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OPERATION PERFORMANCE MEASUREMENT OF PUBLIC RENTAL HOUSING DELIVERY BY PPPS WITH FUZZY-AHP COMPREHENSIVE EVALUATION

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Abstract. As governments promote greatly the Public Private Partnerships (PPPs) to develop the Public Rental Housing (PRH) projects, the effective and efficient operation performance measurement should be pivotal for ensuring the success and sustainable development of these projects. Thus, this paper investigated operation performance indicators (OPIs) and measured the performance level of PRH PPP projects by fuzzy-analytic hierarchy process (AHP) comprehensive evaluation (FACE) method. Four important aspects of PRH PPP projects related to the operation performance and an evaluation indicator system of 21 OPIs from these four aspects were developed, the weights of which were calculated by using the AHP method. Based on fuzzy mathematics and the expert evaluation method, all the OPIs were quantitatively graded according to five ranks of evaluation criteria. Membership functions, weights of OPIs, and maximum membership degree principle were utilized to establish a multi-level FACE model for operation performance measurement of PRH PPP projects. One PRH PPP project of Nanjing, Jiangsu Province in China was chosen as the case study. Evaluation results were derived from the proposed model, and they generally conform to the actual situation. This study provides an effective operation performance measurement framework for PRH PPPs projects.

Keywords: public rental housing (PRH), public private partnerships (PPPs), performance measurement, fuzzy comprehensive evaluation, analytic hierarchy process (AHP).

Introduction

The Public Rental Housing (PRH)[1] as a housing policy in the world is provided for relatively low-income groups to improve the residential environment and reduce their economic burden, through which the tenants of PRH pay a lower rent than the market price level (Byun & Ha, 2016; I. J. Kim, G. Y. Kim, & Yoon, 2004; Sengupta, 2006a). In China, the PRH was targeted at solving the housing problem of "sandwich layer" and designed for a much larger population, covering urban low-middle income families, college fresh graduates, and migrants in some cities (Li et al., 2016b; Shan & Ye, 2013). Since 2014, ambitious development plans of PRH projects have been developed by the central and local government in China. As a result, the PRH has gradually become a predominate form of affordable housing provision and received the universal applause of the public (Yang & Chen, 2014). Similar programmes have also been launched in others countries in the world. For instance, public housing in Nigeria can be provided by government for the residents that are concentrated in urban centers through a mortgage arrangement or outright purchase (Ibem & Aduwo, 2013). Social housing provided for the low-income households in Netherlands (van Kempen & Priemus, 2014) and affordable housing provided in Iran (Riazi & Emami, 2018), Atlanta, America (Paris & Kangari, 2005) and a set of housing adaptation programmes aiming to enhance living standard for

[1] Abbreviations and full names for the special nouns in this paper are listed in Notations.

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occupants in Singapore (Lin & Evelyn, 2012) etc. Thus, according to the specific situation, different countries adopt different housing policies to launch these programmes. In essence, whether these housing programmes are provided by government for rent or for sell, they all serve for the low-income people to resolve their housing problems.

Unfortunately, these PRH programmes (such as public housing, social housing, and affordable housing) around the world do not really perform as well as expected when they are put into operation. In recent years, there are public complaints about the remote location, poor quality and living environment, the imperfect service provided in the housing area, complicated and a long-waiting application process for low and middle income groups to live in PRH units, which have been reported via various medias in different countries (Ibem & Aduwo, 2013; Mohit & Azim, 2012; Xinhua Net, 2012). In terms of quality guarantee and long-term operation of PRH, the government in most countries lack management experience (Liu & Xu, 2014; N. A. Salleh, Yusof, A. G. Salleh, & Johari, 2011). In addition, governments are confronted with tremendous financial distress due to large scale and continuous investment of PRH projects (Abdul-Aziz & Jahn Kassim, 2011; Li et al., 2014; Liu, Chan, & Wang, 2014).

In order to address those aforementioned problems, the Public Private Partnerships (PPPs) has been increasingly adopted to develop PRH as it can exert the private sector's advantages, such as financing capabilities and expertise, as well as efficient management and operation mechanism. For example, in recent years, the housing policy in Italy started to emphasize the role of PPPs in the social housing provision to overcome housing shortage and reduce the accommodation problems of housing difficulties groups (Propersi, Mastrilli, & Gundes, 2012). In India, the PPPs have emerged in the last decade, and currently becomes the most prominent urban housing policy (Sengupta, 2006b). As the participation of the private sector can improve the efficiency of housing delivery, Nigeria has also used PPPs to provide houses to low income people (Adegun & Taiwo, 2011). Similarly, the PPP mode has been actively adopted in China to promote the provision of PRH and deal with housing issues since 2015 (Liu & Xu, 2014; Liu et al., 2014).

Typically, in a PRH PPP project, the private sector selected by the government (the public sector) sets up Special Purpose Vehicle (SPV). SPV signs contracts with the public sector to finance, design, build, operate, maintain and provide the facility management of the project during the contract period. Through the rents paid by the tenants and necessary financial supports from the government, the SPV can receive reasonable returns for the investment. The government is responsible for providing policy support, determining and adjusting the rents of PRH, checking the access and exit of tenants, and strengthening supervision on the service quality provided by SPV. The qualified tenants apply for PRH units to the government and pays to the SPV (Ministry of Finance of the People's Republic of China, 2015). A PRH PPP project should perform especially well during its lifecycle, from decision making to operation, so that it can meet the requirements of tenants, government and private sectors. Thus, in order to figure out what is the actual operation performance level of the PRH PPP project and compare it with the estimated or expected performance level in terms of effectiveness, efficiency and quality, an effective method to systematically assess and evaluate the operation performance (OP) should be explored (Kagioglou, Cooper, & Aouad, 2001; Yuan, Zeng, Skibniewski, & Li, 2009). In this case, the project can be well managed accordingly.

Although some prior studies provide guidance on the performance measurement, there is yet little study on the measurement of operation performance of PRH PPP projects. In addition, the effective method of the operation performance measurement has never been explored for the PRH PPP projects. Offering an effective method of identifying a PRH PPP project's performance level can help assess the quality, utility and allocation efficiency of the project and make the operation performance be understood and interpreted by the government, potential investors and tenants (Huang & Du, 2015). Therefore, the knowledge of the OP level of PRH PPP projects will help the managers or policy makers improve the residential satisfaction to attract more tenants, prompt government to adopt measures for improvements to absorb private participation, and then facilitate the success and sustainable development of PRH PPP projects.

Therefore, to assess and evaluate the OP of PRH PPP projects, 21 operation performance indicators (OPIs) were identified and classified based on the authors' prior research (Yuan, Zheng, & Skibniewski, 2018). In this paper, the evaluation criteria, scoring schemes, and the relative weights of the 21 OPIs will be determined. Moreover, a fuzzy- analytic hierarchy process (AHP) comprehensive evaluation (FACE) method based on fuzzy mathematics theory and AHP is established to measure OP level of PRH PPP projects. To explore the method's effectiveness, the method is applied to a PRH PPP project of Nanjing, capital of east China's Jiangsu Province (a case study measurement of a PRH PPP project's OP is presented). Finally, this paper provides some concluding remarks.

1. Literature review

1.1. Performance management and measurement of PRH projects

Performance management is a process that enables the implementers to perform their roles to the best of their abilities aiming to achieve or exceed established objectives and standards. In the performance management system for PRH projects, the managers and implementers set objectives, measure and recapitulate how these objectives are met, give good performance reward and support continuous improvement (Lebas, 1995). Critical issues of performance management are the definition of objectives, measuring of objective achievement in terms of meeting all stakeholder requirements, the project process of objectives attained and operation management (Otley, 1999).

To achieve performance management, managers or decision makers need to know what performance they seek. Hence, performance measurement constitutes an integral part of the performance management. A PRH project's success depends on a plethora of factors (Fan & Lu, 2014; Huang & Du, 2015; Ibem & Aduwo, 2013), in which performance measurement is very important to ensure the outcome achieved (Liu, Love, Smith, Matthews, & Sing, 2016; Yuan et al., 2009). At the project level, performance management and measurement are used to get a performance score by measuring relevant performance indicators (PIs), proceed analysis based on this score and improve performance continually. Thus, identifying, measuring and managing PIs are at the heart of performance management and measurement (Hu, 2011; Yu, Kim, Jung, & Chin, 2007; Yuan et al., 2009). Former scholars have conducted studies about PIs of PRH projects and indeed got some meaningful results. From different dimensions (e.g., economic, environmental and social), the PIs of PRH projects were identified to measure, improve the performance, and achieve tangible benefits (Density, 2013; Hu, 2011; Ibem, Opoko, Adeboye, & Amole, 2013). In addition, some research also used PIs to reflect a certain aspect of PRH performance, such as building features (Ishiyaku, Rozilah, Harir, & Abubakar, 2014), financial sustainability (Li et al., 2016a), and the stakeholders' satisfaction of rents (Salleh et al., 2011; Yuan, Zheng, You, & Skibniewski, 2017) etc.

Nevertheless, limitations of prior studies still exist. Firstly, prior studies only studied partial stages or aspects of PRH, which can not reflect the comprehensive performance of PRH (Liu et al., 2014). Secondly, most studies focused on the performance measurement of PRH at the city level, not for a single project, however the latter is more important for performance improvement (Fan & Lu, 2015).

With the promotion of PPP mode in public housing, PRH PPP projects have received extensive attentions in academic. Primary topics include operation framework (Liu et al., 2014), financing management (Chen & Zheng, 2011; Gao & Chen, 2014; Shan & Ye, 2013), pricing mechanism (Chen, 2013), risk management (Zhang, Zou, & Pang, 2013), and success factors (Yuan, Guang, Wang, Li, & Skibniewski, 2012a) in the field. The introduction of private sector into the development of PRH makes performance management of these projects become more complicated, especially in a complex political, financial, legal, and regulatory environment (Yuan et al., 2012a). Although many studies have explored PRH PPP projects, little efforts have been made to the application of performance management and measurement for this kind of projects.

For performance management and measurement, project process is the achievement of all stakeholders' requirements and translation of strategy into operative activities (Otley, 1999). In this case, inputs at each stage during the lifecycle of PRH PPP projects constantly generate the accumulated outputs of operation stage (Yuan et al., 2018). Thus, the operation performance of PRH in PPPs is influenced by not only the activities of operation stage, but also the overall performance of all previous stages. In addition, the performance management and measurement for a project is often used to evaluate a performance score through the PIs, and then perform an analysis and assessment based on this score (Yuan, Wang, Skibniewski, & Li, 2012b). Based on the PIs for the operation performance of PRH in PPPs identified through the authors' prior study (Yuan et al., 2018), the current study will further contribute the operation performance measurement of a PRH PPP project through evaluating the PIs with the consideration of lifecycle performance and stakeholders' requirements to fill the gaps above.

1.2. Performance measurement methods

The commonly-used methods for performance measurement include regression analysis, multiple-criteria decision making analysis, ratio analysis, AHP, the Delphi method, balanced scorecard, six sigma, cost-benefit analysis, fuzzy comprehensive evaluation, and data envelopment analysis (DEA) (Ishiyaku et al., 2014; S. S. Kim, Yang, Yeo, & K. W. Kim, 2005; Li et al., 2016a; Lin & Tan, 2013; Salleh et al., 2011). In effect, the performance measurement procedure often has two types of PIs to measure, quantitative and qualitative indicators. Unlike other methods mentioned above, which may only deal with the quantitative indicators, the AHP can solve qualitative problems with quantitative analysis, transform subjective judgments into objective ones, and develop an unbiased weighting or scoring for aggregation (Wu & Hu, 2011). In addition, AHP is a simple and practical multi-criteria evaluation method applied in many fields, and it can establish the weightings in a more methodical way (Kim et al., 2005). As most of the operation performance indicators of PRH PPP projects are qualitative (Yuan et al., 2018), it is difficult to evaluate through other quantitative approach. Thus, the AHP method is more suitable for this study.

The AHP method was developed by Saaty (1980) and used to structure complex decision problems as a three-level hierarchy of goal, criteria and subcriteria (alternatives), and make pairwise comparison of elements at each level of the hierarchy in order to rank the available alternatives on the overall objective (Kablan, 2004; Tiwari & Banerjee, 2001). Based on experts' judgments, the criteria are compared through a pairwise way to determine how they contribute to the goal, and indicators under each criterion are compared in the same way (Wei, Liu, & Yong, 2016). AHP has become one of the most widely-used weight estimation technique in the analysis of performance measurement. Kim et al. (2005) applied the AHP analysis to calculate and analyze the weights of indicator and indicator category of a housing performance evaluation model. Moreover, as a weight estimation technique for assigning weights to indices, AHP has been broadly used in the performance evaluation in many areas. Related application can be found in coastal reclamation suitability (Feng, Zhu, & Sun, 2014), knowledge management adoption in supply chain (Patil & Kant, 2014), safety in coal mine (Liu, Zhang, & Wu, 2011; Wu & Hu, 2011), and wastewater treatment (Wei et al., 2016), etc.

Although the AHP can be used as a weight estimation technique for both qualitative and quantitative indicators, the evaluation of PRH PPP projects' operation performance has other problems like imprecision and uncertainty. Practitioners find it is easier to evaluate PIs in qualitative linguistic words (remarks) from experts, such as excellent, very good, good, fair, and poor (Chen, Hsieh, & Do, 2015; Y. Yu, Wu, N. Yu, & Wan, 2012) ,which are natural language rather than strict numbers. To address these problems, the Fuzzy comprehensive evaluation (FCE) method as a branch of fuzzy set theory can represent and manipulate "fuzzy" terms using membership degree in the set rather than strict true or false membership (Ameyaw & Chan, 2015). In a fuzzy environment, the evaluation words from experts are called linguistic variables, and FCE offers a way to define these variables mathematically and objectively (Ameyaw & Chan, 2015; Zadeh 1965, 1975). This enables FCE to be used for modeling and quantifying the fuzzy variables for performance level of a project (Ma & Chen, 2010; Zheng, Le, Chan, Hu, & Li, 2016).

Besides, FCE is also suitable for synthetic evaluation in a complex multi-objective and multi-participant context involving conflicting goals (Li, Ng, & Skitmore, 2013), which characterizes operation performance measurement decision process of PRH PPP projects (Fan & Lu, 2014). In order to evaluate a project's operation performance, relevant PIs may be classified into packages due to the characteristics of evaluation object (Shao, Liang, Yan, Qin, & Xiang, 2014). Therefore, multi-level FCE can be adopted to evaluate synthetically from lowest-level operation performance to the top-level and obtain the overall performance level consequently (Ameyaw & Chan, 2015; Hsiao, 1998; Shao et al., 2014).

Since the FCE method specializes in dealing with impressive, qualitative and multi-level problems, its application of fuzzy techniques in performance measurement appears to be very promising. A number of researchers have attempted to exploit the FCE method in the field of project performance measurement. Li et al. (2013) developed a multi-factor hierarchical FCE model to measure the performance of major infrastructure and construction projects through stakeholders' satisfaction. The FCE approach was also used to assess the risk level of water supply PPP projects in developing countries (Ameyaw & Chan, 2015). Using the FCE method, a housing performance evaluation model for multi-family residential buildings in Korea was established (Kim et al., 2005).

Based on the combined evaluation method of AHP and FCE, many prior studies have already conducted some performance evaluation issues such as facility layout design improvement for manufacturing and service organizations (Shahin & Poormostafa, 2011), real estate investment environment evaluation for the investment decision of real estate project (Shuai & He, 2012), green logistic performance in urban planning area (Ma & Chen, 2010), housing performance for homebuyers' decision-making of multi-family residential buildings (Kim et al., 2005), risk assessment of water inrush (Chu et al., 2017), and safety production evaluation in coal mine (Wu & Hu, 2011) etc. Above studies demonstrate that a FACE method with the combination of the two methods (i.e., AHP and FCE) can be employed as an efficient way to measure the operation performance of PRH in PPPs. In this research, the AHP method is used as a weight estimation technique to determine the weights of PIs, and the FCE method utilizes linguistic variables of performance evaluation to obtain the performance level of PRH projects delivery by PPPs. Wu and Hu (2011) proposed a fuzzy-AHP comprehensive evaluation method and showed the method's efficiency to solve the complexity and multi-level of safety performance measurement of coal mines.

2. Research method

A FACE method is adopted to measure the operation performance of PRH PPP projects. The procedure can be refined into five steps:

1. Determine the evaluation indicator system and evaluation sets;
2. Calculate the weights of each package and indicator in the evaluation indicator system;
3. Determine the evaluation criteria and rules;
4. Determine the membership grade of the evaluation indicators;
5. Establish the multi-level FCE model. The detailed explanation of each step is given below.

2.1. Step 1: Determine an evaluation indicator system and evaluation sets

In the prior study (Yuan et al., 2018), the authors identified an performance indicator system for PRH PPP projects. Firstly, a thorough analysis of previous studies, e.g., Yang and Chen (2014), Liu et al. (2014), Fan and Lu (2014) was conducted to identify possible OPIs based on stakeholders' satisfaction and overall stage of a PRH PPP project, that is, from decision-making, designing, construction to the operation. Secondly, the initial indicator system was further verified by experts with experience in PRH PPP research and practice. As a result, an indicator system of four indicator packages (i.e., *housing allocation and recycling efficiency* (OPI_1)*, project spatial distribution* (OPI_2)*, living environment* (OPI_3), and *financial situation of the project* (OPI_4) and relevant 21 OPIs were generated for PRH delivery by PPPs as presented in Table 1.

In the performance indicator system, the four indicator packages (OPI_1, OPI_2, OPI_3, and OPI_4) are the critical aspects for the operation of PRH PPP projects, which should be performed well to enable its sustainable development and achieve stakeholders' requirements including government's overall strategic plan, private sector's profit

Table 1. Evaluation indicator system of operation performance of PRH PPPs projects (source: Yuan et al., 2018)

Goal	Packages	Indicators
Operation performance of PRH projects in PPPs	OPI_1 Housing allocation and recycling efficiency	$OPI_{1\text{-}1}$ The rationality of access criteria
		$OPI_{1\text{-}2}$ The rationality of queuing and exit mechanisms
		$OPI_{1\text{-}3}$ The timeliness of dynamic information management and the efficiency of information feedback
		$OPI_{1\text{-}4}$ The strictness of professional supervision department
		$OPI_{1\text{-}5}$ The degree of information disclosure
	OPI_2 Project spatial distribution	$OPI_{2\text{-}1}$ The reasonableness of project location
		$OPI_{2\text{-}2}$ The size of project
		$OPI_{2\text{-}3}$ The intensity of land use
		$OPI_{2\text{-}4}$ The mixing degree of "mixed-income housing"
	OPI_3 Living environment	$OPI_{3\text{-}1}$ The perfection degree of public facilities in surrounding region
		$OPI_{3\text{-}2}$ The rationality of transport planning
		$OPI_{3\text{-}3}$ Living space per capita
		$OPI_{3\text{-}4}$ Living cost per capita
		$OPI_{3\text{-}5}$ The rationality of housing design
		$OPI_{3\text{-}6}$ The perfection degree of community public facilities
		$OPI_{3\text{-}7}$ The perfection degree of facility management
		$OPI_{3\text{-}8}$ Occupancy rate/occupancy growth rate
	OPI_4 Financial status of the project	$OPI_{4\text{-}1}$ The ability of budget control for public sectors
		$OPI_{4\text{-}2}$ The ability of life-cycle cost control for private sectors
		$OPI_{4\text{-}3}$ The return of related commercial facilities
		$OPI_{4\text{-}4}$ The incentive level of related policies on private sectors

objective, and users' expectations for quality and services (Yuan et al., 2009). During the operation stage of PRH PPP projects, the main participants are the public sector, operators (private sectors), and the tenants. For the indicator package OPI_1 (*housing allocation and recycling efficiency*), an effective housing allocation and recycling system can ensure tenants' rights to rent PRH and avoid the inequity, which is the prerequisite for meeting their demands. After the applicants pass the qualification examination and become the potential tenants, the spatial distribution and living environment of project (i.e., indicator package OPI_2 and OPI_3) are their most concerned, which determine their satisfaction with PRH units (Gan, Zuo, Chang, Li, & Zillante, 2016a; Ibem & Aduwo, 2013; Mohit & Azim, 2012). If these two aspects of PRH cannot meet their requirements, the potential tenants may even abandon their applications. For other participants, the public sector tends to alleviate the financial and managerial constrains and provide more quality PRH projects through attracting private investment by PPPs. However, the real attractiveness for private sectors is the long-term and stable cash flow during the operation stage of the PRH PPP project (Li et al., 2016b). Accordingly, from the perspectives of the public and private sector, the financial situation of PRH PPP projects (i.e., indicator package OPI_4, *financial situation of the project*) is a very important aspect to achieve their satisfaction and the sustainability of the projects.

On the other hand, from the perspective of lifecycle management of PRH PPP project, the operation performance is not only focusing on this stage, but also considering the comprehensive effect of the performance of all previous stages (including decision-making, design, and construction performance). In other words, the operation performance could be greatly influenced by the inputs and outputs of each stage in the lifecycle. Finally, the operation performance can be reflected due to cumulative effects from all previous stages' performance (Liu et al., 2016).

For example, in the decision-making stage, normative access, queuing and exit mechanism made by the decision-makers (government) can improve the housing allocation efficiency for the PRH operation. Moreover, in the design stage, whether the physical design aspects of the housing area such as ventilation, lighting, bathroom, common areas are reasonable impacts directly the housing satisfaction and then the final occupancy rate (occupancy rate indicates the tenants agree to live in the PRH units with satisfaction) of PRH project. In the construction stage, poor quality, delay completion and cost overruns may lead to downfall of product or service performance and negatively influence the public trust on the PRH project. While the good construction performance can increase the public's favorable opinions of the project and has positive impact on the residents' renting choice towards the PRH units. As shown in Figure 1, these indicators in different stages impact the operation performance of PRH PPPs projects during their life cycles. Although the work is completed at each stage, the performance of related work throughout the lifecycle (not simply the work at the operation stage) of the PRH PPPs project will finally affect the stakeholders' satisfaction when the project operates. That is, if measuring the performance at the operation stage of PRH PPPs project, the operation performance is the cumulative effects through the implementation of the entire project. In this way, the poor operation performance can be adjusted and improved dynamically and timely through focusing on corresponding aspects of the decision-making performance, design performance or construction performance in the next similar projects.

Based on these four significant aspects of operation performance for PRH PPP projects, the related 21 OPIs were then identified by the authors from the perspectives of project lifecycle management and the satisfaction of different stakeholders (i.e. public sectors, operators, and tenants). Thus, this system is a process-based indicator system for the PRH PPP project focusing on the requirements of different stakeholders.

As seen from the Table 1, the evaluation indicator system for operation performance of PRH PPP projects can be divided into three layers. The topmost layer U is the goal of the operation performance. Four indicator packages including OPI_1, OPI_2, OPI_3 and OPI_4 are defined as the second layer as:

$$U = (u_1, u_2, u_3, u_4). \quad (1)$$

The third layer of the evaluation indicator system, which interprets concretely the meaning of the second layer, consist of 21 OPIs within each package and given as:

$$u_1 = (u_{11}, u_{12}, u_{13}, u_{14}, u_{15}); \quad (2)$$

$$u_2 = (u_{21}, u_{22}, u_{23}, u_{24}); \quad (3)$$

$$u_3 = (u_{31}, u_{32}, u_{33}, u_{34}, u_{35}, u_{36}, u_{37}, u_{38}); \quad (4)$$

$$u_4 = (u_{41}, u_{42}, u_{43}, u_{44}). \quad (5)$$

2.2. Step 2: calculate the weighting functions of each package and indicator

Weights of four packages and 21 indicators can be obtained by the AHP method. Although there are two kinds of structures of the three-level hierarchy from the topmost level to the lowest level in AHP problems, i.e. goal-criteria-alternatives and goal-criteria-subcriteria (Triantaphyllou & Mann, 1995; Feng et al., 2014; Wei et al., 2016; Saaty, 1990), to avoid ambiguity arising from word "alternatives" (model can also have "alternatives"), the latter may be more appropriate (Saaty, 1990). Thus, the second structure (goal-criteria-subcriteria) was adopted in this study. Three-level hierarchy of the AHP method in this study was presented in Figure 2. The topmost level as the goal is the operation performance of PRH PPPs project, the level of criteria are the four packages including OPI_1, OPI_2, OPI_3, OPI_4, and the lowest level as the subcriteria are the 21 indicators under these four packages.

The priories of each package and indicator under each package were determined through a questionnaire survey. As the AHP method is a decision analysis method rather than a statistical analysis method, it is especially superior for small sample problems. Too large sample size may make the results fail to pass the consistency test and cannot be used (Saaty, 1990). Therefore, the expert panel size in this survey for determining the weights through AHP is not large, while only the experts are very familiar with the research topic and able to make professional judgement based on their expertise (Feng et al., 2014; Wei et al., 2016). The size of experts in similar studies using AHP method is usually 20–30 (Feng et al., 2014; Wei et al., 2016; Wu & Hu, 2011). Thus, total 20 respondents of the questionnaires including relevant experts of universities, government, private sectors and the public were invited in this study. As the performance of PRH PPPs projects is a management tool for the government to supervise the private sectors to achieve the public's requirements (Hu, 2011). Thus, the standpoints of the government, private sectors and the public should be considered comprehensively. Besides, considering the professional knowledge of

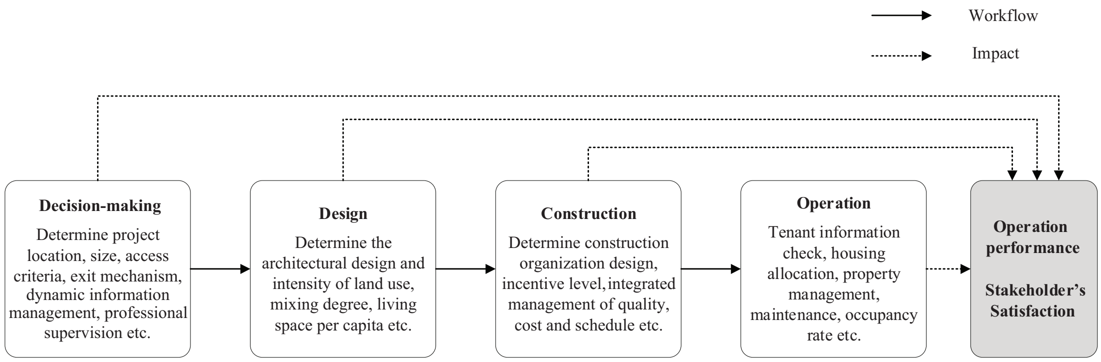

Figure 1. The implemented work at each stage of the PRH PPP project and their impacts on the OP

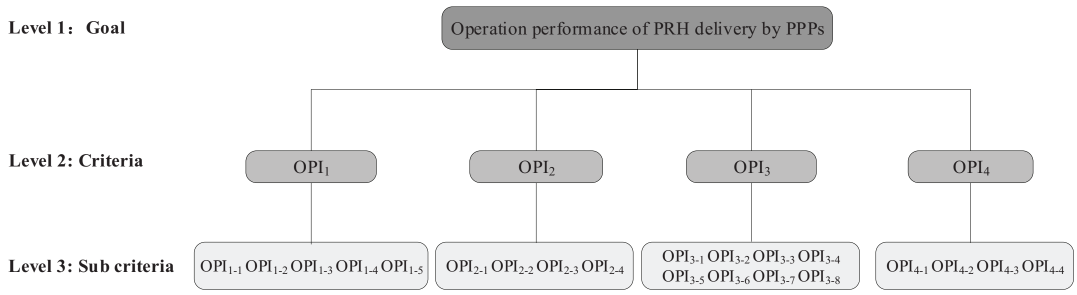

Figure 2. Three layers of operation performance indicator system for PRH delivery by PPPs

scholars in the PRH field, the percentage of universities, government, private sectors and the public is 25%, 35%, 20% and 20%, respectively. In addition, to ensure the reliability of the survey results, there are some experienced experts (five experts) engaged in the field of PRH projects for more than 10 years, and tenants (four tenants) who have or had lived in a PRH unit were also invited to express their opinions (see Table 2).

The relative importance of elements was compared pairwise with respect to a specific element in the layer above. According to the rules determined by Saaty (1990)'s 9-point scale (see Table 3), the experts were asked to make pairwise comparisons at each layer. A judgment matrix (A) of pairwise comparisons for elements X (packages or indicators under one package) can be written as follows (Feng et al., 2014):

$$A = \left(a_{ij}\right)_{n \times m} = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix}, \quad (6)$$

where: a_{ij} represents a quantified judgment by experts on the comparison of element X_i to element X_j; n is the order of matrix A. And the judgment matrix A is reciprocal matrix with $a_{ij} > 0$, $a_{ij} = 1/ a_{ji}$, $a_{ij} = 1(I = j = 1,2,\ldots,n)$ $a_{ij} > 0$,

Table 2. Profile of respondents

	Respondents	Valid questionnaire	Percentage
The role of respondents	Government officer	7	35%
	Managers for private sectors	4	20%
	The general public	4	20%
	Researchers	5	25%
	Total	20	100%
The experiences of respondents	Experiences	In PRH	Percentage
	≤5 years	7	35%
	6–10 years	8	40%
	11–15 years	3	15%
	≥16 years	2	10%
	Total	20	100%

Table 3. Number scale and its description of the relative important comparison

Scale	The description of scale	Explanation
$a_{ij} = 1$	Equal importance	The elements X_i and X_j contribute equally to the objective
$a_{ij} = 3$	Moderate importance	Experience and judgment slightly favor activity X_i over X_j
$a_{ij} = 5$	Strong importance	Experience and judgment strongly favor activity X_i over X_j
$a_{ij} = 7$	Very strong importance	Experience and judgment very strongly favor activity X_i over X_j
$a_{ij} = 9$	Extreme importance	The evidence favor X_i over X_j is of highest possible order of affirmation
$a_{ij} = 2,4,6,8$	Intermediate values between the above values	A compromise judgment numerically on the elements X_i and X_j
Reciprocals of above	The comparison value is a_{ij}	The element X_j compared with the element X_i

$a_{ij} = 1/a_{ij}$, $a_{ij} = 1$ ($i = j = 1,2,\ldots, n$). The scale of a_{ij} with its description and explanation are shown in Table 3.

The next step of calculating weights is to solve the judgment matrix and obtain the eigenvector and eigenvalue using the following equation:

$$AW = \lambda_{\max} W, \tag{7}$$

where: $\lambda_{\max}$ is the maximum eigenvalue of matrix A; W is the corresponding eigenvector. $\lambda_{\max}$ and W were calculated by using the software Matlab. After normalization of W, a new eigenvector matrix W^* was obtained as the weight vector of corresponding elements (packages or indicators under one package) as follows:

$$W^* = \left(w_1, w_2, \ldots, w_n\right)^T, \tag{8}$$

where: n is the number of the eigenvector matrix.

Moreover, a consistency test must be carried out to verify whether the weight distribution above can factually and logically reflect the importance of the judgment matrix. This test can be carried out through the following equation (Wu & Hu, 2011):

$$C.R. = \frac{C.I.}{R.I.} = \frac{(\lambda_{\max} - n)/(n-1)}{R.I.}, \tag{9}$$

where: $C.R.$ is the consistency ratio of judgment matrix; $C.I.$ is the consistency index; $R.I.$ is average random consistency index, and the value of it can be get by a look-up table as shown in Table 4 (Saaty, 1980).

Table 4. The average random consistency index (*R.I.*)

n	1	2	3	4	5	6	7	8	9	10	11	12	13	14
R.I.	0	0	0.52	0.89	1.12	1.26	1.36	1.41	1.46	1.49	1.52	1.54	1.56	1.58

If

$$C.R. = \begin{cases} < 0.1 & \textit{acceptable} \\ \geq 0.1 & \textit{unacceptable}. \end{cases} \tag{10}$$

When $C.R.$ is acceptable, it means that the weight distribution is rational; otherwise, it means the matrix must be adjusted to make the consistency test satisfied (Chu et al., 2017). Finally, the judgment matrices of packages and indicators under each package all satisfied the consistency test. Hence, their corresponding eigenvectors can be regarded as the weighting function set of packages and indicators as follows:

$$W_u = \left(w_1, w_2, \ldots, w_k\right); \tag{11}$$

$$W_{uk} = \left(w_{k1}, w_{k2}, \ldots, w_{kq}\right), \tag{12}$$

where: W_U is the weighting function set of the four packages; k is the number of packages (k = 1, 2, 3, and 4); W_{uk} is the weighting function set of the indicators under each package; q is the number of indicators under this package.

Thus, following the above steps, the weights of four indicators packages, weights of the OPIs under each package of PRH PPP projects and the $C.R.$ value for each matrix can be obtained through the Eq. (7) to (12):

$$W_U = \left(w_1, w_2, w_3, w_4\right) = \left(0.2622, 0.1175, 0.5650, 0.0553\right)$$

$$(C.R. = 0.0438 < 0.1, \text{acceptable}); \tag{13}$$

$$W_{u_1} = \left(w_{11}, w_{12}, w_{13}, w_{14}, w_{15}\right) = \left(0.3621, 0.3621, 0.1607, 0.0762, 0.0389\right)$$

$$(C.R. = 0.0304 < 0.1, \text{acceptable}); \tag{14}$$

$$W_{u_2} = \left(w_{21}, w_{22}, w_{23}, w_{24}\right) = \left(0.5650, 0.2622, 0.0553, 0.1175\right)$$

$$(C.R. = 0.0438 < 0.1, \text{acceptable}); \tag{15}$$

$$W_{u_3} = \left(w_{31}, w_{32}, w_{33}, w_{34}, w_{35}, w_{36}, w_{37}, w_{38}\right) = \left(0.0668, 0.1574, 0.0190, 0.3364, 0.1250, 0.1053, 0.0327, 0.1574\right)$$

$$(C.R. = 0.0680 < 0.1, \text{acceptable}); \tag{16}$$

$$W_{u_4} = \left(w_{41}, w_{42}, w_{43}, w_{44}\right) = \left(0.3199, 0.3199, 0.1524, 0.2079\right)$$

$$(C.R. = 0.0163 < 0.1, \text{acceptable}). \tag{17}$$

2.3. Step 3: Determine the evaluation criteria and rules

The evaluation criteria are assumed as:

$$V = \left(v_1, v_2, \ldots\ldots, v_p\right), \tag{18}$$

where: v_p means the comments given by experts; p is the number of ranks. Considering that the performance measurement of PRH PPP project is not to evaluate the best performance, but for performance improvement after evaluation. Thus, based on literature review in related field (Feng et al., 2014; Kim et al., 2005; Wu & Hu, 2011) and expert consultation, five ranks of comment were chosen in the method: v_1 = excellent, v_2 = good, v_3 = qualified, v_4 = improvable and v_5 = unacceptable (p = 1, 2, 3, 4, and 5). Moreover, the corresponding scores (numerical value) of these five ranks are 100, 90, 80, 70, and 60, respectively (See Table 5).

Table 5. Evaluation criteria and rules for PRH PPP projects

Evaluation criteria	Numerical value	Performance level
excellent	100	The performance can completely support the prospective change of the stakeholders' requirements
good	90	The performance can basically support the prospective change of the stakeholders' requirements
qualified	80	The performance can meet the stakeholders' requirements
improvable	70	The performance can meet the stakeholders' basic requirements
unacceptable	60	The performance cannot meet the stakeholders' basic requirements

These scores of evaluation criteria form a set *C* (Wu & Hu, 2011):

$$C = (100, 90, 80, 70, 60). \tag{19}$$

Based on the available literatures and the five ranks of evaluation criteria, the evaluation rules for the performance evaluation indicators were established in Table A1.

2.4. Step 4: Determine the membership grade of the evaluation indicators

This step is a set of fuzzy mapping revealing relationship between the indicator set *U* and evaluation criteria set *V* by membership functions (You & Zhang, 2017):

$$f : U \rightarrow V : u_q \rightarrow f(u_q) = (r_{q1}, r_{q2}, \ldots, r_{qp}), \tag{20}$$

where: u_q the evaluation indicator; *q* is the number of indicators under one package; r_{qp} is the membership grade of the *q*-th indicator to the *p*-th evaluation rank in the evaluation criteria set *V*. The fuzzy evaluation membership matrix *R* can be expressed as:

$$R = (r_{mn})_{q \times p} = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1p} \\ r_{21} & r_{22} & \cdots & r_{2p} \\ . & . & . & . \\ . & . & . & . \\ . & . & . & . \\ r_{q1} & r_{q2} & \cdots & r_{qp} \end{bmatrix}. \tag{21}$$

In this process, different methods should be taken to determine membership of quantitative and qualitative indicators.

For quantitative evaluation indicators, membership grade of each level can be determined by piecewise linear function in fuzzy mathematics (Wei et al., 2016). According to the classifying standard of evaluation rules in Table A1 and the actual value of these indicators, the membership grades of nine quantitative evaluation indicators to the grading level set can be obtained by applying the above calculating method, and the evaluation matrices can be produced. Taking "*The size of project*" ($OPI_{2\text{-}2}$) of a PRH PPP project as an example, the actual value of this indicator is 24,000 occupants (x_{2-2}), and the number of this indicator *q* is 2 under the second package, hence the membership function of it can be given as follows:

$$\begin{array}{ll} r_{21} = 0 & x_{2\text{-}2}{}^{3}25000 \\ r_{22} = 1 & 10000 \le x_{2\text{-}2} < 25000 \\ r_{23} = 0 & 5000 \le x_{2\text{-}2} < 10000 \\ r_{24} = 0 & 2500 \le x_{2\text{-}2} < 5000 \\ r_{25} = 0 & x_{2\text{-}2} < 2500. \end{array} \tag{22}$$

Therefore, the membership grade of $OPI_{2\text{-}2}$ is $(0,1,0,0,0)$, the evaluation criteria of $OPI_{2\text{-}2}$ is "good", and the score (numerical value) is 90 according to Table 5. Similarly, the membership grade of other quantitative evaluation indicators can be obtained.

For the qualitative evaluation indicators, the membership grade of a given indicator u_q can be obtained through the following equation (Feng et al., 2014):

$$R_q = (t_{1uq}, t_{2uq}, t_{3uq}, \ldots, t_{puq}) = (r_{q1}, r_{q2}, r_{q3}, \ldots, r_{qn}), \tag{23}$$

where: u_q represents the *q*-th indicator under one package of the evaluation indicator system; R_q is the membership function of a specific indicator u_q; t_{puq} (p = 1, 2, 3, 4, 5) is the percentage of the experts from the judgment group who scored the *p*-th evaluation rank for this specific indicator u_q, that is, the grade of membership function r_{qp}. For a specific indicator u_q, the value of t_{puq} ranges between [0,1] and the summation of all the t_{puq} must equal to 1:

$$0 < t_{puq} \le 1, \sum_{p=1}^{5} t_{puq} = 1. \tag{24}$$

2.5. Step 5: establish a multi-level Fuzzy Comprehensive Evaluation model

After determining the indicator system, weights of packages and indicators, and evaluation rules, the operation performance of a project can be evaluated by a multi-level FCE model. Since there are three layers in the evaluation indicator system as shown in Figure 2, two-level fuzzy composite operation should be conducted.

With the weights and membership grades of 21 evaluation indicators (the lowest/third level indicator), the first grade FCE was made as follows (Yu et al., 2012):

$$B_k = W_{uk} \times R_k = (w_{k1}, w_{k2}, \ldots\ldots, w_{kq}) \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1p} \\ r_{21} & r_{22} & \cdots & r_{2p} \\ . & . & . & . \\ . & . & . & . \\ . & . & . & . \\ r_{q1} & r_{q2} & \cdots & r_{qp} \end{bmatrix} = (b_{k1}, b_{k2}, \ldots\ldots, b_{kq}); \tag{25}$$

$$B = \begin{bmatrix} B_1 \\ B_2 \\ . \\ . \\ . \\ B_q \end{bmatrix} = \begin{bmatrix} b_{11} & b_{12} & \cdots & b_{1p} \\ b_{21} & b_{22} & \cdots & b_{2p} \\ . & . & . & . \\ . & . & . & . \\ . & . & . & . \\ b_{q1} & b_{q2} & \cdots & b_{qp} \end{bmatrix}, \tag{26}$$

where: B_k is the fuzzy evaluation membership grade of each package (the second level indicators); *k* is the number of packages; W_{uk} is the weight distribution vector of indicators under *k*-th package; *q* is the number of indicators under this package; R_k is the membership matrix of each indicator under the *k*-th package; r_{qp} is the membership grade of the *q*-th indicator to the *p*-th evaluation rank in the evaluation criteria set; *B* is the fuzzy judgment matrix for the second level indicators.

According to the membership grade and the weight vector of packages, the second grade FCE was then yielded as follows:

$$R^* = W_U \times B = \left(w_1, w_2, \ldots\ldots, w_q\right) \begin{bmatrix} b_{11} & b_{12} & \ldots & b_{1p} \\ b_{21} & b_{22} & \ldots & b_{2p} \\ . & . & . & . \\ . & . & . & . \\ . & . & . & . \\ b_{q1} & b_{q2} & \ldots & b_{qp} \end{bmatrix} = \quad (27)$$

$$\left(b_1, b_2, \ldots\ldots, b_q\right),$$

where: W_U is the weighting function set of the four packages; R^* is the fuzzy evaluation membership grade for a PRH PPP project's operation performance (the first level), which can be quantified by considering the adopted grade alternatives (p = 1, 2, 3, 4, 5) using the following equation:

$$P = R^* \times C^T = \left(r_1, r_2, \ldots, r_p\right) \begin{bmatrix} 100 \\ 90 \\ 80 \\ 70 \\ 60 \end{bmatrix} = \quad (28)$$

$$100 \times r_1 + 90 \times r_2 + 80 \times r_3 + 70 \times r_4 + 60 \times r_5 .$$

3. A case study in Nanjing

3.1. Basic information

In 2009, PRH in China was first launched officially by then-premier Wen Jiabao on the government work report. PRH projects have been developed rapidly nationwide because of the great efforts of governments in China at all levels. Actually, when these projects were put into operation, very few PRH units were rent out (e.g., only 5% in Nanjing, 39% in Shanghai, and 35% in Wuhan), although the rent was relatively low (on average, 60–70% lower than market rent level) and the demand was enormous (Lin, 2012; Yuan, Zheng, You, & Skibniewski, 2017). This phenomenon indicated that the supply of PRH projects were inefficient. Besides, to step out of current puzzle of local government's huge financial burden, China started to adopt the PPPs approach with the private sectors' participation to develop PRH in 2015. Under these circumstances, the operation performance for PRH in PPPs are more complicated due to the benefits of tenants and private sectors should be given careful consideration.

Thus, to exemplify above proposed method and provide an effective way for operation performance measurement, a prospective PRH PPP project in Qixia District of Nanjing city (the capital of Jiangsu Province in Eastern China) is chosen as the only case for this study. This project is financed, built and operated for a period by a company temporarily titled NCG (Nanjing Communications Group) (private sector). This is a PRH PPP project with practical data. The construction period is three years and the operation period is two years so far. Detailed data information of this project illustrated in Table 6 is extracted from some of its documents and obtained through field research.

Table 6. Detailed information for a PRH PPP project performance evaluation case

Indicators	Project Information	Information sources (In Chinese)
$OPI_{1\text{-}1}$ The rationality of access criteria	1.Target tenants should be low- and middle- income families with housing difficulties, new employment and migrant workers in Nanjing; 2.Target tenants' income and present housing area should be examined.	Measures for the administration of Public Rental Housing in Nanjing http://www.nanjing.gov.cn/xxgk/bm/zjw_68249/201603/t20160330_3890033.html
$OPI_{1\text{-}2}$ The rationality of queuing and exit mechanisms	1. Implement multi-channel queuing system to allocate the PRH, e.g. operating a lottery system for allocation and nearby settlement mechanisms; 2. Exit mechanisms: tenants who are no longer eligible for PRH, but meet the standards of Economically Affordable Housing (EAH) can be transferred to the EAH system; if the tenants do not meet standards of any affordable housing system, they can only exit this system.	
$OPI_{1\text{-}3}$ The timeliness of dynamic information management and the efficiency of information feedback	1. Set city-level and district-level housing security management office; 2. Enhance dynamic management and establish housing archives for low-income families with housing difficulties; 3. Introduce social credit investigation mechanism and establish personal credibility declaration, offer audit, community review, and information disclosure etc.	Nanjing Housing Security and Real Estate Management Bureau http://fcj.nanjing.gov.cn/zfbz/
$OPI_{1\text{-}4}$ The strictness of professional supervision department	1. Nanjing Housing and Urban Rural Development Committee (NHURDC) is responsible for the overall management and supervision work; 2. Nanjing housing security office is responsible for the daily management; 3. The taxation authorities are responsible for the implementation of preferential policies; 4. The police departments are responsible for managing the floating population; 5. The supervision department is responsible for the whole process supervision and governance.	Measures for the administration of Public Rental Housing in Nanjing http://www.nanjing.gov.cn/xxgk/bm/zjw_68249/201603/t20160330_3890033.html
$OPI_{1\text{-}5}$ The degree of information disclosure	1. The website of Nanjing Housing Security and Real Estate Management Bureau regularly makes public the basic information of the affordable housing projects that have been started in this year; 2. Makes public quarterly the list of person that have rental subsidies.	Nanjing Housing Security and Real Estate Management Bureau http://fcj.nanjing.gov.cn/zfbz/

End of Tale 6

Indicators	Project Information	Information sources (In Chinese)
$OPI_{2\text{-}1}$ The reasonableness of project location	1. The project is located in the Pioneer Park; 2. A logistics distribution center is in the west of project, a company office area is in its south, a university, a research institute and residential areas are in its east; 3. The project location connects the main city and the center of Qixia district, and the south of project faces two mountains.	Regulatory detailed planning documents of this project http://www.house365.com/planinfo/record.php?threadid=303&pn=9
$OPI_{2\text{-}2}$ The size of project	1.Total land area is 850000 m^2, the used land for building is 440000 m^2, total floorage is 1760000 m^2; 2. Related road area of the project is 170000 m^2, green area is 60000 m^2, public facilities area is 57000 m^2, school area is 70000 m^2; 3. Total number of planned families of residents is 21000 households, and residential population is about 41700.	
$OPI_{2\text{-}3}$ The intensity of land use	1. Floor area ratio should be less than 3.5, building density and ratio of green space are 25.3% and 33.5% respectively; 2. Actual floor area ratio and ratio of green space are 2.2 and 35% respectively.	
$OPI_{2\text{-}4}$ The mixing degree of "mixed-income housing"	1. There are 4800 sets of PRH and 2500 sets of EAH in this community; 2. Commercial housing residential area has been built on the east side of the project.	
$OPI_{3\text{-}1}$ The perfection degree of public facilities in surrounding region	There are three kindergartens, one primary school, one middle school, one farmer's market, one nursing home, some commercial facilities, one theater, two youth cultural centers and two health service centers in this region.	Regulatory detailed planning documents of this project http://www.house365.com/planinfo/record.php?threadid=303&pn=9
$OPI_{3\text{-}2}$ The rationality of transport planning	1. There are three main roads docking with the main city road network completely and rapidly; 2. The project is located at the last station of Metro Line one; 3. There is a quite convenient traffic with dozens of bus routes around the project including bus route 311, 76, 145, 73, 77, and 114 etc.	
$OPI_{3\text{-}3}$ Living space per capita	Living space per capita of Nanjing is 39.5 m^2, living space per capita of PRH project is about 15 m^2.	Field research
$OPI_{3\text{-}4}$ Living cost per capita	1. The Rents (including property costs) of PRH should be no more than 70% rents of similar commercial housing in the same area; 2. Tenants of PRH should pay 6 months' rents as cash deposit; 3. The rent of commercial housing around community is about 20–30 CNY per square meter, and the rent of PRH is 11 CNY per square meter (including property costs and public service fee).	
$OPI_{3\text{-}5}$ The rationality of housing design	1. Apply new materials, new products and new technologies; 2. Ensure green, energy saving and environmental protection; 3. The area of main apartment layout is 40–80 m^2.	
$OPI_{3\text{-}6}$ The perfection degree of community public facilities	1. One community center; 2.One citizen leisure square; 3. One commercial building; 4. About 6200 parking spaces for cars.	
$OPI_{3\text{-}7}$ The perfection degree of facility management	1. Facility management company is responsible for daily security, cleaning, landscaping, fire management, maintenance and customer service, etc. 2. Property costs is about 0.95 CNY per square meter.	
$OPI_{3\text{-}8}$ Occupancy rate	As of the investigation day, the occupancy rate reached 70.51%.	
$OPI_{4\text{-}1}$ The ability of budget control for public sectors	VfM of this project is 87.13 million CNY (0 < 87.13 million CNY < 10% of life-cycle cost of project construction 8355.26 million CNY = 835.526 million CNY), which means that using PPPs mode can save government budget.	Related documents and information of this project provided by Nanjing Anju Construction Group. http://www.njajjt.com/index.php
$OPI_{4\text{-}2}$ The ability of life-cycle cost control for private sectors	Total investment is 8355.26 million CNY, the project construction period is 3 years. The construction costs are under control.	
$OPI_{4\text{-}3}$ The return of related commercial facilities	The demands for these commercial facilities are high because the project location and the project scale. Letting rate of shops of the first year is 100%, and the rate of rents received is 100%.	Field research
$OPI_{4\text{-}4}$ The incentive level of related policies on private sectors	1. Administrative fees and government funds are reduced referring the preferential policies of PRH; 2. Land is provided to SPV for special purpose, and the preconditions of land supply (such as facilities supporting conditions) are defined well; 3. Government may provide partial subsidies to SPV to make up for the difference between the PRH rents and commercial rents; 4. Some taxes are exempted including urban land use tax, stamp duty, deed tax, sales tax, property tax, etc.	Consulting the construction company NCG

3.2. Application of the FACE approach

Using information from the case presented above, measurement of operation performance of this PRH PPP project can be conducted using the proposed FACE approach.

3.2.1. Score performance indicators and calculate the membership grades

To ensure the professionalism and reliability of the evaluation, five experts most relevant to this project from government departments, construction and operation sectors were invited to score the 21 performance indicators in Table 6 according to the evaluation rules in Table A1. Since there are two types of indicator in the evaluation indicator system (See Table A1), quantitative indicator and qualitative indicator. The determination methods of their membership grade are different, so piecewise linear function in fuzzy mathematics was applied to determine membership grade of the quantitative evaluation indicators, and the membership grade of qualitative indicators was obtained by Eq. (23) as described in Section 2.4.

For the quantitative indicators (i.e., indicator OPI_{2-2}, OPI_{2-3}, OPI_{3-2}, OPI_{3-3}, OPI_{3-4}, OPI_{3-8}, OPI_{4-1}, OPI_{4-2}, and OPI_{4-3}), the membership grades of them can be obtained directly by their actual value in Table 6. Take the quantitative indicator OPI_{3-3} (*Living space per capita*) as an example, its value is determined by the ratio of living space per capita of PRH to the living space per capita of Nanjing according to the evaluation rules. The actual value of this indicator is shown in Table 6 in the third package (OPI_3). Therefore, this indicator's membership grade can be given as follows:

$$
\begin{array}{ll}
r_{31}=1 & 35\% \leq x_{3\text{-}3}=\dfrac{15}{39.5}=38\%<40\% \\
r_{32}=0 & 25\% \leq x_{3\text{-}3}<35\% \\
r_{33}=0 & 15\% \leq x_{3\text{-}3}<25\% \\
r_{34}=0 & 10\% \leq x_{3\text{-}3}<15\% \; or \; 40\% \leq x_{3\text{-}3}<50\% \\
r_{35}=0 & x_{3\text{-}3}<10\% \; or \; x_{3\text{-}3}{}^{3}50\%.
\end{array} \quad . \tag{29}
$$

Then, membership grade of OPI_{3-3} is calculated as (1,0,0,0,0).

For the qualitative indicators in the evaluation indicator system, their membership grades can be calculated from the collective evaluations of the five experts through Eq. (23). Using the qualitative indicator "*The rationality of access criteria*" (OPI_{1-1}) as an example, the survey results of five experts showed that the respondents evaluated the rank of its actual situation according evaluation rules as follows: 0 expert evaluated as "excellent"; 4 experts evaluated as "good"; 1 expert evaluated as "qualified"; 0 expert evaluated as "improvable"; 0 expert evaluated as "unacceptable". Hence, the membership grade of OPI_{1-1} is shown through Eq. (23) as: $(0,4/5,1/5,0,0)=(0,0.8,0.2,0,0)$. Based on these two approaches (i.e., approaches for determining membership grade of quantitative and qualitative indicators), the membership grades for all 21 evaluation indicators were determined (see Table 7).

Table 7. Membership grades of 21 performance indicators

Packages	Indicators	Indicator properties	Expert evaluation of indicators					Membership grades
			excellent	good	qualified	improvable	unacceptable	
OPI_1	OPI_{1-1}	Qualitative indicator	0	4/5 = 0.8	1/5 = 0.2	0	0	(0,0.8,0.2,0,0)
	OPI_{1-2}	Qualitative indicator	0	3/5 = 0.6	2/5 = 0.4	0	0	(0,0.6,0.4,0,0)
	OPI_{1-3}	Qualitative indicator	0	2/5 = 0.4	2/5 = 0.4	1/5 = 0.2	0	(0,0.4,0.4,0.2,0)
	OPI_{1-4}	Qualitative indicator	0	2/5 = 0.4	3/5 = 0.6	0	0	(0,0.4,0.6,0,0)
	OPI_{1-5}	Qualitative indicator	0	1/5 = 0.2	3/5 = 0.6	1/5 = 0.2	0	(0,0.2,0.6,0.2,0)
OPI_2	OPI_{2-1}	Qualitative indicator	0	3/5 = 0.6	2/5 = 0.4	0	0	(0,0.6,0.4,0,0)
	OPI_{2-2}	Quantitative indicator	0	1	0	0	0	(0,1,0,0,0)
	OPI_{2-3}	Quantitative indicator	1	0	0	0	0	(1,0,0,0,0)
	OPI_{2-4}	Qualitative indicator	0	3/5 = 0.6	2/5 = 0.4	0	0	(0,0.6,0.4,0,0)
OPI_3	OPI_{3-1}	Qualitative indicator	0	3/5 = 0.6	2/5 = 0.4	0	0	(0,0.6,0.4,0,0)
	OPI_{3-2}	Quantitative indicator	0	0	1	0	0	(0,0,1,0,0)
	OPI_{3-3}	Quantitative indicator	1	0	0	0	0	(1,0,0,0,0)
	OPI_{3-4}	Quantitative indicator	0	0	0	1	0	(0,0,0,1,0)
	OPI_{3-5}	Qualitative indicator	0	2/5 = 0.4	3/5 = 0.6	0	0	(0,0.4,0.6,0,0)
	OPI_{3-6}	Qualitative indicator	0	2/5 = 0.4	3/5 = 0.6	0	0	(0,0.4,0.6,0,0)
	OPI_{3-7}	Qualitative indicator	0	4/5 = 0.8	1/5 = 0.2	0	0	(0,0.8,0.2,0,0)
	OPI_{3-8}	Quantitative indicator	0	1	0	0	0	(0,1,0,0,0)
OPI_4	OPI_{4-1}	Quantitative indicator	0	0	1	0	0	(0,0,1,0,0)
	OPI_{4-2}	Quantitative indicator	0	0	1	0	0	(0,0,1,0,0)
	OPI_{4-3}	Quantitative indicator	1	0	0	0	0	(1,0,0,0,0)
	OPI_{4-4}	Qualitative indicator	1/5 = 0.2	4/5 = 0.8	0	0	0	(0.2,0.8,0,0,0)

3.2.2. Quantify operation performance of PRH PPP project

Recall that the FCE approach has three levels of membership grades, from level 3 to level 1as illustrated in Figure 2.

Level 3 (the lowest level) is derived from the survey based on experienced evaluations of 21 performance indicators from the five experts. The membership matrices of these indicators under each package are established and presented as follows:

$$R_1 = \begin{bmatrix} 0 & 0.8 & 0.2 & 0 & 0 \\ 0 & 0.6 & 0.4 & 0 & 0 \\ 0 & 0.4 & 0.4 & 0.2 & 0 \\ 0 & 0.4 & 0.6 & 0 & 0 \\ 0 & 0.2 & 0.6 & 0.2 & 0 \end{bmatrix} \quad R_2 = \begin{bmatrix} 0 & 0.6 & 0.4 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 \\ 0 & 0.6 & 0.4 & 0 & 0 \end{bmatrix}; \quad (30)$$

$$R_3 = \begin{bmatrix} 0 & 0.6 & 0.4 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0.4 & 0.6 & 0 & 0 \\ 0 & 0.4 & 0.6 & 0 & 0 \\ 0 & 0.8 & 0.2 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 \end{bmatrix} \quad R_4 = \begin{bmatrix} 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 \\ 0.2 & 0.8 & 0 & 0 & 0 \end{bmatrix}. \quad (31)$$

Moreover, the weights of four packages (W_U) and weights of indicators under these four packages $(W_{u_1}, W_{u_2}, W_{u_3}, W_{u_4})$ of PRH PPP projects have been calculated through the AHP method in section 2.2. The results are shown as follows:

$$W_U = (0.2622, 0.1175, 0.5650, 0.0553); \quad (32)$$

$$W_{u_1} = (0.3621, 0.3621, 0.1607, 0.0762, 0.0389); \quad (33)$$

$$W_{u_2} = (0.5650, 0.2622, 0.0553, 0.1175); \quad (34)$$

$$W_{u_3} = \begin{pmatrix} 0.0668, 0.1574, 0.0190, 0.3364, 0.1250, 0.1053, \\ 0.0327, 0.1574 \end{pmatrix}; \quad (35)$$

$$W_{u_4} = (0.3199, 0.3199, 0.1524, 0.2079). \quad (36)$$

Then, applying the weights of indicators under each package to this case, the membership grades of the second level corresponding to indicator packages of operation performance of this PRH PPP project are obtained through the first grade FCE. The calculation results are as follows:

$$B_1 = W_{u_1} \times R_1 = (0.3621, 0.3621, 0.1607, 0.0762, 0.0389) \begin{bmatrix} 0 & 0.8 & 0.2 & 0 & 0 \\ 0 & 0.6 & 0.4 & 0 & 0 \\ 0 & 0.4 & 0.4 & 0.2 & 0 \\ 0 & 0.4 & 0.6 & 0 & 0 \\ 0 & 0.2 & 0.6 & 0.2 & 0 \end{bmatrix} = (0, 0.609, 0.351, 0.040, 0); \quad (37)$$

$$B_2 = W_{u_2} \times R_2 = (0.055, 0.672, 0.273, 0, 0); \quad (38)$$

$$B_3 = W_{u_3} \times R_3 = (0.176, 0.158, 0.329, 0.336, 0); \quad (39)$$

$$B_4 = W_{u_4} \times R_4 = (0.194, 0.166, 0.640, 0, 0). \quad (40)$$

Therefore, the fuzzy judgment matrix of the four packages (the second-level indicator) can be established:

$$B = \begin{bmatrix} 0 & 0.609 & 0.351 & 0.040 & 0 \\ 0.055 & 0.672 & 0.273 & 0 & 0 \\ 0.176 & 0.158 & 0.329 & 0.336 & 0 \\ 0.194 & 0.166 & 0.640 & 0 & 0 \end{bmatrix}. \quad (41)$$

Given the weights of four packages as $W_U = (0.2622, 0.1175, 0.5650, 0.0553)$, and using Eq. (26), the final fuzzy evaluation matrix of overall operation performance level of this PRH PPP project is quantified as:

$$R^* = W_U \times B = (0.2622, 0.1175, 0.5650, 0.0553) \begin{bmatrix} 0 & 0.609 & 0.351 & 0.040 & 0 \\ 0.055 & 0.672 & 0.273 & 0 & 0 \\ 0.176 & 0.158 & 0.329 & 0.336 & 0 \\ 0.194 & 0.166 & 0.640 & 0 & 0 \end{bmatrix} = (0.117, 0.337, 0.345, 0.200, 0). \quad (42)$$

Therefore, the overall operation performance level of this PRH PPP project can be quantified through Eq. (28):

$$P = R^* \times C^T = (0.117, 0.337, 0.345, 0.200, 0) \begin{bmatrix} 100 \\ 90 \\ 80 \\ 70 \\ 60 \end{bmatrix} = 100 \times 0.117 + 90 \times 0.337 + 80 \times 0.345 + 70 \times 0.200 + 60 \times 0 = 84 \quad (43)$$

Similarly, based on the fuzzy comprehensive procedure, using the related membership grades and Eq. (28), the evaluation scores of 21 indicators and four packages are determined as presented in Table 8.

Due to $80 \le 84 < 90$, the overall operation performance of this PRH PPP project is "good". To verify the reliability of the evaluation results of the model, a semi-structured survey through a questionnaire was conducted with 30 experts of this project's related construction and operation departments, 87% of these respondents (26 respondents) were involved in the PRH project field for more than 10 years. Based on the evaluation rules of Table A1 and their practice experience of this PRH PPP project, these 30 experts were asked to rate their opinions about agreement with the evaluation results of the case on a scale of 1–6 (1 = "strong disagree", 2 = "disagree", 3 = "somewhat disagree", 4 = "somewhat agree", 5 = "agree", 6 = "strongly agree") (see Table 9).

As shown in Figure 3, the mean scores of the level of agreement are all over 4.5, which indicated that respondents agreed with the evaluation results of each indicator,

Table 8. Membership grades and scores for operation performance indicator of PRH PPPs project

Packages	Indicators	Membership grades of indicators r_{qp}	Scores of indicators $P_{qp} = r_{qp} \times C^T$	Membership grades of packages b_{kp}	Scores of packages $P_k = b_{kp} \times C^T$	Evaluation rank (Linguistic)	Ranking
OPI_1	OPI_{1-1}	(0,0.8,0.2,0,0)	88	(0,0.609,0.315,0.040,0)	86	Good	2
	OPI_{1-2}	(0,0.6,0.4,0,0)	86				
	OPI_{1-3}	(0,0.4,0.4,0.2,0)	82				
	OPI_{1-4}	(0,0.4,0.6,0,0)	84				
	OPI_{1-5}	(0,0.2,0.6,0.2,0)	80				
OPI_2	OPI_{2-1}	(0,0.6,0.4,0,0)	86	(0.055,0.672,0.273,0,0)	88	Good	1
	OPI_{2-2}	(0,1,0,0,0)	90				
	OPI_{2-3}	(1,0,0,0,0)	100				
	OPI_{2-4}	(0,0.6,0.4,0,0)	86				
OPI_3	OPI_{3-1}	(0,0.6,0.4,0,0)	86	(0.176,0.158,0.329,0.336,0)	82	Good	4
	OPI_{3-2}	(0,0,1,0,0)	80				
	OPI_{3-3}	(1,0,0,0,0)	100				
	OPI_{3-4}	(0,0,0,1,0)	70				
	OPI_{3-5}	(0,0.4,0.6,0,0)	84				
	OPI_{3-6}	(0,0.4,0.6,0,0)	84				
	OPI_{3-7}	(0,0.8,0.2,0,0)	88				
	OPI_{3-8}	(0,1,0,0,0)	90				
OPI_4	OPI_{4-1}	(0,0,1,0,0)	80	(0.194,0.166,0.640,0,0)	86	Good	2
	OPI_{4-2}	(0,0,1,0,0)	80				
	OPI_{4-3}	(1,0,0,0,0)	100				
	OPI_{4-4}	(0.2,0.8,0,0,0)	92				

Note: C= (100,90,80,70,60).

Table 9. Survey for the level of agreement of the evaluation results of the case

Indicators & packages	Scores	Evaluation rank	Agreement					
			1	2	3	4	5	6
OPI_{1-1}	88	Good	☐	☐	☐	☐	☐	☐
OPI_{1-2}	86	Good	☐	☐	☐	☐	☐	☐
OPI_{1-3}	82	Good	☐	☐	☐	☐	☐	☐
OPI_{1-4}	84	Good	☐	☐	☐	☐	☐	☐
OPI_{1-5}	80	Good	☐	☐	☐	☐	☐	☐
OPI_1	86	Good	☐	☐	☐	☐	☐	☐
OPI_{2-1}	86	Good	☐	☐	☐	☐	☐	☐
OPI_{2-2}	90	Excellent	☐	☐	☐	☐	☐	☐
OPI_{2-3}	100	Excellent	☐	☐	☐	☐	☐	☐
OPI_{2-4}	86	Good	☐	☐	☐	☐	☐	☐
OPI_2	88	Good	☐	☐	☐	☐	☐	☐
OPI_{3-1}	86	Good	☐	☐	☐	☐	☐	☐
OPI_{3-2}	80	Good	☐	☐	☐	☐	☐	☐
OPI_{3-3}	100	Excellent	☐	☐	☐	☐	☐	☐
OPI_{3-4}	70	Qualified	☐	☐	☐	☐	☐	☐
OPI_{3-5}	84	Good	☐	☐	☐	☐	☐	☐
OPI_{3-6}	84	Good	☐	☐	☐	☐	☐	☐
OPI_{3-7}	88	Good	☐	☐	☐	☐	☐	☐
OPI_{3-8}	90	Excellent	☐	☐	☐	☐	☐	☐
OPI_3	82	Good	☐	☐	☐	☐	☐	☐
OPI_{4-1}	80	Good	☐	☐	☐	☐	☐	☐
OPI_{4-2}	80	Good	☐	☐	☐	☐	☐	☐
OPI_{4-3}	100	Excellent	☐	☐	☐	☐	☐	☐
OPI_{4-4}	92	Excellent	☐	☐	☐	☐	☐	☐
OPI_4	86	Good	☐	☐	☐	☐	☐	☐

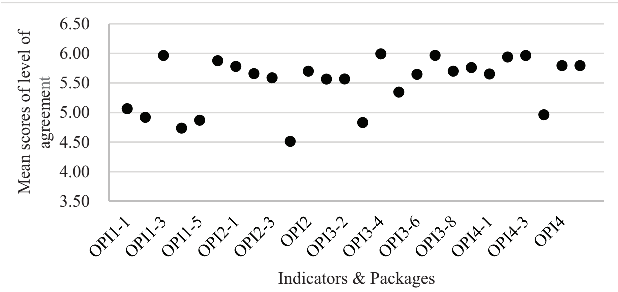

Figure 3. Mean scores of levels of agreement of evaluation results of the PRH PPP project case

each package and the overall operation performance of this project.

Thus, the above evaluation results conform to the objective reality of this PRH PPP project.

3.3. Implications for practice

However, as presented in Table 8, not all operation performance of this PRH PPP project are high. For example, some OPIs of OPI_3 *(Living environment)* still need to be improved as shown in Figure 4, which implies the operation performance could be raised to a more desirable condition.

For the four packages of operation performance of this PRH PPP project, indicators of the first (OPI_1, *Housing allocation and recycling efficiency*) and second (OPI_2, *Project spatial distribution*) package all have reached or exceeded the evaluation rank "good". Meanwhile, the evaluation scores of these two packages (86 and 88 respectively) are also at this evaluation rank (see Table 8). Relatively speaking, in the view of the evaluation results of four packages and the OPIs under the packages, these two packages represent the best performing aspects of this case.

For the third package (OPI_3, *Living environment*), there are 2, 5 and 1 indicators in which scores are at the excellent, good, qualified evaluation rank respectively. This package gets the lowest score (82) among four packages. In addition, one indicator ($OPI_{3\text{-}4}$, *Living cost per capita*) falls into the qualified rank and even the bottom line of this rank. Thus, this package represents the worst performing aspects of this case, and a great deal needs to be done to improve the performance. The lowest score (70, qualified) and the highest weight (0.3364) of the indicator $OPI_{3\text{-}4}$ (*Living cost per capita*) may have led to the lowest score of this package (82, good). In addition, although indicator $OPI_{3\text{-}2}$ (*The rationality of transport planning*) is at the good evaluation rank, the score 80 of it is relatively low. Therefore, there exists comparable broad space for operation performance improvement through improving living environment. For example, the family income of the vulnerable target tenants of PRH is low, and these households are vulnerable group in the housing market, so the living costs of them in the PRH units (such as rent and property costs) should be reduced appropriately to ensure "decent housing for every household at a cost within their means" (Yang & Chen, 2014). In addition, something can also be done about improving their transportation accessibility through providing more public transportation services operating from this PRH project area to main area of the city and the industrial areas in the future. Thus, the score of $OPI_{3\text{-}4}$ (*Living cost per capita*) and $OPI_{3\text{-}2}$ (*The rationality of transport*

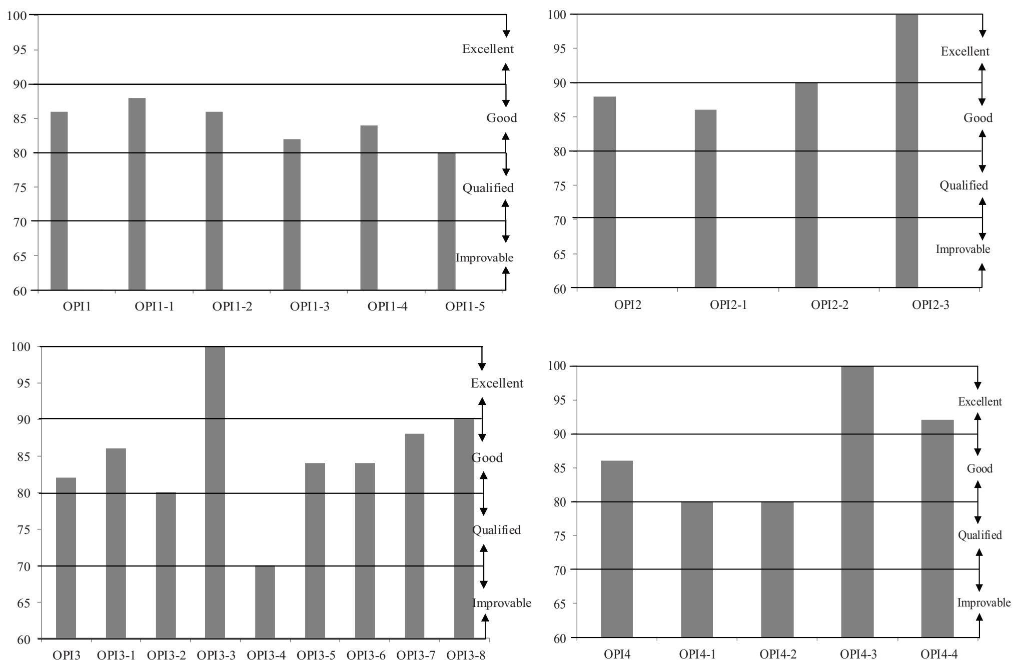

Figure 4. Scores of 21 OPIs in each package of the PRH PPP project

planning) will be renewed and be better. Meanwhile, the performance level of this package and the overall operation of this PRH PPPs project will get better.

For the last package (OPI_4, *Financial status of the project*), the scores of 2 indicators fall into the excellent evaluation rank, and another 2 indicators fall into the good evaluation rank. This package represents the moderate performing aspects with the second-highest score (86) among all the four packages. In this package, the scores of indicator $OPI_{4\text{-}1}$ (*The ability of budget control for public sectors*) and $OPI_{4\text{-}2}$ (*The ability of life-cycle cost control for private sectors*) of this package (all 80) are relatively low. As a PRH project delivery by PPPs rather than a traditional construction project, the VfM (value for money) and process control should be stressed greatly to provide value-added to stakeholders. Thus, for this PRH PPP project, the operation performance of this package and its indicators are potential to be improved. With improving these two indicators ($OPI_{4\text{-}1}$ and $OPI_{4\text{-}2}$) to a better state, the overall operation performance of this PRH PPPs project will be also renewed to be better accordingly.

4. Discussion on improvement of OP for PRH PPP projects

Operation of PRH PPP projects is related to a series of strategies and actions aiming to achieve stakeholders' satisfaction and requirements with the main principles of sustainability. All the different aspects at the operation stage (e.g., administration, planning and development, humanistic concern, and finance) could determine the level of operation performance of PRH project in PPPs. Thus, these aspects can significantly influence the operation performance. After a careful examination, the weights of OPIs in Table 10 further indicates that for the PRH PPP projects, *living environment* (weight = 0.5650) should give first priority in order to improve the performance of PRH projects' humanistic concern, which is also the tenants' most concern. Thereafter, *housing allocation and recycling efficiency* (weight = 0.2622) showed up as the second worthy of notice factor. *Project spatial distribution* (weight = 0.1175) and *financial status of the project* (weight = 0.0553), by contrast, have the least influence on operation performance of the PRH PPP project. For different PRH PPP projects, the evaluation criteria (such as criteria in different regions) and the membership grade will be different, but the weights of the four indicators and OPIs under each package will not change. Thus, for all the PRH PPP projects, making a further analysis of the weights of each package and OPIs can help the government and private participants figure out how to better improve and manage the operation performance of these projects.

Table 10. Weights of four packages and the 21 OPIs

Indicator packages	Weights	Ranking	Operation performance indicators	Weights	Ranking
OPI_1 (Housing allocation and recycling efficiency)	0.2622	2	$OPI_{1\text{-}1}$	0.3621	1
			$OPI_{1\text{-}2}$	0.3621	1
			$OPI_{1\text{-}3}$	0.1607	2
			$OPI_{1\text{-}4}$	0.0762	3
			$OPI_{1\text{-}5}$	0.0389	4
OPI_2 (Project spatial distribution)	0.1175	3	$OPI_{2\text{-}1}$	0.5650	1
			$OPI_{2\text{-}2}$	0.2622	2
			$OPI_{2\text{-}3}$	0.0553	4
			$OPI_{2\text{-}4}$	0.1175	3
OPI_3 (Living environment)	0.5650	1	$OPI_{3\text{-}1}$	0.0668	5
			$OPI_{3\text{-}2}$	0.1574	2
			$OPI_{3\text{-}3}$	0.0190	7
			$OPI_{3\text{-}4}$	0.3364	1
			$OPI_{3\text{-}5}$	0.1250	3
			$OPI_{3\text{-}6}$	0.1053	4
			$OPI_{3\text{-}7}$	0.0327	6
			$OPI_{3\text{-}8}$	0.1574	2
OPI_4 (Financial status of the project)	0.0553	4	$OPI_{4\text{-}1}$	0.3199	1
			$OPI_{4\text{-}2}$	0.3199	1
			$OPI_{4\text{-}3}$	0.1524	3
			$OPI_{4\text{-}4}$	0.2079	2

4.1. OPI_1 – Housing allocation and recycling efficiency

With a high weight of 0.2622, this principal indicator package ranks second and underlies five significant OPIs as shown in Table 10. PRH is a kind of social housing which is defined by UNECE (United Nations Economic Commission for Europe) as "housing where the access is controlled by the existence of allocation rules favoring households that have difficulties in finding accommodation in the market" (Chen, Yang, & Wang, 2014a). The rules of allocation are set up by the local governments' administrative authority. For the operation of PRH, this package is the first and very important step of the government to meet the basic living expectation of the eligible applicants. And this package corroborates earlier assertions that housing allocation and recycling efficiency is the key to better realization of the social inclusion goals for a city's residents (Gan et al., 2016a; Huang & Du, 2015). Thus, it is self-evident that this indicator package is vital to the operation performance of PRH PPP projects. The most significant indicators constituent in this package include the rationality of access criteria (OPI_{1-1}), the rationality of queuing and exit mechanisms (OPI_{1-2}), and the timeliness of dynamic information management and the efficiency of information feedback (OPI_{1-3}). Although strict and hard access criteria can overcome corruption, large portions of target tenants will lose their applicant qualifications of the PRH PPP projects and be excluded from these low-income housing programmes, thus these projects can be considered to have failed (Chen, Tan, Peng, & Yang, 2014b; Huang, 2012). The unreasonable queuing and exiting mechanism often has a damaging impact on social equity purpose and the authority of the housing policy (Luo, 2014). Because of lacking the reasonable system on the operation stage of PRH PPP project, the PRH units cannot be allocated to the validated applicants according to priority, which will arouse intense dissatisfaction among the general public (Chen et al., 2014a). On the other hand, the "sitting tenants" in PRH PPP projects with their economic conditions improving and enhancing, are no longer eligible households, will keep occupy the PRH units, resulting in lots of would-be tenants could not get in (Yin, Zhao, & Wu, 2013). As the information management and feedback system is the basis for allocating PRH equally, absence of the dynamic information management and efficient feedback system cannot ensure the standardization and transparency of the information of PRH operation, and reflect the fair and impartial management of PRH (Luo, 2014). The implication is that the operational participants of PRH PPP projects should thoroughly analyze these OPIs if they want to improve the operation performance through this indicator package.

4.2. OPI_2 – Project spatial distribution

Ranking third with the weight of 0.1175, this principal indicator package contains four indicators (including OPI_{2-1}, OPI_{2-2}, OPI_{2-3}, and OPI_{2-4}) as shown in Table 10. There is a strong possibility that the project spatial distribution (such as remote project location, high density of PRH, unreasonable land use, and high mixing degree) can reduce the satisfaction of tenants (Mohit & Nazyddah, 2011), and so it did in some PRH practices as reported by Xinhua Net (2012). As a result, the habitability and sustainability of the PRH projects will be seriously deteriorated. Although the weight of this package is not very high, the indicators in this package are all related to the satisfaction of the end users (i.e. tenants). The performance of each indicator in this package will have a direct impact on their rental choice of the PRH units. The most significant indicators in this package include the reasonableness of project location (OPI_{2-1}) and the size of project (OPI_{2-2}). For the PRH PPP projects, the location and size are associated with residential comfort of the tenants, as well as their satisfaction and expectations (James, 2008; Zhang, Liu, & Li, 2003). The main cause of "abandon to rent" phenomenon and high vacancy rate of PRH projects relates to inferior locations of these projects, which can bring in not only a heavy financial burden for the government and investors, but also a great waste of public resources (Chen et al., 2014b; Gan et al., 2016b; Mohit & Nazyddah, 2011). The size project determines the scale of land use and the residents, Mohit and Nazyddah (2011) assert that tenants report significantly low levels of satisfaction with their neighborhoods due to the density of PRH. The results confirm that enhancing the degree of satisfaction of tenants from these two aspects in this indicator package is another way to improve the operation performance for PRH PPP projects.

4.3. OPI_3 – Living environment

This indicator package has the highest weight of 0.5650 with eight significant indicators as shown in Table 10. Based on the eight indicators, the term "*living environment*" supports the concept of PRH with the property of humanistic concern, which can not only solve the housing problems faced by vulnerable households, but also stabilize living conditions through enhancing and improving economic and social welfare (Yang & Chen, 2014). The most significant OPIs in this package include living cost per capita (OPI_{3-4}), the rationality of transport planning (OPI_{3-2}), and occupancy rate/occupancy growth rate (OPI_{3-8}) (see Table 10). The targeted tenants of PRH PPP projects with limited family income are sensitive to the rental level (Yuan et al., 2017). Although the development of PRH has been subsidized by a number of policies, the cost of living in PRH units is still unaffordable to most low-income households (Chen et al., 2014a). When the affordability problems arising among the PRH targeted tenants, they would easily give up the application rights. The transport planning around the PRH PPP projects not only determines the life convenience of the residents, but also has influences on the daily living costs of them due to the accessibility to public services, and thus affects the residential satisfaction (Huang & Du, 2015; Yang & Chen, 2014). Existence of low occupancy rate of PRH units is always caused by the resource misallocation between the housing supply and real demand of the target tenants (Chen et al., 2014b). Thus, it is critical to provide PRH projects which can achieve the tenants' actual expectations, so that the potential applicants are attracted and retained (Gan et al., 2016a). Possible ways of improving the operation performance for PRH PPP projects through this indicator package include reducing living cost per capita, reasonable transport planning around the projects, and increasing the occupancy rate.

4.4. OPI_4 – Financial status of the project

With the lowest weight of 0.0553, this least significant package consists of four OPIs. The definition and targeted tenants of the PRH project determine its nature of welfare housing. However, the financial status of PRH PPP projects should be considered carefully to ensure the attractiveness for private sectors when introducing private sectors into construction and operation of PRH projects in consideration of the profit-driven nature of private sectors. Instead, the lowest weight of this package (0.0553) shows the particularly low level of attention. As we all know, in the traditional PRH projects provided by government, there exist negative effects such high construction costs, government's financial deficit and supply inefficiency appear frequently (Li et al., 2014). Thus, to make the private sectors active in the provision of PRH and introduce the abundant funds and efficient management mechanism of them, this whole indicator package deserves greater attention from the perspective of sustainable development of PRH projects. In addition, as the most significant indicators within this indicator, the ability of budget control for public sectors ($OPI_{4\text{-}1}$) and the ability of life-cycle cost control for private sectors ($OPI_{4\text{-}2}$), should also be given due attention to. Losing control of budget for public sectors and life-cycle cost of private sectors is often associated with high rate of project failures. In order to achieve VfM and control the life-cycle cost within budget or save money in construction and operation, the right processes and competitive capabilities of the SPV of the PRH PPP projects should be guaranteed to improve the performance and achieve the performance objectives (Yuan et al., 2009).

Conclusions

PRH projects delivery by PPPs are the development emphasis and future mainstream in many developed and developing countries. Meanwhile, the operation performance of these projects should be given prominence, as it is related to the willingness of private sector to participate in and the satisfaction of the tenants. Therefore, to offer an effective method to systematically evaluate and accordingly manage the operation performance of PRH projects in PPPs. An operation performance measurement framework using an FCE method and AHP procedure was proposed and applied to a PRH PPP project in this study. An evaluation system and the evaluation process with five steps were proposed based on the evaluation indicator system identified by the authors' prior studies. The application of FACE enables the utilization of qualitative fuzzy variables in the measurement of the weights and performance level of identified OPIs. This method makes the linguistic variables of the indicators can be used to be quantified, and to determine the overall operation performance of PRH PPP projects. A case study of a PRH PPP project in Nanjing city in China was chosen to exemplify the practicability of the proposed FACE method. The results of FACE analysis of this case indicate that the *living environment* package as the most important (weight = 0.5650, performance level = 82), with the *housing allocation and recycling efficiency* ranking second (weight = 0.2622, performance level = 86), the *project spatial distribution* (weight = 0.1175, performance level = 88) and *financial status of the project* (weight = 0.0553, performance level = 86) ranking third and last, respectively. Moreover, the FACE analysis reveals that the operation performance level of the PRH PPP case is good, with an overall evaluation score of 84. And through the verification of field survey and investigation of related departments, this evaluation results were proved to be accord with the actual situation of this PRH PPP project. In addition, to raise the operation performance of this project to a more desirable condition, this paper provided some implications for practice mainly from the two lower level performance packages (i.e., OPI_3, *Living environment* and OPI_4, *Financial status of the project*). Furthermore, through a carefully examination the weights of four indicator packages and the most significant OPIs within these packages, some possible ways of improving the operation performance of PRH PPP projects were proposed to achieve the stakeholders' requirements and the sustainable development of the projects. The proposed operation performance measurement model of PRH PPPs projects can evaluate the projects' performance effectively from the lifecycle management perspective, which can indicate the advantages and disadvantages of the projects in next and accordingly put forward advices to strengthen management of PRH PPPs projects. Take the evaluation results of the presented case in this paper as an example, the good performance of *housing allocation and recycling efficiency* (OPI_1, 86) and *project spatial distribution* (OPI_2, 88) are the advantages of this PRH PPPs project. Thus, measures related to guaranteeing the fair and equitable housing allocation and the habitability of the PRH units should be kept. However, for the disadvantages of *living environment* (OPI_3, 82) and *financial status of the project* (OPI_4, 86, the lowest weight 0.0553), more measures for improvement such as properly reducing living costs, providing more public transportation services for tenants and stressing greatly the VfM and process control should be implemented to overcome these disadvantages in the future.

Although an indicator system of 21 OPIs of PRH PPPs projects have been identified and the operation performance can also be improved by theoretical path analysis through authors' prior studies, what exactly the value of operation performance is and how many each improvement can achieve in practice must be determined through operable evaluation model and criteria. Thus, this paper offers the following contributions to the operation performance measurement of PRH PPP projects:

- Provides an analytical tool for the performance measurement and management of PRH PPP projects that can be applied to reflect the operation performance of specific projects with appropriate modifications, such as fine tuning the indicators, some evaluation criteria and the size of expert panel;
- Assists the public and private decision-makers to undertake more objective operation performance evaluation and improvements. Makes them have a clearer understanding of the most significant operation performance indicators and packages, and the overall performance level of a PRH PPP project;
- Provides an analytical tool for the performance measurement and management of PRH PPP projects that can be applied to reflect the operation performance of specific projects with appropriate modifications, such as fine tuning the indicators, some evaluation criteria and the size of expert panel;
- Assists the public and private decision-makers to undertake more objective operation performance evaluation and improvements. Makes them have a clearer understanding of the most significant operation performance indicators and packages, and the overall performance level of a PRH PPP project.

Although proposed method in this research can be used to measure the operation performance of PRH delivered by PPPs, there are still some limitations of the study. Firstly, as the case of this study is from a district of Nanjing city, Jiangsu province, and the evaluation rules are all based on the Nanjing city. Although the proposed methods offered in this study is transferable and suitable for the same type PRH PPP projects in China and other developing countries, and the evaluation rules can be adjusted to other cities or countries. In order to increase the applicability of the research methods, more cases in the national level or the international domain can be investigated in future study. In addition, the FCE method also has some limitations in its application, this research method requires a lot of calculations based on matrix operations in the Excel sheet, especially when more evaluation indicators are involved in the evaluation process. Thus, to reduce the calculation time and improve the calculation precision, a computerized FCE model needs to be developed in the future.

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Author contributions

Jingfeng Yuan and Wei Li conceived the study and were responsible for the design and development of the data analysis. Wei Li and Jingfeng Yuan wrote the first draft of the article. Bo Xia, Yuan Chen and Mirosław J. Skibniewski were responsible for revise the work, add new ideas and adjust the logic of the article.

Disclosure statement

All authors declare that we do not have any competing financial, professional, or personal interests from other parties.

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Appendix

Table A1. Evaluation rules for 21 OPIs of PRH PPPs projects

Indicators	Indicator characteristics	Evaluation criterion
$OPI_{1\text{-}1}$ The rationality of access criteria	Qualitative indicator	**Excellent –** The access criteria should comprehensively consider household registration, income, current living conditions and social security with strong operability and executability. **Good –** The access criteria should considers most of the criteria mentioned above with good operability and executability. **Qualified –** The access criteria should meet the requirements of government with normal operability and executability. **Improvable –** The access criteria only considers part of the criteria mentioned above with relatively weak operability and executability. **Unacceptable –** The access criteria does not consider criteria mentioned above with very weak operability and executability.
$OPI_{1\text{-}2}$ The rationality of queuing and exit mechanisms	Qualitative indicator	**Excellent –** The mechanism is completely designed including waiting echelon, contract period, annual inspection system, reward and punishment as well as exiting standard with high strictness, fairness and efficiency of the PRH allocation. **Good –** The mechanism is designed including queuing and exit system with relatively high strictness, fairness and efficiency of the PRH allocation. **Qualified –** The mechanism is designed including queuing and exit system with normal strictness, fairness and efficiency of the PRH allocation. **Improvable –** The mechanism is designed with imperfect queuing and exit system as well as weak reward and punishment. **Unacceptable –** The mechanism has not been well designed with no queuing and exit system as well as no reward and punishment system.

Continue of Table A1

Indicators	Indicator characteristics	Evaluation criterion
$OPI_{1\text{-}3}$ The timeliness of dynamic information management and the efficiency of information feedback	Qualitative indicator	**Excellent** – The completed dynamic information platform has been established. The related information can be updated and shared on time. **Good** – The collection and update of household information has been addressed by government. The related information can be shared with others. **Qualified** – The household information can be dynamically updated by local government. The feedback is in time. **Improvable** – The householder information dynamic update is relatively backward. The feedback is not in time and effective. **Unacceptable** – No household information has been updated. Lack of feedback for a long time.
$OPI_{1\text{-}4}$ The strictness of professional supervision department	Qualitative indicator	**Excellent** – The local supervision department of housing security has a hierarchical and distinct organization. General public can participate the supervision actively. The construction and allocation process of PRH can be supervised effectively. **Good** – A local supervision department of housing security has been set up with relatively high degree public participation. The construction and allocation process of PRH can be supervised. **Qualified** – A local supervision department of housing security has been set up with public participation. **Improvable** – A supervision group of housing security has been set up by local government with no public participation. **Unacceptable** – Local supervision department of housing security has not been set up.
$OPI_{1\text{-}5}$ The degree of information disclosure	Qualitative indicator	**Excellent** – On the premise of respecting the privacy of the applicants, the information of the applicants is released in time, the housing information is transparent and accurate, and the fairness of PRH allocation can be effectively guaranteed. **Good** – The publicity of the applicants' information is strict. There is a special way of housing information release. **Qualified** – There are special release ways of applicants' information and housing information. The transparency and fairness of PRH allocation can be basically guaranteed. **Improvable** – The publicity of the applicants' information and the release of housing information are not in time. **Unacceptable** – There is no platform for the publicity of the applicants' information and the release of housing information. The process of PRH allocation is not transparent.
$OPI_{2\text{-}1}$ The reasonableness of project location	Qualitative indicator	**Excellent** – Downtown area. **Good** – Sub center. **Qualified** – Around the last station of rail transit. **Improvable** – Suburb. **Unacceptable** – Outskirts and adjacent to industrial area.
$OPI_{2\text{-}2}$ The size of project	Quantitative indicator	**Excellent** – The size of residential population is more than 25000. A large number of employment opportunities, services and facilities can be provided here. The public transport services are convenient. **Good** – The size of residential population is 10000 to 25000. A small number of employment opportunities, schools, supermarkets, transportation and other conveniences can be provided here. **Qualified** – The size of residential population is 5000 to 10000. Schools, supermarkets, transportation and other conveniences can be provided here. **Improvable** – The size of residential population is 2500 to 5000. Primary schools, supermarkets and other basic facilities can be provided here. However, high schools, transportation and other services cannot be provided here. **Unacceptable** – The size of residential population is less than 2500. Only daily life service can be provided here. Schools, transportation and other conveniences cannot be provided here.
$OPI_{2\text{-}3}$ The intensity of land use	Quantitative indicator	**Excellent** – The intensity of land use is 10% to 20%. **Good** – The intensity of land use is 20% to 25%. **Qualified** – The intensity of land use is 25% to 30%. **Improvable** – The intensity of land use is 30% to 35%. **Unacceptable** – The intensity of land use is more than 35% or less than 10%.

Continue of Table A1

Indicators	Indicator characteristics	Evaluation criterion
$OPI_{2\text{-}4}$ The mixing degree of "mixed-income housing"	Qualitative indicator	**Excellent** – People from different social classes can live together with high degree mixture. Public resources can be fully shared. A large number of employment opportunities can be provided. **Good** – People from different social classes can live together with relatively high degree mixture. Public resources can be shared. A certain amount of employment opportunities can be provided. **Qualified** – People from different social classes can live together with normal degree mixture. Public resources can be shared to a certain extent. **Improvable** – People from the same career background can live together as a group. The mobility of different groups is small. The residents are easy to isolate from the main city. **Unacceptable** – People from different social classes cannot live together with very low degree mixture. Different residential areas are isolated from each other, which is easy to generate a slum gathering area.
$OPI_{3\text{-}1}$ The perfection degree of public facilities in surrounding region	Qualitative indicator	**Excellent** – There are very perfect financial services, medical services, educational services, commercial support. **Good** – There are relatively perfect financial services, medical services, educational services, commercial support. **Qualified** – There are basic financial services, medical services, educational services, commercial support. **Improvable** – There are part of financial services, medical services, educational services, commercial support. **Unacceptable** – There are no basic financial services, medical services, educational services, commercial support.
$OPI_{3\text{-}2}$ The rationality of transport planning	Quantitative indicator	**Excellent** – The average time consuming for the residents to work is less than 15 minutes. **Good** – The average time consuming for the residents to work is 15 to 30 minutes. **Qualified** – The average time consuming for the residents to work is 30 to 40 minutes. **Improvable** – The average time consuming for the residents to work is 40 to 60 minutes. **Unacceptable** – The average time consuming for the residents to work is more than 60 minutes.
$OPI_{3\text{-}3}$ Living space per capita	Quantitative indicator	**Excellent** – The ratio of the actual living space per capita of PRH community to the average living space per capita of the local area is 35% to 40%. **Good** – The ratio of the actual living space per capita of PRH community to the average living space per capita of the local area is 25% to 35%. **Qualified** – The ratio of the actual living space per capita of PRH community to the average living space per capita of the local area is 15% to 25%. **Improvable** – The ratio of the actual living space per capita of PRH community to the average living space per capita of the local area is 10% to 15% or 40% to 50%. **Unacceptable** – The ratio of the actual living space per capita of PRH community to the average living space per capita of the local area is less than 10% or more than 50%.
$OPI_{3\text{-}4}$ Living cost per capita	Quantitative indicator	**Excellent** – The ratio of the sum of rent and property costs to the average monthly income is less than 10%. **Good** – The ratio of the sum of rent and property costs to the average monthly income is 10% to 15%. **Qualified** – The ratio of the sum of rent and property costs to the average monthly income is 15% to 20%. **Improvable** – The ratio of the sum of rent and property costs to the average monthly income is 20% to 30%. **Unacceptable** – The ratio of the sum of rent and property costs to the average monthly income is more than 30%.
$OPI_{3\text{-}5}$ The rationality of housing design	Qualitative indicator	**Excellent** – The PRH units have good lighting and ventilation conditions, waterproof and moisture-proof, high space utilization and good independence, rational kitchen and bathroom function design. There are many types of units for different families to choose. **Good** – The PRH units have good lighting and ventilation conditions, waterproof and moisture-proof, high space utilization and rational function design. **Qualified** – The PRH units have general lighting and ventilation conditions, and space utilization. The units can meet the basic living function of residents. **Improvable** – the lighting and ventilation conditions, waterproof and moisture-proof of the PRH units can meet the minimum requirements of residents. There are very few types of units for different families to choose. **Unacceptable** – The lighting and ventilation conditions, waterproof and moisture-proof of the PRH units cannot meet the minimum requirements of residents. There are few types of PRH units. The units cannot meet the basic living function of residents.

Continue of Table A1

Indicators	Indicator characteristics	Evaluation criterion
$OPI_{3\text{-}6}$ The perfection degree of community public facilities	Qualitative indicator	**Excellent** – There are very perfect social facilities, landscaping, commercial support, civil air defense facilities and parking spaces in PRH community. **Good** – There are relatively perfect social facilities, landscaping, commercial support, civil air defense facilities and parking spaces in PRH community. **Qualified** – There are basic social facilities, landscaping, commercial support, civil air defense facilities and parking spaces in PRH community. **Improvable** – There are part of social facilities, landscaping, commercial support, civil air defense facilities and parking spaces in PRH community. **Unacceptable** – There are no basic social facilities, landscaping, commercial support, civil air defense facilities and parking spaces in PRH community.
$OPI_{3\text{-}7}$ The perfection degree of facility management	Qualitative indicator	**Excellent** – The community environmental sanitation, security management, maintenance, and community activity organization are very perfect. **Good** – The community environmental sanitation, security management, maintenance, and community activity organization are relatively perfect. **Qualified** – The community environmental sanitation, security management, maintenance, and community activity organization can meet the basic requirements. **Improvable** – The community environmental sanitation, security management, maintenance, and community activity organization are not very comprehensive. **Unacceptable** – The community environmental sanitation, security management, maintenance, and community activity organization can meet the basic requirements.
$OPI_{3\text{-}8}$ Occupancy rate	Quantitative indicator	**Excellent** – The proportion of household with a monthly electricity consumption exceeding 10 degrees (i.e. occupancy rate) is more than 90%. **Good** – The proportion of household with a monthly electricity consumption exceeding 10 degrees (i.e. occupancy rate) is 70% to 80%. **Qualified** – The proportion of household with a monthly electricity consumption exceeding 10 degrees (i.e. occupancy rate) is 60% to 70%. **Improvable** – The proportion of household with a monthly electricity consumption exceeding 10 degrees (i.e. occupancy rate) is 50% to 60%. **Unacceptable** – The proportion of household with a monthly electricity consumption exceeding 10 degrees (i.e. occupancy rate) is less than 50%. **If this indicator get the result of "unacceptable", the result of this indicator package (OPI_3) is "unacceptable" too.**
$OPI_{4\text{-}1}$ The ability of budget control for public sectors	Quantitative indicator	**Excellent** – The VfM (Value for Money) of the project is greater than or equal to 20% of life-cycle cost of project construction. **Good** – The VfM (Value for Money) of the project is between 10% and 20% of life-cycle cost of project construction. **Qualified** – The VfM (Value for Money) of the project is between 0 and 10% of life-cycle cost of project construction. **Improvable** – The VfM (Value for Money) of the project is equal to 0. **Unacceptable** – The VfM (Value for Money) of the project is less than 0. **If this indicator get the result of "unacceptable", the result of this indicator package (OPI_4) is "unacceptable" too.**
$OPI_{4\text{-}2}$ The ability of life-cycle cost control for private sectors	Quantitative indicator	**Excellent** – The control of reconnaissance and design and initial engineering costs, construction and installation costs of project's main part, residential infrastructure construction costs is all very strict and get good effect. **Good** – The control of reconnaissance and design and initial engineering costs, construction and installation costs of project's main part, residential infrastructure construction costs is effective. **Qualified** – The control of reconnaissance and design and initial engineering costs, construction and installation costs of project's main part, residential infrastructure construction costs can meet the basic requirements. **Improvable** – Part of the reconnaissance and design and initial engineering costs, construction and installation costs of project's main part, residential infrastructure construction costs lose control and overspend. **Unacceptable** – All of the reconnaissance and design and initial engineering costs, construction and installation costs of project's main part, residential infrastructure construction costs overspend.

End of Table A1

Indicators	Indicator characteristics	Evaluation criterion
$OPI_{4\text{-}3}$ The return of related commercial facilities	Quantitative indicator	**Excellent** – Letting rate of shops of the first year is more than 80%, the rate of rents received is more than 90%. **Good** – Letting rate of shops of the first year is more than 70%. The annual growth rate is more than 5%. The rate of rents received is more than 80%. **Qualified** – Letting rate of shops of the first year is more than 60%. The annual growth rate is more than 5%. The rate of rents received is 60% to 80%. **Improvable** – Letting rate of shops of the first year is 30% to 40%. The annual growth rate is less than 5%. The rate of rents received is 50–60%. **Unacceptable** – Letting rate of shops of the first year is less than 30%. The annual growth rate is less than 5%. The rate of rents received is less than 50%.
$OPI_{4\text{-}4}$ The incentive level of related policies on private sectors	Qualitative indicator	**Excellent** – There are comprehensive incentive measures to encourage the private sectors and more than 7 enterprises participating the bidding. **Good** – There are relatively comprehensive incentive measures to encourage the private sectors and 5 to 7 enterprises participating the bidding. **Qualified** – There are general incentive measures to encourage the private sectors and 3 to 5 enterprises participating the bidding. **Improvable** – There are a relatively small number of incentive measures encourage the private sectors and 1–3 enterprises participating the bidding. **Unacceptable** – There are very few incentive measures to encourage the private sectors and 0 to 1 enterprise participating the bidding.

Notations

Abbreviations:

PRH – Public Rental Housing;
PPPs – Public Private Partnerships;
OPIs – Operation Performance Indicators;
OP – Operation Performance;
PIs – Performance Indicators;
FCE – Fuzzy Comprehensive Evaluation;
AHP – Analytic Hierarchy Process;
FACE – Fuzzy-Analytic Hierarchy Process Comprehensive Evaluation;
DEA – Data Envelopment Analysis;
UNECE – United Nations Economic Commission for Europe;
SPV – Special Purpose Vehicle;
VfM – Value for Money.