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Exploration of Current Builders' Capacities to Deliver Zero Energy Buildings in China

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Abstract: To strengthen the global fight against climate change, China pledges to reach carbon neutrality by 2060. As one of the major energy consumption sectors in China, the building industry's role in CO_2 emission reductions is critical to the successful pursuit of the carbon neutrality goal. The concept of zero energy buildings (ZEBs) has gained increasing attention in China due to its effective efforts on energy saving and emission reduction. The objectives of this research are to investigate current builders' capacities for delivering ZEBs in China, to explore the differences in design and construction capacities of conventional and ZEB builders in China, and to assess the potentials of boosting Chinese builders' capacities for delivering ZEBs in the future. The research methods embrace several steps. Firstly, a checklist was developed based on the literature review to assess Chinese builders' capacities to deliver ZEBs. Secondly, relationships between different checklist questions were analyzed using association rule in software SPSS modeler. Thirdly, builders were clustered using TwoStep Cluster Analysis in software SPSS modeler. The findings of this research suggest that most Chinese builders, even ZEB builders have insufficient ZEB design and construction knowledge. ZEB demonstration projects are mainly developed in cooperation with foreign professional institutions. Moreover, conventional builders are less competitive than ZEB builders in passive design capacity, energy efficient building design capacity, renewable energy generation capacity and research capacity, which are the key skills that conventional builders are supposed to improve. Furthermore, one-third of conventional builders have NZEBs or ULEBs production experience. They have acquired related ZEB delivery capacities and they are the most likely ZEB builders in the future.

Keywords: Zero energy buildings; Builders' capacity; China

1. Introduction

To strengthen the global fight against climate change, in September 2020, the Chinese president announced that China pledges to reach carbon neutrality by 2060. As one of the three major energy consumption sectors in China, the construction industry accounts for 34.3% of the country's carbon dioxide (CO2) emissions [1]. With the economic growth and the rapid development of urbanization, it is estimated that the carbon emissions in the Chinese building sector will increase and the figure could be doubled by 2050 [2]. Accordingly, the building industry's role in CO2 emission reductions is critical to the successful pursuit of the carbon neutrality goal. The definition of zero energy building (ZEB) was originally proposed by Esbensen and Korsgaard in the 1970s, where a ZEB could be heated in winter by adopting solar energy as the main energy source [3]. The concept of ZEB has evolved constantly from its original description to a comprehensive concept for sustainable development, but there is currently no internationally agreed definition of ZEB [4]. Table 1 summarises the various definitions in different countries. Although these definitions are not the same, generally, a ZEB is a building with reduced energy demands via efficiency gains and its energy demand can be met through renewable energy sources [5]. They all share common goals of making full use of renewable energy and reducing carbon emissions.

Table 1. Definitions of ZEB in different countries

Time	Country	Definition	Content	Reference
1976	Denmark	Zero-Energy House	Buildings that use solar energy to satisfy the heating energy requirements in winter.	Esbensen and Korsgaard (1977)
1992	Germany	Energy Autonomous House	Connection to an external energy infrastructure is unnecessary, and the solar thermal/photovoltaic system can be integrated with the energy storage technology to satisfy the energy requirements at all times.	Voss et al. (1996)
2007	USA	Zero-energy Building	An energy-efficient building, for which the actual annual delivered source energy is less than or equal to the on-site renewable exported energy.	DOE (2015)
2007	UK	Zero-Carbon Home	Net CO2 emissions from all energy consumption in residential buildings are zero.	Department of Communities and Local Government (DCLG) (2007)
2010	EU	Nearly Zero-energy Buildings	Buildings with a very high energy efficiency, whose energy demand is close to zero or very low, and their energy supply is largely from renewable energy sources at or near the site	European Commission (2020)
2013	Canada	Net Zero-Energy Home	A home that only uses as much energy as it can produce from on-site renewable energy.	NetZero (2020)

China's efforts on building energy conservation have started since 1986, and the concept of ZEB has gained increasing attention since 2010 due to its effective efforts on energy saving and emission reduction [4]. In 2015, the Chinese Ministry of Housing and Urban-Rural Development (MOHURD) initiated the Building Energy-Efficiency Improvement Program (BEEIP), this is the first time that developing net (or nearly) ZEBs was formally presented in China (Wu et.al., 2015). As a multi-ethnic developing country with diverse climate zones, China has unique features in building type, living habits, indoor environment, and architectural characteristics, and there is no mature experience for reference, which has increased the difficulty of ZEB research and development.

Figure 1. Climate zones in China

As shown in Figure 1, China is mainly divided into five climate zones, including temperate zone, hot summer and warm winter, hot summer and cold winter, cold zone, and severe cold zone. The climate is related to the temperature, humidity and solar radiation of the region, which significantly impacts the building performance and the design strategies of ZEBs [6]. Adapting to local conditions and making reasonable use of ambient environment resources to create a comfortable indoor environment is necessary when design ZEBs. The complex and diverse climate has increased the difficulties to deliver ZEBs in China. Furthermore, ZEBs in developed countries are mostly low-rise buildings with up to three floors. However, the majority of buildings in Chinese urban areas are medium-to-high-rise buildings [7]. Li (2018) suggested that for residential buildings, the maximum number of floors is three when the rooftop PV system is the only energy source. Therefore, it is difficult to achieve ZEBs in Chinese cities [8].

Currently, it is difficult for China to directly move from the current building standard to the ZEB level [9]. Therefore, a roadmap for 2016-2030 building codes upgrading was developed to achieve ZEB [7]. China has completed the "30%-50%-65%" three-step energy-saving plan after 30 years of continuous efforts since 1986 (Figure.2) [7]. And a new three-step approach to setting national standards between 2016-2030 was put forward, including Low Energy Building Standard, Ultra Low Energy Building Standard, Nearly Zero Energy Building Standard. The definitions of ultra low energy building (ULEB), nearly zero energy building (NZEB) and zero energy building (ZEB) are summarised in Table 2 [10]. The Chinese standard for building energy efficiency in effect in 2015 is that residential buildings are more than 65% energy saving, and public buildings are more than 50% energy saving than 1980's baseline performance.

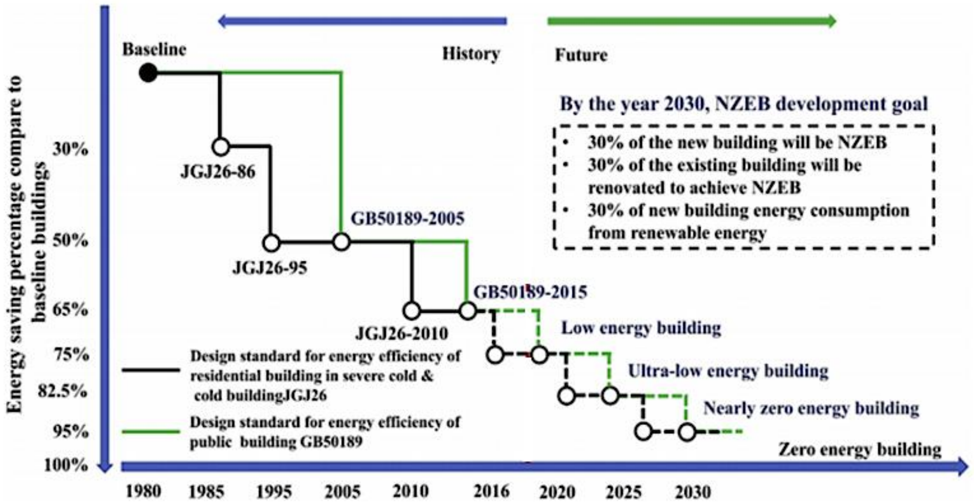

Figure 2. Roadmap of ZEB standard in China (Xu, 2017)

Table 2. The definition of ULEB, NZEB, and ZEB (MOHURD, 2019).

Definitions	Energy Reduction rate compared to 1980's baseline (Fig 2)	Energy reduction rate compared to standards in effect in 2015
Ultra-low energy building (ULEB)	82.50%	50%
Nearly zero energy building (NZEB)	95%	65%–70%
Zero-energy building (ZEB)	100%	100%

Driven by the national policies launched by the central government, some provinces and cities have also actively initiated related standards and guidelines to promote the development of ZEB based on local conditions, such as Beijing, Hebei, Shandong, and Shanghai [11]. Among the five climatic regions in China, the related policies in cold climate are dominated. Table 3 summarizes standards related to ZEBs in some provincial-level regions in China. In response to government policies, a number of ULEB or NZEB demonstration projects has been built in different climate zones to play a leading role in improving building energy performance.

Table 3. A summary of standards related to ZEB in China

Provincial-level region	Title and number	Enforcement date	Note
China	Passive Ultra Low Energy Green Building Technical Guide (Residential building)	2015.11.10	For design, construction, operation
	National Standard Chart Passive Low Energy Buildings - Residential Buildings in Cold and Cold Areas(16J908-8)	2016.09.01	For design, construction
	Nearly Zero Energy Buildings Technology Standard	2019.09.01	For design, construction, operation, evaluation
	Detection and Evaluation Standard for Nearly Zero Energy Building	2019	Detection and Evaluation Standard
	Technical Standard for Ultra-Low Energy Buildings in Public Institutions T/CECS 713-2020	2020.12.01	For design, construction, operation, evaluation
Beijing	Design Standard for Ultra-low Energy Residential Buildings	2020.04.01	For design
	Application Guide for Beijing Ultra-low Energy Consumption Demonstration Construction Project	2018.04.19	For farm house
	Guidelines for the Design and Construction Acceptance of Ultra-low Energy Residential Buildings in Beijing	Under development	For design, construction, evaluation
	Technical Regulations for Construction of Ultra-low Energy Residential Buildings in Beijing	Under development	For construction
Hebei	Design Standard for Energy Efficiency of Passive Ultra-Low Energy Residential Buildings DB13(J)T 177-2015	2015.05.01	For design
	Passive Low-Energy Residential Building Energy-Saving Structure DBJT02-109-2016	2016.06.01	For design
	Passive Low Energy Building Construction and Evaluation Procedures DB13(J)/T 238-2017	2017.09.01	For construction, evaluation
	Design Standard for Energy Efficiency of Passive Ultra-Low Energy Public buildings DB13(J)/T 263-2018	2018.09.01	For design, construction
Shandong	Passive Ultra-Low Energy Residential Building Energy-Saving Design Standards DB37/T5074-2016	2016.12.01	For design
	Key Points for Special Acceptance of Passive Ultra-low Energy Green Building Demonstration Project in Shandong Province	2017.07.05	For evaluation
	Technical Guidelines for Construction of Ultra-low Energy Buildings in Shandong JD 14-041-2018	2018.10.01	For construction
Shanghai	Technical Standard for Ultra-Low Energy Buildings in Shanghai	2019.03	For design, construction, operation, evaluation
	Green building evaluation standard in Shanghai DGTJ08-2090	2020.07.01	For evaluation

With the development of building design technologies in China, more ZEBs have emerged, such as Nanjing Green Lighthouse and the 0+ house in Tianjin. ZEB design strategies in China include three steps. First, adopting passive design strategies to reduce the energy demand of the building. Passive building design strategies refer to approaches that maximize the use of free energy from the surrounding environment to reduce energy demand for space heating or cooling [12, 13]. Major approaches include buildings' orientation and location, high-performance building envelopes, natural ventilation and daylighting [14, 15]. The second step is improving the efficiency of the building energy system through active measures. Active measures refer to using energy efficient technologies to reduce the energy consumption of heating, ventilation and air conditioning (HVAC), lighting, and domestic hot water (DHW). Typical measures include high-efficient lighting, lighting dimming controls, combined heating and power and solar water heaters [16-19]. The last step is applying renewable energy as the energy source and achieving "zero energy consumption" in the annual operation cycle [4]. In China, the majority of ZEBs or NZEBs or ULEBs use a solar photovoltaic (PV) system to generate renewable energy.

The development of ZEBs has made some progress over the past decade. Researchers have investigated the feasibility of achieving ZEBs in different climate zones in China using model simulation software eQUEST for energy performance evaluation, the result indicates that it is possible to achieve ZEBs in model simulation when the building is well designed with passive strategies, active strategies and a PV system [20, 21]. But the number of ZEBs in China is minimal. And the majority of existing studies related to ZEBs focus only on theories and model simulations. There is a lack of existing studies that have explored builders' capacities to deliver ZEBs in China. ZEB development in China is still facing a lot of challenges. To provide a clear perspective or guidance for China's ZEB development, the exploration of current builders' capacities to deliver ZEBs in China is needed.

2. Materials and Methods

2.1 Checklist development

Firstly, to investigate current builders' capacities to deliver ZEBs in China, a checklist was developed based on the literature review. To facilitate data analysis, all questions are designed as 'yes' or 'no' questions. Q1 is to explore builders' ZEB production experience, so ZEB builders and conventional builders can be separated and the difference between them can be explored. Q2 to Q8 are designed to understand builders' ZEB related capacities. Moreover, Q9 and Q10 are to investigate whether willingness or responsibility can be a drive for the builder to deliver ZEBs. Then, 50 builders were selected for the checklist assessment, including 10 existing ZEB builders, and 40 conventional builders. Conventional builders were selected from the top 50 of '2020 China Real Estate Companies Comprehensive Strength Ranking' [22]. Top companies are selected because they better represent the capabilities of Chinese builders and their data are more publicly available, which can be easily obtained for analysis. The checklist questions were answered for all the companies using secondary data sources, such as related government databases, the company website and annual reports. And Microsoft Excel was used to generate tables and figures for a simple descriptive evaluation of the capacities of builders.

Table 4. Checklist questions and explanations

No.	Objectives	Questions	Explanations
1	ZEB production experience	Q1. Has the company ever produced zero energy buildings (ZEBs) in China?	This question is to separate ZEB builders and conventional builders to explore the difference between them.
2	NZEB or ULEB production experience	Q2. Has the company ever produced nearly zero energy buildings (NZEBs) or ultra low energy buildings (ULEBs) in China?	Some builders do not have ZEB production experience, but they have delivered NZEB or ULEB projects, which is an important experience for them to explore ZEBs in the future.
3	Design and construction knowledge	Q3. Can the company produce ZEB projects without the help of other organizations?	Some builders have ZEB production experience, but they sought the help of other organizations during the design process. This question is to explore builders' own design and construction knowledge.
4	Passive design capacity	Q4. Does the company apply passive design strategies to its buildings?	Applying passive design strategies energy is an essential step to achieve ZEBs in China. This question is to explore builders' passive design capacity.
5	Energy efficient building design capacity	Q5. Does the company apply energy efficient measures to most of its buildings in 2020?	Applying energy efficient measures is an essential step to achieve ZEBs in China. This question is to explore the builder's energy efficient building design capacity.
6	Renewable energy generation awareness and implementation capacity	Q6. Does the company install a solar photovoltaic (PV) system in its buildings?	Solar energy resources are abundant in 2/3 of the area in China. Solar energy is mainly used as renewable energy resource to achieve ZEBs in China. This question is to explore builders' renewable energy generation awareness and implementation capacity.

7	Construction innovation	Q7. Does the company deliver modular buildings?	Delivering modular buildings is an important construction innovation for builders to reduce the cost of ZEBs. This question is to explore builders' construction innovation capacity.
8	Research capacity	Q8. Does the company attend ZEB related seminars or conferences	Companies that have attended ZEB related seminars or conferences have ZEB research capacity. This question is to explore builders' research capacity.
9	Willingness	Q9. Does the company emphasize ZEBs as a market strategy ?	Companies that emphasize green buildings as a market strategy are willing to deliver ZEBs. This question is to explore builders' willingness to deliver ZEBs.
10	Responsibility	Q10. Is the company committed to building a sustainable future?	Companies who committed to building a sustainable future might feel responsible to deliver ZEBs. This question is to explore builders' responsibilities to deliver ZEBs.

2.2 Applied machine learning techniques

Two machine learning techniques were applied in this research, including the association rule (Apriori) algorithm and the TwoStep Cluster Analysis.

2.2.1 Association rule (Apriori) algorithm

A rule-based machine learning technique, the association rule (Apriori) algorithm was used to explore the differences in design and construction capacities of conventional and ZEB builders. Associations between different checklist questions were analyzed using the association rule in software SPSS modeler. As a well-recognized data mining approach, the association rule intends to discover interesting associations between variables in large databases [23, 24]. One advantage of the association rule algorithm is that associations and rules can be found between any of the variables, and each of them may have a different conclusion [25]. In this research, the Apriori algorithm, a well-known association rule approach, has been employed to find rules and associations that exist between the checklist questions. It can efficiently search association rules using straightforward and easy to understand computations [26].

An association rule can be defined as X ⇒ Y, where X and Y are subsets of an itemset. X and Y usually refer to the antecedent and the consequent of the rule respectively. The support, confidence and lift are essential perimeters in association rules. The support indicates how frequent a combination of antecedent and consequent of a rule appears together in the database. The confidence shows the strength or the credibility of the association by measuring the share of cases in which the consequent occurs given that the antecedent has occurred [27]. The lift determines the increase in the probability of the occurrence of a rule relative to the probability of the antecedent and consequent being independent [28]. If the lift is 1, it means that the antecedent and the consequent are independent and hence the rule is not useful in predicting future occurrences. But a lift above 1 implies that the antecedent and the consequent are positively correlated, which makes the rule possibly helpful. The larger the lift, the more significant the association rule. The support, confidence and lift can be estimated using the following equations:

$$Support(X \Rightarrow Y) = \frac{Transactions\ containing\ both\ X\ and\ Y}{Total\ number\ of\ transactions} \quad (1)$$

$$\text{Confidence}(\text{X} \Rightarrow \text{Y}) = \frac{\text{Transactions containing both X and Y}}{\text{Transactions containing both X}} \quad (2)$$

$$\text{Lift}(X \Rightarrow Y) = \frac{\text{Transactions containing both X and Y}}{\text{Transactions containing X} \times \text{Transactions containing Y}} \quad (3)$$

In this research, the SPSS modeler was applied to generate the association rules. In the SPSS modeler, the checklist result was imported in Excel format, and then the minimum support and confidence need to be predefined to filter associations. A minimum support value of 0.2 and a minimum confidence value of 0.8 were adopted in this data analysis. Then the association rule satisfied predefined minimum thresholds can be generated by the software.

2.2.2 TwoStep Cluster analysis

To assess the potentials of boosting Chinese builders' capacities for delivering ZEBs in the future, builders were clustered using another machine learning technique, TwoStep Cluster analysis in software IBM SPSS modeler. The TwoStep Cluster analysis is an exploratory tool designed to find natural clusters in a dataset that is otherwise not apparent [29]. Different from traditional hierarchical clustering techniques, the TwoStep Cluster analysis employs a likelihood-based approach to model distances between categorical variables, which is suitable for clustering binary valued data [30]. The minimum number of clusters is set as 5 in this research. By comparing the values of a model selection criterion across different clustering solutions, the optimal number of clusters can be automatically determined. In this research, a discussion is provided by ranking different company categories from the most likely ZEB builders of tomorrow to the least likely ZEB builders in the future.

3. Results

3.1 Current builders' capacities to deliver ZEBs in China

A checklist was employed to investigate current builders' capacities to deliver ZEBs in China. The results of checklist questions for all 50 companies are shown in Table 5 below. Figure 3 illustrates the results of each checklist question. Fifty companies are involved in the analysis, and the majority of them are conventional builders who have no ZEB production experience, accounting for 80%. Generally, ZEB builders perform better than conventional builders under all question contexts. But the result of Q3 shows that only four out of ten ZEB builders have the ability to produce ZEB without the help of others. Most builders do not acquire enough ZEB design and construction knowledge to deliver ZEB projects on their own, and they need the help of other organizations. Besides, 32.5% of conventional builders have produced ULEB or NZEB, which can be an important experience for them to explore ZEBs in the future. The results of Q4, Q5, Q6 and Q8 show that some conventional builders have passive design capacity, energy efficient building design capacity, renewable energy generation awareness and implementation capacity or research capacities, but they have no ZEB production experiences due to some barriers. Moreover, the result of Q7 shows that 60% of ZEB builders and 30% of conventional builders deliver modular buildings, which is considered as an important construction innovation to reduce the cost of ZEBs. Furthermore, the results of Q9 and Q10 show that 82.5% of conventional builders are committed to building a sustainable future, but they do not emphasize ZEBs as a market strategy.

Table 5. Results of checklist questions

No.	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10
1	Y	Y	N	Y	Y	Y	Y	Y	Y	Y
2	Y	Y	N	Y	Y	Y	N	Y	Y	Y
3	Y	N	N	Y	Y	Y	N	Y	Y	Y
4	Y	N	N	Y	Y	Y	N	Y	Y	N
5	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
6	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
7	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
8	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
9	Y	Y	N	Y	Y	Y	N	Y	Y	Y
10	Y	N	N	Y	Y	Y	N	Y	N	N
11	N	Y	N	Y	Y	Y	N	Y	N	Y
12	N	Y	N	Y	N	Y	Y	Y	N	Y
13	N	N	N	N	N	N	N	N	N	N
14	N	Y	N	Y	N	Y	N	Y	N	Y
15	N	Y	N	Y	N	Y	Y	N	N	N
16	N	N	N	N	N	N	Y	N	N	Y
17	N	Y	N	Y	Y	Y	N	Y	N	Y
18	N	N	N	N	N	N	Y	N	N	Y
19	N	N	N	N	N	N	N	N	N	N
20	N	N	N	N	N	N	Y	Y	N	Y
21	N	Y	N	Y	Y	Y	Y	Y	N	Y
22	N	N	N	N	N	Y	Y	N	N	N
23	N	N	N	N	N	Y	Y	N	N	N
24	N	N	N	N	N	N	Y	N	N	Y
25	N	N	N	N	N	N	N	N	N	Y
26	N	Y	N	Y	N	Y	Y	Y	N	Y
27	N	Y	N	Y	Y	Y	N	Y	N	Y
28	N	N	N	N	N	N	Y	N	N	Y
29	N	N	N	Y	N	N	N	N	N	Y
30	N	Y	N	Y	N	N	N	N	N	Y
31	N	N	N	N	N	N	N	N	N	Y
32	N	Y	N	Y	N	Y	N	Y	N	Y
33	N	N	N	N	N	N	N	N	N	Y
34	N	N	N	N	N	N	N	N	N	Y
35	N	N	N	N	N	N	N	N	N	Y
36	N	N	N	N	N	N	N	N	N	Y
37	N	Y	N	N	N	Y	N	Y	N	Y
38	N	N	N	N	N	N	N	N	N	Y
39	N	Y	N	Y	Y	Y	N	Y	N	Y
40	N	N	N	N	N	N	N	N	N	N
41	N	N	N	N	N	N	N	N	N	Y
42	N	N	N	N	N	N	N	N	N	N
43	N	N	N	N	N	N	N	N	N	Y
44	N	Y	N	Y	Y	Y	N	Y	N	Y
45	N	N	N	N	N	N	Y	N	N	Y
46	N	N	N	N	N	N	N	N	N	Y
47	N	N	N	N	N	N	N	N	N	Y
48	N	N	N	N	N	N	N	N	N	Y
49	N	N	N	Y	Y	N	N	Y	N	Y
50	N	N	N	N	N	N	N	Y	N	Y

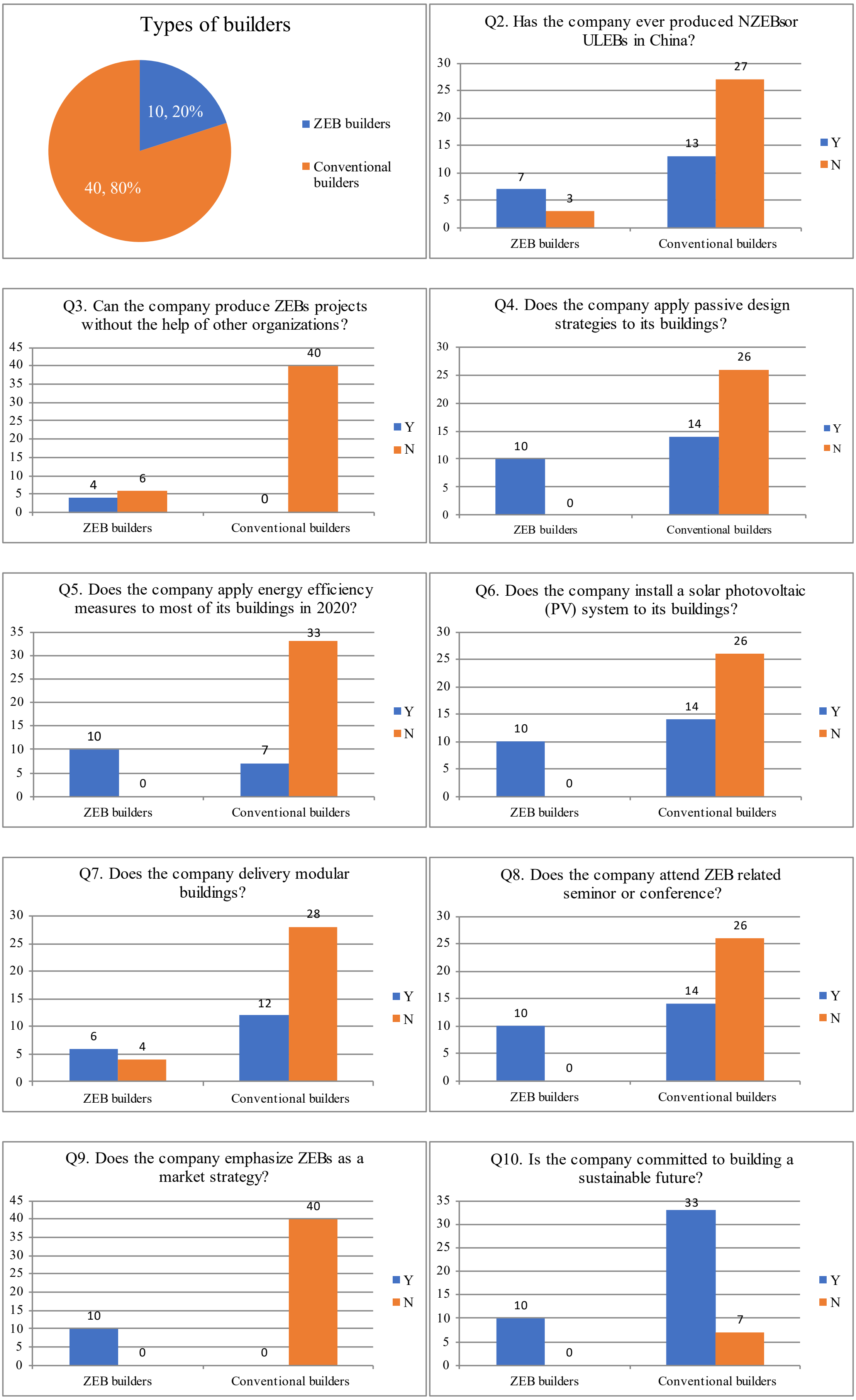

Figure 3. Results of checklist questions

3.2 Differences between conventional builders and ZEB builders

The association rule analysis employing the Apriori algorithm was adopted to explore the differences in design and construction capacities of conventional and ZEB builders. The minimum support and minimum confidence were set as 0.2 and 0.8 respectively in the association rule analysis. Table 6 shows the associations identified with Q1 set as the antecedent. Five association rules that meet minimum criteria were generated. The lift values of all associations are above 1. The results indicate that ZEB builders have passive design capacities, energy efficient building design capacities, renewable energy generation capacities, ZEB research capacities and ZEB production willingness. Table 7 shows association rules generated with Q2 set as the antecedent. The results indicate that builders' NZEB or ULEB production experiences are associated with passive design capacities, research capacities, renewable energy generation awareness and implementation capacities and responsibilities. There is no rule generated with Q3 set as antecedent when the minimum support is set as 0.2. As shown in Table 8, the support and confidence of all associations are 0.08 and 1 respectively when Q3 is set as antecedent. This means that builders' design and construction knowledge is, to some extent, related to all other questions, but not explicitly related to a particular factor. Table 9 shows association rules generated with Q4 set as the antecedent. The results indicate that builders' passive design capacities are associated with their renewable energy generation capacities, research capacities and responsibilities. Table 10 shows association rules generated with Q5 set as the antecedent. The results indicate that builders' energy efficient building design capacities are associated with their passive design capacities, renewable energy generation awareness and implementation capacities, research capacities and responsibilities.

Table 11 shows association rules generated with Q6 set as the antecedent. The results indicate that builders' renewable energy generation awareness and implementation capacities are associated with their passive design capacities and research capacities. Table 12 shows association rules generated with Q7 set as the antecedent. The results indicate that builders' construction innovation capacities are associated with their renewable energy generation awareness and implementation capacities and responsibilities. Table 13 shows association rules generated with Q8 set as the antecedent. The results indicate that builders' research capacities are associated with their passive design capacities, renewable energy generation awareness and implementation capacities and responsibilities. Table 14 shows association rules generated with Q9 set as the antecedent. The results indicate that builders' ZEB production willingness is associated with various factors, including ZEB production experience, passive design capacities, energy efficient building design capacities, renewable energy generation awareness and implementation capacities and responsibilities, research capacities and responsibilities. Table 15 shows that there is no rule generated with Q10 set as antecedent when the minimum confidence is set as 0.8. Three associations are generated when the minimum confidence is set as 0.4, which means that builders' responsibilities are associated with their NZEB or ULEB production experience, passive design capacities and research capacities. Moreover, Q9 and Q10 are designed to investigate whether willingness (Q9) or responsibility (Q10) can be the driving force for the company to deliver ZEBs. The lift value of the association between Q1 and Q10 is below 1, which means that there is no positive correlation between Q1 and Q10. So, the result indicates that ZEB builders produce ZEBs more out of willingness rather than out of responsibility.

Table 6. Associations with Q1 as antecedent

Consequent	Antecedent	Support %	Confidence %	Lift
Q5	Q1	20	100	2.94
Q8	Q1	20	100	2.17
Q6	Q1	20	100	2.08
Q4	Q1	20	100	2.08
Q9	Q1	20	90	5

Table 7. Associations with Q2 as antecedent

Consequent	Antecedent	Support %	Confidence %	Lift
Q6	Q2	40	95	1.98
Q4	Q2	40	95	1.98
Q10	Q2	40	95	1.16
Q8	Q2	40	90	1.96

Table 8. Associations with Q3 as antecedent

Consequent	Antecedent	Support %	Confidence %	Lift
Q9	Q3	8	100	5.56
Q1	Q3	8	100	5
Q7	Q3	8	100	2.94
Q5	Q3	8	100	2.94
Q2	Q3	8	100	2.5
Q8	Q3	8	100	2.17
Q6	Q3	8	100	2.08
Q4	Q3	8	100	2.08
Q10	Q3	8	100	1.22

Table 9. Associations with Q4 as antecedent

Consequent	Antecedent	Support %	Confidence %	Lift
Q8	Q4	48	87.5	1.9
Q6	Q4	48	87.5	1.82
Q10	Q4	48	87.5	1.07

Table 10. Associations with Q5 as antecedent

Consequent	Antecedent	Support %	Confidence %	Lift
Q8	Q5	34	100	2.17
Q4	Q5	34	100	2.08
Q6	Q5	34	94	1.96
Q10	Q5	34	88	1.08

Table 11. Associations with Q6 as antecedent

Consequent	Antecedent	Support %	Confidence %	Lift
Q8	Q6	48	88	1.90
Q4	Q6	48	88	1.82

Table 12. Associations with Q7 as antecedent

Consequent	Antecedent	Support %	Confidence %	Lift
Q10	Q7	34	82	1.00
Q6	Q7	34	65	1.35

Table 13. Associations with Q8 as antecedent

Consequent	Antecedent	Support %	Confidence %	Lift
Q6	Q8	46	91	1.90
Q4	Q8	46	91	1.90
Q10	Q8	46	91	1.11

Table 14. Associations with Q9 as antecedent

Consequent	Antecedent	Support %	Confidence %	Lift
Q1	Q9	18	100	5.00
Q5	Q9	18	100	2.94
Q8	Q9	18	100	2.17
Q6	Q9	18	100	2.08
Q4	Q9	18	100	2.08
Q10	Q9	18	89	1.08

Table 15. Associations with Q10 as antecedent

Consequent	Antecedent	Support %	Confidence %	Lift
Q8	Q10	82	51	1.11
Q4	Q10	82	51	1.07
Q2	Q10	82	46	1.16

Table 16. Associations regarding Q9 and Q10

Consequent	Antecedent	Support %	Confidence %	Lift
Q9	Q1	20	90	5
Q10	Q1	20	80	0.98

3.3 Categories of builders in China

To assess the potentials of boosting Chinese builders' capacities to deliver ZEBs in the future, the TwoStep Cluster analysis was employed to cluster builders. Five clusters were generated through the TwoStep Cluster analysis (Figure 4). Figure 5 demonstrates the clusters inputs. Cluster 1 is ZEB builders who have acquired ZEB design and construction capacities. Cluster 2 represents conventional builders who have NZEBs or ULEBs production experience. They have acquired some level of ZEB delivery capacities, such as passive design capacity, energy efficient building design capacity, renewable energy generation capacity, and research capacities, but their ZEB design and construction knowledge is insufficient to deliver ZEB projects. Cluster 3 refers to conventional builders who deliver modular buildings and are committed to building a sustainable future, but they do not acquire any ZEB delivery capacities. Cluster 4 is conventional builders who are committed to building a sustainable future, but they also do not acquire any ZEB delivery capacities. Cluster 4 is the largest cluster among all the clusters, accounting for 32% of builders. Cluster 5 refers to conventional builders delivering modular buildings without any ZEB delivery capacities. Cluster 5 is the smallest cluster, with only 6% of builders in Cluster 5.

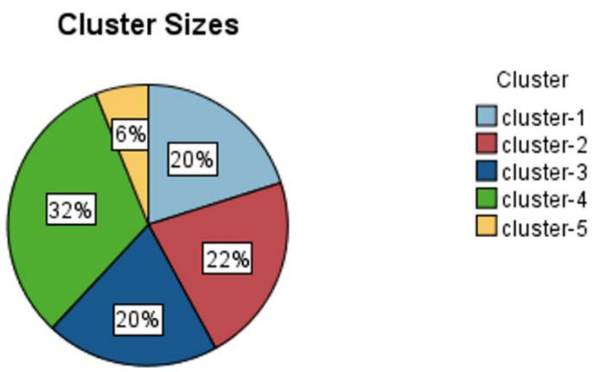

Figure 4. Clusters generated through TwoStep Cluster analysis

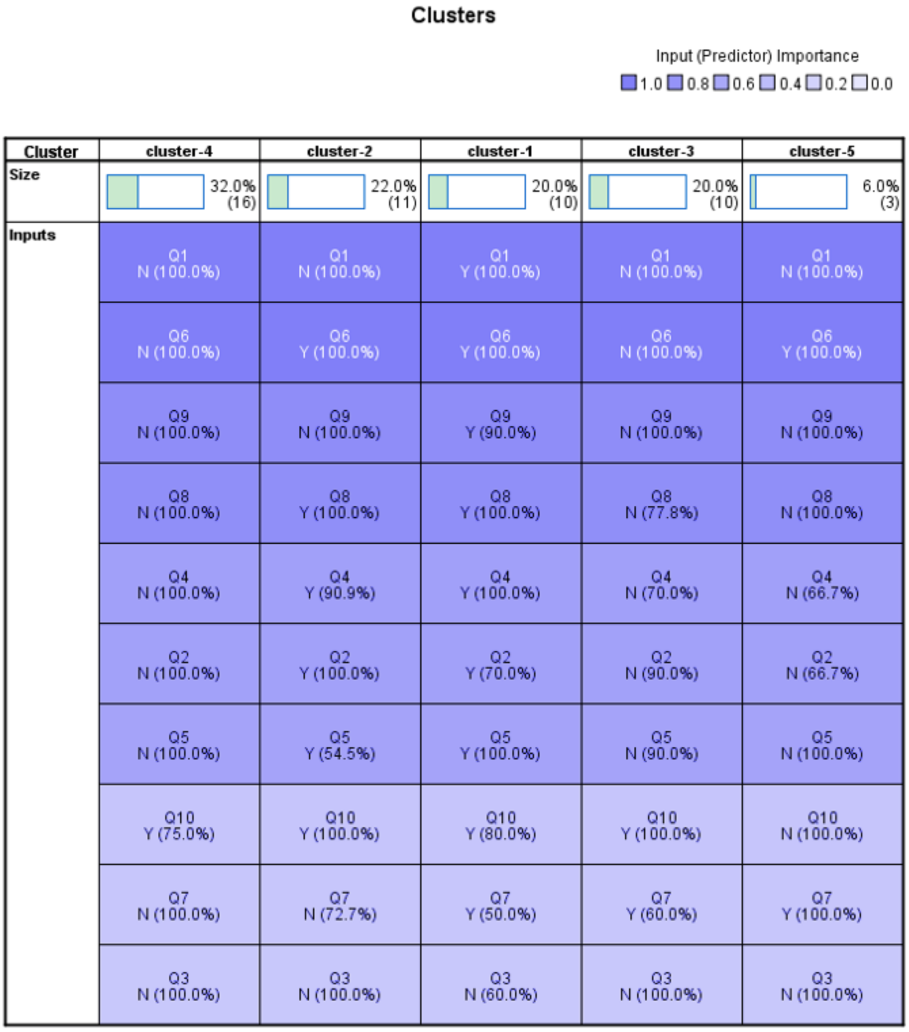

Figure 51. Clusters inputs

4. Discussion

4.1 Current builders' capacities to deliver ZEBs in China

The findings of this research show that only a small number of builders have delivered ZEBs in China. Most ZEB builders only have one ZEB production experience, their knowledge is insufficient for them to produce ZEBs on their own. So ZEB demonstration projects are usually developed in cooperation with foreign professional institutions. Due to the lack of relevant experience and knowledge, the development of ZEBs in China mainly refers to the experience of developed countries [31]. But China has diverse climate zones and unique features in building type and living habits. Completely referring to foreign standards cannot support a large-scale promotion of ZEBs. Therefore, research capacities and technological innovation capabilities are important for Chinese builders. The findings support the arguments of Tang, S. [32], who suggested that enhancing enterprises' independent research capacity and technological innovation capability is critical in the development of ZEBs in China.

The results also show that all ZEB builders and 35% of conventional builders have attended ZEB related seminars or conferences, which can be an important way for them to strengthen their research capacities and technological innovation capabilities. But related research activities seem to be inadequate now. 82.5% of conventional builders are committed to building a sustainable future, but they do not emphasize ZEBs as a market strategy. This might be due to the inadequate education and promotion of ZEBs and immature ZEB related technologies in China. It is reported that most builders and consumers have an inadequate understanding of ZEBs and they are not aware of the values of

ZEBs [31]. Besides, there is a lack of enough policies and standards support for ZEB projects [9]. So, it is recommended that the Chinese government should take actions to strengthen the education and promotion of ZEBs in China, and the builders in China should actively participate in related activities.

Moreover, the findings of this research show that 32.5% of conventional builders have ULEB or NZEB production experience, they have acquired some level of ZEB delivery capacities, such as passive design capacity, energy efficient building design capacity, renewable energy generation awareness and implementation capacity. But they have not delivered ZEBs. The design and construction methods of ULEB and NZEB are similar to that of ZEB, but has lower requirements in energy consumption (MOHURD, 2019). Due to the complex context of China, the ZEB design and construction technologies in China is immature [31]. It is difficult for China to directly move from the current building standard to the ZEB level [9]. But the exploration of ULEB and NZEB can be an important experience for builders to become ZEB suppliers in the future.

4.2 Differences between conventional builders and ZEB builders

The results of the association rule analysis indicate that builders' ZEB production experience is associated with passive design capacities, energy efficient building design capacities, renewable energy generation awareness and implementation capacities, research capacities and ZEB production willingness. Besides, builders' NZEB or ULEB experience is associated with passive design capacities, renewable energy generation awareness and implementation capacities and responsibilities. Compared with ZEB builders, NZEB or ULEB builders lack research capacities and ZEB production willingness. This can also be explained by the lack of ZEB standards and guidelines. China has published NZEB and ULEB standards in some climate zones, but there is no published ZEB standard currently. Immature technology can be one of the main barriers to develop ZEBs in China.

Compared with other conventional builders, ZEB/NZEB/ULEB builders have acquired passive design capacities, renewable energy generation awareness and implementation capacities, and research capacities, which are identified to be the key skills for builders to deliver ZEB projects. Conventional builders should learn from ZEB builders and improve related capacity. Additionally, the financial conditions of a company might impact its capacity to deliver ZEBs. The construction costs of ZEBs are usually much high than conventional buildings [33]. In addition, current ZEB projects are mainly delivered in cooperation with foreign institutions, where additional consulting fees are required. Therefore, ZEB projects are mainly delivered by companies that have sufficient financial strength.

The results also indicate that ZEB production willingness, rather than responsibility is the main driver for builders to deliver ZEBs, which is also a major difference between ZEB builders and conventional builders. So, the government can introduce more policies to provide a supportive environment for builders to deliver ZEBs. Incentive policies and economic measures are important drivers for the development of building energy efficiency [34]. Developed countries, such as United States, Japan, and Germany have introduced a series of incentives to encourage building energy efficiency improvement, including financial subsidies, tax deductions and exemptions, and loan concessions [35-37]. However, most government policies in China are mandatory and there is a lack of incentives and economic measures to encourage the development of ZEBs [4]. The high initial costs and insufficient incentives have led to the loss of competitiveness and market of ZEBs in China [38]. Therefore, more incentive policies and economic measures can be introduced to encourage conventional builders to deliver ZEBs.

4.3 Potentials of boosting builders' capacities to deliver ZEBs

Through the TwoStep Cluster analysis, the builders are divided into five categories. Table 17 shows the summary of the cluster analysis. Cluster 1 is ZEB builders who have acquired ZEB design and construction capacities. Cluster 2 represents conventional builders who have NZEBs or ULEBs production experience. Cluster 2 accounts for 20% of the builders, they are the most likely ZEB builders in the future. Among all the conventional builders, only builders in Cluster 2 acquire related ZEB delivery capacities, such as passive design capacity, energy efficient building design capacity, renewable energy generation awareness and implementation capacity, and research capacities, but their ZEB design and construction knowledge might be insufficient for them to deliver ZEB projects. In addition, compared with ZEB builders, they lack the willingness to build ZEBs and they did not seek the help of other foreign organizations as most ZEB builders do.

The second likely ZEB builders in the future are builders in Cluster 3. They are conventional builders who deliver modular buildings and are committed to building a sustainable future, but they do not acquire any ZEB delivery capacities. Researchers have suggested that adopting modular design strategies can enable large quantities of prefabrication in the factory and assembly on site, which can greatly reduce production costs of ZEBs, and make them more competitive in the market [39]. Compared with other builders, modular building suppliers have construction innovation capabilities, as well as better cost control abilities. Additionally, they are committed to building a sustainable future. They are very promising to become future ZEB builders as long as they are willing to learn relevant ZEB design and construction skills. Strengthening the education and promotion of ZEBs can help turn them into ZEB suppliers in the future.

Cluster 4 has the third-highest possibility of becoming ZEB builders in the future. They are conventional builders who are committed to building a sustainable future, but they do not acquire any ZEB delivery capacities. Cluster 4 contains the largest number of builders, accounting for 32%. Similar to builders in cluster 3, they have an inadequate understanding of ZEBs and are not aware of the values of ZEBs. Education and promotion of ZEBs are important to encourage them to become ZEB builders in the future. Cluster 5 refers to conventional builders who deliver modular buildings. Cluster 5 is the smallest cluster, with only 6% of builders in Cluster 5. They have construction innovation capacities. However, different from builders in other clusters, they are not committed to building a sustainable future. The chance for them to become ZEB builders in the future is the lowest. Education on the importance of sustainable development is a prerequisite for persuading them to build ZEBs.

Table 17. Cluster analysis and ranks

	Rank of possibility of becoming futuer ZEB builders	NZEBs or ULEBs production experience	Sufficient Design and construction knowledge	ZEB related capacities (Passive design, energy efficiency design, renewable energy generation, research capacity)	Construction innovation (Modular building)	Willingness (Emphasize ZEB as a market strategy)	Responsibility (Build a sustainable future)
Cluster 1 (ZEB builders) (20%)		Y	-	Y	Y	Y	Y
Cluster 2 (Conventional builders) (22%)	1	Y	-	Y	-	-	Y
Cluster 3 (Conventional builders) (20%)	2	-	-	-	Y	-	Y
Cluster 4 (Conventional builders) (32%)	3	-	-	-	-	-	Y
Cluster 5 (Conventional builders) (6%)	4	-	-	-	Y	-	-

5. Conclusions

5.1 Main conclusions

The building sector is one of the major energy consumption sectors in China, reducing its CO2 emission is critical to the successful pursuit of the country's carbon neutrality goal. Developing ZEBs is an important measure for China to reduce its carbon emission. Although ZEB has witnessed some progress in the past decade and there are some existing ZEB projects in China, ZEB development in China is still facing a lot of challenges. Currently, there is only a small number of builders who have delivered ZEBs, and most builders, even ZEB builders lack enough ZEB design and construction knowledge to deliver ZEB projects on their own. So, most ZEB demonstration projects are developed in cooperation with foreign professional institutions. China has diverse climate zones and unique national contexts, which means ZEB development in China cannot completely referring to foreign standards. Therefore, enhancing enterprises' independent research capacity and technological innovation capability is critical to generalise the country's ZEB movement.

Most conventional builders in China are committed to building a sustainable future, but they do not emphasize ZEBs as a market strategy. Furthermore, one-third of conventional builders have NZEBs or ULEBs production experience. They are the most likely ZEB builders in the future since the design and construction strategies of ULEB/NZEB are very similar to that of ZEB. They have acquired related ZEB delivery capacities, such as passive design capacity, energy efficient building design capacity, renewable energy generation capacity, and research capacities, but they lack adequate design and construction knowledge to deliver ZEB projects. Compared with ZEB builders, they also lack the willingness to build ZEBs and they did not seek the help of other foreign organizations as most ZEB builders do.

The barriers for conventional builders to deliver ZEBs could be immature domestic technology, inadequate understanding of ZEBs, economical deficiency and lack of incentives. The results also indicate that ZEB builders produce ZEBs more out of willingness rather than out of responsibility. Improving technology and enhancing education and promotion of ZEBs are essential to turn conventional builders into ZEB suppliers in the future. Additionally, the government can introduce more policies to provide a supportive environment for builders to deliver ZEBs. Moreover, conventional builders are less competitive than ZEB builders in passive design capacity, energy efficient building design capacity, renewable energy generation capacity and research capacity, which are identified to be the key skills that conventional builders need to learn.

5.2 Recommendations

In order to facilitate a wide delivery of ZEBs in China, the following recommendations are provided.

1) Conventional builders should learn from ZEB builders and improve their passive design capacities, energy efficient building design capacities, renewable energy generation awareness and implementation capacities, and research capacities.
2) All builders in China should actively participate in ZEB related training and research activities, and improve their independent research capacity and technological innovation capability.
3) The Chinese government should strengthen the education and promotion of ZEBs, as well as education on the importance and benefits of sustainable development.
4) The Chinese government needs to introduce more incentive policies and economic measures to promote the delivery of ZEBs.

5.3 Importance, limitations and further research

This research improves the existing understanding of builders' capacities to deliver ZEBs in China today. Differences in design and construction capacities of conventional and ZEB builders are discussed. The potentials of boosting Chinese builders' capacities for delivering ZEBs in the future are also assessed. In addition, possible solutions have been provided to help transfer current conventional builders into future ZEB suppliers. This research can provide implications for Chinese builders and policymakers to develop the most effective and appropriate approaches to generalise the country's ZEB movement in response to the country's urgent need for CO2 mitigation.

However, it should be noticed that this research has some limitations. One of the limitations is that only secondary data are used for analysis. The local builders or staff were not contacted directly due to the absence of ethics approval as well as COVID-19 disturbance in business operation. Therefore, future research can be conducted based on a combination of secondary data and primary data, which can achieve a higher level of data reliability. Moreover, only top companies are analysed in this research. Further research can build on this research and include small companies for a more in-depth and comprehensive analysis. Additionally, based on the findings of this research, future explorations can focus on how to improve builders' understanding of ZEBs and increase their willingness to deliver ZEBs.

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References

1. Shi, Q.; Chen, J.; Shen, L. Driving factors of the changes in the carbon emissions in the Chinese construction industry. *Journal of cleaner production*, 2017, p. 615.
2. Tsinghua University. Annual Report on China Building Energy Efficiency Beijing. *China Architecture & Building Press*, 2017.
3. Esbensen, T.V.; Korsgaard, V. Dimensioning of the solar heating system in the zero energy house in Denmark. *Solar Energy*, 1977. **19**(2), p. 195-199.
4. Liu, Z., et al. A comprehensive analysis on definitions, development, and policies of nearly zero energy buildings in China. *Renewable and Sustainable Energy Reviews*, 2019. **114**, p. 109314.
5. Torcellini, P., et al. *Zero Energy Buildings: A Critical Look at the Definition*. 2006.
6. Hou, Q.; Hu, M. Analysis on characteristics of climate and building energy saving measures in different regions of China. . *Architect Design Manage*, 2010. **27**(10), p. 34-39.
7. Xu, W. Nearly zero energy building research and development in China. *Sci. Technol. Rev*, 2017. **35**(10), p. 38-43.
8. Xu, W., et al. Thoughts of development of Chinese nearly zero energy buildings. *Build. Sci.*, 2016. **34**(4), p. 1-5.
9. Yuan, B. The now and future of nearly zero energy building: an interview with Xu wei,dean of institute of building environment and energy of CABR. *Eco- city Green Build.*, 2016(3), p. 14-17.
10. MOHURD. *China Technical Standard for Nearly Zero Energy Buildings*. 2019, Ministry of Housing and Urban-Rural Development (MOHURD): China.
11. Green Building Academy. *Beijing Chuanghuituyuan Education & technology*. Green Building Academy 2019 [cited 10th April; Available from: www.gba.org.cn.
12. Lin, Y., et al. A review on research and development of passive building in China. *Journal of Building Engineering*, 2021. **42**.
13. Xing, R., et al. Achieving zero emission in China's urban building sector: opportunities and barriers. *Current Opinion in Environmental Sustainability*, 2018. **30**, p. 115-122.
14. Perlova, E., et al. Concept Project of Zero Energy Building. *Procedia Engineering*, 2015. **100**, p. 1505-1514.
15. Congedo, P.M., et al. Cost-optimal design for nearly zero energy office buildings located in warm climates. *Energy*, 2015. **91**, p. 967-982.
16. Seddegh, S., et al. Solar domestic hot water systems using latent heat energy storage medium: A review. *Renewable and Sustainable Energy Reviews*, 2015. **49**, p. 517-533.
17. Mohamed, A.; Hasan, A.; Sirén, K. Fulfillment of net-zero energy building (NZEB) with four metrics in a single family house with different heating alternatives. *Applied Energy*, 2014. **114**, p. 385-399.
18. Li, D.H.W., et al. Study of daylight data and lighting energy savings for atrium corridors with lighting dimming controls. *Energy and Buildings*, 2014. **72**, p. 457-464.
19. Ahn, B.-L., et al. Effect of LED lighting on the cooling and heating loads in office buildings. *Applied Energy*, 2014. **113**, p. 1484-1489.
20. Li, Y. *The Feasibility and Operation Analysis of Zero Energy Buildings in Chinese Cold Areas*. 2014, Tianjing University: Tianjing, China.
21. Huang, H. *The Feasibility of Net Zero Energy Buildings in China for Residential Buildings*, in *Tianjing University*. 2014, Tianjing University: Tianjing, China.
22. China Real Estate Association. *2020 China Real Estate Companies Comprehensive Strength Ranking*. 2020 [cited 2021 23th May]; Available from: http://www.fangchan.com/industry/23/2020-05-26/6670723129482220468.html.
23. Chih-Hsuan, H.; Yi-Chen, L.; Hsin-Hung, W. Association Rule Mining to Identify Critical Demographic Variables Influencing the Degree of Burnout in A Regional Teaching Hospital. *TEM Journal*, 2017. **6**(3), p. 497-502.

24. Lee, S., et al. Application of association rule mining and social network analysis for under- standing causality of construction defects. *Sustainability*, 2019. **11**(3).
25. IBM Corporation. *IBM SPSS modeler 15 modeling nodes*. 2012, IBM Corporation.
26. Hong, J.; Tamakloe, R.; Park, D. Discovering Insightful Rules among Truck Crash Characteristics using Apriori Algorithm. *Journal of Advanced Transportation*, 2020, p. 1-17.
27. Moubayed, A., et al. Relationship Between Student Engagement and Performance in E-Learning Environment Using Association Rules. in 2018 IEEE World Engineering Education Conference (EDUNINE). 2018.
28. Zhang, C.; Zhang, S. *Association rule mining : models and algorithms*. Lecture notes in computer science: 2307. Lecture notes in artificial intelligence. 2002: Springer.
29. IBM. *TwoStep Cluster Analysis*. SPSS Statistics 2020 26th May]; Available from: https://www.ibm.com/docs/en/spss-statistics/27.0.0?topic=features-twostep-cluster-analysis.
30. Şchiopu, D. Applying Two-Step Cluster Analysis for Identifying Bank Customers' Profile. *Aplicarea metodei Two-Step Cluster în identificarea profilului clienţilor unei bănci.*, 2010, p. 66-75.
31. Lin, Y., et al. Towards zero-energy buildings in China: A systematic literature review. *Journal of Cleaner Production*, 2020. **276**.
32. Tang, S. Research on China's building energy-saving technology policy. *Chin Overseas Architect*, 2007(4), p. 80-83.
33. Zhou, Z., et al. The operational performance of "net zero energy building": A study in China. *Applied Energy*, 2016. **177**, p. 716-728.
34. Xu, W. Research on China passive ultra low energy building technology system. *Constr. Sci. Technol*, 2015(23), p. 15-16.
35. Liu, Y., et al. Study of zero energy building development in Korea. *Build. Sci*, 2016. **32**(6), p. 171-177.
36. Wang, N.; Xu, W. International zero energy building technology policy research. *Constr. Sci. Technol*, 2016(10), p. 30-33.
37. Wu, Y.; Ge, W. Improve building energy conservation policies and promote the development of building energy efficiency in China. *Heating Refrige*, 2007(4), p. 16-20.
38. Wang, J.; Sun, P. Analysis on the evolution law of China's building energy efficiency policy research. *Gansu Soc. Sci*, 2011(6), p. 223-225.
39. Zhang, H.; Li, J.; Dong, L. *Integration Design and Practice in the Net-Zero Energy House: Experiences in Solar Decathlon China of the O-House of Team*. 2013, Tsinghua University: Beijing, China.