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Integrated Sustainability Assessment of Public Rental Housing Community Based on a Hybrid Method of AHP-Entropy Weight and Cloud Model

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Abstract: As an essential part of a city, community is significant to the sustainable development of the city. At present, research on community sustainability assessment systems is relatively scarce. The existing community sustainability assessment systems often lack integrated consideration of community sustainability. For example, these systems especially place emphasis on the ecological and environmental aspects, but the economic and social aspects of sustainability are partially ignored. In order to comprehensively evaluate the sustainability of a community, this paper draws on the “participatory philosophy” and constructs an integrated assessment indicator system that includes five dimensions: environment; economy; society; institution; and culture. On this basis, a new hybrid evaluation method based on analytical hierarchy process (AHP)-entropy weight and the cloud model is proposed to evaluate community sustainability. This method combines AHP and the entropy weight method to determine index weight, thus making full use of their respective advantages. At the same time, it makes use of the superiority of the cloud model to transform qualitative remarks into quantitative representations and to reflect fuzziness and randomness. To verify the feasibility of this method, a case study is carried out on the “Minxinjiayuan” public rental housing community in Chongqing, China. The results show that the overall sustainability of the community lies between the “middle” and “good” level, and closer to the “middle” level. The level of the economic and social sustainability is higher than that of the environmental, institutional and cultural sustainability.

Keywords: AHP-entropy weight; cloud model; public rental housing community; sustainability assessment; indicator system

1. Introduction

Since the concept of “sustainable development” was defined in the Brundtland Report [1] in 1987, it has gradually been accepted by organizations and governments around the world [2] and spread to a variety of disciplines. The construction industry has significant impacts on the economy, society and natural environment due to its huge consumption of resources [3,4]. It is necessary to realize the transformation from traditional building to sustainable building [5]. Building sustainability assessment systems can help systematically evaluate the sustainability of the design, construction, operation and management stages of a building’s whole life cycle [6]. It is one of the most important tools in promoting sustainable building development. Recently, more and more scholars

have made an active exploration of building sustainability assessment systems and tools, and have obtained rich theoretical achievements [4,7–9]. Nevertheless, research on this aspect is still far from enough. Until now, the definition of sustainable building is not clear in the academic world [10–12]. However, in general, a sustainable building is considered to achieve balanced development in the dimensions of environment, economy and society [13–16]. There is a lack of comprehensive consideration of multidimensional sustainability indicators in the existing building sustainability assessment systems. Most of these systems focus attention on the ecological environment, especially construction energy-saving performance, while paying little attention to the economic and social aspects of sustainability [17–20].

In order to consider multiple dimensions of sustainability comprehensively, in recent years, more and more literature has discussed going beyond the research paradigm of single-building assessment and expanding the evaluation scale so as to fully consider the connection between buildings and people as well as the surrounding environment [10,21,22]. Wu defined the scope of the sciences of human settlements on five levels: globe; region; city; community; and construction [23]. As an essential part of a city, community is very important to urban development. The general sustainability development of the city depends on the sustainability level of urban communities [24]. For example, the development of community can help promote urban employment and improve the appearance of a city; community is closely related to the life of urban residents, so it is also the root of some social problems. The overall sustainability of a city is in doubt if its own components are not sustainable [24]. However, previous research on sustainability evaluation mainly concentrated on the macro city level [25,26] and the micro building level [27], while the research on the intermediate-level of community sustainability assessment (CSA) systems is still not enough [28,29]. So far, studies have shown that sustainable communities have a notable positive effect on house price [30]; environmentally friendly buildings in the community tend to attract property buyers and people are willing to pay more for them; residents in sustainable communities have a higher sense of wellbeing [31]; and they enjoy a better quality of life [25]. As the planning unit of urban development, community plays a significant role in city sustainable development. Thus, it is very important to conduct research on community sustainability assessment systems and tools [28,32].

Public rental housing is a specific product of the Chinese government to meet the housing demand of medium-low income groups in China. This new type of affordable housing appeared in 2010. Originally, it was a transitional form to meet the housing demand of the “sandwich layer” group [33], who neither satisfy the application standard for cheap rental housing or economically affordable housing nor can afford commercial housing. However, with the transformation of the Chinese affordable housing system, public rental housing projects have become a national strategy. By 2013, public rental housing had become the mainstream of affordable housing in China. Survey data in 2014 showed that, by the end of 2013, there were 14.25 million suites of public rental housing in China, of which newly built ones accounted for 94.7%. According to the Minister of Housing and Urban-Rural Development of the People’s Republic of China, by the end of 2016 there were 10 million households living in public rental housing, and the monetization of public rental housing was also advancing. It can be predicted that in the near future, public rental housing projects will continue to flourish in China. Public rental housing community gathers medium-low income people and has a high level of population mobility. It has an inherent particularity compared to the traditional urban community [34,35]. The scale of the public rental housing community is larger than general urban community. A large number of residents from different professions live there. The living conditions in it are very complex. Hence, realizing sustainable development of the public rental housing community is a great challenge for the Chinese government. China has begun large-scale public rental housing construction only in recent years. It has not yet formed a sound theoretical system of the design, construction, operation and management of public rental housing community. Both theoretically and practically, the sustainability of the public rental housing community is a very important new issue. Research into sustainability assessment systems and tools of the public rental housing community is crucial to guide Chinese

public rental housing toward sustainable development. It can also be used as a reference for the study of housing and community sustainability assessment in other countries. Existing CSA systems are mainly established by developed countries according to their national conditions. There are many limitations in their application in other developing countries [28,36]. Since sustainable communities have different meanings in different regions and environments [29], this paper attempts to establish a specific sustainability assessment indicator system, including multiple dimensions of sustainability, for the Chinese public rental housing community based on previous studies, relative policy analysis and evaluator scoring. In addition, this paper proposes a new hybrid method of analytical hierarchy process (AHP)-entropy weight and cloud model for the evaluation. The system and method can provide a new integrated perspective for sustainability assessment, and could be a theoretical reference for the research on sustainability evaluation systems and tools of China and other countries.

2. Literature Review

2.1. Community Sustainability Assessment System

The sustainability assessment system has been used in the construction industry for more than 20 years [37]. It was originated in Europe and North America and other developed countries [17,38]. After years of research and development, a variety of sustainability assessment systems and theories have been developed in the building environment, such as sustainable building rating systems, sustainable building certification systems, life cycle assessment methodology, sustainable building assessment technical guidelines, evaluation framework and checklists [39] etc. Relevant research shows that there are more than 600 rating systems for sustainability assessment available worldwide currently [40]. Among them, there are a lot of building evaluation systems developed by various organizations including the government [41] such as BREEAM (Britain), LEED (America), CASBEE (Japan), DGNB (Germany) and GBTool (Canada) etc. However, these assessment tools rarely have an integrated consideration of multiple dimensions of sustainability. Especially, most of them pay insufficient attention to the social and economic aspects of sustainability [17–20]. In order to make a more reasonable and comprehensive assessment of the multi-pillars of sustainability, it is necessary to expand the spatial boundary of the evaluation. For this reason, CSA or neighborhood sustainability assessment (NSA) has been paid more and more attention in the academic world [41]. In recent years, especially with the emergence of BREEAM Communities, LEED-ND, CASBEE-UD, etc., CSA and NSA have become hot topics in academic circles [42].

Most researchers tended to study the theory aspect of community or neighborhood sustainability assessment systems. They conducted deep research and comparisons of the types and evaluation criteria of different CSA or NSA systems to provide a general description of them. For example, Berardi compared BREEAM Communities, LEED-ND and CASBEE-UD and found that these evaluation systems lack a rational and comprehensive evaluation of the environmental, economic and social aspects of sustainability [28]. Reith and Orova conducted a detailed three-level comparison of five sustainability assessment systems (i.e., CASBEE-UD, the 2009 and 2012 versions of the BREEAM Communities, LEED-ND and DGNB-UD) [43]. The result indicated that DGNB-UD has done the best to consider the environmental, economic and social aspects of sustainability in a comprehensive and balanced way; CASBEE-UD differs from other evaluation systems in many respects due to its particular background; the BREEAM and LEED systems showed average results in main respects. In order to study the present situation of urban CSA systems, Haapio analyzed three typical systems (LEED-ND, BREEAM Communities and CASBEE-UD) [39]. He stated that sustainability evaluation systems should be connected with regional characteristics, and emphasized the importance of knowledge- and experience-sharing for the improvement of evaluation methods. Sharifi and Murayama critically and comprehensively analyzed seven NSA tools (i.e., LEED-ND, CASBEE-UD, BREEAM Communities, HQE2R, Ecocity, SCR and ECC) [29]. They pointed out that most of these systems did not perform well considering the coverage of social, economic and institutional respects of sustainability, and lacked

mechanisms for local adaptability and participation. They also analyzed the feasibility of establishing a global standard for sustainability evaluation systems [32]. They focused on the evaluation results of different NSA systems in different environments and found that the evaluation results of the same evaluated projects are different in different NSA systems. They then proposed that the criteria and indices should be selected according to the specific environment of the neighborhood. Lin and Shih conducted a qualitative and quantitative study on the sustainability assessment systems of the internationally renowned countries and developed Asian countries [44]. They found that the NSA systems of many countries emphasize resources and energy but neglect the development of economy. The NSA systems of Asian countries had their particular characteristics compared with other countries. They also stated that it is necessary to ensure links between each indicator of the NSA system and public participation.

Additionally, there are some researchers concerned about the empirical aspect of CSA or NSA systems. They are trying to find the gap between the prospective design and practical application of the sustainability assessment systems. For example, Garde carried out a survey of 73 LEED-ND registered pilot projects in the United States [45] and studied the satisfaction degree of these projects to the standard of the evaluation system. He pointed out that the sustainable development of a community could not be guaranteed according only to LEED-ND standards, and that local and regional conditions should also be taken into account. Sharifi and Murayama analyzed the scorecard of 97 LEED-ND pilot programs [46]. They obtained the application frequency of evaluation criteria in these programs, and the results are basically consistent with Grade. Säynäjoki et al. found that some indicators of the existing NSA systems are not suitable for use in Finland [47]. Kyrkou et al. and Cable respectively studied the application rationality of LEED-ND in the English and German context [48,49]. They finally got similar conclusions with Säynäjoki et al. Komeily and Srinivasan studied a series of cases from the macro and micro levels of the application of NSA systems [50]. They pointed out that most of the existing systems tend to ignore the environmental characteristics of different neighborhoods and often attempt to establish a “one-size-fits-all” universal paradigm. They also put forward that NSA systems should consider the characteristics of different neighborhoods, such as local culture and the concept of residents. The evaluation systems of different neighborhoods should have a certain degree of specificity and diversity.

2.2. Public Rental Housing and Sustainability Assessment of Public Rental Housing Community

Public rental housing is an important form of affordable housing in China. It is an outcome of the livelihood policy implemented by the Chinese government to meet the housing demand of the medium-low income groups in China [34]. The affordable housing system is mainly formulated for low-income people in the society. Since there is a big gap between the supply of the government and the demand of the society, the Chinese government began to vigorously carry out the construction of public rental housing in 2010. In recent years, it has developed rapidly all over the country. With the rapid development of public rental housing, it has formed a new type of residence community composed of medium-low income groups. As a special product of the Chinese government to improve people’s livelihoods, the public rental housing community has its own particularity compared with the traditional urban community. Although public rental housing is started in the form of rent, the tenants are allowed to purchase the houses after a few years of living in them. The renters and house buyers have formed a mixed case in the community [35]. Residents in public rental housing are a large number of medium-low income people such as migrant workers and newly graduated students. These people can only rely on temporary rental housing to solve the housing problem. Therefore, the population movement within public rental housing is relatively great. In addition, as one kind of affordable housing, the rent and house prices of public rental housing are lower than the market price level. At present, public rental housing projects have been growing rapidly throughout the country; however, the sustainability of these projects in environmental, economic and social aspects is not optimistic. For example, many cities manifested the phenomenon of public rental housing application rates being too low because of their remote locations, lack of supporting facilities, excessive introduction of market

mechanisms and many other reasons [51]. Most of the public rental housing projects had serious impacts on the ecological environment regarding the use of traditional technology for design and construction [52]. The government mainly invests in the construction of public rental housing projects and it hasn't fully mobilized the enthusiasm of social forces [53,54]. All these problems are all not conducive to the sustainable development of public rental housing projects.

Since public rental housing has become a research hotspot in recent years in China, there are many research achievements about it. A number of similar concepts of public rental housing have been adopted in the global scope, such as social housing, public housing, affordable housing and social rented housing, etc. Sometimes these concepts can be replaced by each other [55]. To avoid overlooking the related literature of public rental housing, we do not specifically distinguish them herein. In the literature of sustainability of public rental housing, most researchers have only been concerned with the environmental, economic or social aspect. For example, Zhao et al. studied the impact on ecological environment of public rental housing projects by using traditional environmental impact assessment approach [52]. Hoppe and Chikamoto et al. explored strategies on how to reduce carbon emissions efficaciously by improving energy efficiency [56,57]. Li et al. analyzed the financial sustainability assessment and optimization of public rental housing projects through a case study of a public rental housing program in Nanjing [58]. Taiwo proposed qualitatively policy recommendations to encourage private institutions to participate in the construction of public housing through public-private partnerships (PPP) in Nigeria [59]. Peng and Fu analyzed the social sustainability of the public rental housing community from the perspective of residents and neighborhood committees within the community, and discussed a new governance mechanism for it [34]. Patulny and Morris investigated the effect of the government-introduced policy of social mix on the social sustainability of public rental housing programs by conducting a questionnaire survey [60]. In the literature about comprehensive evaluation of public rental housing projects, Li et al. assessed the integrated sustainability including environmental, economic and social dimensions of a public rental housing program from the perspective of complex ecosystem [55], and put forward some suggestions for improving the comprehensive sustainability of public rental housing. However, the research on the comprehensive sustainability of public rental housing community is still very sparse. The research on the integrated sustainability of public rental housing projects is just at the beginning stage and still has a lot of deficiencies. For instance, Carter and Chris believed that there was no reasonable weight allocation given to environmental, economic and social aspects in the sustainability assessment of British social housing projects and it failed to reflect the government's policy of sustainable development [61]. Therefore, this paper attempts to establish an integrated sustainability assessment system of public rental housing communities according to the characteristics of Chinese public rental housing communities and the existing literature about CSA systems, which is of great significance for promoting the sustainable development of Chinese public rental housing and providing reference for the establishment of CSA systems in other countries.

2.3. Research on Sustainability Assessment Index

Although there is no agreement on the definition and scope of "sustainable development" in academic circles [29], a traditional framework of sustainability assessment index systems can be divided into subsystems about environment, economy and society from the "triple bottom-line" perspective of sustainable development [62]. There are also scholars such as Valentin and Spangenberg, and Parris and Kates who emphasized the importance of incorporating an institutional dimension into the framework of sustainability assessment [63,64]. Spangenberg indicated that an institutional dimension could help facilitate the linkage between other dimensions of sustainability and be a supplement to them [65]. Turcu listed a series of indicators of sustainability assessment from dimensions of environment, economy, society and institution [22]. Such environmental sustainability indicators include energy use, water use, green open space etc.; economic sustainability indicators include business activity, house prices and housing affordability etc.; social sustainability indicators include a

sense of community, crime and safety etc.; institutional sustainability indicators include local authority service and local partnership etc. In the integrated assessment of Chinese public rental housing projects, Li et al. [55] summarized some ecological sustainability indices such as reasonable design, energy saving, water saving, land resource conservation, green practices and environmental protection etc.; economic sustainability indices such as financial situation and budgeted-price measures etc.; social sustainability indices such as employment condition and home security etc. Yigitcanlar et al. [36] listed some environmental, economic and social indices according to the characteristics of the Malaysia community such as open space provision, education, public transportation, local service and affordable housing etc. In their paper about NSA tools, Yoon and Park [42] mentioned some environmental indices including pollution, air emission, water use and air quality etc.; economic indices including direct cost and indirect cost etc.; and social indices including health and safety and community development etc. In addition, scholars such as Wu et al. called for the inclusion of a cultural dimension in the evaluation system of a green community [66]. They argued that culture can act as a connecting and mediating factor for other dimensions of sustainable development through the creative sensitivity and aesthetic experience that the building provides. They then listed a number of indicators of cultural sustainability of green buildings, such as cultural vitality, cultural continuity, cultural diversity and so on. In general, environment, economy and society are considered as the three pillars of sustainability [29,67–69], but some scholars also suggest that institutional [41,63,64] and cultural dimensions [66,70] should be included in the sustainability evaluation system. Therefore, in order to make an integrated evaluation of the public rental housing community, the sustainability assessment indicators are selected according to these five dimensions by combining relevant literature and the characteristics of Chinese public rental housing.

3. Establishment of the Sustainability Assessment System of Public Rental Housing Communities

The sustainability assessment system of public rental housing communities is established on the foundation of the indicator-based approach. The indicators can provide information about the state or change of the system [37], so as to intuitively describe the sustainability level of public rental housing community. They play very important roles in the output evaluation of sustainability. The sustainability level indicates the sustainable development degree of the community. It is the overall assessment of the community resulting from summarizing the values of the individual indicators. The indicator can be used individually as part of a set, or in the form of a composite index, whereby individual indicators' scores are combined into a single number to represent the sustainability level. As we discussed in Section 2, we will respectively determine the corresponding indicators from the dimensions of environment, economy, society, institution and culture (see Figure 1).

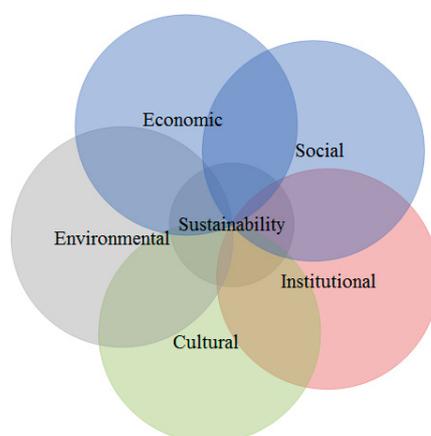


Figure 1. Five dimensions of sustainability.

In this paper, some important indicators of the sustainability assessment of public rental housing communities are extracted and summarized by referring to the relevant literature about sustainability assessment systems and public rental housing. We then analyzed some valuable policy information from the Chinese government and transformed it into the corresponding indicators by combining it with China’s specific national conditions. One of the departure points of sustainability assessment is to help make or implement policy. As a result, it is necessary to involve the experts and policy makers to select the indicators. However, there is also a need to pay attention to the role of public participation in developing sustainability assessment indicators for a specific type of community. The sustainable development of a community should fully engage its end-users or target group from the very beginning [22]. It is more likely that if the target audience is allowed to participate in the conceptualization or development of the indicators, they will also use and appreciate the results [71]. Integrating the expert-led and resident-led ways of indicator development has been seen as salient to tapping into various levels of knowledge of sustainability, and thus a better way of evaluating sustainability [22]. Including the views of the stakeholders who are ultimately intended to benefit from the indicators can make the indicator system more effective [71] and more likely to cover the substantial issues associated with the sustainability of public rental housing communities. Based on this line of reasoning, we organized some experts and scholars in the field of sustainability assessment and public rental housing, some project managers of public rental housing, some administrators of government relevant department and some residents of public rental housing to score the importance of the indicators. The weight of their scoring is determined according to the authority and relevance of different types of personnel. We collected the weighted total scores of each indicator and then adjusted the indicators of higher scores according to the systematic and comprehensive principle to get the final sustainability assessment indicator system of public rental housing communities (see Figure 2). There are a total of 31 indicators in the integrated sustainability assessment system of public rental housing communities. Among them, there are seven indicators of environmental sustainability, six indicators of economic sustainability, eight indicators of social sustainability, four indicators of institutional sustainability and six indicators of cultural sustainability. The descriptions of each indicator are shown in Table 1.

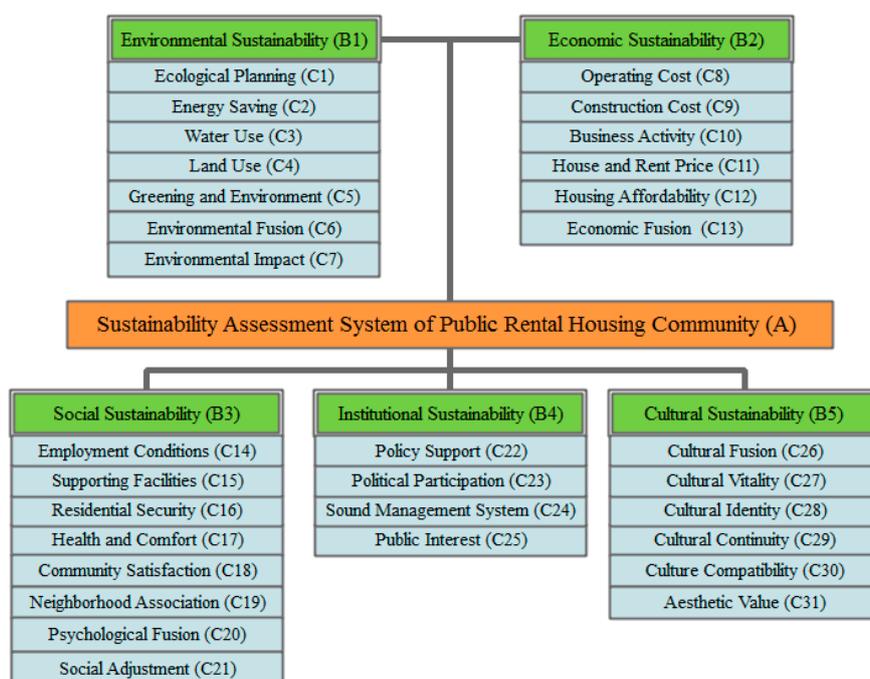


Figure 2. Sustainability assessment system of public rental housing communities.

Table 1. Description of each indicator.

Indicator	Indicator Description and Reference
Ecological Planning (C1)	There is a reasonable design through ecological identification and system planning and it makes full use of the natural conditions of the site [72,73].
Energy Saving (C2)	Energy saving of construction technology and community equipment, utilization of energy saving materials and considering recycling performance when selecting materials, etc. [55,73,74].
Water Use (C3)	Comprehensive utilization of different kinds of water resources, water-saving appliances and equipment, landscape irrigation ways, rainwater savings and utilization, etc. [22,55,75].
Land Use (C4)	Protection of local cultural relics, natural water systems and basic farmland, etc.; rational development and utilization of underground space; brownfield redevelopment; disposal and utilization of contaminated waste land, etc. [20,55,75].
Greening and Environment (C5)	Ratio of green space and plant diversity, etc. [55].
Environmental Fusion (C6)	Satisfaction of public space and public environment [76,77].
Environmental Impact (C7)	The impact of pollution, emissions, domestic waste, etc. on the environment [42].
Operating Cost (C8)	The cost of community operations and management [78].
Construction Cost (C9)	Total construction cost of the community [79].
Business Activity (C10)	Business activities within and around the community [22].
House and Rent Price (C11)	The relative house and rent price compared with the general level [22].
Housing Affordability (C12)	Housing affordability of community residents [22,36].
Economic Fusion (C13)	The situation of purchasing and renting, local purchase intentions, number of local relatives, etc. [80].
Employment Conditions (C14)	Employment opportunities, distance from the working place to the community, employment needs nearby the community, diversity of employment, etc. [55].
Supporting Facilities (C15)	The situation of schools, hospitals, public transportation and business, etc. nearby the community [36].
Residential Security (C16)	Personal privacy protection, fire prevention and security measures [22,36,55].
Health and Comfort (C17)	Indoor and outdoor air quality, thermal, sound and visual comfort, etc. [9].
Community Satisfaction (C18)	Residents' satisfaction with the community and the activity participation degree [81].
Neighborhood Association (C19)	Association with the surrounding communities and residents, interaction with friends in the community [76,77].
Psychological Fusion (C20)	Family identity, job satisfaction, housing satisfaction, community popularity, etc. [80].
Social Adjustment (C21)	Intention to settle in the community, the degree of discrimination, values of social reference, etc. [82].
Policy Support (C22)	Local government service level, tax and interest rate concessions, etc. [22].
Political Participation (C23)	Community residents' ability to participate in politics.
Sound Management System (C24)	Sound level of community management systems such as property supervision system.
Public Interest (C25)	Social security, health care, children's enrollment, public consultation, etc. [83].
Cultural Fusion (C26)	Master degree of local language, familiar degree of local customs, acceptance degree of local values, local dietary adaptation degree, etc. [80].
Cultural Vitality (C27)	The community has dynamic cultural activities and a compound pattern of land use [66].
Cultural Identity (C28)	The community can protect local history and the character of a place and can reflect collective memories. The residents have a sense of place, rootedness and belongingness [66].
Cultural Continuity (C29)	The community involves traditional practices, traditional craftsmanship and materials, and traditional architectural style such as vernacular architecture [66].
Culture Compatibility (C30)	Cultural diversity of the community; the community encourages cultural exchange and hosts different cultures; people with different backgrounds are respected and appreciated in the community [66].
Aesthetic Value (C31)	Aesthetic and cultural value of the buildings and landscape [66].

4. Assessment Approach

There are a lot of approaches be used in sustainability assessment, such as the fuzzy analytical hierarchy process (FAHP), the fuzzy comprehensive evaluation (FCE) method, principal component analysis (PCA) etc. However, these methods all have some insurmountable defects. For example, FAHP is a subjective method to determine weight, so it is easy to form a bias due to subjective factors.

FCE cannot solve the problem of the association of fuzziness and randomness in the evaluation process. PCA solves the problem of determining the evaluation weights, but it can lead to a loss of information. In order to conduct a rational evaluation on the assessment system established in Section 3, we put forward a new hybrid evaluation method that is suitable for the sustainability assessment of Chinese public rental housing community. It uses the AHP-entropy weight method to obtain the index weight, and then uses the cloud model to evaluate. This method can make full use of the respective advantage of the AHP and entropy weight method in determining weights. It can also make use of the qualitative evaluation information and transform it into quantitative evaluation data by using cloud model-related theories. The evaluation results can be expressed in the form of a cloud chart and provide guidance for managers and decision makers. Combined with the use of relevant calculation software, we can reduce the complexity of calculation and improve the efficiency and accuracy of sustainability evaluation.

4.1. Using AHP-Entropy Weight Method to Determine the Index Weights

The method to obtain weight can be divided into two categories: subjective weighting method and objective weighting method. The subjective weighting method includes the Delphi method, AHP etc.; the objective weighting method includes entropy weight method, variation coefficient method and so on [84]. AHP takes into account the experience and knowledge of experts and the intention and preference of decision makers. The ranking of index weights often has a high degree of rationality, but it has a defect of large subjective arbitrariness. Entropy weight can neither reflect experts' knowledge and experience nor decision-makers' opinions, but it can fully tap the information contained in the original data, so results have certain objectivity. According to the advantages and disadvantages of these two methods, we attempt to provide a unified method with AHP and entropy where entropy is adopted to complement the functions of AHP. Although no complete work is yet presented, the idea of combining information theory with AHP is not new. For example, Basak presented an example of utilizing entropy for selecting the most appropriate statistical model for the judgment data used in AHP [85]. The AHP-entropy weight method can help determine criteria weights both subjectively and objectively based on different types of assessing data and under variant levels of knowledge and experience [86]. In fact, for some important decision problems of high complexity, different types of people, including experts, decision makers or some other related personnel, are needed to participate in the evaluation. Since their knowledge background and preference differ, their understanding of the different aspects of the evaluation problems is also different. In the AHP evaluation process, the weighted arithmetic or geometric average is often used to synthesize the evaluators' opinion, which cannot reflect the difference between each evaluator and may cause bias in the evaluation results. Fortunately, the entropy weight method can reflect the uncertainty and difference of expert evaluation, so it has recently been used in conjunction with AHP by more and more researchers to get more scientific and comprehensive weight results in many fields [86,87]. On the basis of previous research achievements, the organic combination of AHP and the entropy weight method can be realized through the combined weight method [88]. Similar to the indicator selection, the determination of indicator weights in this paper also needs to integrate experts' and residents' understanding of sustainability to avoid ignoring some local issues and better reflect local priorities, values and needs of sustainability. We decide to continue drawing on the "participatory philosophy" [22] and have an overall consideration of the views of different stakeholders. The AHP-entropy weight method can better deal with variant levels of knowledge and experience from different types of evaluators. Therefore, this paper combines AHP with the entropy weight method, so as to get the weight comprehensively considering the subjective and objective factors.

4.1.1. Analytical Hierarchy Process (AHP)

AHP was proposed by American operations research expert Saaty in 1970s. It is a practical multi-objective decision-making method and can be combined with qualitative and quantitative analysis and solve the complex system problems composed of interrelated factors [89]. AHP divides

the problem into different elements by analyzing the factors and their relationships. These elements are classified into different levels, and then the hierarchical structure is formed by these levels. At each level, according to a certain rule, the elements of the hierarchy are compared one by one, and then the judgment matrix is established. By calculating the maximum eigenvalue of the judgment matrix and the corresponding orthogonal feature vector, the weight of the element is obtained. On this basis, the weight of each level of elements can be obtained. AHP has a strong operability and it can fully consider the experts' experience and knowledge and decision-makers' preference, so it is used in many studies to get the weight of index.

Steps of AHP to obtain weight are as follows:

Step 1: Compare the importance of each indicator one by one according to the hierarchy structure of the indicator system. Then assign the relative importance value of the indices in the lower level by using the indices in the upper level as the benchmark and establish the judgement matrices. In order to make the judgement quantitative, we use the nine-point scale pair-wise comparison to score (as shown in Table 2).

Table 2. Relative importance scale.

Scale (a_{ij})	Meaning
1	Index x_i is as important as index x_j
3	Index x_i is slightly more important than index x_j
5	Index x_i is obviously more important than index x_j
7	Index x_i is strongly more important than index x_j
9	Index x_i is extremely more important than index x_j
2, 4, 6, 8	Middle value of the above adjacent judgments
Reciprocal	If $x_j/x_i = a_{ji}$, then $x_i/x_j = a_{ij} = 1/a_{ji}$

Step 2: Carry out the hierarchical single ranking. That is conducting the relative importance ranking of the lower-level evaluation indicators to the upper level. It is usually to calculate the maximum eigenvalue and the corresponding eigenvector of the comparative judgment matrix. The judgment matrices established according to Table 2 are all positive reciprocal matrices. Therefore, the maximum eigenvalues and the corresponding eigenvectors exist and are unique, and can be calculated by the Matlab or yaahp software. Then, through normalizing the eigenvectors, the weight of each indicator can be obtained. The calculation steps are as follows:

- (1) Normalize the column vector of the comparative judgment matrix A , i.e., $A_{ij} = \frac{a_{ij}}{\sum_{k=1}^n a_{kj}}$.
- (2) Sum of each line of A_{ij} , i.e., $V_i = \sum_{j=1}^n A_{ij}$ ($i = 1, 2, \dots, n$).
- (3) Standardize V_i to get Λ_i ($i = 1, 2, \dots, n$), $\Lambda_i = \frac{V_i}{\sum_{i=1}^n V_i}$.
- (4) Calculate the maximum eigenvalue of the judgement matrix λ_{\max} , through the equation $A*\Lambda = \lambda*\Lambda$, λ_{\max} can be obtained. $\lambda_{\max} = \sum_{i=1}^n \frac{(A\Lambda)_i}{n\Lambda_i}$.

Step 3: The rationality of the weight of each index will directly impact on the correctness of the results. Therefore, in order to prevent the appearance of the judgement contrary to common sense in the process of assigning the relative importance values, we need to conduct the consistency test. The consistency test mainly includes the following 3 steps:

- (1) Calculate the consistency index (CI), $CI = \frac{\lambda_{\max} - n}{n - 1}$.
- (2) Determine the average random consistency index RI. Table 3 shows the average random consistency index of an n order matrix.
- (3) Calculate the consistency ratio CR, $CR = CI/RI$. Only when $CR < 0.1$ can the judgment matrix pass the consistency test. Otherwise, it cannot meet the requirement and we need to score again.

Table 3. Average random consistency index RI.

Matrix Order (n)	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

4.1.2. Entropy Weight Method

The conception of entropy was originally proposed by the physicist Rudolph Clausius. It was used to describe the irreversible phenomena of motion in thermodynamics. In 1948, American mathematician Shannon put it into information theory for the first time, and used it to represent the uncertain relationship between things and problems as a measure of uncertainty [90]. Entropy weight is a method using the value of information entropy to calculate the weight of each index according to their variation degree [91]. Entropy weight method can help avoid the interference of human factors to the weight of each evaluation index, so the evaluation results are more objective. By calculating the entropy of each index, the amount of information can be measured, so as to ensure that the indicators can reflect the vast majority of the original information.

In order to obtain the index weight comprehensively considering subjective and objective factors, in this paper, AHP and entropy weight method are used together. The steps of using entropy weight method to get weight are as follows:

Step 1: Establish judgement matrix D composed by m evaluation schemes and n evaluation indices.

$$D = (A_{ij})_{m \times n}, (i = 1, 2, \dots, m; j = 1, 2, \dots, n)$$

Step 2: Because of the differences of the evaluation index in the unit and property aspects, we need to carry out the standardized processing of matrix D to obtain the non-dimensional index matrix: $R = (r_{ij})_{m \times n}$, the standardized process is shown in Formulas (1) and (2).

If the evaluation index is a benefit indicator (i.e., the bigger the better), then

$$r_{ij} = \frac{A_{ij} - \min_j \{A_{ij}\}}{\max_j \{A_{ij}\} - \min_j \{A_{ij}\}} \tag{1}$$

If the evaluation index is a cost indicator (i.e., the smaller the better), then

$$r_{ij} = \frac{\max_j \{A_{ij}\} - A_{ij}}{\max_j \{A_{ij}\} - \min_j \{A_{ij}\}} \tag{2}$$

Step 3: According to the definition of entropy in the information theory, the information entropy of the jth evaluation indicator is:

$$E_j = -\frac{1}{\ln(n)} \sum_{i=1}^n P_{ij} \ln(P_{ij}), (j = 1, 2, \dots, n) \tag{3}$$

In Formula (3), $P_{ij} = \frac{r_{ij}}{\sum_{i=1}^m r_{ij}}, E_j \in [0,1]$, if $P_{ij} = 0$, then define $\ln(P_{ij}) = 0$.

Step 4: Calculate the weight of each index through the information entropy:

$$\mu_j = \frac{1 - E_j}{n - \sum_{j=1}^n E_j} \tag{4}$$

From the above equation it can be drawn that the smaller the entropy value, the greater the entropy weight, the larger amount of corresponding evaluation index's information and the more important the indicator. By contrast, the greater the entropy value, the smaller the entropy weight,

and the less important the indicator. On the basis of the index weights obtained by the entropy weight method, combining with AHP, the comprehensive weights of the sustainability assessment indices can be obtained. The step is as follows:

Step 5: Use AHP to get the preference vector of each evaluation index: $\Lambda_i = (\lambda_1, \lambda_2, \dots, \lambda_n)$; then use the index weights μ_j determined by the aforementioned entropy weight method to revise the weights of each indicator Λ_i determined by AHP. In addition, then the comprehensive weight [88] of the j th evaluation index is:

$$\bar{w}_j = \frac{\mu_j \lambda_j}{\sum_{j=1}^n \mu_j \lambda_j} \quad (5)$$

4.2. Cloud Model

The cloud model was proposed by Li et al. in 1995 [92]. It is a model of reciprocal conversion between qualitative conception and quantitative representation formed by a specific structure algorithm based on the interaction between probability theory and fuzzy mathematics theory. The cloud model reflects the uncertainty of the concept in natural language as well as the linkage between randomness and fuzziness; it can constitute the mutual mapping between qualitative concept and quantitative data [92]. Since the cloud model can realize the conversion between uncertain linguistic information and quantitative concept, it is more objective than other methods and it can achieve less information loss [93]. It has been successfully applied in a lot of different fields, such as data mining [94], network security [95] and image segmentation [96].

In this paper, we proposed a series of indicators from different dimensions in a bid to improve the completeness in sustainability coverage. Some of the indicators are quantitative (e.g., construction cost), which can be easily measured, while there are also some qualitative indicators (e.g., community satisfaction) that are important to community sustainability. In the existing sustainability assessment systems and tools, these “soft indicators” are very difficult to evaluate since there is no standard reference for the evaluators. In general, the evaluators usually tend to express their views by fuzzy linguistic terms containing important information, which is hard to quantify. Fortunately, the cloud model is outstanding at dealing with this problem [93]. Hence, we attempt to use the cloud model to measure the sustainability of public rental housing community.

4.2.1. Cloud Definition

Let U be a quantitative domain composed of precise numerical data, and C is a qualitative conception related to U . x ($x \in U$) is a random number with stable trend of C , and the membership degree of x to C is $\mu(x)$ ($\mu(x) \in [0, 1]$). If:

$$\mu : U \rightarrow [0, 1], \forall x \in U, x \rightarrow \mu(x)$$

Then the distribution of x in the quantitative domain U is called a cloud, which is made up of a number of cloud droplets [97].

4.2.2. The Digital Eigenvalues of the Cloud

In the cloud theory, three digital eigenvalues [93] of the cloud are used to reflect the overall characteristics of the conception, i.e., Expectation (Ex), Entropy (En) and Hyper Entropy (He). Expectation (Ex) is the most representative point of the qualitative conception C . Entropy (En) reflects the measurable granularity of C . It is determined by the randomness and fuzziness of the qualitative conception. The greater En , the greater fuzziness and randomness of the object. Hyper Entropy (He) measures the uncertainty of En , i.e., entropy's entropy. It reflects the condensation degree of the cloud droplets and is determined by the randomness and fuzziness of En .

4.2.3. Cloud Generator

The cloud generator is used to realize the reciprocal conversion between quantification and qualification in the cloud model theory [98]. The cloud generator can be classified into two types: positive cloud generator; and reverse cloud generator. The positive cloud generator can realize the transformation from a qualitative concept to a quantitative representation, which is a qualitative to quantitative mapping; it can output a series of droplets according to the digital eigenvalues of the cloud (Ex , En , He) and quantitatively express the qualitative concept through the uncertainty transformation of the cloud model. The reverse cloud generator can realize the transformation from a quantitative representation to a qualitative concept. It can transform a certain number of cloud drops to the three digital eigenvalues of the cloud (Ex , En , He). The processes of the positive cloud generator and the reverse cloud generator are shown in Figure 3.

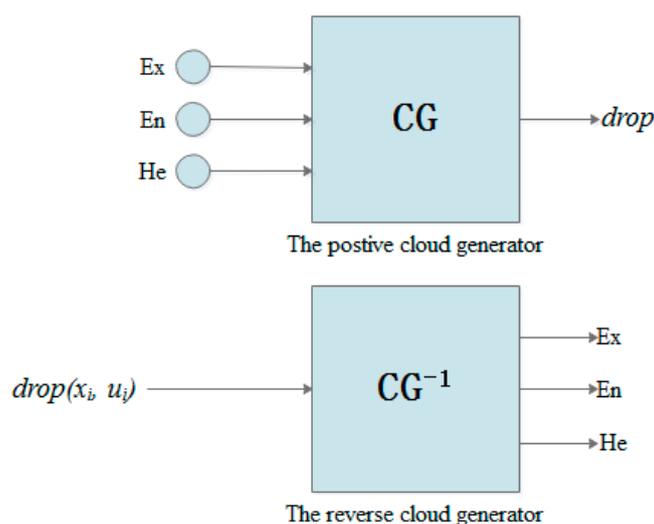


Figure 3. The positive cloud generator and the reverse cloud generator.

4.3. Integrated Sustainability Assessment of Public Rental Housing Community Based on the Cloud Model Theory

4.3.1. Establishment of the Evaluation Index System

We have established the integrated sustainability assessment index system of public rental housing community according to literature and policy analysis and evaluator scoring including five first-level evaluation indices (i.e., environmental sustainability, economic sustainability, social sustainability, institutional sustainability and cultural sustainability) and 31 second-level evaluation indices (see Figure 2).

4.3.2. Cloud Model Representation of Qualitative Comment Set

Determine the comment of each index to form a comment set V . Then divide the comment set V into five levels: {very bad, bad, middle, good, very good}. Among them, “very bad” and “very good” belong to the unilateral constraints; “bad”, “middle” and “good” are middle segment comments, they belong to the bilateral constraints. For the bilateral constraint comments, we choose the symmetric cloud model to describe. The digital eigenvalues of the cloud model can be obtained by the following formula [99,100]:

$$\begin{cases} E_x = \frac{V_{max} + V_{min}}{2} \\ E_n = \frac{V_{max} - V_{min}}{6} \\ H_e = k \end{cases} \quad (6)$$

For the unilateral constraint comments, we use the semi cloud model to describe. The comments “very bad” and “very good” can be respectively described by “0” and “10”. We select half of the corresponding symmetric cloud’s entropy as their respective entropy [101]. In this formula, “k” is a constant, and it can be adjusted according to the uncertainty degree of the variables [102]. We assume that the corresponding theory domain of the comment set is [0,10], so the corresponding intervals and cloud model digital eigenvalues of each comment can be obtained as shown in Table 4.

Table 4. The corresponding intervals and cloud model digital eigenvalues of each comment.

Comment	Very Bad	Bad	Middle	Good	Very Good
Interval	(0,2]	(2,4]	(4,6]	(6,8]	(8,10]
E_x	0	3	5	7	10
E_n	1/6	1/3	1/3	1/3	1/6
H_e	k	k	k	k	k

4.3.3. Cloud Model Representation of the Second-Level Indices

The sustainability assessment indices are related to the viewpoints of experts and different stakeholders of public rental housing community. In order to improve public participation and have an overall consideration of sustainability, in this paper, the qualitative comments of each index are determined by delivering questionnaires to different types of evaluators. We use the reverse cloud generator [103] to get the cloud model digital eigenvalues (E_x, E_n, H_e) of each index.

4.3.4. Cloud Model Determination of the First-level indices

The second-level indices under each first-level index are basically independence of each other and the correlation between each index is very low. Thus, we can use the already determined cloud model digital eigenvalues of the second-level indices to determine the comprehensive cloud of the first-level evaluation indices. The following formula can be used [104]:

$$\begin{cases} E_x = \frac{E_{x1}\omega_1 + E_{x2}\omega_2 + \dots + E_{xn}\omega_n}{\omega_1 + \omega_2 + \dots + \omega_n} \\ E_n = \frac{\omega_1^2}{\omega_1^2 + \omega_2^2 + \dots + \omega_n^2} E_{n1} + \frac{\omega_2^2}{\omega_1^2 + \omega_2^2 + \dots + \omega_n^2} E_{n2} + \dots + \frac{\omega_n^2}{\omega_1^2 + \omega_2^2 + \dots + \omega_n^2} E_{nn} \\ H_e = \frac{\omega_1^2}{\omega_1^2 + \omega_2^2 + \dots + \omega_n^2} H_{e1} + \frac{\omega_2^2}{\omega_1^2 + \omega_2^2 + \dots + \omega_n^2} H_{e2} + \dots + \frac{\omega_n^2}{\omega_1^2 + \omega_2^2 + \dots + \omega_n^2} H_{en} \end{cases} \quad (7)$$

In the formula, ω_i is the weight of each second-level index; (E_{xi}, E_{ni}, H_{ei}) is the cloud model digital eigenvalues of each second-level index; n is the number of evaluation indices, $i = 1, 2, \dots, n$.

4.3.5. Establishment of Comprehensive Cloud Model

There is a certain correlation between the first-level indices; the indicators will have an impact on each other. For example, environmental sustainability may have an impact on social sustainability and institutional sustainability may have an impact on economic sustainability. Therefore, it is necessary to carry out the comprehensive cloud computing in virtual cloud [105] when determining the comprehensive cloud model. The following formula can be used to integrate the cloud model of the five first-level evaluation indices into a more generalized cloud.

$$\begin{cases} E_x = \frac{E_{x1}E_{n1}\omega_1 + E_{x2}E_{n2}\omega_2 + \dots + E_{xn}E_{nn}\omega_n}{E_{n1}\omega_1 + E_{n2}\omega_2 + \dots + E_{nn}\omega_n} \\ E_n = E_{n1}\omega_1 + E_{n2}\omega_2 + \dots + E_{nn}\omega_n \\ H_e = \frac{H_{e1}E_{n1}\omega_1 + H_{e2}E_{n2}\omega_2 + \dots + H_{en}E_{nn}\omega_n}{E_{n1}\omega_1 + E_{n2}\omega_2 + \dots + E_{nn}\omega_n} \end{cases} \quad (8)$$

In the formula, ω_i is the weight of each first-level index; (E_{xi}, E_{ni}, H_{ei}) is the cloud model digital eigenvalues of each first-level index; n is the number of evaluation indices, $i = 1, 2, \dots, n$.

By using the digital eigenvalues of the comprehensive cloud model to draw the cloud chart of the comprehensive sustainability assessment of public rental housing community, we can get the specific information of the overall sustainability of public rental housing community. In this way, we use the AHP-entropy weight method to determine the weight of each indicator, and then use the cloud model theory to finish the comprehensive sustainability evaluation of public rental housing community. The specific process is shown in Figure 4.

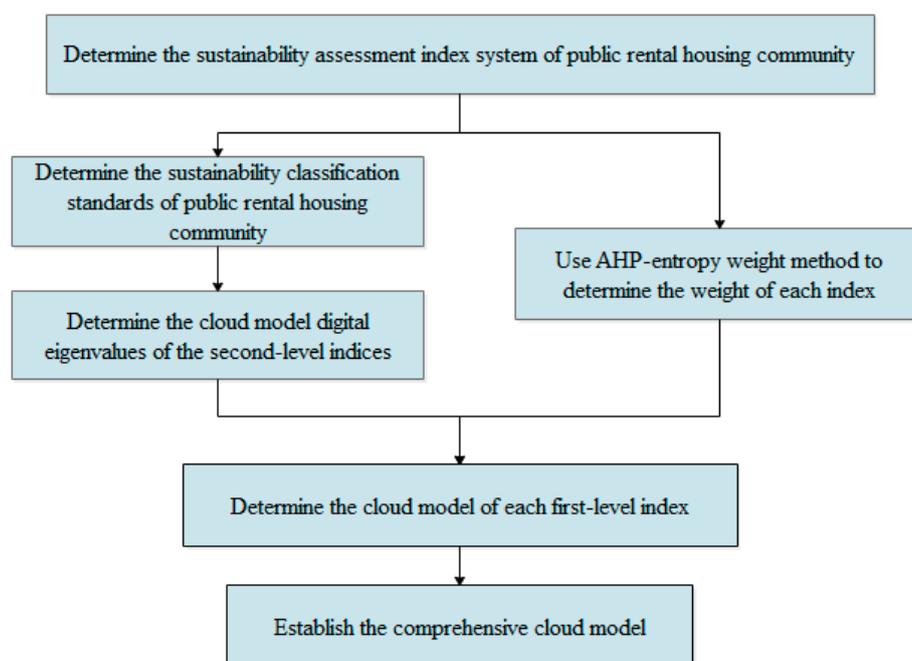


Figure 4. Sustainability assessment process of public rental housing community.

5. Case Study

As one of the national urban and rural comprehensive reform pilot areas, Chongqing plans and constructs the largest amount of public rental housing in China [106]. The public rental housing coverage of Chongqing is larger than other cities, and the development of public rental housing projects in Chongqing is also more mature than in other cities. Therefore, we select one of the earliest planning projects (the “Minxinjiayuan” community) as an example to carry out the integrated sustainability assessment, so as to verify the feasibility of the aforementioned method and provide a reliable reference for other similar projects.

5.1. Project Profile

The “Minxinjiayuan” public rental housing project began construction in 28 February 2010. It was the earliest public rental housing community of Chongqing. A lot of national leaders have visited and inspected there. The community was completed in 2012, and it has become a model of Chinese public rental housing. It is located in the northern new area of Chongqing: Yuanyang area. It has a total of 54 residential buildings, with a total construction area of 1.08 million square meters, and has a complete range of infrastructure and supporting projects. The “Minxinjiayuan” community has completed the residential occupancy for nearly five years, and has formed a relatively mature community culture. Like other public rental housing communities, it has many institutional problems. The already-formed culture in the community can influence the environmentally sound behaviors or individual and societal wellbeing to some extent. Thus, it is relatively suitable to use the assessment system with institutional and cultural dimensions to evaluate it. The integrated sustainability assessment of the community is of great significance to guide public rental housing towards sustainable development.

5.2. Determination of the Evaluation Index Weight

5.2.1. Using AHP to Determine the Subjective Weight of the Evaluation Index

We used a questionnaire to obtain index weight. We selected 10 Chinese experts and scholars in the field of public rental housing and sustainability assessment, 10 project managers of the design, construction, operation and management of the community, 10 administrators of relevant government department and 10 residents of the community, and conducted face-to-face questionnaires with them. Experts, scholars and government administrators have more authority in the theoretical determination of the index weight, but they do not have enough living and working experience compared with project managers and residents. In order to comprehensively take account of the authority, relevance and local contextual perspective, we conducted the same number of questionnaires with each kind of personnel. We then established the initial judgement matrices according to the recycling questionnaires. By using the yaahp software and the expert data aggregation method, we can get the subjective weights of the evaluation indices determined by AHP: $\lambda_j = [0.0193 \ 0.0522 \ 0.0338 \ 0.0505 \ 0.0409 \ 0.0534 \ 0.0620 \ 0.0407 \ 0.0230 \ 0.0427 \ 0.0368 \ 0.0699 \ 0.0393 \ 0.0336 \ 0.0393 \ 0.0316 \ 0.0228 \ 0.0175 \ 0.0134 \ 0.0276 \ 0.0178 \ 0.0222 \ 0.0114 \ 0.0165 \ 0.0184 \ 0.0426 \ 0.0196 \ 0.0370 \ 0.0207 \ 0.0167 \ 0.0265]$.

5.2.2. Using the Entropy Weight Method to Determine the Objective Weight of the Evaluation Index

Same as above, we conducted another face-to-face questionnaire with each of the respondents. The respondents are the same as above, i.e., 10 Chinese experts and scholars in the field of public rental housing and sustainability assessment, 10 project managers of the design, construction, operation and management of the community, 10 administrators of government relevant department and 10 residents of the community. These 40 respondents scored respectively from 1–9 according to the importance of the 31 second-level indices. Then, according to the questionnaire data and Formulas (1)–(4), we can use the Matlab software to get the objective weights of the evaluation indices:

$\mu_j = [0.0491 \ 0.0235 \ 0.0060 \ 0.0177 \ 0.0126 \ 0.0273 \ 0.0530 \ 0.0398 \ 0.0310 \ 0.0439 \ 0.0427 \ 0.0530 \ 0.0181 \ 0.0514 \ 0.0227 \ 0.0353 \ 0.0471 \ 0.0293 \ 0.0162 \ 0.0195 \ 0.0040 \ 0.0287 \ 0.0687 \ 0.0219 \ 0.0453 \ 0.0353 \ 0.0361 \ 0.0104 \ 0.0427 \ 0.0170 \ 0.0505]$.

According to Formula (5), the final comprehensive weights are obtained: $\bar{\omega}_j = [0.0292 \ 0.0376 \ 0.0062 \ 0.0274 \ 0.0158 \ 0.0447 \ 0.1008 \ 0.0498 \ 0.0219 \ 0.0575 \ 0.0482 \ 0.1136 \ 0.0218 \ 0.0531 \ 0.0274 \ 0.0342 \ 0.0329 \ 0.0157 \ 0.0067 \ 0.0165 \ 0.0022 \ 0.0196 \ 0.0240 \ 0.0111 \ 0.0256 \ 0.0461 \ 0.0217 \ 0.0118 \ 0.0271 \ 0.0087 \ 0.0411]$.

5.3. Cloud Model Representation of the Second-Level Indices of “Minxinjiayuan” Community

We used the questionnaire survey method to obtain comments on each second-level index. To comprehensively consider the authority, relevance and local perspective, we conducted 50 face-to-face questionnaires with residents living in the community and experts in the field of public rental housing and sustainability assessment. Among them, there were 25 residents and 25 experts. Experts have a certain degree of authority when evaluating some indicators (e.g., ecological planning), but the residents score more rationally when evaluating some other indicators (e.g., community satisfaction) due to their living experience in the community. Therefore, we selected the same number of expert and resident respondents. We then collected the questionnaires and used the reverse cloud generator [103] to get the cloud model digital eigenvalues of each second-level index, the results are shown in Table 5.

Table 5. The weight and cloud model digital eigenvalues of each second-level index.

First-Level Index: B	Second-Level Index: C	Cloud Model Digital Eigenvalues (E_x, E_n, H_e)	Weight	
			ω_i	ω_{ij}
Environmental Sustainability B1	Ecological Planning C1	(5.4286, 0.8185, 0.3517)	0.2617	0.0292
	Energy Saving C2	(5.5429, 0.8164, 0.3419)		0.0376
	Water Use C3	(5.6286, 0.9269, 0.2990)		0.0062
	Land Use C4	(6.6286, 0.9351, 0.3235)		0.0274
	Greening and Environment C5	(5.9714, 0.9044, 0.1848)		0.0158
	Environmental Fusion C6	(5.7714, 0.8287, 0.3057)		0.0447
	Environmental Impact C7	(5.6000, 0.9024, 0.3943)		0.1008
Economic Sustainability B2	Operating Cost C8	(5.7714, 0.9392, 0.4137)	0.3128	0.0498
	Construction Cost C9	(5.8286, 0.9494, 0.3288)		0.0219
	Business Activity C10	(5.8286, 1.0088, 0.4737)		0.0575
	House and Rent Price C11	(6.2857, 0.8390, 0.2865)		0.0482
	Housing Affordability C12	(6.6286, 0.9699, 0.2309)		0.1136
	Economic Fusion C13	(5.8571, 0.9208, 0.2734)		0.0218
Social Sustainability B3	Employment Conditions C14	(5.6857, 0.9290, 0.2301)	0.1887	0.0531
	Supporting Facilities C15	(5.8286, 0.8083, 0.3741)		0.0274
	Residential Security C16	(6.2857, 0.7162, 0.2599)		0.0342
	Health and Comfort C17	(6.9714, 0.7653, 0.1764)		0.0329
	Community Satisfaction C18	(7.0000, 0.5729, 0.4486)		0.0157
	Neighborhood Association C19	(6.0571, 0.8819, 0.1281)		0.0067
	Psychological Fusion C20	(5.4286, 0.8083, 0.3273)		0.0165
Social Adjustment C21	(5.4000, 0.8881, 0.2666)	0.0022		
Institutional Sustainability B4	Policy Support C22	(6.2286, 0.8451, 0.2492)	0.0803	0.0196
	Political Participation C23	(5.2286, 0.9883, 0.1682)		0.0240
	Sound Management System C24	(4.8571, 0.9208, 0.3655)		0.0111
	Public Interest C25	(5.6286, 0.8369, 0.3273)		0.0256
Cultural Sustainability B5	Cultural Fusion C26	(4.8857, 0.6978, 0.1704)	0.1565	0.0461
	Cultural Vitality C27	(5.7429, 0.7980, 0.2953)		0.0217
	Cultural Identity C28	(5.6857, 0.6384, 0.2609)		0.0118
	Cultural Continuity C29	(5.5143, 0.9883, 0.3624)		0.0271
	Culture Compatibility C30	(5.5143, 0.7735, 0.3254)		0.0087
Aesthetic Value C31	(5.5714, 0.7776, 0.3424)	0.0411		

5.4. Cloud Model Determination of the First-Level Indices of “Minxinjiayuan” Community

By substituting the digital eigenvalues and weights of each second-level index under each first-level index into Formula (7) and conducting the comprehensive cloud computing, we obtained the cloud model digital eigenvalues of the five first-level indices as shown in Table 6.

Table 6. The cloud model digital eigenvalues of each first-level index.

First-Level Index	Cloud Model Digital Eigenvalues (E_x, E_n, H_e)
Environmental Sustainability B1	(5.7329, 0.8821, 0.3687)
Economic Sustainability B2	(6.1826, 0.9569, 0.2970)
Social Sustainability B3	(6.1363, 0.8287, 0.2553)
Institutional Sustainability B4	(5.5480, 0.8949, 0.2601)
Cultural Sustainability B5	(5.3888, 0.7728, 0.2687)

5.5. Establishment of the Comprehensive Sustainability Cloud Model of “Minxinjiayuan” Community

By conducting the comprehensive cloud computing of each first-level index in virtual cloud through Formula (8), we can obtain the cloud model digital eigenvalues of the integrated sustainability assessment of “Minxinjiayuan” community: (5.8953, 0.8793, 0.3015).

5.6. Determination of the Sustainability Level of “Minxinjiayuan” Community

In the finally gotten cloud model digital eigenvalues of the integrated sustainability assessment of “Minxinjiayuan” community, $He = 0.3015$. In order to compare the integrated cloud model and the corresponding cloud of each comment, we adjusted the value of k in Table 4, and took $k = 0.3$. We then input the integrated cloud model digital eigenvalues and the corresponding cloud model digital eigenvalues of each comment into the positive cloud generator, and used the Matlab software to draw the corresponding cloud charts as shown in Figure 5. From Figure 5, we can find that the overall sustainability of the community lies at a “middle” to “good” level and closer to a “middle” level. Therefore, the overall sustainability of this community needs yet to be improved.

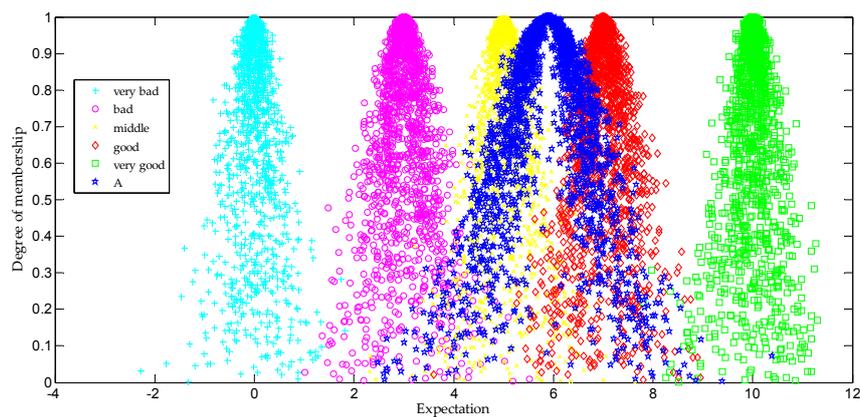


Figure 5. The cloud chart of the overall sustainability.

After that, we input the digital eigenvalues of the five first-level indices (i.e., environmental sustainability B1, economic sustainability B2, social sustainability B3, institutional sustainability B4 and cultural sustainability B5) and the corresponding digital eigenvalues of each comment into the positive cloud generator and used the Matlab software to draw the corresponding cloud charts as shown in Figures 6–10. It can be found that in Figures 6, 9 and 10 that the environmental, institutional and cultural sustainability of “Minxinjiayuan” community lies between the “middle” and “good” level, and closer to the “middle” level; while Figures 7 and 8 shows that the economic and social sustainability are closer to the “good” level. This means that the overall sustainability of “Minxinhuayuan” community lies between the “middle” and “good” level; in the pursuit of economic and social sustainability, the consideration of environmental, institutional and cultural sustainability is still insufficient. The level of economic and social sustainability is relatively higher than that of other dimensions, mainly because the aim of developing public rental housing is to improve the housing affordability of medium-low income groups and meet their housing demand. In addition, through the cloud model digital eigenvalues of each second-level index in Table 5, we can easily find that the scores of Sound Management System (C24) and Cultural Fusion (C26) are relatively low, while the scores of Community Satisfaction (C18) and Health and Comfort (C17) are relatively high. This information can provide guidance for the management and decision-making of the government and project administrators. Therefore, in the future, more attention should be paid to the environmental, institutional and cultural sustainability aspects in the design, construction, operation and management processes of public rental housing projects, such as improving the ecological planning, promoting the energy saving through the improving of technology, improving the management system of public rental housing community, promoting the cultural fusion of the community by organizing various activities etc.

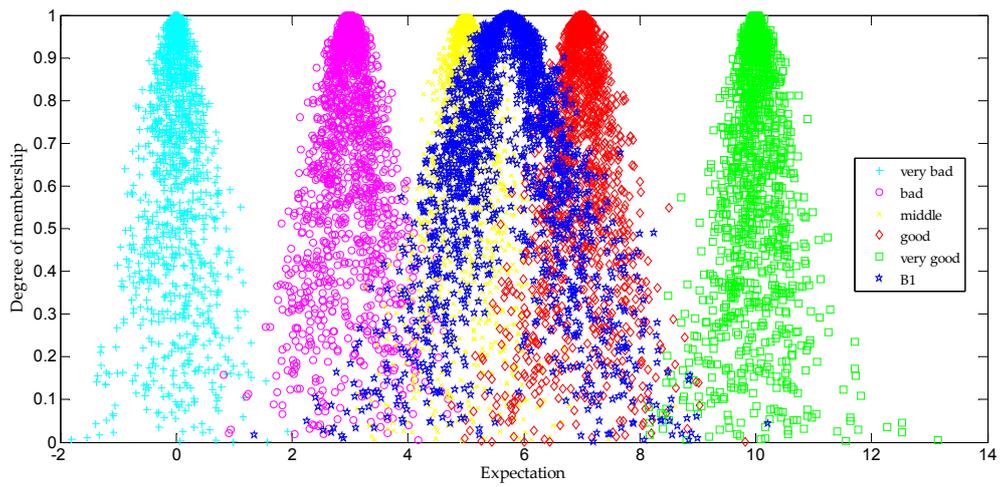


Figure 6. The cloud chart of the environmental sustainability.

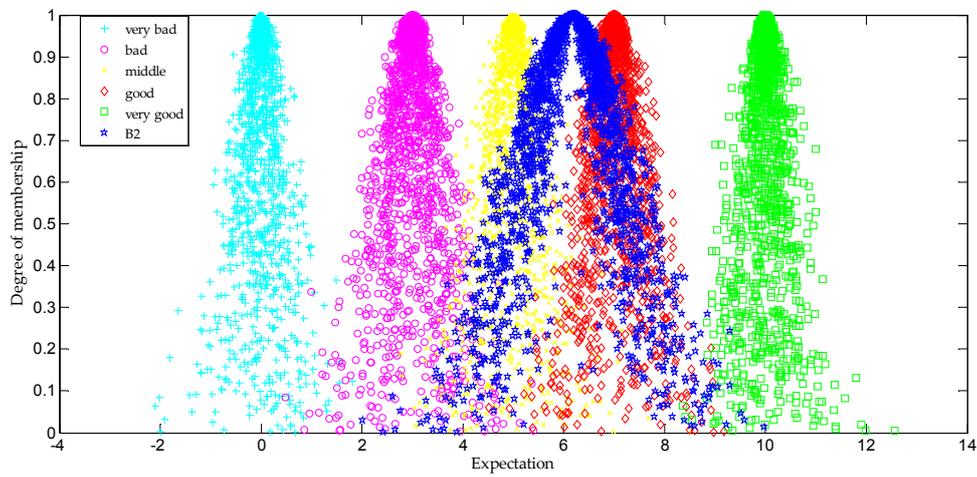


Figure 7. The cloud chart of the economic sustainability.

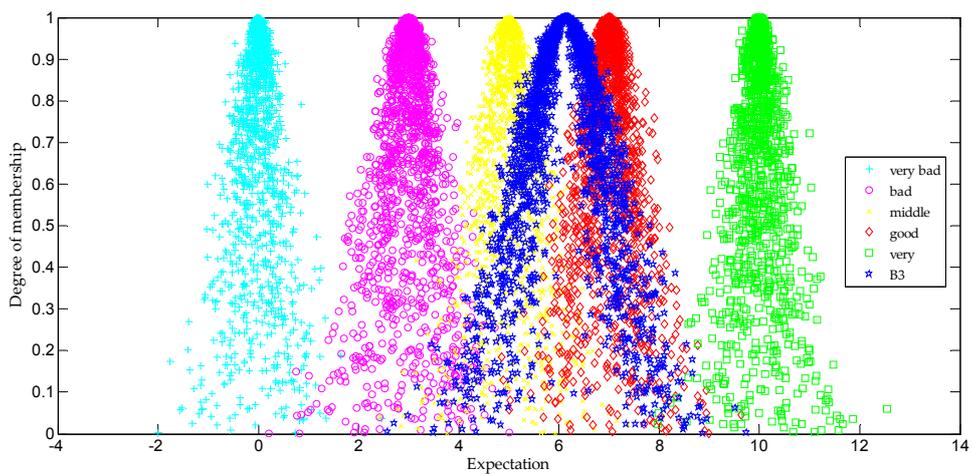


Figure 8. The cloud chart of the social sustainability.

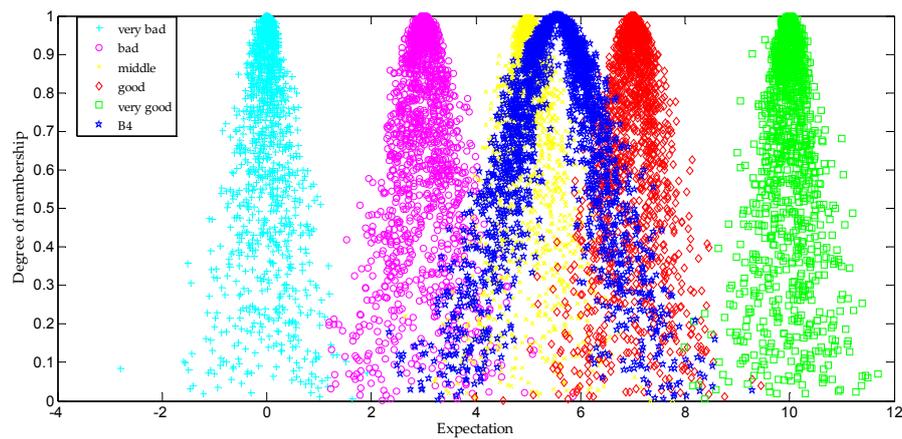


Figure 9. The cloud chart of the institutional sustainability.

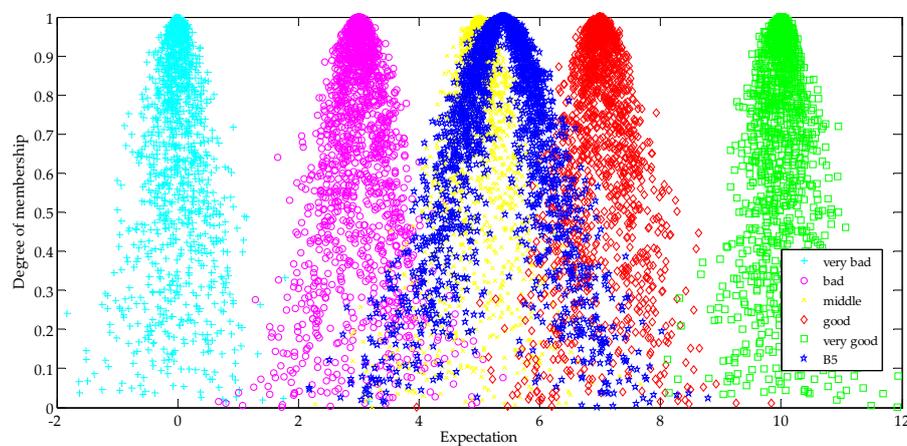


Figure 10. The cloud chart of the cultural sustainability.

6. Conclusions

This paper establishes an integrated sustainability assessment indicator system for Chinese public rental housing communities including environmental, economic, social, institutional and cultural dimensions by drawing on the “participatory philosophy”. On this basis, this paper proposes a new hybrid evaluation method—that is, using AHP-entropy weight method to determine the weight of each evaluation index—and then using the cloud model theory to realize the transformation between qualitative comments and quantitative representations. In order to improve the degree of local participation and take regional characteristics into consideration, different types of people, including experts and scholars, project managers, government administrators and community residents, are asked to participate in the evaluation. The AHP-entropy weight method can determine the weight of each indicator under varying levels of knowledge and experience so as to help us to get a more scientific and comprehensive weight result. On the other hand, the cloud model has the superiority to convert between qualification and quantification and reflect fuzziness and randomness, so it provides a possibility for reasonably measuring some “soft indicators” that are difficult to evaluate in the existing assessment systems and tools. To verify the feasibility of this method, a case study is carried out on the “Minxinjiayuan” public rental housing community in Chongqing, China. We find that the overall sustainability of the community lies at a “middle” to “good” level and closer to a “middle” level; the level of economic and social sustainability is higher than that of environmental, institutional and cultural sustainability.

The index system proposed in this paper can help comprehensively consider multi-dimensions of sustainability and improve public participation of public rental housing community at the same time, while the method opens up windows of opportunity that address the needs to properly evaluate by different types of evaluators with varying levels of knowledge and experience and rationally measure both quantitative and qualitative indicators. The evaluation results are relatively intuitive and rational, at least to some degree. This paper can provide a new reference for the sustainability assessment of Chinese public rental housing community and the research on sustainability assessment systems and approaches. However, since sustainable development is a dynamic process which passes in time and depends on numerous parameters, there is no coincident conception of sustainability and the indicators were not unambiguously qualified. There are regional differences between different types of communities in different regions, so it is not appropriate to establish a universal indicator system. The index system established in this paper can supply a new integrated perspective for community sustainability assessment, while it is still far from enough to search a right direction for Chinese public rental housing communities towards sustainable development. The research on the CSA system is only in the initial stage. Public rental housing communities are also a very new phenomenon. Thus, exploration is still necessary into sustainability assessment systems and approaches to it. In future research, more consideration may need to be taken into the balance between completeness in sustainability coverage, adaptability and simplicity of operation, so that the system can be applied in other cases. For example, the mechanism for further utilizing the method proposed in this paper to more specific projects or other fields, and customizing a specific software package to run the method to improve operating efficiency could also comprise research points.

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