Study on Comprehensive Evaluation on Green-targeted Energy-saving Renovation Design for Existing Buildings

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Abstract. The renovation for existing buildings will be a trend for architectural transformation in the future. The selection of architectural design plan is a vital step for determining the effect of energy-saving renovation. Based on the analysis of renovation evaluation system for existing industrial buildings and the energy-saving renovation target for existing buildings, this paper sets up the evaluation criteria and factors and determines weight by adopting AHP to produce a quantified evaluation model, as well as makes a practical verification for a specific renovation design case.

1. Introduction

China has entered fast development of urbanization since the 21st century. With the increasing emphasis on sustainable development, renovation and reuse targeting at circular sustainability and low energy consumption have become the main trend of developing the existing buildings, especially the historical buildings. Renovation of the existing buildings could not only maintain the original historical, cultural, social and economic values of the buildings with the smallest impact for the environment, but also create new space to meet the new requirements for development so as to reduce the pollution for new construction or removal of the old buildings.

The traditional renovation or protection design for Existing Buildings mainly focuses on the digging into the historical, cultural, social and economic values of the buildings. However, the renovation of the architectural buildings should be combined with the green construction concept with the implementation of energy-saving and emission-reduction strategies. The design of the interior and exterior environment of the renovation plan should take into account of the ideas of energy-saving and emission-reduction, so that it can satisfy the requirements for a green renovation plan.

This article generalizes the previous evaluation principles for existing buildings, proposes the green renovation target and constructs the evaluation model for existing buildings through setting up related evaluation criteria and factors, and adopts AHP to quantify the evaluation model to produce an evaluation system. Finally, a practical case study is made. Through the quantified evaluation and selection of various design plans, the feasibility and reliability of the evaluation system are tested to make a justified choice of a plan which can both maintain the original historical, cultural, social, and economic values of existing buildings and meet the green-targeted developing requirements, so as to provide theoretical basis for the renovation design of existing buildings.
2. Traditional Renovation Evaluation System for Existing Buildings

Historical buildings, which are carrying important social, historical, cultural and economic significance, have witnessed the development of a city. In 1961, Jane Jacobs wrote in her famous The Death and Life of Great American Cities that the old buildings in different periods had played an important role in maintaining the variety of cities. The recognition towards existing buildings has improved as the society has developed. As a result, domestic and foreign comprehensive and detailed studies and practices emerged in large numbers. In the theoretical aspect, the renovation significance of the historical buildings is mainly studied from the perspective of protection and reuse of the industrial constructions; in the practical aspect, the industrial buildings are mainly reconstructed into different varieties including business and entertainment, cultural exhibition, creative office buildings, such as England Tate Museum of Modern Art in London, Shuang’ an Shopping Mall in Beijing and The Bridge 8 Creative Park in Shanghai.

Based on the feasibility and reasonable structural design, the traditional renovation design emphasizes the discovery of the historical cultural information of the existing buildings, and realizes the maximization of the social, historical, cultural and economic values of the buildings through the exploration of the design’s widest social influence. The study on the successful domestic and foreign renovation cases of industrial buildings and the current study achievements on the renovation of existing buildings have indicated that the traditional renovation evaluation system for existing buildings are making evaluation from two aspects of feasibility and performance indicators, with a consideration of environmental indicators (Table 1).

| Target layer (A) | Criteria layer (B) | Indicator layer (C) | Factor layer (D) |
|------------------|-------------------|---------------------|------------------|
| Evaluation of Design (A1) | Feasibility (B1) | Feasibility of the structure (C11) | safety of the structure(D111) |
|                  |                   | Conjunction with the original architectural functions (C12) | durability of the structure(D112) |
| Performance indicators (B2) | realization of social values (C21) | solution to problems in citizens’ daily life(D211) | influence to surrounding environment(D212) |
|                  |                   | educational significance to the society(D213) | |
|                  |                   | discovery of historical and cultural values (C22) | inheritance to the historical and cultural values in the traditional renovation of existing Industrial Buildings(D221) |
|                  |                   | continuation of enterprise’s cultural spirit (D222) | influence on industrial culture (D223) |
|                  |                   | realization of economic values (C23) | reasonability of renovation cost (D231) |
|                  |                   | comprehensive balance on input-output (D232) | economic benefit after the renovation (D233) |
|                  |                   | utilization degree of niche advantages (D234) | |
| Environmental indicator (B3) | degree of resources’ reuse (C31) | utilization ratio of the original site (D311) | utilization ratio of the original construction materials(D312) |

3. Green Renovation Evaluation Model for Existing Buildings

According to Green Buildings Evaluation Standards GB/T50378—2014, six indicators are considered in an evaluation system for newly-built green public buildings: ① land saving and exterior
environment; ② energy saving and utilization; ③ water saving and utilization; ④ material saving and utilization; ⑤ indoor environment quality; ⑥ comprehensive performance in full life circle. Some indicators are not suitable for existing industrial buildings because Standards is targeted for newly-built constructions. For example, the renovation of existing buildings should consider the utilization ratio of the original site instead of land saving. Based on the traditional renovation evaluation system for existing buildings and the current adopted Green Buildings Evaluation Standards GB /T50378—2014, and combined with the present academic study achievements and professional opinions, a green renovation evaluation system for existing buildings (Table 2) is put forward with concerning of reducing energy consumption, improving comfort level and realizing architectural values.

3.1. Evaluation of feasibility
Feasibility of a renovation design is a critical part in the primary design of a renovation project. The traditional renovation for existing industrial buildings makes tests on the safety and durability of the original structure and re-divides the interior functional system from two aspects of feasibility and its conjunction with the original architectural functions, so as to combine the new and original functional systems. Compared with the traditional renovation evaluation system of existing industrial buildings, the green renovation can take the heat and sound insulation of the original structure into account in the feasibility test. Moreover, the adaptability of the site in the renovation should also be considered in the feasibility indicators.

Firstly, the heat and sound insulation of the original buildings are taken into consideration in addition to the safety and durability of the structure in the green renovation design. Because of the early construction time point and lacking of maintenance in a long time, the structure of existing industrial buildings is easily damaged. At the same time of energy saving, green renovation can provide comfortable interior environment for users, which can control the construction cost, reduce the energy consumption after renovation and satisfy the human needs for comfort in the construction standards through the tests for heat and sound insulation of the original buildings.

Secondly, adaptability of the site should be evaluated in the green renovation. In the past, the poisonous and harmful substance generated during the industrial production may damage human bodies, however, the safety of the site is the important premise for green construction. Before renovation, the pollution source of excessive emission, dangerous chemicals, flammable and explosive source of danger, as well as the threat of radiation and radon-containing soil should be evaluated.

3.2. Evaluation on performance indicators
Similar to the performance indicators in traditional renovation evaluation system of existing industrial buildings, the green renovation evaluation system includes the three indicators of realization of social values, discovery of historical and cultural values, and realization of economic values. Furthermore, this evaluation system also covers the demands for future development of the green buildings.

• The realization of social values includes the solutions to the problems in citizens’ daily life, providing more than two available architectural functions to the society, creating public space, constructing common shared infrastructures, and the demonstration significance of green renovation. ① Green buildings call for multiple functional constructions so as to achieve a more flexible land usage, as well as to increase the compatibility and utilization ratio of the constructions. ② Green buildings treat the architectural design as an organic part of the city design instead of an individual case. Open spaces are designed for social communications so as to attract more citizens into the utilization of sites, buildings and public facilities. ③ As a newly spouted idea, green renovation of old buildings can be served as a model to strengthen the environmental protection concept in the society.
Green renovation evaluation has the same contents of the discovery of historical and cultural values with the traditional one, which includes the inheritance to the historical and cultural values, the continuation of enterprise’s cultural spirit, and the influence on industrial culture. However, the realization of economic values includes the evaluation of the shortened construction time because of the renovation and the estimated saved cost in operation in later construction period other than the reasonability of renovation cost, the comprehensive balance on input-output, the economic benefit after the renovation, and the utilization degree of niche advantages. The shortened construction time can effectively reduce the air pollution and noise pollution to the surrounding area. Green construction means saving the energy and resources at the greatest extent in the full construction life cycle, therefore, the cost of construction management and the energy cost after the renovation should be evaluated. It is worth mentioning that although some existing industrial buildings in China have finished the transition of architectural functions, the renovation cost is always higher than that of constructing a new building. The green renovation design must not violate the primary target of saving resources, and not sacrifice renovation cost for the improvement of the outlook and comfort level of the building.

3.3. Environmental indicators
Taking the idea of “Four savings and one environmental protection” in Green Buildings Evaluation Standards into the green renovation evaluation system is one of its outstanding points and also the biggest difference from the traditional evaluation system. The environmental indicators of green renovation evaluation system include material saving and utilization, water saving and utilization, energy saving and utilization, and improvement of indoor environment.

- In the aspect of material saving and utilization, the utilization ratio of the original site, the utilization ratio of the original construction materials, and the utilization ratio of recyclable and reusable construction materials are evaluated. The utilization ratio of the original site refers to the utilization ratio of the pipeline network in the original site and increasing utilization ratio of the site through the re-layout of the site. The utilization ratio of the original construction materials includes not only the utilization of the structure, equipments and materials in the original buildings, but also the utilization ratio of the materials produced and can be continued to use during the construction, removal and cleaning-up activities in the construction site. At the same time, the green renovation plan should use as more environmental protection materials and technologies as possible and reduce energy consumption and environmental pollution brought by the production of new materials.

- Water saving and utilization is one of the important environmental indicators for green renovation, the evaluation will be made from the aspects such as the implementation of water-saving facilities and equipments, and the use of non-traditional water source. The non-traditional water source mainly includes the recycle of raindrop and seawater for the water landscape design, cleaning of roads, afforestation irrigation, and so on.

- In the aspect of energy saving and utilization, the evaluation will made upon the aspects such as the heat insulation of the exterior protected constructions, the appropriate opening-up of glass curtain wall and outer windows, and the reasonable use of energy-saving electrical equipments. For instance, the green renovation of existing Industrial Buildings can use the greening of roofs and walls as an effective green renovation way, which can provide heat insulation, reduce energy consumption, saving land use in the city, and optimize the landscape layout.

- In the aspect of improvement of indoor environment, the evaluation will made from the aspects such as the improvement of natural ventilation, the improvement of lighting, the improvement of thermal environment, and the improvement of acoustic environment. For example, the natural lighting and ventilation should be fully used by green renovation.
Table 2. Green renovation evaluation model for Existing Buildings.

| Target layer (A)          | Criteria layer (B) | Indicator layer (C)                                                                                                                                                                                                 | Factor layer (D)                                                                                                                                                                                                 |
|---------------------------|--------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Evaluation of Renovation  | Feasibility(B1)    | Feasibility of the structure(C11)                                                                                                                                                                                   | safety of the structure(D111)                                                                                                                                                                                  |
| Design (A1)               |                     | Conjunction with the original architectural functions(C12)                                                                                                                                                         | durability of the structure(D112)                                                                                                                                                                              |
|                           |                     | Adaptability of the site in the renovation(C13)                                                                                                                                                                     | heat and sound insulation of the structure (D113)                                                                                                                                                              |
|                           |                     | Performance indicators of Green renovation of existing industrial buildings (B2)                                                                                                                                   |                                                                                                                                                      |
|                           |                     | Realization of social values(C21)                                                                                                                                                                                   | no pollution source of excessive emission(D131)                                                                                                                                                              |
|                           |                     | Discovery of historical and cultural values(C22)                                                                                                                                                                    | no dangerous chemicals, flammable and explosive source of danger, no threat of radiation and radon-containing soil(D132)                                                                                 |
|                           |                     | Realization of economic values(C23)                                                                                                                                                                                  |                                                                                                                                                      |
|                           |                     | Environmental indicators(B3)                                                                                                                                                                                       |                                                                                                                                                      |
|                           | Material saving and | Utilization ratio of the original site(D311)                                                                                                                                                                        |                                                                                                                                                      |
|                           | utilization(C31)    | Utilization ratio of the original construction materials(D312)                                                                                                                                                     |                                                                                                                                                      |
|                           |                     | Utilization ratio of recyclable and reusable construction materials(D313)                                                                                                                                              |                                                                                                                                                      |
|                           | Water saving and    | Implementation of water-saving utilities and equipments(D321)                                                                                                                                                       |                                                                                                                                                      |
|                           | utilization(C32)    | Use of non-traditional water source (D322)                                                                                                                                                                           |                                                                                                                                                      |
|                           | Energy saving and   | Heat insulation of the exterior protected constructions (D331)                                                                                                                                                      |                                                                                                                                                      |
|                           | utilization(C33)    | Appropriate opening-up of glass curtain wall and outer windows (D332)                                                                                                                                                 |                                                                                                                                                      |
|                           | Improvement of      | Reasonable use of energy-saving electrical equipments(D333)                                                                                                                                                         |                                                                                                                                                      |
|                           | indoor environment   |                                                                                                                                                                                                                   |                                                                                                                                                      |
|                           | (C34)               | Improvement of natural ventilation(D341)                                                                                                                                                                            |                                                                                                                                                      |
|                           |                     | Improvement of lighting(D342)                                                                                                                                                                                       |                                                                                                                                                      |
|                           |                     | Improvement of thermal environment(D343)                                                                                                                                                                             |                                                                                                                                                      |
|                           |                     | Improvement of acoustic environment(D344)                                                                                                                                                                            |                                                                                                                                                      |
4. Weight Analysis on Evaluation System Based on AHP

4.1. AHP (Analytic Hierarchy Process)

Analytic Hierarchy Process, proposed by Prof. Thomas L. Saaty from Pittsburg University in 1970s, is a multi-objective decision-making method that combining qualitative analysis and quantitative analysis based on a structural model which establishes a hierarchy of decision-making problems in order of general goals, sub-goals, and evaluation criteria. The analytic hierarchy process is characterized by simplification and organization of complex problems, objective quantification of subjective cognition, and quantification of qualitative analysis, so as to achieve a more objective, fair and scientific evaluation of target problems.

The first step of constructing a hierarchical model (Figure 1) is to decompose a complex problem into several components, and the influencing factors are hierarchically classified. The hierarchical structure model is established from top to bottom according to target layer, project evaluation layer and factor layer. The target layer represents the goal of AHP; the project evaluation layer is the intermediate link to achieve the predetermined goal which plays a dominant role in the elements in its subordinated level, and serves as the evaluation criteria for the elements in its higher level; the factor layer represents the specific aspects of the objectives of the evaluation project.

![Figure 1. A hierarchical model](image)

4.2. Construction of Judgment Matrix

The judgment matrix is used to present the comparison of the relative importance of an element with respect to the previous level and its related units within the hierarchy. According to the established hierarchical structure model and the importance of each factor at each level, the judgment matrix A of relevant factors is constructed through expert consultation, empirical analysis and data statistics.

| Gi | A1  | A2  | ...... | An   |
|----|-----|-----|-------|------|
| A1 | a11 | a21 | ...... | a1n  |
| A2 | a21 | a22 | ...... | a2n  |
| ...... | ...... | ...... | ...... | ...... |

Judgment matrix A has the following properties: ①aij > 0; ②aij=1/aij; ③aii=1. The judgment matrix is usually constructed using a 9-level scale method (Table 3). That is, the relative importance of one element to the other when comparing these two. For example, when two elements have the equal importance, “equivalent” will be marked and denoted as 1; if one element is more important than the other, “extremely important” will be marked and denoted as 9. Finally, the corresponding quantity scale is given for different plans.
Table 3. Element assignment with scale method.

| ai/aj | Equivalent | Relatively important | Important | Quite important | Extremely important |
|-------|------------|----------------------|-----------|-----------------|---------------------|
| aij   | 1          | 3                    | 5         | 7               | 9                   |

4.3. Determination of the relative weights of elements

Weight refers to the status of each evaluation element in the overall evaluation of the system, reflecting the importance of the element to the attributes of the decision system. Using the constructed judgment matrix, the eigenvalue of the judgment matrix is solved, the maximum eigenvalue \( \lambda_{\text{max}} \) is calculated, and the corresponding normalized eigenvector \( W = (w_1, w_2, \ldots, w_n) \) T is found, and then the consistency test is performed. Here, \( W \) is the weight vector of each influence factor of the corresponding evaluation unit.

Based on the previous-mentioned evaluation system for green renovation plan for existing industrial buildings and the principles of the 9-level scale method, experts and scholars in architecture, civil engineering and urban planning are invited to independently evaluate and score the elements in the evaluation layer, the factor layer, and the factor interpretation layer in the evaluation system. According to the summary of the expert opinions, a comparison matrix is constructed to determine the weight of each element in the green renovation evaluation system for existing industrial buildings (Table 4).

Table 4. Green renovation evaluation model for existing buildings.

| 1st level indicator and corresponding weight | 2nd level indicator and corresponding weight | 3rd level indicator and corresponding weight | Evaluation Matrix |
|--------------------------------------------|---------------------------------------------|---------------------------------------------|-------------------|
| Indicator | Weight | Indicator | Weight | Extremely important | Quite important | Important | Relatively important | Equivalent |
| B1 0.349 C11 0.422 | | D111 0.419 | 7 | 2 | 0 | 0 | 0 | | |
| | | D112 0.310 | 2 | 4 | 2 | 1 | 0 | | |
| | | D113 0.271 | 1 | 2 | 5 | 1 | 0 | | |
| | | D121 0.609 | 2 | 2 | 5 | 0 | 0 | | |
| | | D122 0.391 | 0 | 1 | 3 | 5 | 0 | | |
| | | D131 0.479 | 2 | 3 | 3 | 1 | 0 | | |
| | | D132 0.521 | 2 | 4 | 3 | 0 | 0 | | |
| | | D211 0.219 | 2 | 1 | 4 | 2 | 0 | | |
| | | D212 0.193 | 0 | 4 | 3 | 1 | 1 | | |
| | | D213 0.187 | 2 | 1 | 2 | 4 | 0 | | |
| | | D214 0.234 | 1 | 5 | 2 | 0 | 1 | | |
| | | D215 0.177 | 1 | 2 | 3 | 1 | 2 | | |
| | | D221 0.447 | 2 | 3 | 3 | 0 | 1 | | |
| | | D222 0.201 | 0 | 1 | 0 | 5 | 3 | | |
| | | D223 0.352 | 1 | 1 | 2 | 5 | 0 | | |
| | | D231 0.184 | 2 | 5 | 4 | 1 | 1 | | |
| | | D232 0.187 | 0 | 8 | 1 | 0 | 0 | | |
| | | D233 0.203 | 4 | 3 | 2 | 0 | 0 | | |
| | | D234 0.124 | 0 | 1 | 6 | 1 | 1 | | |
| | | D235 0.150 | 2 | 2 | 3 | 1 | 1 | | |
| | | D236 0.153 | 2 | 1 | 4 | 2 | 0 | | |
| B2 0.380 C21 0.519 | | D311 0.337 | 1 | 2 | 5 | 1 | 0 | | |
| | | D312 0.271 | 0 | 3 | 3 | 2 | 1 | | |
| | | D313 0.392 | 1 | 4 | 4 | 0 | 0 | | |
| | | D321 0.555 | 1 | 5 | 1 | 2 | 0 | | |
| | | D322 0.445 | 1 | 2 | 4 | 1 | 1 | | |
| C32 0.242 C31 0.243 | | D331 0.420 | 1 | 5 | 3 | 0 | 0 | | |
| | | D332 0.292 | 0 | 1 | 3 | 0 | 1 | | |
| | | D333 0.288 | 3 | 1 | 2 | 3 | 0 | | |
| C33 0.316 C32 0.242 | | D341 0.258 | 1 | 4 | 4 | 0 | 0 | | |
| | | D342 0.273 | 3 | 3 | 2 | 1 | 0 | | |
| | | D343 0.254 | 2 | 3 | 3 | 1 | 0 | | |
| | | D344 0.216 | 0 | 4 | 3 | 2 | 0 | | |

4.4. Weight calculation of the comprehensive evaluation results

The above-mentioned individual factors are evaluated layer by layer to obtain the corresponding evaluation results, and the comprehensive evaluation results of the target layer are obtained according
to the evaluation results of each factor. The following part will take the Outpatient Building of the Second People's Hospital of Hefei as an example to adopt and verify the above results.

5. Adoption of Evaluation Model

5.1. Introduction to the renovation design for the Outpatient Building of the Second People's Hospital of Hefei

The Outpatient Building of the Second People's Hospital of Hefei was first built in 1980s, is a 5-storey reinforced-concrete structured building with an area about 5000 m³. Due to long-term use and the adjustment of the internal functions of the hospital, it is necessary to renovate the original outpatient building.

Renovation plan 1: A comprehensive reconstruction about the internal space and the external façade as well as the surrounding sites is made on the premise of retaining the original structure. The diversion of people and vehicles, laying permeable bricks, adding green land and public facilities are carried out. On the basis of making full use of the original building space structure, the structural safety, durability and thermal insulation are tested, the original non-insulated wall is demolished, the main body of the building is structurally reinforced, and the demolished clay brick is used for indoor partitioning. Part of the wall is remodeled with insulation and double-glazed floor-to-ceiling windows. In addition, some roofs adopt greening roofs; water-saving water appliances are used; rainwater recovery systems are installed, and recycled rainwater is used to irrigate outdoor green spaces. (Figure 2)

Renovation plan 2: A large open space, which is formed after the rearrangement of the sites, is used for centralized parking after being paved by rigid materials; the building structure and the wall are retained without construction of heat preservation; the wall is reinforced; no greening process for the roofs; no utilization of the water-saving appliances; no raindrop-recycling equipment is adopted, etc. (Figure 3)
5.2. Comparison and evaluation of renovation plans

According to the above-mentioned renovation plans, relevant experts are invited to score according to the evaluation system of Green renovation design for existing buildings. After the comprehensive summary of the experts’ scoring, the conclusions are shown in the following table (Table 5).

Table 5. Summary of evaluation scores of green renovation designs for the outpatient building.

| Indicator | Score for Plan No.1 | Score for Plan No.2 | Indicator | Score for Plan No.1 | Score for Plan No.2 |
|-----------|---------------------|---------------------|-----------|---------------------|---------------------|
| B1        | 8.83                | 7.37                | C11       | 8.80                | 6.65                |
| B2        | 8.40                | 6.90                | C21       | 9.23                | 7.37                |
| B3        | 8.82                | 6.80                | C31       | 8.37                | 7.37                |

Seen from the comprehensive evaluation scores of the two renovation plans, the score of the plan 1 is 8.67 points, the score of the plan 2 is 7.04 points, and the comprehensive score of plan 1 is 23.13% higher than that of plan 2.
In the sub-item category, plan 1 scores 8.83 which is 19.79% higher than plan 2 whose score is 7.37 on “feasibility of the plan” (B1). The main difference is that Plan 1 is significantly better than plan 2 in its functional conjunction and structural reasonability with the original building.

Plan 1 scores 8.40, which is 21.71% higher than plan 2 whose score is only 6.90 in terms of “Design of value performance indicator” (B2). The main difference is that the scores of plan 1 in the realization of social value, discovery of historical and cultural values, and realization of economic value realization are 9.23, 8.25, and 7.73, respectively; and plan 1 also scores a almost full mark in “solving problems in citizens’ daily life”. However, the scores of plan 2 in these aspects are lower than that of plan 1, which are 7.37, 5.88, and 7.47, respectively.

In the aspect of “environmental performance indicator design” (B3), the score of plan 1 is 8.82, which is 29.67% higher than that of plan 2, whose score is 6.80. It is obvious that plan 1 is superior to plan 2. For example, the “improvement of indoor environment” of plan 1 scores 8.12, while plan 2 scores 6.92.

Based on the above-mentioned score conclusions and specific differences analysis, plan 1 better combines the architectural features of the existing buildings with the key points of energy-saving in the evaluation comparison of the renovation designs for the green-targeted outpatient building. Therefore, plan 1 should be selected as the renovation plan.

6. Conclusion
The renovation and reuse of existing buildings has important values in multiple aspects of social economy, history and culture, and ecological environment. The combination with green energy-saving concept is the trend for future development of existing building renovation. This paper compares the traditional renovation evaluation system for existing buildings, explores the established green renovation evaluation system for existing buildings, adopts AHP to determine evaluation weights, quantifies and verifies the evaluation model, and provides a reliable basis for the quantitative evaluation of the implementation of the design results of existing building renovation plans.

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