable to evaluate or label energy efficiency based entirely on the calculation results.

Table 9. Relevant literature based on building energy simulation method.

In the study of Jutta et al. [157],	five façade greening prototypes were proposed, and the BIM platform was adopted to create the digital models, respectively, for each of the five façade greening systems.	Based on the BIM platform, an integrated evaluation system for the building life cycle was established for the five façade greening prototypes.	The script introduced in the study was only applicable to RHINO, as the GeometryGymIFC plug-in currently only supports RHINO. Integration trials of the plug-in with other system platforms will be required in the future.
In the study of Yan Wan et al. [158],	an optimal design approach and an integrated decision system were proposed for building indoor environmental comfort and energy saving.	Based on the BIM system, the artificial neural network (ANN) and the genetic algorithm (GA) were integrated, and the optimization design of green buildings was adopted.	In the study, much attention was paid to the optimal design of green building interior energy saving based on the intelligent GANN-BIM model. It is technically difficult to operate such a model. A user-friendly decision system needs to be developed for laymen in the future.
In the study of Taki et al. [159],	an approach of retrofitting building information model (RBIM) was proposed to achieve optimal design with a trade-off between minimizing the overall heat transfer value (OTTV) and minimizing the retrofitting cost.	In this method, BIM tools (e.g., Autodesk Revit), visualization scripts (e.g., Dynamo) and a non-dominated ranking genetic algorithm (NSGA-II) in MATLAB are integrated.	In terms of the RBIM approach proposed in this study, attention was only paid to the energy efficiency of the building envelope. In the future, more decision metrics/parameters can be integrated into the workflow, such as energy use index (EUI), energy consumption (EPS), etc. With the RBIM optimization, multiple constraints and parameters in MATLAB need to

			be set. However, most designers have no programing background. Therefore, to facilitate the practical application of RBIM, user-friendly plug-ins will be further developed for integration with BIM in the future.
In the study of Elżbieta et al. [160],	a decision process applicable to the schematic design stage was proposed, with a near-zero energy retrofitting of a building at the Warsaw University of Technology in Poland as example.	According to the study, a clear set of sustainable design processes were set in the early design stage, thus facilitating the collaborative operation of multidisciplinary technical staff who could make near-zero energy design decisions from the energy-saving perspective of a whole life cycle.	In the study, much attention was paid to the schematic design stage. Further discussion can be held in the future on how to make decisions in the operational stage of buildings of near-zero energy consumption.

Agencies such as government development departments can use the above evaluation methods of building performance for design decision analysis, thus developing reasonable design strategies and achieving the climate resilience goals of buildings. The established literature related to decision systems is shown in Table 10.

Zhou et al. [161] classified these methods in three categories: single-objective decision analysis, multi-criteria decision analysis (MCDA) and decision support system (DSS). Here, the MCDA refers to the evaluation of alternatives based on multiple competing objectives. DSS refers to an interactive software system that supports decision makers in dealing with complex decision problems. MCDA methods can be further divided into two main categories: 1. multi-objective planning models, where alternatives are defined by a set of constraints to identify a set of compromise solutions (no single best solution is available); 2. discrete alternative models, where alternatives are known, and the goal is to help decision makers choose or sort among this limited set of alternatives based on two or more criteria. Both of these categories are currently used in building climate responsive projects.

Table 10. Literature related to the development of decision systems based on the calculation of building performance simulation.

In the study of P. Michael Pelken [162],	the Virtual Design Studio (VDS) was developed for the comprehensive, coordinated and optimized design of buildings and their energy and environmental systems.	In the study, the relationship between VDS and the architectural design process and its performance optimization strategy were summarized. The specific working stages, design factors and performance standards of all participants (designers of architecture and system and project management teams) are linked via the VDS. This facilitates the coordination of work of each stage.	The integration scope of the study will be expanded in the future. A user-friendly interface will be created for non-professional people.
In the study of Yu-Hao et al. [163],	an integrated decision-making system was proposed to solve the discrete optimization problem based on the regression equation.	In the study, the regression equation was proposed to replace the complex energy simulator. The integrated calculation was carried out for the structure performance of office	In the study, the parameters of active energy-saving equipment are not considered. Therefore, the multi-objective optimization algorithm can

		building envelope. Here, the building materials, types of sunshade, length of sunshade, number of windows, length and width of windows are involved.	also be used to verify the validity of the regression equation in future studies.
In the study of In-Ae Yeo et al. [164],	an energy integrated support system (EnerISS) modeler was developed to support the strategic and technical implementation of environmentally friendly local energy plans.	The three-dimensional (3D) modeling of comprehensive urban space was automated. The visual information was provided to support the decision-making process. The system architecture of modeler includes the formation of architectural polygons, the classification of textures and shapes of land, terrain and 3D urban space.	No method has been developed to modify geometry according to the given feedback of energy planning information. The extensibility of the web platform needs to be further strengthened.
Liu et al. [165]	developed the BIM cloud platform to encourage project stakeholders to conduct green building evaluation by digital collaboration according to regulatory requirements.	In the study, the automatic analysis and digital analysis technology platforms based on cloud platform were proposed. The thermal performance analysis of envelope based on Green Mark was carried out under BIM and 3D graphics environment.	In the overall thermal conductivity of building envelope (ETTV), only the heat gain from the building's exterior walls and windows is considered. It is more like a passive strategy used to minimize the solar heat gain. However, the actual energy efficiency of buildings is impacted by the HVAC system performance, operation strategy and energy-related occupant behaviors. In future studies, more attention should be paid to the relationship between ETTV and building energy consumption.
Tamer et al. [166]	put forward the online system of Green2.0 to guide users to participate in the project at the early design stage.	In their study, the Green2.0 online system was constructed. According to the system, the building information model (BIM), energy efficiency simulation tools and online social network analysis are adopted to realize data-driven building planning and construction and maintenance methods, so that a shared platform for communication between users and professionals can be established.	Considering that the AEC industry covers a wide range of fields, different tools are used in different disciplines, and different building work models are produced, it is very difficult to integrate the shared platform of multiple professional operation processes.

4. Discussion

4.1. Comparison between Integrated Design Method and Conventional Method

Integrated building climate responsive design is a result of the adoption of the second-generation design method based on the concept of energy saving. It is a dynamic, comprehensive and cyclic method for optimization system design instead of a single linear energy-saving design method. Compared with conventional energy-saving design methods, it has witnessed great progress in design content, design process, design goal, evaluation method, achievement form, the tools used and the composition of design groups.

(1) Diversification of design factors

In the conventional energy-saving design, attention is only paid to the design factors that have a direct impact on energy for the operation of a building. In addition, the design can only be used in the building itself. Moreover, here, the energy-saving technology is especially stressed, while the energy-saving potential of the design itself is ignored. This excessive attention to technology can easily lead to a misunderstanding, especially for non-professionals. This one-sided, static way of analyzing the problem also makes the content of energy-saving design limited to the subject area and not systematic.

In the integrated building climate responsive design, attention is paid to both the building itself and the environment in which the building is set. The interaction between building energy use and the environment is examined at the level of urban design and even urban planning. It advocates the collection and use of environmental resources to reduce fossil energy consumption as much as possible. For example, solar photovoltaic technology, heat collection technology, sunrooms and more, are adopted. The design content goes much beyond the technology itself. Here, the design innovation is emphasized; equal importance is attached to both the technology and the design. It is advocated that different technical strategies are integrated via effective design. For example, solar photovoltaic panels are designed to have a function of shading the sun; and green roofs are designed to have the functions of keeping warm and shading the sun, and so on.

(2) Openness of the design process

The conventional energy-saving design includes two parts: the pre-design assumption and the post-design energy-saving evaluation. However, the design process here refers to the post-design evaluation and design optimization process. The established studies indicate that during the schematic design phase, the focus of the energy-saving design is the interaction between building parameters, environmental parameters and the prediction of performance impacts. Meanwhile, as the design process progresses, the focus of energy efficiency in the subsequent phase is the adjustment of equipment (e.g., air conditioner and primary air system) parameters when building parameters have been determined. Thus, in the pre-programing phase of design, architects have more strength and freedom to adjust the design parameters out of concern for the interaction between the building and its environment. Meanwhile, the adjustment of each factor will make a huge difference to the environmental benefits of the building. For example, the design parameter of building orientation can only be adjusted at the scheme stage. Different orientations have a huge impact on building performance. When the design is advanced to the construction drawing stage, the orientation of the building is difficult to change because the scheme has already been determined. At this stage, designers can only compensate by adjusting the cooling and heating sources or adopting other means, such as the use of renewable energy, if they want to achieve the established energy-saving goals. It is thus clear that the decisions on building energy-saving design at the scheme stage largely determine the direction of the subsequent design process.

The conventional design process is that after the program is basically determined, the relevant parameters of the energy-saving design program are compared with the design target values. If the requirements are met, the evaluation is adopted; otherwise, special energy simulation software is used to perform trade-off calculations. The program is optimized according to the results until the energy-saving requirements are met. Since the scheme is basically determined, the design optimization can only be adjusted locally on a small scale. Therefore, the energy efficiency that can be improved is very limited.

The integrated building climate responsive design is a systematic, open and dynamic cyclic process of seeking a solution. It covers the whole design process, involving site selection planning, layout design, the design of the single unit form, orientation, window opening and exterior wall insulation design, the selection of interior decoration, room layout and equipment system. Since the energy-saving evaluation is applied in the early stage of program design, it can guide the overall energy-saving design optimization more effectively, thus minimizing the building energy use. In addition, unlike the conventional energy-saving design methods, the design here requires a more extensive and detailed design analysis in the early stages to accumulate a rich design experience and guide the subsequent energy-saving design practices. Therefore, it is more scientific and reasonable.

(3) Integration of design goals

Conventional energy-saving designs are finally generated to achieve energy-saving design specifications or relevant evaluation standards. Meanwhile, they generally only involve the energy demand for the building's operation stage, mainly the energy demand for heating and cooling throughout the year. The corresponding energy consumption of building equipment systems, primary energy consumption, carbon dioxide emissions and more, are not considered.

In actual building projects, the requirements for building climate responsive design are very complex and may also be constrained by the acoustic environment, wind environment, local policies and social development. Therefore, the integrated building climate responsive design is generated to achieve the energy-saving and emission reduction of a larger range and even involving cost-optimal comprehensive indicators. Meanwhile, the indoor thermal comfort conditions under extreme climate conditions must be considered, that is, the overall performance of the building must be improved as much as possible on the premise that the indoor environmental quality is guaranteed.

(4) Flexibility of evaluation methods

In conventional energy-saving designs, prescriptive indices are generally adopted, that is, the evaluation is performed by means of limited values of key energy-saving parameters determined by authoritative institutions, or the evaluation is made by means of energy use comparisons among the used solutions of the benchmark solution. For example, prescriptive indices, such as a calculation book and a dynamic calculation book given by PKPM, can be adopted. The former is not flexible enough due to the rigid stipulation of limit values for each specific parameter, while, although energy consumption simulation tools are introduced in the latter, only year-round energy use comparisons are involved. There is a lack of overall consideration of seasonal over-cooling or over-heating phenomena.

Based on the actual needs of the integrated building climate responsive design, systematic energy-saving evaluation methods, such as the inventory evaluation method, life cycle evaluation method and evaluation methods based on energy consumption calculation or simulation, are used separately or in combination, involving various evaluation contents, such as energy use demand of the terminal, equipment system energy consumption, carbon dioxide emission from primary energy consumption and energy-saving investment return. Inventory evaluation methods are commonly used to establish evaluation systems for building energy efficiency, while life cycle evaluation methods are often used to analyze the comprehensive energy-saving and cost performance. Meanwhile, energy consumption calculation methods or simulation-based evaluation methods are commonly applied to various types of qualitative and quantitative analyses and comparisons. At present, in many evaluation systems, the life cycle evaluation methods and evaluation methods based on energy consumption calculation or simulation begin to be introduced; therefore, more scientific and rational evaluation results can be obtained. In summary, it can be seen that compared with conventional energy-saving design methods, the integrated building climate responsive design contains more comprehensive contents, more flexible evaluation methods and more scientific evaluation results.

(5) Diversification of the expression of results

The results of conventional energy-saving designs are usually presented in the form of an energy-saving design calculation book. Here, the evaluated contents mainly focus on whether the values of the main energy-saving parameters of the scheme meet the standard requirements. If they do not, they need to be determined through further energy consumption simulations, as well as the analysis and comparison of the annual operating energy consumptions of the benchmark scheme.

The results of the integrated building climate responsive design can be expressed in various forms, including the dynamic digital model showing the progress of the project construction or the book about the evaluation of energy saving or the impact of carbon emission or energy-saving design guideline or building use manual. The visualization of the results and the operability of the design implementation are emphasized. More humanistic care is given to the project construction and building use.

(6) Collaboration of multi-disciplinary design teams

The conventional energy-saving design is usually carried out by architects and HVAC and electrical engineers, with other professionals only helping to solve problems that arise in their own professions.

Integrated building climate responsive design encourages discipline crossing. The design team consists of various professionals, such as planners, architects, HVAC engineers, structural engineers and interior designers; it also advocates for the joint participation of experts from multiple fields and the public, and it requires the participation of the government, developers, users and contractors from the very beginning of the design. Energy-saving design needs not only the work of designers and engineers but also the cooperation of experts from multi-disciplinary fields. It is the crystallization of collective wisdom.

4.2. Constraints on the Application of Integrated Building Climate Responsive Design

(1) Clear professional division of labor

The traditional architectural design team is composed of architectural, structural, electrical and equipment professionals. Each professional designer is only responsible for solving the problems of his or her own profession. Generally speaking, the architect's task is to propose a design plan that meets the requirements of the specifications and Party A and then to deepen the design according to the site and the surrounding environmental conditions; the structural engineer takes over the structural design of the building after the completion of the plan and draws the structural construction drawings; the electrical engineer is responsible for the design of strong and weak electricity; the equipment engineer mainly carries out the calculation of the building's HVAC, water supply, drainage and gas power to ensure the efficient operation of the equipment system. The clear design division of labor contributes to the lack of cooperation between the professions. Unless there are conflicts, there will be no information exchange and communication between the professions. Building design is difficult to be performed at a later stage. This organizational status deviates from the design concept of professional cooperation and public participation advocated by integrated building climate responsive design. It will seriously hinder the development and popularization of integrated building climate responsive design.

The clear division of professional work facilitates the formation of a flowing design mode, i.e., only after the work in the previous stage is completed can the work in the next stage be carried out. The division of labor is clear at each stage; thus, the vertical information exchange is very limited. This seriously impacts the possibility of integrated design implementation. With the schematic design stage as an example, the traditional schematic design mainly refers to the creative activities architects conduct on the premise that the building performance requirements are met. However, due to the restrictions of architects' own professional background, it is difficult to refer to all aspects of the scheme. Various problems in the implementation process are often encountered. The schemes need to be handed over in stages as planned. The design needs to be adjusted and modified until the problem is solved. This phenomenon greatly increases the duplication of efforts of the entire design team and reduces design efficiency. In the integrated building climate responsive design, the anticipation can be performed effectively; thus, the possible problems can be avoided, since all phases of work tasks are integrated. Nevertheless, adjustments and optimizations of the traditional design process are difficult to be achieved in a short period of time due to conventional thinking.

(2) Incomplete basic database

The lack and opacity of basic data are the biggest problem faced by the integrated building climate responsive design at present. The development of integrated building climate responsive design is achieved based on a large amount of information and data analysis. Therefore, a huge information base is needed as the basis. The information includes meteorological data, thermal performance of materials, prices of materials and components, and so on. At present, the database of architecture is not complete, and there are some problems, such as diverse data sources, lack of basic data and poor transparency, which are not conducive to a comprehensive development of integrated design. Although many simulation software and design platforms provide the custom features of a database, the lack of basic data still seriously affects the accuracy and scientificity of the integrated design.

(3) Complexity of design platform

The integrated building climate responsive design is so professional and complicated that higher requirements are posed to the design groups. With the BIM as an example, the design platform involves professional knowledge in many disciplines, such as architecture, structure, heating and ventilation, engineering management, etc. The resource consumption and investment expenditure can be simulated in the whole life cycle process, involving design, construction, operation and maintenance and final destruction. The accuracy of the simulation design requires not only the support of a strong basic database but also the proficiency and cooperation of professionals in the design tools. Over-limited or over-simplified tools may make the model fail to represent reality.

In addition, at present, most of the energy consumption simulation software can only be used to simulate single building energy consumption or indoor thermal environment. They can be used to roughly estimate the energy consumption on an urban scale (including urban planning and urban design) instead of estimating it accurately. The energy consumption simulation on the urban scale involves two levels: urban planning and urban design. It is necessary to consider the influence of design factors, such as building mutual shelter, building density and heat island effect (transportation planning and energy planning), on building energy consumption. The lack of energy consumption simulation software on an urban scale is not conducive to the development of integrated building climate responsive design.

(4) Lack of professionals who control the design process

In the IDP process, both LCA and BES are regarded as too complicated by the stakeholders. Previous studies have also shown that these tools (especially LCA) provide excessive information and require professional explanation of the results. However, at present, in most projects, there is a lack of professional and technical personnel who can grasp the whole design process. Therefore, it is suggested that experts in life cycle and energy be hired to test the various design assumptions in the whole process, so as to provide objective information on key performance.

5. Conclusions

With the improvement of building performance requirements and the development of building climate responsive design, the drawbacks gradually emerge in the traditional design process. Therefore, it is necessary to promote IDP to guarantee a higher success rate of building delivery and the degree of control over building performance objectives.

However, the feasibility index and theoretical model of IDP are still not perfect. Meanwhile, the application of IDP requires significant cultural and technical changes due to the traditional contracting models and inertia in the work and thinking among the contractors, engineering consultants and architects. Project stakeholders and academia need to work hard to make the integrated design process a reality and to make the necessary adjustments to contracts, schedules and costs. As sustainable design and practice evolve, the need for IDP as a standard workflow grows. Therefore, stakeholders need to develop appropriate IDP processes to meet the needs of sustainable building projects.

In the article, a comprehensive review of the current research progress of IDP applied to building climate responsive design is put forward; the existing integrated design processes are classified based on the method framework, design process, software platform, evaluation and decision-making methods; the corresponding measures for improvement are proposed.

In the future, empirical case analysis will be carried out to analyze the potential, constraints, advantages and disadvantages of the application of IDP in building climate responsive design, so that the academia can have a more comprehensive understanding of IDP and promote the popularization and application of IDP in the current building climate responsive design, building energy-saving design and other fields.

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