Economic analysis of prefabricated buildings based on value engineering analysis

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Abstract. Combined with the value engineering theory, this paper compares the project’s value of output at different time by calculating the incremental cost and incremental benefit of the prefabricated building and the cast-in-place building. The calculations show that all aspects of prefab building are improving over time, but government subsidies have yet to have a significant effect on the overall value output.

1. Introduction
In recent years, with the active promotion of the state, prefabricated buildings are developing rapidly, but the high incremental cost makes many enterprises have low enthusiasm for the adoption of prefabricated design. Based on the theory of value engineering, this paper compares the incremental cost and incremental benefit generated by the prefabricated building, compares the project value output at different times, and analyzes the economy of prefabricated building from the perspective of enterprise and government, and puts forward some suggestions.

2. Value Engineering
Value Engineering (VE), also known as Value Analysis (VA), was proposed by Lawrence D.Miles from America in the 1940s. Later, it was integrated with total quality management in Japan and developed a more mature Value Analysis method. In July 1988, the basic terms and general process of value engineering (GB 8223-1987) which drafted by standardized comprehensive research institute of China, issued by the national bureau of standards, came into effect. It defines value engineering, "Value engineering is a kind of thought method and management technology that aims to improve the value of the object by the systematic analysis of the function and cost of the object studied through the cooperation of various related fields".

Value engineering has a very wide range of applications, which mainly includes two aspects, one is the development of construction and production, the other is the management of business organization. In the construction industry, value engineering has been applied to investment1, design2, construction3, transformation4, environmental protection5 and other links. Its mathematical expression is as follows:

\[
V = \frac{F}{C} \quad (1)
\]
Where, V represents value, and its numerical value can directly reflect the economic benefit of the object. F stands for function, which is the attribute of an object that can satisfy a certain requirement; C stands for cost, whose value reflects the total cost of the object to achieve the target function.

3. Incremental cost and incremental benefits

3.1 Incremental cost

On the basis of relevant documents such as Prefabricated Construction Engineering Consumption Quota (TY01-01(01)-2016) and Building Construction and Decoration Engineering Consumption Quota (TY01-31-2015), this paper obtained the incremental cost index system as shown in Table 1 by referring to research ideas of many scholars and traditional engineering cost calculation methods. It not only comprehensively differentiates the composition of incremental cost and improves the coverage of incremental cost index, but also considers the implementability. As the analysis object of incremental cost, the calculation of each secondary index includes direct cost (labor, material, machinery), measure cost, regulation cost, tax and other cost, etc. By calculating the costs of prefabricated building and the equivalent simulated cast-in-place building respectively and reducing them, the specific incremental cost value can be obtained.

In the construction cost composition of prefabricated residence and traditional residence, other project costs are mainly unforeseen costs in actual construction, which can be temporarily not calculated in the comparative analysis. If such costs occur in the actual construction process, they can be calculated again. Through analysis can draw, the differences of prefabricated house and traditional residential project construction cost are mainly concentrated in cost of division component project and the technical measures project fee, due to technical measures fee which closely related to construction organization design is difficult to confirm and has smaller influence on the incremental cost estimates, this paper focuses on prefabricated construction mode and the traditional cast-in-situ construction design drawings within the scope of project and prefabricated components significantly related to the partial cost analysis of the reinforced concrete formwork engineering calculation, reducing the complexity of the index system and making the incremental cost data be easier to obtain at the same time.

Table 1. Incremental cost indicator system.

| Level indicators       | The secondary indicators       |
|------------------------|--------------------------------|
| prefabricated part     | operating cost                 |
|                        | Hoisting cost                  |
|                        | transportation cost            |
| Post cast concrete     | rebar                          |
|                        | template                       |
| grout sleeve           | grout sleeve                   |
| Caulking and gluing    | Caulking and gluing            |

3.2 Incremental Benefits

Based on the research results of Siwei Chang and relevant authoritative documents, this paper conducts an optimization analysis on the algorithm of incremental benefits of prefabricated buildings from three aspects: resource conservation, time limit reduction and policy subsidies.

3.2.1 Incremental benefit of resources. According to the documents of Prefabricated Construction Engineering Consumption Quota (TY01-01(01)-2016), Building Construction and Decoration Engineering Consumption Quota (TY01-31-2015) and National Unified Machinery Consumption Quota, comparative analysis method was adopted to produce, install and post-pour concrete for prefabricated components. The resource consumption of water, electricity and oil is compared. The difference coefficient of resource consumption of unit components is shown in Table 2.
Table 2. Difference coefficient of resource consumption.

| sequence number | Construction activities | water (m³) | Electricity (kw) | Oil (t) |
|-----------------|-------------------------|------------|-----------------|--------|
| 1               | Component production    | -1.03      |                 |        |
| 2               | Post cast concrete beam column joint | -0.0005 | 4.41            |        |
| 3               | Post-cast concrete composite beams and slabs | 0.6235 | 0.555           |        |
| 4               | Post-cast concrete composite shear wall | 1.51    | 2.868           |        |
| 5               | Post cast concrete connecting wall columns | 0.5395 | 2.823           |        |
| 6               | Post cast concrete ribbed reinforcement HRB400 with diameter <=10mm | -1.154 |                 |        |
| 7               | Post cast concrete ribbed reinforcement HRB400 with diameter <=18mm | -0.705 |                 |        |
| 8               | Post cast concrete ribbed reinforcement HRB400 with diameter <=25mm | 0.065  |                 |        |
| 9               | Post cast concrete ribbed reinforcement HRB400 with diameter <=40mm | -0.449 |                 |        |
| 10              | The diameter of post-cast concrete ribbed reinforcement above HRB400 with diameter <=10mm | -16.4977 |                 |        |
| 11              | The diameter of post-cast concrete ribbed reinforcement above HRB400 with diameter <=18mm | -0.7306 |                 |        |
| 12              | The diameter of post-cast concrete ribbed reinforcement above HRB400 with diameter <=25mm | -0.6219 |                 |        |
| 13              | The diameter of post-cast concrete ribbed reinforcement above HRB400 with diameter <=40mm | -0.4939 |                 |        |
| 14              | HPB300 of post-cast concrete round steel bar is bound with diameter <=10mm | -0.595  |                 |        |
| 15              | HPB300 of post-cast concrete round steel bar is bound with diameter <=18mm | -2.8767 |                 |        |
| 16              | HPB300 of post-cast concrete round steel bar is bound with diameter <=25mm | 0        |                 |        |
| 17              | Spot welding of HPB300 in post cast concrete round steel bar diameter <=18mm | 0        |                 |        |
| 18              | Stirrup within HRB400 diameter <=10 | 0        |                 |        |
| 19              | Stirrup within HRB400 diameter >10 | 0        |                 |        |
| 20              | Stirrup outside HRB400 diameter <=10 | 0        |                 |        |
| 21              | Stirrup outside HRB400 diameter >10 | 0        |                 |        |
| 22              | Post cast concrete beam column joint formwork | 0.80922 |                |        |
| 23              | Post - cast concrete wall column joint formwork | 0.192  |                |        |
| 24              | Post-cast concrete slab belt | 0.17661 |                 |        |
| 25              | Integrated bracket | -2.9212 |                 |        |
| 26              | vertical transport | -0.15 | -0.15           |        |

As shown in Table 2, the table coefficient is derived from the above-mentioned authority of current industry standards and regulations. Each unit of water, electricity, oil resources consumption difference coefficient is equal to the consumption per unit of traditional building minus consumption per unit of industrial building. The positive coefficient in the table represents the more resources consumed compared with the cast-in-place buildings, while the negative coefficient represents the resources saved compared with the cast-in-place building. According to the difference coefficient of unit consumption of each resource in the table, the calculation model of saving benefits of industrial building resources is constructed, as shown in Formula 2:

$$\sum_{k=1}^{n} \left[ \sum_{i=1}^{m} (V_i \cdot i) \cdot P_k \right]$$

(2)
3.2.2 Calculation model for the benefit of shorter construction period. Project construction investment mainly comes from self-owned funds and borrowed funds. The former requires the opportunity cost of giving up the use, while the latter requires the payment of interest. The essence is the cost of funds, which should be included in the total investment amount. The total construction period is a time factor, so the total investment can be calculated using compound interest method. Due to the long construction period, it is generally paid in non-equal amount annually. Considering the time value of funds, the formula for calculating the total benefit of the shortened construction period is shown in Formula 3:

\[
\sum_{j=1}^{N_1} \left( \sum_{k=1}^{j-1} P_k + P_j/2 \right) \times i - \sum_{j=1}^{N_2} \left( \sum_{k=1}^{j-1} P_k + P_j/2 \right) \times i
\]

(3)

- \( P_j \) — Number of loan plans in year \( J \) of construction period
- \( i \) — Annual interest rate
- \( N_1 \) — Number of years of on-site interest calculation
- \( N_2 \) — Assembly interest-bearing year

3.2.3 Policy subsidy benefit measurement model. Current regional latest policy terms and conditions, mainly including three types of financial subsidies, preferential taxes and fees, and area awards. To improve the applicability of the calculation model, this paper build the policy subsidy benefit measurement model basing on the above three kinds of subsidies policy type. Due to the different subsidy intensity in different regions, the above four benefit variables are set as parameters to facilitate the use of this calculation model by users in different regions. The compound interest method is adopted to calculate the cost saved by the three parts of the self-owned capital, namely the increase in interest, the reduction in taxes and fees, and the reduction in land cost, so as to construct the economic benefits of the industrial construction policy, as shown in Formula 4:

\[
(S \cdot a + R) + \left( P_2 \cdot J + b \cdot P_{q} \right) + (r \cdot S \cdot P_{d} + b \cdot S \cdot P_{b} + c \cdot S \cdot P_{b})
\]

(4)

- \( S \) — Covered area
- \( a \) — Financial subsidy per square meter
- \( P_2 \) — Total VAT expenditure
- \( J \) — VAT reduction ratio
- \( P_{q} \) — Total expenditure of enterprise income tax
- \( S \) — Land area
- \( P_{d} \) — The price is subsidized per square meter of land
- \( P_{b} \) — The price per square meter
- \( c \) — Proportion of building area reward
- \( b \) — Proportion of enterprise income tax reduction or exemption
- \( r \) — Volume ratio reward ratio

4. Case analysis
This paper investigates and calculates the projects in Shenzhen, Beijing, Tianjin and Shanghai with different starting times.

4.1 Project Overview
A project in Shenzhen, consisting of 24 high-rise towers, two-storey commercial podium buildings and supporting facilities, with a total construction area of about 1.15 million square meters, including prefabricated composite panels, prefabricated stairs, prefabricated air conditioning panels and other components, will be completed from April 10, 2019 to May 26, 2021.
A project in Beijing has 5 residential buildings with a total construction area of 72,813 square meters, including 49,906 square meters on the ground, including prefabricated walls, prefabricated laminated panels, prefabricated stairs, prefabricated air conditioning panels and other prefabricated components. The project will be completed from December 29, 2017 to October 15, 2020.

A project in Tianjin has a total of 10 prefabricated buildings with a total floor area of 59,964.32 square meters, including prefabricated composite floors, prefabricated staircases, prefabricated air conditioning panels, prefabricated balcony panels and other prefabricated components. The construction period will be from September 8, 2017 to July 15, 2021.

A project in Shanghai has a total of 10 residential buildings, with a total floor area of about 52,719.09 square meters, with prefabricated interior walls, PC laminated floors, prefabricated stairs, balconies, PCF boards, prefabricated beams, prefabricated exterior walls and other industrial components. The project was completed on April 18, 2019.

4.2 Data calculation

4.2.1 Cost index calculation. Based on the construction drawings, construction component procurement contract and budget documents provided by the project, this paper calculates the actual cost of each index of Shenzhen Project 1#, Beijing project 1#-3#, Tianjin project 1#-4#, and Shanghai Project 6#-8#. Moreover, it simulates and estimates the cast-in-place construction cost of the same specification through BIM modeling. The calculation results are shown in Table 3.

| project name        | Incremental cost (yuan/m²) | cost indices |
|---------------------|---------------------------|--------------|
| Beijing project 1#  | 207.9554                  | 0.0680       |
| Beijing project 2#  | 180.3233                  | 0.0589       |
| Beijing project 3#  | 206.9833                  | 0.0677       |
| Shanghai Project 6# | 557.6595                  | 0.1823       |
| Shanghai Project 7# | 557.8145                  | 0.1823       |
| Shanghai Project 8# | 557.8145                  | 0.1823       |
| Tianjin project 1#  | 159.8807                  | 0.0523       |
| Tianjin project 2#  | 160.4572                  | 0.0525       |
| Tianjin project 3#  | 150.4288                  | 0.0492       |
| Tianjin project 4#  | 151.8513                  | 0.0496       |
| Shenzhen Project 1# | 167.9559                  | 0.0549       |
| aggregate           | 3059.1243                 | 1.0000       |

It can be seen from the calculation results that the incremental cost of the Shanghai project is much higher than that of other projects, which is greatly related to the number and types of components used. The main sources of incremental costs are prefabricated floors and wallboards. Considering the correlation between the calculation results and the amount of components used, the highest incremental costs of single components are prefabricated wallboards, especially prefabricated exterior wallboards. There are two main reasons for this, One is the complexity of vertical component production and processing, and exterior wall board still often can have all sorts of door and window mouth, formwork utilization rate is low, bring about amortize cost is higher; Second, it is difficult to install the vertical components, and the cost of connecting the vertical reinforcement and the wall panel with the cast-in-place part is high. Shanghai project not only used a large amount of overall components, but also used a lot of vertical components, which leads to its high cost increment.

4.2.2 Function index calculation. According to the feasibility study report, construction organization design and other documents provided by the project side, as well as various subsidy policies of various
places, this paper calculated the incremental benefit of each building, and the results are shown in Table 4.

Table 4. Calculation results of functional index.

| project name      | economy of resources (yuan/m²) | Time limit for a project benefits (yuan/m²) | Policy benefit (yuan/m²) | Incremental benefits (yuan/m²) | function index |
|-------------------|---------------------------------|---------------------------------------------|--------------------------|-------------------------------|----------------|
| Beijing project 1#| 20.4230                         | 13.6319                                     | 1235.8200                | 1269.8750                    | 0.2102         |
| Beijing project 2#| 20.3983                         | 15.8903                                     | 1235.8200                | 1272.1086                    | 0.2106         |
| Beijing project 3#| 20.3937                         | 18.4973                                     | 1235.8200                | 1274.7109                    | 0.2110         |
| Shanghai Project 6#| 20.5103                        | 22.9656                                     | 481.9095                 | 525.3854                     | 0.0870         |
| Shanghai Project 7#| 20.5842                        | 23.3124                                     | 481.2335                 | 525.1301                     | 0.0869         |
| Shanghai Project 8#| 20.5054                        | 20.5891                                     | 479.8703                 | 520.9648                     | 0.0862         |
| Tianjin project 1#| 20.2401                         | 9.5299                                      | 100.0000                 | 129.7700                     | 0.0215         |
| Tianjin project 2#| 20.2638                         | 8.2743                                      | 100.0000                 | 128.5381                     | 0.0213         |
| Tianjin project 3#| 20.2833                         | 7.7181                                      | 100.0000                 | 128.0014                     | 0.0212         |
| Tianjin project 4#| 20.2837                         | 7.6710                                      | 100.0000                 | 127.9547                     | 0.0212         |
| Shenzhen Project 1#| 22.4265                        | 116.6276                                    | —                         | 139.0542                     | 0.0230         |
| aggregate         | 226.3124                        | 264.7074                                    | 5550.4733                | 6041.4931                    | 1.0000         |

It can be seen from the calculation results that policy subsidies account for a large proportion in incremental benefits. Policies related to prefab buildings vary greatly in different regions. Beijing and Shanghai receive higher subsidies due to the high housing price and the subsidy policy of floor area ratio. Because the Shenzhen project is fully invested by the government, it does not receive additional policy subsidies.

Without considering the policy benefits, the functional indices for each project are shown in the table below.

Table 5. Calculation results of functional indexes without policy benefits.

| project name      | economy of resources (yuan/m²) | Time limit for a project benefits (yuan/m²) | Incremental benefits (yuan/m²) | function index |
|-------------------|---------------------------------|---------------------------------------------|-------------------------------|----------------|
| Beijing project 1#| 20.4230                         | 13.6319                                     | 34.0550                      | 0.0694         |
| Beijing project 2#| 20.3983                         | 15.8903                                     | 36.2886                      | 0.0739         |
| Beijing project 3#| 20.3937                         | 18.4973                                     | 38.8909                      | 0.0792         |
| Shanghai Project 6#| 20.5103                        | 22.9656                                     | 43.4759                      | 0.0885         |
| Shanghai Project 7#| 20.5842                        | 23.3124                                     | 43.8966                      | 0.0894         |
| Shanghai Project 8#| 20.5054                        | 20.5891                                     | 41.0945                      | 0.0837         |
| Tianjin project 1#| 20.2401                         | 9.5299                                      | 29.7700                      | 0.0606         |
| Tianjin project 2#| 20.2638                         | 8.2743                                      | 28.5381                      | 0.0581         |
| Tianjin project 3#| 20.2833                         | 7.7181                                      | 28.0014                      | 0.0570         |
| Tianjin project 4#| 20.2837                         | 7.6710                                      | 27.9547                      | 0.0569         |
| Shenzhen Project 1#| 22.4265                        | 116.6276                                    | 139.0542                     | 0.2832         |
| aggregate         | 226.3124                        | 264.7074                                    | 491.0198                     | 1.0000         |

It can be seen that, without considering the policy subsidies, shenzhen project has a prominent performance in terms of resources and time limit for a project, which shows that it is superior to other projects in architectural design and construction management.
4.2.3 Value index calculation. According to Formula 1, the data processing results are shown as follows.

| project name        | function index | cost indices | value index |
|---------------------|----------------|--------------|-------------|
| Beijing project 1#  | 0.2102         | 0.0680       | 3.0920      |
| Beijing project 2#  | 0.2106         | 0.0589       | 3.5721      |
| Beijing project 3#  | 0.2110         | 0.0677       | 3.1184      |
| Shanghai Project 6# | 0.0870         | 0.1823       | 0.4770      |
| Shanghai Project 7# | 0.0869         | 0.1823       | 0.4767      |
| Shanghai Project 8# | 0.0862         | 0.1823       | 0.4729      |
| Tianjin project 1# | 0.0215         | 0.0523       | 0.4110      |
| Tianjin project 2# | 0.0213         | 0.0525       | 0.4056      |
| Tianjin project 3# | 0.0212         | 0.0492       | 0.4309      |
| Tianjin project 4# | 0.0212         | 0.0496       | 0.4267      |
| Shenzhen Project 1# | 0.0230         | 0.0549       | 0.4192      |

aggregate 1.0000 1.0000 13.3025

Table 7. Calculation results of value index without policy benefit.

| project name        | function index | cost indices | value index |
|---------------------|----------------|--------------|-------------|
| Beijing project 1#  | 0.0694         | 0.0680       | 1.0203      |
| Beijing project 2#  | 0.0739         | 0.0589       | 1.2538      |
| Beijing project 3#  | 0.0792         | 0.0677       | 1.1706      |
| Shanghai Project 6# | 0.0885         | 0.1823       | 0.4857      |
| Shanghai Project 7# | 0.0894         | 0.1823       | 0.4903      |
| Shanghai Project 8# | 0.0837         | 0.1823       | 0.4590      |
| Tianjin project 1# | 0.0606         | 0.0523       | 1.1601      |
| Tianjin project 2# | 0.0581         | 0.0525       | 1.1081      |
| Tianjin project 3# | 0.0570         | 0.0492       | 1.1597      |
| Tianjin project 4# | 0.0569         | 0.0496       | 1.1469      |
| Shenzhen Project 1# | 0.2832         | 0.0549       | 5.1581      |

aggregate 1.0000 1.0000 14.6124

4.3 Comprehensive analysis
Overall, the Shenzhen and Beijing projects performed better, achieving a relatively high return on benefits through fewer cost increments. The function output of the newly started Shenzhen project mainly comes from the saving of resources and construction period, while the Beijing project comes from policy subsidies, and the Shanghai project, the first one started, does not have advantages in all aspects. It can be seen that with the passing of time, all aspects of prefabricated construction standards are gradually improving.

However, by comparing the calculation results of the two Tables, it can be seen that the government subsidy can significantly improve the benefits of enterprises, but it has no obvious effect on the overall value output.

5. Summarize
At present, the construction scale of prefabricated buildings is expanding rapidly, but compared with the cast-in-place buildings, there are still no obvious advantages. The technology and personnel in all aspects are not mature enough, and more guidance and development are needed. At the present stage,
local policies are mainly based on the assembly rate and project type as the conditions for granting subsidies, and the construction area and land area are taken as the basis for calculating the payment amount. This leads companies to design projects just below the threshold of subsidies, and to measure the value and profit of building prefab buildings directly as part of the benefits, rather than delving into prefab building optimization.

For provincial and municipal governments, there are mainly the following Suggestions:
1. Accelerate the formulation of national, industrial and local standards for prefab construction; Supporting enterprises in compiling standards and strengthening technological innovation; Encourage social organizations to compile group standards. By gradually establishing and improving the standard system of prefabricated building covering the whole process, the standardization degree of prefabricated building will be improved, so as to reduce the construction cost;
2. Increasing the training of professional talents in design, production, construction and management of prefabricated buildings and increasing the investment of vocational skills training funds are not only the essential factors to promote the market development, but also the necessary conditions to ensure the quality of prefabricated construction projects;
3. Encourage all kinds of innovation, guide enterprises to develop and apply technologies, equipment, machines and tools suitable for prefabricated construction, and improve the assembly construction connection quality and building safety performance of parts and components; Encourage enterprises to innovate the construction organization mode, promote green construction, and apply the new mode of coordinated construction of structural engineering and sub-project.

For enterprises, there are mainly the following Suggestions:
1. Component production enterprises should actively participate in component production technology and mode innovation, optimize vertical component production process, improve mold utilization rate, strengthen production efficiency, achieve professional, standardized, large-scale and information-based production, and optimize logistics management, reasonably organize distribution;
2. Construction general contracting enterprises should pay attention to the cultivation of professional management personnel and construction personnel, carry out reasonable construction organization design, achieve unified management and deep integration of engineering design, parts and components production, construction and procurement, optimize project management mode;
3. Equipment manufacturing enterprises should improve the level of automation and flexible processing technology, research and development of targeted parts production equipment and tools.

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