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Assessing the integrated sustainability of a public rental housing project from the perspective of complex eco-system

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a b s t r a c t

Public rental housing (PRH) projects are the mainstream of China's new affordable housing policies, and their integrated sustainability has a far-reaching effect on medium-low income families' well-being and social stability. However, there are few quantitative researches on the integrated sustainability of PRH projects. Our study tries to fill this gap through proposing an assessment model of the integrated sustainability for PRH projects. First, this paper defines what the sustainability of a PRH project is. Second, after constructing the sustainable system of a PRH project from the perspective of complex eco-system, the paper explores the internal operation mechanism and the coupling mechanism among the ecological, economic and social subsystems. Third, it identifies fourteen indices to represent the sustainability system of a PRH project, including six indices of ecological subsystem, five of economic subsystem and three of social subsystem. Fourth, it qualifies the weights of three subsystems and their internal representative indices. In addition, an assessment model is established through expert surveys and analytic network process (ANP). Finally, the paper carries out an empirical research on a PRH project in Nanjing city of China, followed by suggestions to enhance the integrated sustainability. The sustainability system and its evaluation model proposed in this paper are concise and easy to understand and can provide a theoretical foundation and a scientific basis for the evaluation and optimization of PRH projects.

Keywords:
Sustainability
Public rental housing
Complex eco-system
ANP
China

1. Introduction

In recent years, along with progressive economic growth and acceleration of urbanization, the Chinese real estate industry has been developing rapidly, resulting in the high housing price and the affordability problems faced by low-income groups in many cities in China. For instance, a new phenomenon “ant tribe” has appeared and become well-known among the low-income groups, especially new university graduates, who earns little and live in small residences collectively. It was reported that 8 new university graduates lived together in a small unit of about 40 square meters.[1] In view of this, the Chinese government not only issues a series of stringent readjustment policies but also promulgates various politic documents to reinforce affordable housing, including Economical and Comfortable Housing (ECH) and Cheap Rental Housing (CRH). Most of affordable housing projects are funded by governments, while some government offices and public institutions built ECH and CRH for their employees. Although residents in ECH and CRH must pay for their ownership and tenancy respectively, the prices are both distinctly lower than market level. According to the Ministry of Housing and Urban-Rural Development of China (MOURD),12.5% of urban residents have benefited from the affordable housing system until the end of2012.[2] However, the ECH projects are designed for urban medium-low income families, and the CRH projects are available for families with the lowest income (Huang & Du, 2015). There are still families who neither meet the application criteria for CRH nor afford ECH. They are commonly called “sandwich layer”.

In order to meet the housing needs of the “sandwich layer” group, seven ministries including MOURD made joint efforts to formulate the Guidance to Speed up the Development of Public Rental perfect the affordable housing system and meet the basic housing needs of medium-low income households. PRH has been repeatedly declared as the development emphasis and future mainstream of reconstructed affordable housing system in many official documents like The Twelfth Five-Year Plan for National Economic and Social Development of the People's Republic of China and recognized as an important measure to perfect the affordable housing system and solve the housing difficulties of “sandwich layer” group. Under the overall scheme and vigorous promotion of the Chinese central government, many local governments have started to explore and construct PRH actively. For example, the Beijing Housing Security Programming in the Twelfth Five-Year promised to supply PRH projects accounting for 60% of the affordable houses from 2011 through 2015. On December 6, 2013, MOURD, Ministry of Finance and National Development and Reform Commission jointly promulgated Notice on merger of public rental housing and Cheap Rental Housing to urge local governments to merge CRH into PRH since 2014.

Under the historical background of PRH projects becoming the national strategy, PRH is developing rapidly throughout the country (Li, Guo, You, & Hui, 2016). Nevertheless, a disturbing and inevitable fact at present is that PRH projects seem hard to develop sustainably in social, economic and environmental terms. For example, due to the remote location, centralized construction and lack of amenities, many PRH projects are rejected by medium-low income families, who prefer severe housing conditions with ample amenities nearby in urban areas (Lin, 2012). In addition, most of the projects have exerted serious influence on ecology and environment using the timeworn designing and constructing technology (Zhao, Zhang, Zhang, & Xie, 2011). The government also suffers from huge financial pressure because PRH construction is almost solely supported by state investment, and very few of private enterprise would like to participate in the provision of PRH (Li, Chen, Huang, & Cui, 2012). Since these problems have seriously undermined the sustainability of PRH projects, this paper aims to propose a scientific approach to assessing and further enhancing the integrated sustainability of PRH, with a view to improving the livelihood of medium-low income families.

2. Literature review

In China, PRH has become a research hotspot with its increasing importance in the affordable housing system and the commencement of a large number of public housing construction projects. A large number of concepts similar to PRH also have been adopted worldwide, including social rented housing, public housing, social housing and affordable housing. Sometimes they are indistinguishable and replaceable. To avoid ignoring PRH-related literature, those concepts are not specifically distinguished herein. Taking the above-mentioned concepts and related terms, such as “sustainability”, “energy”, “environmental impact”, “sustainable”, “social” and “stratification”, as keywords, it can be discovered that researchers abroad mainly have been carrying out researches related to the sustainability of PRH projects from four aspects, namely ecological, economic, social and integrated (Chen, Li, Deng, & Xie, 2014; Choguill, 2007). Among them, the ecological sustainability of a PRH project is the sustainability behavior of the ecological subsystem, while economic sustainability and social sustainability are the sustainability behavior of the economic and social subsystem respectively. Firstly, as regards ecological sustainability, Hoppe (2012) and Chikamoto, Kobayashi, and Enomoto (2013) explored strategies to effectively reduce carbon emissions by improving energy efficiency. Wong and Kuan (2014) explored the application of building information modeling (BIM) in the evaluation of ecological sustainability. Secondly, researches related to economic sustainability of PRH projects mainly refer to the functions of various forces in the supply of PRH, including for-profit organizations, non-profit organizations and governments. For instance, Arku (2009) and Taiwo (2015) qualitatively proposed policy suggestions to encourage profit organizations to participate in the construction of public houses in Ghana, Nigeria or some other areas through public-private partnerships (PPP). Sedhain (2005) and Blessing (2015) explored the potential roles non-profit organizations play in meeting the housing demand of the poor residents in Nepal, the United Kingdom and Holland. Thirdly, in terms of social sustainability of PRH projects, McCormick, Joseph, and Chaskin (2012) analyzed the impact of social stigma of relocated public housing residents. Ibem and Aduwo (2013) provides an assessment of residential satisfaction of newly designed public low-cost housing dwellers of Kuala Lumpur, Malaysia, with forty-five variables grouped into five components. Lang and Novy (2014) analyzed the effectiveness of housing cooperative society in Vienna on strengthening the social integration. Fourthly, there are few researches done on integrated sustainability of PRH, which mainly focused on sustainable evaluation indices. de Azevedo, Silva, and Silva (2010) proposed to give full consideration to ecological, social and economic aspects and take them as sustainable evaluation indices of social housing projects, while Carter and Chris (2007) considered that weights of the three categories (i.e. ecological, economic and social category) were not reasonable in the process of sustainability evaluation of British social housing projects, failing to reflect the sustainable development policy.

To sum up, there are plentiful researches relating to the sustainability of PRH projects, which are mainly classified into four aspects, namely ecological, economic, social and integrated sustainability. As regards the integrated sustainability of PRH projects, very few publications focus on mechanism analysis and consider the non-linear interaction among the evaluation indices. To fill in this gap, our study constructs a sustainability evaluation system based on the complex eco-system theory, establishes a sustainability evaluation index system and set up a sustainability evaluation model for a PRH project through the analytic network process (ANP). Moreover, this paper carries out an empirical study of Daishan PRH project in Nanjing, China.

3. The sustainability system

3.1. Definition

In 2012, it was made clear in Management Method of Public Rental Housing, deliberated and approved by MOHURD, that PRH projects are affordable houses that strictly restricted in construction standards and rental expenses, and limited to medium-low income households, newly-employed workers without houses and migrant workers with stable employment. As regards sustainability, it is a state that can last for a long time and is a description of sustainable development level. Plentiful definitions to sustainable development have been determined internationally from various perspectives (Gan, Zuo, Ye, Skitmore, & Xiong, 2015). The most widely accepted one is from the Brundtland Report which was published by the World Commission on Environment and Development in 1987, referring sustainability development to meeting the needs of the present without compromising the ability of future generations to meet their own needs.

Considering the characteristics of PRH and the concept of sustainability, the sustainability of a PRH project can be defined as a developmental level of PRH project to meet the housing needs of present medium-low income groups without compromising the ability to meet the housing needs of their future groups. It must be reasonable to develop and harness natural resources in pursuit of integrated sustainability in ecological, economic and social aspects. As a short form for social-economic-natural complex ecosystem theory, the complex eco-system theory created by Professor Ma Shijun, an ecologist in The Academy of Sciences of China (CAS), and his PhD student Wang Rusong, later to be a professor in CAS and academician of Chinese Academy of Engineering (CAE), provides a feasible way to realize this goal. The Complex eco-system theory believes that many contemporary vital issues are directly or indirectly influenced by a complex system consisting of social system, natural environment and economic development (Ma & Wang, 1984). Complex eco-system is composed of three subsystems: social one, economic one and natural one. The integrated sustainability of complex eco-system is achieved through coordinated development among the three subsystems, on the basis of the sustainability of each subsystem. In other words, under the guidance of ecological economics, specific social, economic and ecological targets are formulated to maximize the comprehensive benefits and minimize the system risk in pursuit of the greatest chance of survival.

3.2. Composition

After proposed by Ma and Wang (1984), the complex ecosystem theory is adopted Wang and Ouyang (2012) in environmental protection and ecological planning of some areas, such as Dafeng county of Yangzhou city (in Jiangsu Province) and Hainan Province successively and established an ecological development mode with a high sustainability. With the popularity of the complex eco-system theory, researchers in many fields started to apply it in their researches. For example, Su, Han, and Chen (2011) and Yuan and Zhang (2013) respectively established comprehensive evaluation index system of optimization design of expressway horizontal alignment and city overpass site planning under the guidance of complex eco-system. However, no research is found in the field of PRH with the aid of complex eco-system theory yet.

Applying the complex eco-system theory and considering the definition of PRH project sustainability in Section 3.1, the sustainability system of a PRH projects is divided into three subsystems, namely social, economic and ecological subsystems (Fig. 1). Among them, the social subsystem aims to meet the material requisite and cultural pursuit of residents and reduce the unstable factors in society, whose sustainability is mainly determined by the satisfaction degree of residents in society. The economic subsystem is related to the economic relations among direct participants of PRH projects, whose sustainability is determined by the expenses balance receipt in the construction and operation of PRH projects. The sustainability of ecological subsystem is determined by the degree of influence of PRH projects on the environment.

3.3. Interconnection

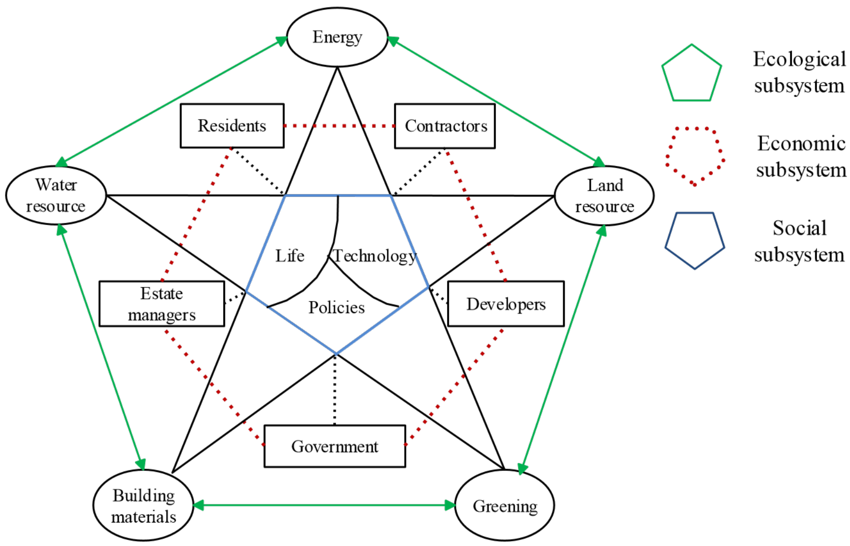


Fig. 1. The composition of sustainability system in a PRH project.

It needs the orderly operation of social, economic and ecological subsystems to guarantee the sustainable development of PRH projects, whose integrated sustainability is determined by the degree of coordination of the three subsystems. Therefore, the internal operating modes (Fig. 2) and coupling modes among the three subsystems play a decisive role in realizing the integrated sustainability. In social subsystem, mutual effects of good living conditions, perfect amenities (e.g. shops, libraries, transport and schools), rich cultural activities (e.g. entertainment shows and calligraphy exhibition) and proper resident structure (i.e. relative proportions of different PRH residents) can meet the physical demands of PRH residents. The economic subsystem is operated through the internal chain of value transfer. For instance, the estate manager is responsible for property management service for residents who pay the property cost, and the developer provides PRH units to residents who pay the rent.

The three subsystems of PRH sustainable system couple with one another through the material circulation, value exchange and information flow in certain spatial and temporal scale, forming into the integrated sustainability in a PRH project. Specifically, the material circulation is a process in which wastes of resources and energy during PRH construction and operation process are discharged into the nature and housing service is provided for PRH residents. In this process, the coupling elements of economic subsystem act on the ecology subsystem and promote the completion of the material circulation. For example, in the construction process, the participation of contractors in economic subsystem ensures the building materials, land and other resources in ecology subsystem to transfer into the housing being built. Value exchange is a process in which economic elements (e.g. building materials, land and water) are transferred into PRH projects, supporting facilities and operation management through the joint efforts of the government, the developer and contractors. Information flow refers to the information transfer and communication among developers, contractors and residents, which must be guaranteed to be effectively obtained, stored, processed and delivered in the life cycle of a PRH project. For example, in order to timely feedback the housing needs of target households to the construction program of PRH projects, it is necessary for governments and developers to pay close attention to the housing demands of medium-low income households. Therefore, sustainable development of PRH projects is probably to take shape with the coordination of material circulation and value exchange, with the aid of information flow.

4. The ANP-based assessment model

4.1. Assessment indices

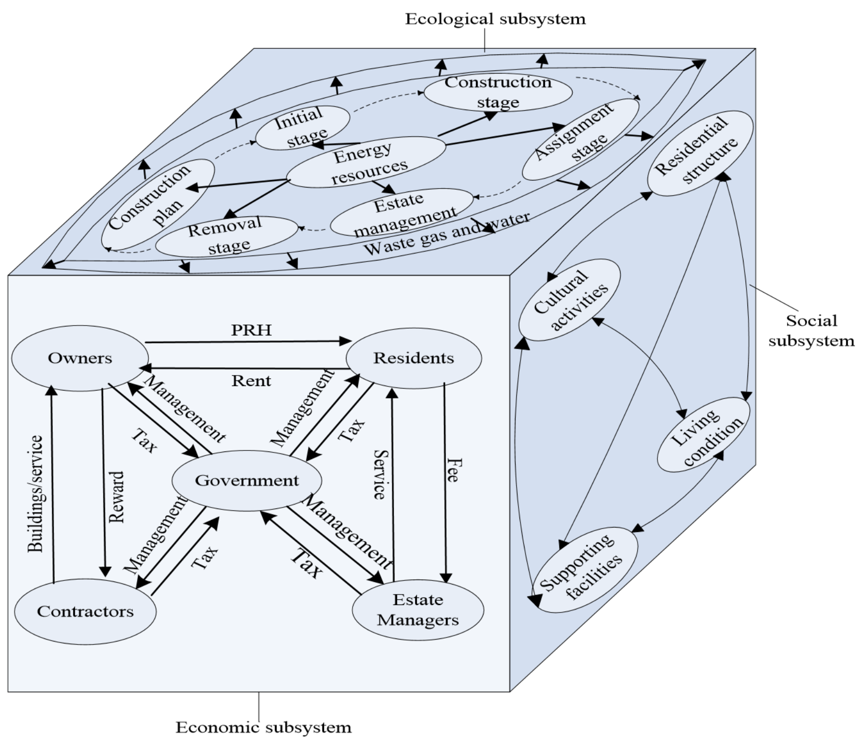


Fig. 2. Coupling of sustainability system for PRH projects.

To intuitively describe the sustainability system of a PRH project, it is important to quantitatively assess its integrated sustainability. Therefore, it is essential to select the most representative factors among the various influencing factors mentioned above on the sustainability of PRH projects. Under the guidance of the principles of objectivity, systematization, universality, initiative and operability, this paper determines the assessment indices combining theory and practices (e.g. literature review, questionnaires and frequency statistics). Although few research achievements can be found on the sustainability of PRH projects, their relevant evaluation indices are collected and classified as Basis 1 in Table 1. Due to the similarity, evaluation indices concerning the sustainability of affordable housing projects in the past are collected and classified as Basis 2 in Table 1. Furthermore, evaluation indices about green buildings, energy-saving buildings and general buildings in past publications are collected and summarized as Basis 3 in Table 1. All these indices are divided into 4 grades by the degree of importance, namely unimportant (1point), general (2 points), important (3 points) and very important (4 points) and made into 50 questionnaires in total distributed to the experts with 47 valid questionnaires retrieved. All selected experts are familiar with PRH projects, coming from universities, real estate developers and local governments. Of the 50 experts, 24% have a PhD degree and 46% have a master degree, while 30% have a bachelor or other degree. In addition,10 experts are older than 60 and 8 experts are between 51 and 60, while 32 experts are younger than 50. The indices whose average score weighted less than 2.4 (60% of full marks) were removed from the valid indices. The result was shown in Table 2 as Basis 4.

Taking the authority of experts in to consideration, each index in the Basis 4 is assigned as 4 point. In addition, considering the distinctions among PRH, affordable housing and commercial housing, every index in the Base 1, the Base 2 and the Base 3 is assigned as 3 points, 2 points and 1 point separately. It is obvious that some indices only appear in one Base, while other indices appear in two or more indices. After removing the indices whose total score weighted less than 5 (when the score was 5, it means that the index would appear in at least two bases), remaining indices were used as the assessment indices of the sustainability assessment indices system in PRH projects (as shown in Table 3). Indices in Table 3 described the sustainability of each subsystem with science, representativeness and rationality when comparing with the sustainability system and its coupling elements in Figs. 2 and 3.

4.2. ANP-based weights

In Table 3, the sustainability evaluation indices of a PRH project show the diversity of characteristic indices and these indices in each subsystem are not single. Every index in each subsystem is interdependent to another, and thus the change of one index often influence other indices and even influence the sustainability of the whole system. In addition, there are underlying cycles of interaction effect among first-grade indices and second-grade indices in PRH projects sustainability evaluation system. Therefore, this indices system is an interdependent network structure with a non-

Table 1
Assessment indices of PRH projects through literature review.

Category	Source	Summary of Indices
Basis1	Literatures on PRH projects	Financial situation, preferential policies, price ratio, supporting facilities, reasonable design, facilities management, energy-saving materials, budgeted-price measures, water saving, land conservation, greening and environmental protection and home security.
Basis2	Literatures on affordable housing projects	Preferential policies, heat transfer coefficient of building envelope, facilities management, financial situation, supporting facilities, employment condition, estate management, reasonable design, greening and environmental protection, land conservation, energy-saving materials, budgeted-price measures, energysaving facilities, property bidding qualification and sound estate supervision mechanism.
Basis3	Literatures on the green buildings, energy-saving buildings and general buildings	Land saving and outdoor environment, land conservation, greening and environmental protection, supporting facilities, energy-saving materials, energy-saving facilities, water saving, budgeted-price measures, energy-saving construction technology, facilities management and underground space development.

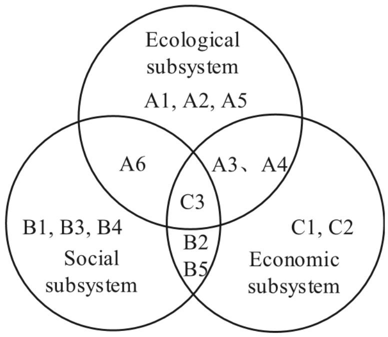
Table 2
Assessment indices of PRH projects through questionnaires.

Category	Source	Summary of Indices
Basis4	Questionnaire investigation	Reasonable design, greening and environmental protection, energy-saving facilities, energy-saving construction technologies, energysaving materials, land conservation, water saving, employment condition, price ratio, facilities management, home security, estate management, supporting facilities, estate bidding qualification qualifications, financial situation, budgeted-price measures and preferential policies.

Table 3
The sustainability assessment indices of

First-grade indices	Second-grade indices
Ecological sustainability (A)	Reasonable design A1, energy-saving facilities A2, energy-saving materials A3, land conservation A4, water saving A5, greening and environmental protection A6.
Social sustainability (B)	Employment condition B1, price ratio B2, facilities management B3, home security B4 and supporting facilities B5.
Economic sustainability (C)	Financial situation C1, budgeted-price measures C2 and preferential policies C3.

Fig. 3. Diagram of the sustainability system of a PRH project.



linear interaction among the indices in each of the subsystems (Fig. 3), In view of this, ANP is the best tool to investigate the relationships between these evaluation indices and is adopted as a guiding strategy of quantitative analysis assisted by Super Decision (SD) software in this paper and specifically shown as follows.

1) ANP-based modeling

Based on the sustainability evaluation index system in Table 3 and Fig. 4, an ANP model for the sustainability system is constructed and shown in Fig. 4, where the "sustainability" in the goal layer refers to "the integrated sustainability" and the criteria layer is made up of assessment indices in Table 3. In Fig. 5, each arrow represents an influencing relationship among subsystems, and an arc arrow expresses the interrelationship among indices in one subsystem.

2) Quantifying index weights

This paper determines the weights of indices in Table 3 through questionnaires in which the relative importance of the criteria and indices is scaled from 1 to 9. Questionnaires were handed out to relevant experts and researchers online with 54 completed in total and 50 valid (4 unqualified in test of consistency) input to SD software to calculate the index weight.

Taking the first valid questionnaire as an example, an analysis is done to calculate the importance of each index in the criterion for ecological sustainability, through inputting comparative data to the established ANP model. The calculation process and corresponding results are shown in Fig. 5. Similarly, the corresponding weights of indices in the criterion for social and economic sustainability can be obtained.

According to the valid questionnaires, W_k, the kth (=1, 2, ..., 13) second grade index in Table 1, can be calculated as:

$$W_k = W_i W_{ij} \tag{1}$$

$$W_i = \sum_{m=1}^{50} Q_{mi} \tag{2}$$

$$W_{ij} = \sum_{m=1}^{50} Q_{mij} \tag{3}$$

where W_i means the weight of the ith (i = 1, 2, 3) first grade index; W_{ij} is the weight of the jth second grade index for the ith first grade index; Q_{mi} is the weight of the ith first grade index in the mth questionnaire; Q_{mij} is the weight of the jth second grade index for

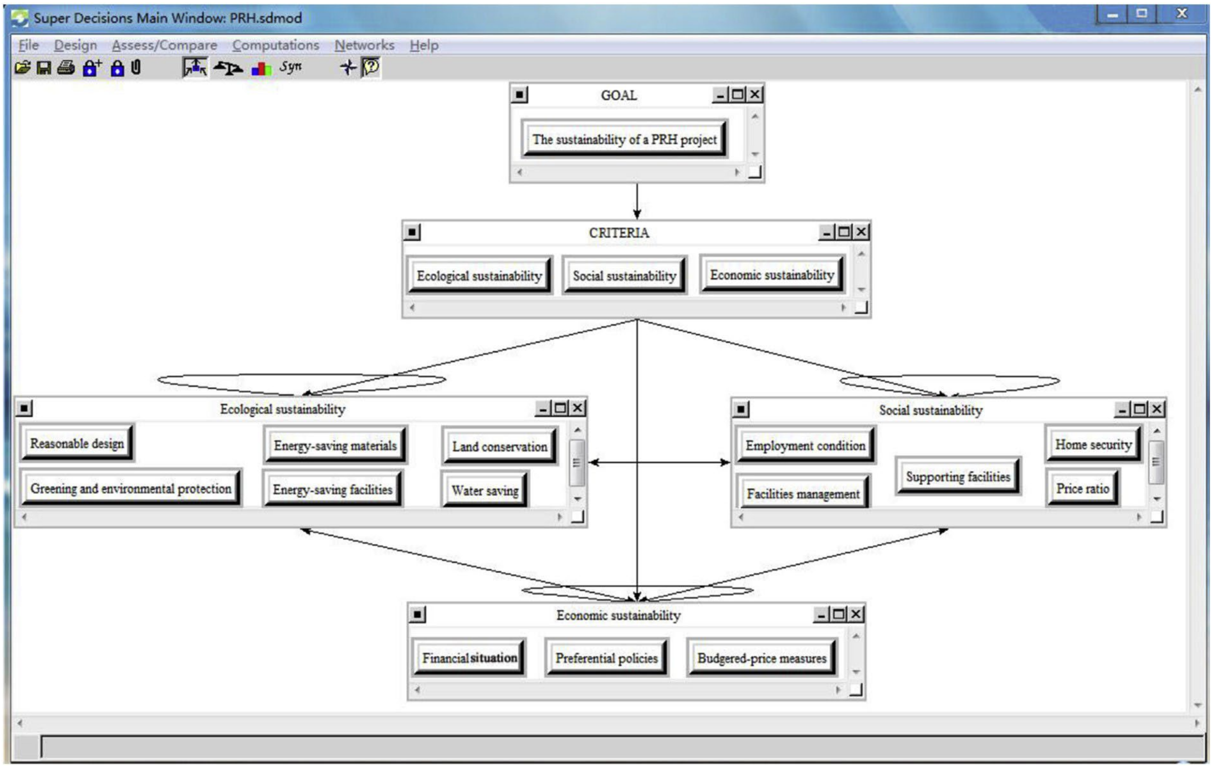


Fig. 4. ANP-based modeling of sustainability system for PRH projects in SD software.

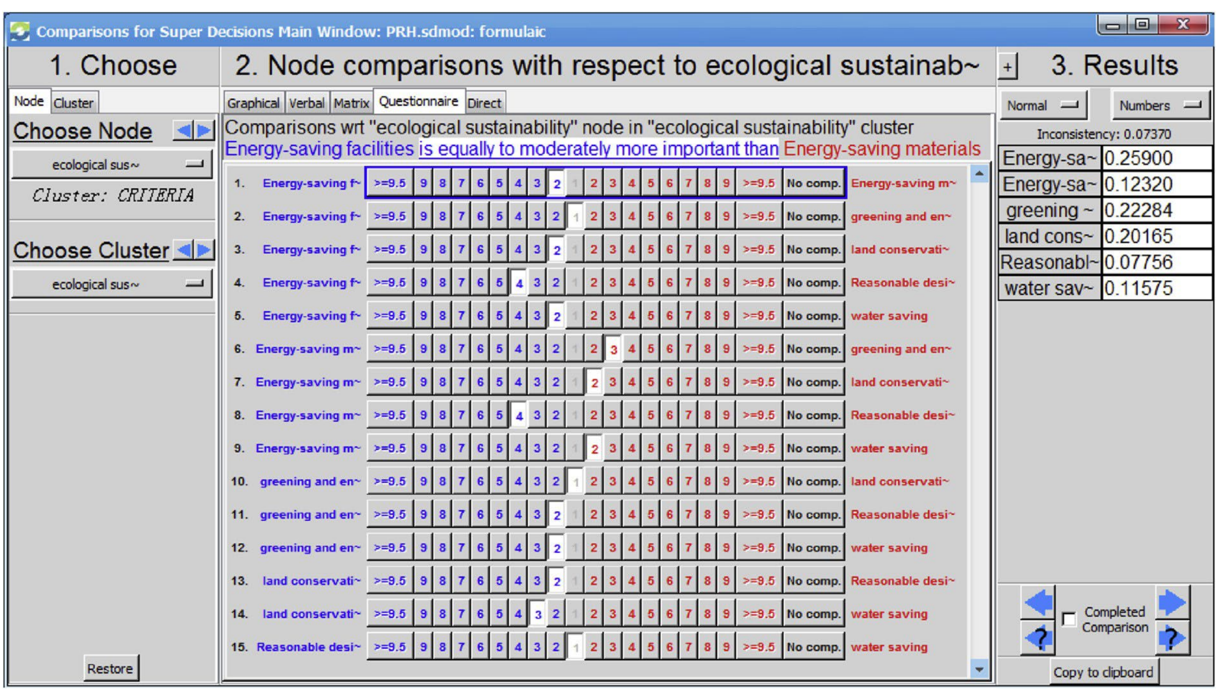


Fig. 5. Weight quantifying and consistency checking on the criterion of ecological sustainability.

the ith first grade index in the mth questionnaire.

Applying Formula (1) ~ Formula (3) into valid 50 questionnaires, the sustainability evaluation indices for a PRH project are obtained as shown in Table 4.

4.3. Assessment criteria

Firstly, the indices are classified into five grades: good (B_k 90), relatively good (80B_k < 90), normal (40B_k < 80), relatively poor (30B_k < 40), and poor (B_k < 30).

Then, referring to relevant

Table 4
Weights of the sustainability evaluation indices for a PRH project.

Goal	Criteria		Indices		Comprehensive weight
	Name	Weight W_i	Name	Weight W_{ij}	$W_k = W_i * W_{ij}$
Sustainability of a PRH project	Ecological sustainability	0.3852	Land conservation	0.1607	0.0619
			Water saving	0.1775	0.0684
			Greening and environmental protection	0.1482	0.0571
			Energy-saving materials	0.1186	0.0457
			Energy-saving facilities	0.1926	0.0742
			Reasonable design	0.2024	0.0780
	Social sustainability	0.3493	Employment condition	0.1598	0.0558
			Home security	0.2094	0.0731
			Price ratio	0.2217	0.0774
			Facilities management	0.2409	0.0841
			Supporting facilities	0.1682	0.0587

standards including Guidelines for the construction of the national harmonious community demonstration community, Design standard for energy efficiency of public buildings(GB50189-2005), Evaluation standard for green building(GB/T 50378-2014) and Design standard for energy efficiency of residential buildings in serve cold and cold zones (JGJ26-2010), the scoring criteria of each index is determined. Due to the limited space, the assessment criteria of index 'employment condition' are introduced below as an example.

Good: Secondary industry and tertiary industry are highly centralized around the PRH project that provide extensive job opportunities for multiple sexes, ages and education backgrounds, enabling nearby PRH residents diverse choices for employment.

Relatively good: Secondary industry and tertiary industry are concentrated around the PRH project that provide extensive job opportunities for multiple sexes, ages and education backgrounds meeting the employment needs of PRH residents nearby.

Normal: Secondary industry and tertiary industry are relatively concentrated around the PRH project that provide narrow job opportunities for multiple sexes, ages and education backgrounds, meeting the employment needs of most PRH residents nearby.

Relatively poor: Secondary industry and tertiary industry dispersedly scatter around the PRH project that provide narrow job opportunities for simplex sexes, ages and education backgrounds, meeting the employment needs of partial PRH residents nearby.

Poor: Secondary industry and tertiary industry scatter around the PRH that provide narrow job opportunities for simplex sexes, ages and education backgrounds, meeting the employment needs of a small part of PRH residents nearby.

Finally, the final score F can be calculated as:

$$F = \sum_{k=1}^{13} F_k = \sum_{k=1}^{13} (B_k W_k) \qquad (4)$$

To correspond to the evaluation grade F, the sustainability results for PRH projects are also divided into five grades: good, relatively good, normal, relatively poor and poor, referring the meanings as defined below.

Good: $90 \le F \le 100$. The integrated sustainability of the PRH projects is significantly high in ecological, social and economic aspects with perfect performance in energy-saving, good environment, very high community resident satisfaction and highly efficient operation.

Relativelygood: $80 \le F < 90$. The integrated sustainability of the PRH projects is relatively high in ecological, social and economic aspects with good performance in energy-saving, good environment, high community resident satisfaction and efficient operation.

Normal: $40 \le F < 80$. The integrated sustainability of the PRH projects is common in ecological, social and economic aspects with general performance in energy-saving, environment, community resident satisfaction and operation.

Relatively poor: $30 < F < 40$. The integrated sustainability of the PRH projects is relatively poor in ecological, social and economic aspects with relatively bad performance in energy-saving, environment, community resident satisfaction and operation. .

Poor: $F < 30$. The integrated sustainability of the PRH projects is poor in ecological, social and economic aspects with bad performance in energy-saving, environment, community resident satisfaction and operation.

5. Case study

5.1. Basic information

In order to verify the applicability of the above-mentioned sustainability assessment model, this paper carries out an empirical analysis of the PRH project in Daishan affordable housing district, the largest one among four mega affordable housing districts in Nanjing city of China. The Daishan project is located in Xuanwu

District, about 36 km from the urban commercial center–Xinjiekou. Its total building area is 3, 867, 300 m^2 and the total investment is 13.36 billion yuan.[1] The number of households is up to 35,130, nearly 90,000 people. The PRH project is located in the northeast of the whole project with the total building area of 197,600 m^2, including eight buildings and an underground garage. All the buildings of the PRH project are apartment types, and there are 3534 apartment units of six types (A1, A2, B1, B2, Q1 and Q2) in total. The area of Q1 is 37 m^2, Q2 is 48 m^2, B1is 46 m^2 and B2 is 58 m^2. In addition, the area of both A1 and A2 is 47 m^2. The project was commissioned by Nanjing affordable housing construction Group Co., Ltd., a state-owned company. It was constructed by GREENTOWN, a large real estate development enterprise, whose headquarters is located in Hangzhou and is listed in Hong Kong Exchanges and Clearing Limited. The project was constructed from March 2011 to December 2013 and supplied with refined decoration. Detailed information is shown in Table 5.

5.2. Assessment results

Applying the assessment criteria of Section 4.3 into the basic information of Daishan PRH project of Section 5.1, the evaluation score of each index can be determined and shown in Table 6. Then, combining weights in Table 4, the assessed integrated sustainability value of Daishan PRH project is 87.46. So, the sustainability grade of Daishan PRH project is relatively good. In other words, the project partly reaches the goal of energy-saving, suitable environment,

Table 5
Basic information of Daishan PRH project.

Index	Description
Reasonable design	Design of the PRH project takes full advantage of natural conditions in Daishan, combining with the surrounding terrain. The design of the hollow windows with PVC-steel indoor takes advantage of natural lighting and reaches goals of thermal insulation and noise reduction.
Energy-saving facilities	Air-conditioning system is controlled by the owner. Balcony wall type solar water heaters provide centralized heat for individual heat storage (mode of heat collection is based on the circulation of fixed temperature difference between the solar collector and the water tank, as the system is closed and pressurized). A timed lighting system, used in the area with better day lighting such as halls and stairwells, is in full use of renewable resources and reduces energy consumption.
Energy-saving materials	Building facades, beams, column sand roof are made of polyurethane composite for thermal insulation. The lateral surfaces of basement walls are polystyrene insulation board with waterproof. The remaining supplies are qualified with the national standards.
Land conservation	In accordance with the construction plan, abandoned sites are in rational use, cleaning up the construction waste in time. The project doesn't do any damage to local cultural relics and natural river system. In addition, considering the underground space, the basement is integrated underground garage, equipment room sand air-raid shelters into one for both peacetime and wartime.
Water saving	The rainwater recycling system of collection and purification for landscape engineering and roads cleaning reaches the aims of environmental protection, water-saving and cost reduction. Sprinkler irrigation applies to landscape irrigation.
Greening and environmental protection	The greening rate of Daishan PRH project is up to 40.93%. Combination of arbor, bush and ground cover creates a beautiful environment. Qualification of estate bidding is first grade. Equipment rooms with sound insulation walls reduce noise influence.
Employment condition	According to field visit and interviews, there are 36 hotels, 18 entertainment places and 46 service places including park, gas station and car-washing shop nearby. Business district, market and health service station are in the planned area, which create some employment opportunities.
Price ratio	In this PRH project, average floor space per person is 15 m^2. According to the rent to standard for Nanjing public rental housing rent, the rent paid by the low-income groups is 8 yuan per square meters per month. Besides, rent is separated from subsidies. Residents can enjoy nice living conditions and supporting facilities.
Facilities management	Daishan PRH project is pure apartment projects without dorms, operated by Nanjing Affordable Housing Construction Group Co., Ltd (a state-owned company). Low income families with housing problems in Nanjing city can directly apply for those houses. To contract the date, the first as long as the advance of rent for six months with margin that is the same with the cost of rent for six months and after that, rent is paid every half a year. With reference to Regulations for Nanjing public rental housing, the applicant may enjoy the policy support that rent is obviously lower than the market price. However, once specified events (such as sub-tenancy, sub-lease) happen, qualifications for renting must be canceled.
Home security	The project is equipped with an electronic fence system, a monitoring system, an entrance guard system and an electronic patrol system. It also has pedestrian system separated from vehicle system in residential quarters. The fire protection system is equipped with fire detectors, manual alarm buttons, fire protection telephones and fire stations in the buildings. In addition, there are alarms and emergency exits in compliance with the national standard in the kitchen.
Supporting facilities	The project is equipped with a commercial district, stadiums, community health service centers and schools, meeting residents' daily need.
Financial situation	The construction funds are made up of government grants, bank loan and self-prepare capital of Nanjing affordable housing construction Group Co., Ltd. The follow-up auditing at construction stage is completed by Nanjing Audit Bureau. Government, bank and the developer thus take risks together.
Budgeted-price measures	The architectural design is kept as simple as possible with few ornamental elements. To reach the economic principle, building materials are chosen nearby. High performance concrete and high strength steel are used reasonably in structure. Integration of design and construction is adopted in civil work and decoration. The construction doesn't destroy the existing buildings and remove facilities in the construction.
Preferential policies	The land is provided free by the government. The loan rate of construction fund is no more than benchmark interest rate. There are no taxes except for business tax and its additional. Rent subsidies are separated from rent and are directly supplied to the tenants.

Table 6
Sustainability indices and the comprehe

System	Criteria	Index	Evaluation score B_k	Weight W_k	Index score F_k ¼ B_k*W_k
sustainability system of PRH project	Ecological sustainability	Land conservation	100	0.0619	6.19
		Water saving	70	0.0684	4.79

[1] Yuan is the official currency in P. R. China, and one yuan is about 0.16 US dollar.

		Greening and Environmental protection	100	0.0571	5.71
		Energy-saving material	60	0.0457	2.74
		Energy-saving facilities	70	0.0742	5.19
		Reasonable design	100	0.0780	7.80
	Social sustainability	Employment condition	80	0.0558	4.46
		Home security	100	0.0731	7.31
		Price ratio	100	0.0774	7.74
		Facilities management	80	0.0841	6.73
		Supporting facilities	100	0.0587	5.87
	Economic sustainability	Budgeted-price measures	80	0.0681	5.45
		Preferential policies	100	0.0840	8.40
		Financial situation	80	0.1135	9.08
Comprehensive score		$F = 87.46$			

high community resident satisfaction and efficient operation.

5.3. Possible recommendations

To further enhance the integrated sustainability of Daishan PRH project, the paper analyzes the ecological, social and economic subsystems in detail. In Table 4, direct comparisons of scores are not appropriate because of the different weights in each subsystem. So a centesimal system is used in the paper. For instance, in the case of the economic subsystem, referring to Tables 4 and 6, its score is calculated as:

$$F_{economic} = \frac{5.45+8.40+9.08}{0.2655} \times 100 = \frac{22.93}{0.2655} \times 100 = 86.37 \tag{5}$$

Similarly, scores of ecological and social subsystems can be calculated and shown in Table 7. Therefore, it could be inferred that social sustainability in Daishan PRH project is the most significant, economic sustainability takes second place, and ecological sustainability comes last. As a result, by improving the ecological and economic subsystems, the integrated sustainability of Daishan PRH project will be enhanced.

Since the sustainability of each subsystem is determined by their indices, specific suggestions for enhancing the integrated sustainability of Daishan PRH project could be found through analyzing the gap between current and full score of each index. Taking an example of the index “water saving” of ecological subsystem, the gap can be determined from Table 6 as:

$$DF = 100 \times 0.0684 - 4.79 = 2.05 \tag{6}$$

The gaps of other indices can be determined in the same way and shown in Fig. 6, namely the distance between the solid line and broken line. There are some big gaps in Fig. 6, such as the indices of “financial situation”, “water saving” and “energy-saving facilities”. Hence, the integrated sustainability of Daishan PRH project could be improved by addressing these indices, like broadening the construction financing resources, reinforcing the utilization of water and energy-saving facilities.

6. Conclusions

As the mainstream of China's affordable housing policies, PRH projects have been numerously constructed throughout the whole country. However, the level of their integrated sustainability is rather questionable in general. Local and foreign studies mainly focus on the sustainability of PRH projects from ecological, economic and social perspectives separately, and ignore the idea of integrated sustainability. Moreover, previous studies lack scientific analysis on the mechanism of the sustainability of a PRH project and fail to address the possible non-linear interaction of influencing indices. The sustainability of PRH projects is defined as a developmental level of PRH project that meets the housing needs of medium-low income groups at present, without compromising the ability to meet their next generation's housing needs. Based on the complex eco-system theory, the sustainability system of a PRH project is divided into three subsystems: social, economic and ecological. Then, the internal function of each subsystem has been analyzed, and the interconnection among those three subsystems through material circulation, value exchange and information flow have been outlined. The study has established an ANP model to determine the weights of indices of each subsystem. Finally, an empirical study is done on Nanjing Daishan PRH project, revealing its integrated sustainability degree. Accordingly, appropriate measures are proposed to improve the integrated sustainability magnitude from the perspectives of subsystems and internal indices.

Table 7
Centesimal score of each subsystem.

Name	Subsystem score	Full scores of subsystem	Centesimal score
Ecological sustainability	32.42	38.52	84.16
Social sustainability	32.11	34.93	91.93
Economic sustainability	22.93	26.55	86.37

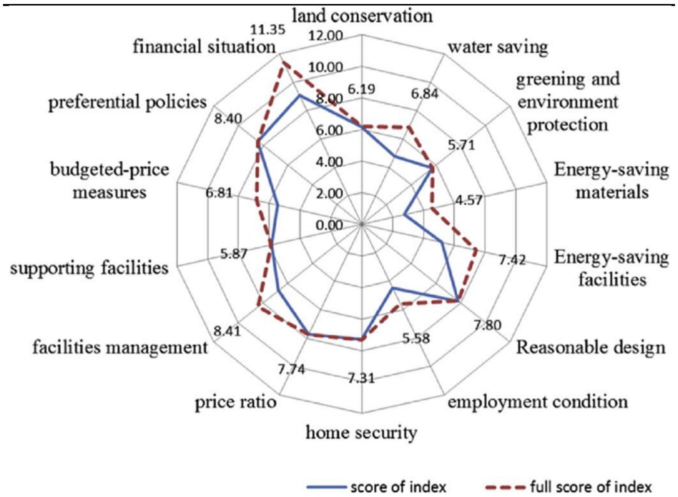


Fig. 6. The radar chart between indices and full scores.

The proposed model not only builds a solid foundation for decision making in the early stage and measures for improving the sustainability of PRH projects, but also provides implications for assessing the integrated sustainability of a PRH project. For example, the integrated sustainability assessment model of a PRH project should take a holistic view on social, economic and ecological aspects. The non-linear interaction relationships among the three subsystems should be taken into consideration through proper methods like ANP. As regards possible future studies, the weights of assessment indices in Table 3 may be obtained from other methods, such as Delphi and grey relational analysis. In addition, the proposed methodology in this paper may further be applied to other PRH projects as a way to establish measures for elevating the level of integrated sustainability in China.

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