ISSN 1330-3651 (Print), ISSN 1848-6339 (Online)
https://doi.org/10.17559/TV-20230315000439
Preliminary communication

System Dynamics-Based Simulation Analysis of the Policy of the Prefabricated Building Industry Chain

Jiawei LUO

Abstract: With the development of my country's industrial level, the prefabricated building (PB) model has gradually become the mainstream. In order to more scientifically study the development policy of the prefabricated building industry, a system dynamics model with the boundary of resource input, technology research and development, production capacity and market demand system is constructed from the perspective of industry chain development, based on the influence of external subjects of the industry chain on the development of the industry chain. Afterwards, dynamic simulations of the development trend of prefabricated buildings under different policy scenarios are carried out. The results show that the increase in capital investment in the industrial chain and the improvement of the prefabricated assembly rate of government-invested construction projects are strong short-term incentive policies, while corporate tax incentives and prefabricated building purchase loan incentives are long-term incentive policies. Combined with the simulation results, the policy formulation recommendations based on the development trend of the industry chain are put forward.

Keywords: industry chain; policy simulation; prefabricated building; system dynamics

1 INTRODUCTION

With the advancement of urbanization, the pillar role of the construction industry in the national economy has been continuously strengthened. The construction industry plays an important role in the development of the national economy, but the hazards it brings to the environment and the limitations of its own development are problems that cannot be ignored. In a situation where natural resources are increasingly stretched, the construction industry, with its own huge energy consumption and the pollution forces caused by the production process, is a problem. In recent years, my country's economic development model has shifted from investment-driven to quality development, and the requirements for green buildings, ecological environment, and building energy consumption have been continuously improved, making prefabricated buildings the only way for the transformation and upgrading of my country's construction industry [1]. Under the stimulus of local policies, the enthusiasm of enterprises has increased, and at the same time, in order to implement the important measures of supply-side structural reform and new urbanization [2]. In February 2016, the State Council issued the "Several Opinions of the Central Committee of the Communist Party of China and the State Council on Further Strengthening the Management of Urban Planning and Construction", striving to make prefabricated buildings account for 30% of new buildings in about 10 years [3]. As of 2018, the prefabricated building market in Asia accounted for 56% of the global market, and the European market accounted for 25.6%. China's prefabricated building started relatively late, and after the 12th Five-Year Plan, prefabricated building has really entered a period of rapid development in China. As of 2019, China's assembly building market size has climbed to 42.75% of the global share. With the characteristics of shortening the construction period, reducing energy consumption, and lowering environmental pollution such as dust, noise, and construction waste, prefabricated buildings bring significant energy saving and environmental protection effects. Therefore, systematic simulation of government policy changes to promote the development of the prefabricated building industry is an issue that needs to be explored in depth in this study.

Faced with real problems such as housing shortages, long construction periods for traditional cast-in-place construction, and high pressure on energy conservation and emission reduction, foreign countries have begun to explore the development of the prefabricated construction industry very early. The development of the prefabricated building industry in foreign countries is more mature, and the use of prefabricated buildings in engineering gradually occupies a mainstream position, and foreign scholars have conducted more research on the theory of the development model of the prefabricated building industry. For example, Lou et al. [4] uses social network analysis to develop a prefabricated building supply chain risk system and build a risk network structure to give priority to the stakeholder-related supply chain risk control, and draw bad resources and schedules, Work process control and bad information sharing between stakeholders are the main challenges of the prefabricated construction supply chain. Marchesi et al. [5] and others applied axiomatic design to the analysis of the supply chain of prefabricated buildings and the design and development of prefabricated building systems to promote the mass customization of prefabricated houses and improve their economic benefits. Du et al. [6] used RFID technology to establish the information connection in the entire prefabricated building supply chain, created the possibility of zero inventory of prefabricated components in the supply chain, and proposed to meet the dynamic supply in order to reduce the impact of demand fluctuations on the supply chain. Demand-based industry alliance mechanism. Chang et al. [7] established a mixed optimization model of assembly-type building supply chain component production considering continuity and discreteness by analyzing the characteristics of prefabricated components and fully considering staffing constraints, process constraints, and construction constraints, to minimize the cost of the manufacturer. Based on the perspective of the assembly building supply chain, Wang et al. [8] used a game system dynamics model to analyse the implementation effects of low carbon practices. The results show that low carbon practices can effectively reduce carbon emissions while increasing the profitability of the participants. Zhao et al. [9] established an evaluation system for the performance of the assembly construction supply chain based on structural equation modelling (SEM) and virtual frontier surface SBM-DEA (relaxation-based measurement and data envelopment analysis) from the perspective of sustainable development; the results show that the factors affect the performance of the supply chain of enterprises. By analysing the acceptance of prefabrication in developed and lagging countries, Steinhardt and Manley [10] identify the main factors that influence the adoption of prefabrication and reveal the potential interactions between these factors, providing guidance to decision makers in future demonstration projects and promoting the long-term development of the prefabricated building industry. Hanna et al. [11] suggested the use of prefabrication in the power industry in order to increase the performance of production projects and analysed past qualitative data, which showed that prefabrication can reduce labour wages and speed up the construction process, and finally future trends suggest that prefabricated components can enhance the development of the industry.

Domestic prefabricated buildings started relatively late, but in recent years related research on the development of the prefabricated building industry chain has achieved preliminary results. For example, Liu et al. [12] combined basic policy tools, prefabricated building drivers, and industrial value chains into a three-dimensional research framework from the perspective of policy tools. Using this framework, the content analysis method is used to measure and analyze the policy tools used in the prefabricated building policy text. Sun and Tian [13] studied the transfer effect between the risks of the prefabricated building supply chain based on the complex network theory, determined the key risks, and proposed four risk immunity strategies, and carried out dynamic simulation analysis on the immunity effects. Liu et al. [14] based on the SCOR theory, identified the factors affecting the sustainable development of the prefabricated building supply chain, and used the factor decomposition structure method to establish the prefabricated building supply from the four dimensions of economic development, ecological environment, resource utilization, and social development. The sustainability evaluation index system of the chain, and the COWA operator and cloud matter element model are used to evaluate and analyze the sustainability of the prefabricated building supply chain. Qu et al. [15] combining the characteristics of the prefabricated construction supply chain, from the aspects of transportation coordination, inventory management coordination, information sharing coordination, cost control coordination, customer service coordination, risk sharing coordination, etc., build a prefabricated construction enterprise supply chain coordination performance evaluation Index system with comprehensive use of the ANP-Fuzzy evaluation model to evaluate the collaborative performance of the supply chain of a prefabricated construction enterprise in a district of Jiangsu Province. According to the research results of previous scholars on the development of the prefabricated industrial chain, it can be found that most of the research focuses on supply chain development policy recommendations, risk management, sustainable development, technology improvement, and revenue distribution perspectives, ignoring prefabricated buildings. Industrial development has the characteristics of system dynamic change affected by policy and timeliness. Zhu and Lin [16] use a clear set of qualitative comparative analysis methods to study the development of assembly in various regions of the country, and the results show that it is feasible to develop assembly nationwide, and that localities should focus on the formulation of policy systems to promote assembly development. Liu and Jia [17] find that the main problems in the development of the assembly building industry can be solved through the development of industry-university-research cooperation, and that further deepening the content of industry-university-research cooperation can promote higher quality development of the assembly building industry. By sorting out the development history and current situation of China's prefabricated buildings, Liao [18] then analyses the problems existing in the development of prefabricated buildings from the perspective of green buildings and proposes corresponding innovative strategies. By analysing the existing supply chain of prefabricated buildings, Huang et al. [19] incorporate the theory of supply chain operation reference model for the operation principle of green supply chain, and at the same time establish a green supply chain model for prefabricated buildings, which provides reference for the sustainable development of the prefabricated building industry.

The issuance of government policies has a huge role in promoting the development of prefabricated buildings, and most scholars at home and abroad have conducted studies on the corresponding policies regarding the industrial policies of prefabricated buildings one after another. For example, from the perspective of supply-side reform, Wang et al. [20] argue that the weak foundation related to theory, technology and policy, the inability to fully match supply and demand as well as low supply capacity are also key issues. Adopting a content analysis approach, Zhang et al. [21] analysed government policy texts on prefabricated buildings released between 1950 and 2018, showing that the current policy system is biased towards project construction in the basic policy tool dimension, with a more balanced application of policy tools in the policy objective dimension. Qi et al. [22] used the full-weight TOPSIS method to establish an evaluation model to analyse national and local data from 2013-2017 to quantitatively evaluate the policy strength of each province. Li et al. [23] studied the policies on prefabricated buildings in Shenyang, constructed an evaluation system in terms of evaluation objectives, evaluation contents and evaluation methods, and used the Logit model to rank the effects of five policies. Liu et al. [24] conducted a systematic comparative case study of prefabricated building development at the district level to explore the incentive effects of demand-led policies for prefabricated buildings at the district level and the interaction between prefabricated building projects and industrial development. It also incorporates system dynamics to support the important contribution of the relevant policies to the increase in the proportion of prefabricated buildings and the output value of the related industry chain component parts in the two districts. Based on the three main stakeholders in the development of prefabricated buildings, Chen et al. [25] constructed an evolutionary game model of "government-developer" and "government-consumer" to study the strategic choice behaviour of the government, developers and consumers in the process of implementing incentive policies, and proposed strategies to achieve Pareto optimal equilibrium. Shazmin et al. [26] developed a property tax incentive model from the perspective of taxation policy and found that taxation policy promotes the development of green buildings to a certain extent, which in turn increases local government revenue. Simcoe and Toffel [27] concluded that the procurement policy for green buildings has a "spillover effect" from the perspective of public procurement policy, which will both induce suppliers to invest in green building expertise and increase the value of green building evaluation standards (LEED). Zhou et al. [28] used partial least squares structural equation modelling (PLS-SEM) to find that reputational and financial incentives were effective in promoting the development behaviour of real estate firms towards prefabricated buildings.

In summary, foreign scholars have focused their research on the theoretical study of the development model of the assembly building industry, exploring the development of the assembly building industry from the perspectives of industrial applicability, competition and technology, respectively, while domestic scholars have focused their research on the cooperation, policies and factors influencing the development and risks of the industry, ignoring the role of the development of the assembly building industry as influenced by government policy. Therefore, this article draws on previous research results, introduces the system dynamics theory into the development research of the prefabricated building industry chain, and establishes a system dynamics model to simulate the changes in the development trend of the prefabricated building industry under different policy scenarios. This provides a reference for the formulation of my country's prefabricated construction industry development policy.

2 SYSTEM DYNAMICS MODEL CONSTRUCTION

System dynamics is a science founded in 1956 by Professor Jay W. Forrester of the Massachusetts Institute of Technology to study the dynamic complexity of systems. It is mainly based on feedback theory, through the combination of qualitative and quantitative, systematic comprehensive reasoning, and computer simulation technology is mainly used to study the relationship between the structure, function and dynamic behavior of complex systems [29, 30]. It has been widely used in the construction industry for housing demand [31], construction waste treatment [32], green housing market [33], green building cost benefit estimation [34], building energy consumption forecasting [35] and other fields.

2.1 Model Boundaries and Assumptions

The development of the prefabricated construction industry chain involves many and complex subjects, including government departments, investors, consumers [36], and upstream, midstream and downstream companies within the industry chain. For example, upstream companies include raw material manufacturing companies, architectural design companies, and construction equipment manufacturing companies; midstream companies include component manufacturing companies, transportation companies, and construction companies, and downstream companies mainly include prefabricated building sales companies, property management companies, etc. [37]. In order to facilitate the system modeling and simulation, this paper mainly selects the influence of the external entities of the industrial chain on the development of the prefabricated construction industrial chain, and on the basis of which comprehensively considers the influence of different types of policies on the internal industrial chain, and further refines the model boundary, constructed an SD model with resource input, technology research and development, production capacity and market demand system as the boundary. Fig. 1 reflects the theoretical model of the system simulation for the development of the prefabricated building industry chain.

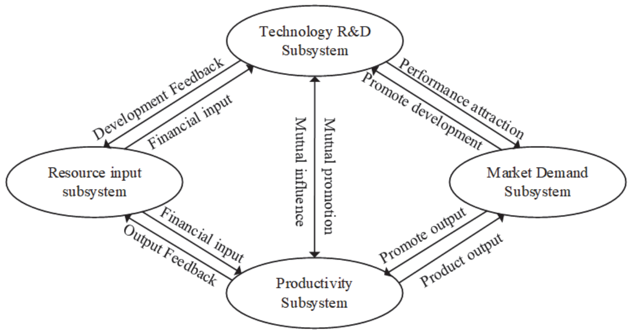


Figure 1 Theoretical model for the development of prefabricated construction industry chain

In order to better focus on the researched problem, analyze and choose the factors that have a greater impact on the development of the assembly industry, and eliminate the secondary factors to simplify the model built. Based on this, this article makes the following assumptions: (1) The goal of this article to establish a system dynamics model is to analyze the development trend of the prefabricated building industry chain under different policy backgrounds. Therefore, this article focuses on analyzing the cumulative demand and the prefabricated building market during the system simulation period and the development level of the prefabricated construction industry chain. (2) In the resource input subsystem, considering that material resources are not restricted in the prefabricated construction market, this article mainly incorporates capital investment into the subsystem. (3) During the model simulation period, the real estate market continued to develop healthily, the premium rate of the construction product market was normal, and the development of prefabricated buildings was in direct proportion to the development level of the real estate market.

2.2 Causal Loop Analysis

The causal loop diagram is composed of the variables of the system and the feedback loop formed between the variables. The positive feedback loop means that a certain variable in the loop will strengthen its original deviation trend under the influence of other variables. The negative feedback loop means that a certain variable in the loop will reduce its original deviation trend under the influence of other variables. The main feedback loops for each subsystem are shown in Tab. 1 below. This paper analyzes the interrelationship of the various subsystems; after establishing the boundaries of each subsystem, the system dynamics Vensim-PLE software is used to construct the causal circuit diagram of the composite system as shown in Fig. 2. The causal loop diagram is the basis for establishing the system flow diagram. It is a qualitative analysis of the variables in the entire system. By analyzing the feedback loop of each subsystem, the mechanism of each element's action on other elements can be clarified.

Table 1 Main feedback loops

Subsystems		Main feedback loops
Resource input subsystem	①	Developers' willingness to invest → proportion of investment in PB → internal capital raising by developers → capital investment in the PB industry chain → cumulative capital investment in the industry chain → investment in PB component production lines → level of development of component production lines → level of development of the prefabricated industry chain→ developers' willingness to invest
	②	Government funding for the PB industry chain → funding for the PB industry chain → cumulative funding for the industry chain → investment in technology R&D → increase in technology R&D projects → level of technology development → level of development of the PB industry chain → area of PB construction starts → total output value of PB → government support → government funding for the assembly industry chain
Technical subsystem	③	Level of technological development → cost of using PB→ consumers' willingness to buy → consumers' purchase → market demand → sales area of PB → economic effect of PB→ government support → maturity of the industry → increase in technological R&D projects → level of technological development
	④	Technology development level → quality performance level → product quality problems → development level of the assembly building industry chain → developers' willingness to invest → investment ratio in assembly buildings → internal capital raising by developers' enterprises → capital investment in the assembly building industry chain → cumulative capital investment in the industry chain → investment in technology R&D → increase in technology R&D projects → technology development level
Production capacity subsystem	⑤	Number of PB industry bases → level of industry chain development → area of PB starts → total output value of PB→ government support → industry maturity → number of PB industry bases Market demand → Sales area of PB → Economic effect of PB → Government support → Government demand → Market demand
Market demand Subsystem	⑥	Market demand → sales area of PB → economic effect of PB → government support → government demand → market demand
	⑦	Market demand → sales area of PB → economic effect of PB→ government support → preferential rate of loans for acquisition of PB→ purchase price → consumer willingness to buy → consumer purchase → market demand

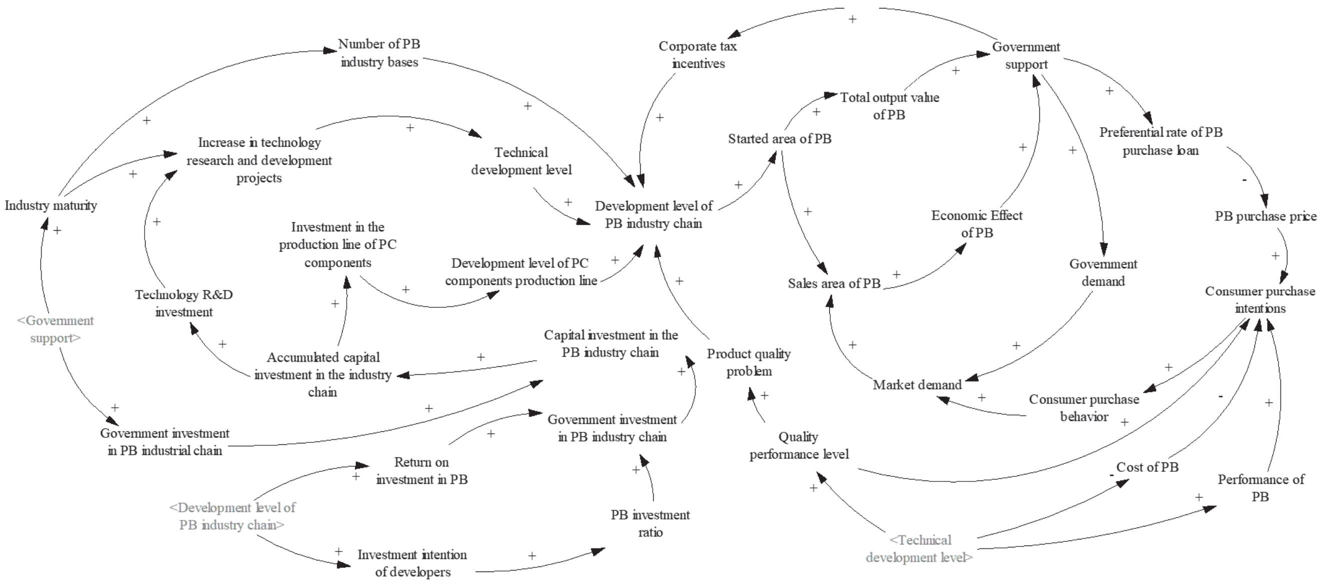


Figure 2 Causal loop of prefabricated construction industry chain development

Feedback loop ① in the table above is a positive feedback loop., which indicates that the developer's capital investment can improve the development level of the PC component production line, thereby accelerating the development of the prefabricated construction industry and improving the development level of the prefabricated industry chain. A mature industry chain will increase the developer's willingness to invest and increase capital investment.

Feedback loop ② in the table above is a positive feedback loop. The investment of government funds has promoted the improvement of the production technology of prefabricated building components, and has promoted the quality improvement and production efficiency of prefabricated buildings, which can expand the area of prefabricated buildings and increase the total output value of prefabricated buildings. The value-added effect of the coming industry can continue to stimulate the government's capital investment in the prefabricated construction industry.

Feedback loop ③ in the table above is a negative feedback loop, which mainly reflects that the improvement of technology level has reduced the use cost of prefabricated buildings, stimulated consumers' willingness to purchase, thereby increasing the market demand for prefabricated buildings, driving the national economic development, and increased government support has formed a virtuous circle.

Feedback loop ④ in the table above is a positive feedback loop, which shows that the improvement of the development level of prefabricated buildings can improve the quality of prefabricated building products, thereby promoting the development level of the industrial chain, attracting more investment from developers, and obtaining more technology research and development funds to develop more research and development projects, so as to raise the development level of prefabricated building technology to a further upgrade.

Feedback loop ⑤ in the table above is a positive feedback loop, which mainly reflects that the increase in the number of prefabricated construction industry bases promotes the development of the industrial chain, stimulates the increase in total output value, and then affects the government's support for the prefabricated construction industry.

Feedback loop ⑥ in the table above is a positive feedback loop, which shows that market demand can drive the economic effect of prefabricated buildings, promote the government's demand for prefabricated buildings, and increase the government's investment demand for prefabricated buildings.

Feedback loop ⑦ in the table above is a positive feedback loop, which indicates that market demand can promote economic development, increase government support for prefabricated buildings, increase financial support, and reduce the preferential rate of purchase loans for prefabricated buildings, thereby increasing consumers' willingness to buy and driving market demand.

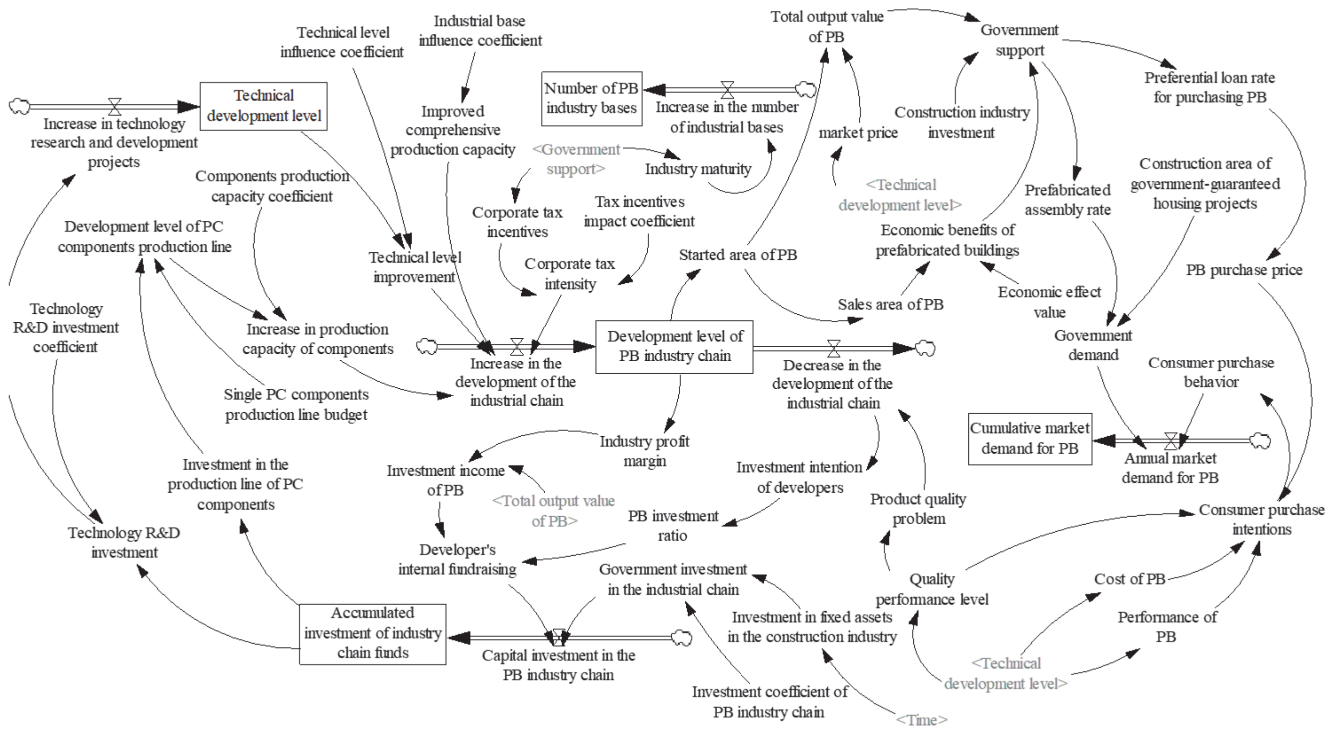


Figure 3 Stock flow chart of prefabricated construction industry chain development

2.3 Construction of System Stock Flow Diagram

Cause-and-effect circuit diagrams can clearly reflect the paths and relationships between many variables, but it is difficult to deal with the interactions between different types of variables, and is limited to qualitative treatment of variables, not quantitative analysis, in order to more clearly reflect the operating mechanism of the prefabricated building industry chain development system, considering the feasibility of the system simulation and the accessibility of the data; the relationships between the system variables are described in an intuitive and operational notation, and the feedback form of the system is clarified. Therefore, based on the analysis of the causal relationships of the four subsystems mentioned above, the variables in the system are classified and new auxiliary and constant variables are added, based on the entire causal loop diagram, taking into account the need to evaluate the output results of the indicators. On the basis of the causal flow diagram, distinguish the nature of the variables, determine their state variables, auxiliary variables, rate variables, etc., construct a system flow diagram. Using Vensim software to draw the stock flow diagram of the development of the prefabricated construction industry chain is shown in Fig. 3.

2.3.1 Variable Description

Considering the complexity of the system flow diagram variables, this article selects some important variables for detailed description, as shown in Tab. 2, where *L* represents the state variable, *R* represents the rate variable, and *A* represents the auxiliary variable.

2.3.2 Parameter and Variable Equation Setting

In order to facilitate further quantitative research on the relationship between system variables, to ensure the authenticity of the data and the scientific nature of the simulation results, the data in the article mainly come from the 2011-2020 China Statistical Yearbook, China

Prefabricated Building Network, and China Housing and the official websites of the Ministry of Urban and Rural Development. The assignment of each parameter in the model is mainly set according to the data released by authoritative websites, expert consultation scoring estimates and existing research results, as shown in Tab. 3.

Table 2 Stock flow chart variable description

No.	Variable name	Included indicators	Unit	Interval
L1	Technical development level	Total amount of technology research and development projects	Item	[0, ∞]
L2	Number of PB industry bases	National and provincial industrialization bases and industrial parks	PCS	[0, ∞]
L3	Accumulated capital investment in the industry chain	All funds invested in the prefabricated construction industry chain	RMB 100 million yuan	[0, ∞]
L4	Development level of PB industry chain	All funds invested in the prefabricated construction industry chain	—	[−1, 1]
L5	Market demand for PB	The demand for prefabricated buildings in the construction market	10000m2	[0, ∞]
R1	Increase in technology research and development projects	Comprehensive index	Item	[0, ∞]
R2	Increase in the number of industrial bases	Comprehensive index	PCS	[0, ∞]
R3	Capital investment in the PB industry chain	Comprehensive index	RMB 100 million yuan	[0, ∞]
R4	Improvement in the development of the industrial chain	Comprehensive index	—	[−1, 1]
R5	Decrease in the development of the industrial chain	Comprehensive index	—	[−1, 1]
A1	Technology R&D investment coefficient	Technology R&D investment as a percentage of total investment	—	[0, 1]
A2	Development level of PC components production line	The number and production capacity of PC component production lines	strip	[0,∞]
A3	Investment intention of developers	The degree of response of construction developers to the development level of the prefabricated construction industry chain	—	[0, ∞]
A4	PB investment ratio	Investment in prefabricated construction accounts for the proportion of developers' investment in the entire construction market	—	[0, 1]
A5	Government support	Policy Guidance	—	[0, ∞]
A6	Investment coefficient of PB industry chain	The ratio of government investment in the prefabricated construction industry chain to investment in the entire construction industry	—	[0, 1]
A7	Corporate tax incentives	The government's tax incentives for enterprises in the industry chain	—	[0, 1]
A8	Industry maturity	Proportion of mature prefabricated construction industry bases in total	—	[0, 1]
A9	Economic effect of PB	The additional economic effects of prefabricated buildings sold per 10,000 square meters to the national economy	RMB100 million yuan	[0, ∞]
A10	Consumer purchase intentions	Consumers' recognition of prefabricated buildings in the construction market	—	[0, 1]

Table 3 The main parameters of the system are assigned

Parameter	Value	Data Sources
Single PC component production line budget	RMB 100 million yuan/strip	China Prefabricated Construction Network
Construction industry investment	RMB 404.315 billion yuan	China Statistical Yearbook Average Construction Industry Investment in the Past Five Years
Economic effect value	RMB 238.1 billion/ten thousand square meters	References [38]
Construction area of government-guaranteed housing projects	315 million square meters	China's Ministry of Housing and Urban-Rural Development releases data
Industrial base influence coefficient	$7e^{-4}$	Expert Consultation Scoring Estimate

Table 4 Expressions of the main equations

Variables	Equations
Level of development of the PB industry chain	INTEG (industry chain development increase - industry chain development decrease, 0)
Government demand	Area of government guaranteed housing projects started * prefabricated assembly rate
Sales area of PB	Cumulative demand in the market for prefabricated buildings + DELAY1I (area of prefabricated building starts, 3, 0.4*area of prefabricated building starts)
Industry profitability	IF THEN ELSE (level of development of assembly building industry chain <0.5, 0.1, IF THEN ELSE (level of development of assembly building industry chain >= 0.5: AND: level of development of PC industry chain <0.7, 0.15, 0.2))
Increase in production capacity of structural components	PC component production line development level * component production capacity influence coefficient
Prefabricated assembly rate	IF THEN ELSE (Government Support <= 3, 0.25, IF THEN ELSE (Government Support > 3: AND Government Support <= 4, 0.3, IF THEN ELSE Government Support > 4: AND: Government Support <= 5, 0.4, 0.5)))
Fixed asset investment in the construction industry	WITH LOOKUP (Time([(2011, 0) - (2026, 5000)], (2011, 3357.12), (2012, 3738.97), (2013, 3669.76), (2014, 4125.76), (2015, 4956.6), (2016, 4614.9)))
Increase in technology R&D projects	WITH LOOKUP (investment in technology R&D ([(0,0) - (12334, 500000)], (921.2, 53641), (3185.9, 194400), (6230.6, 287524), (7294.5, 322567), (9146.1, 309895), (10064.3 360997), (11990.2, 445029), (12333.5, 472299)))

The relationship between the various variables in the system mainly uses regression analysis, statistical analysis, and trend extrapolation in mathematical methods to fit and analyze the data and give a scientific and reasonable equation. For those that are difficult to describe with a simple linear relationship Variables are assigned using the table function method. The main equations are shown in Tab. 4.

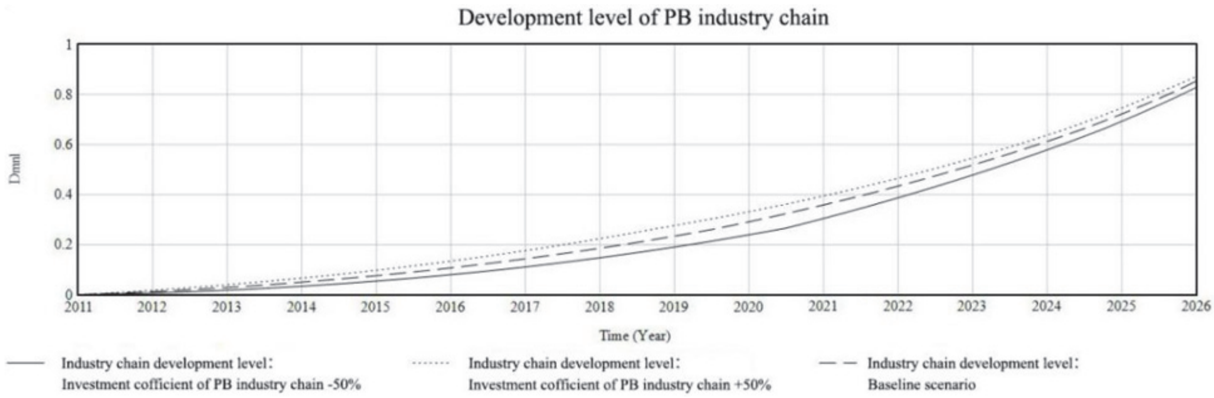
3 MODEL SIMULATION

After the system dynamics model is established, it needs to be tested for validity to judge whether the model can more accurately reflect the display situation of the research object. This article mainly uses two inspection methods and one is the dimension consistency inspection. According to the inspection function of the Vensim software, the structure of the model and the dimension unit of the variables are inspected, and the result shows that it is qualified. The second is the historical test method. The historical test refers to comparing the difference between the simulation value of the system and the historical statistical data to judge the validity of the model. This paper selects the historical value of the purchase price of prefabricated buildings from 2011 to 2016 to compare with the simulation value. The results show that the absolute value of the error range is within 10%, which meets the simulation requirements. SO, the model can be used for simulation research.

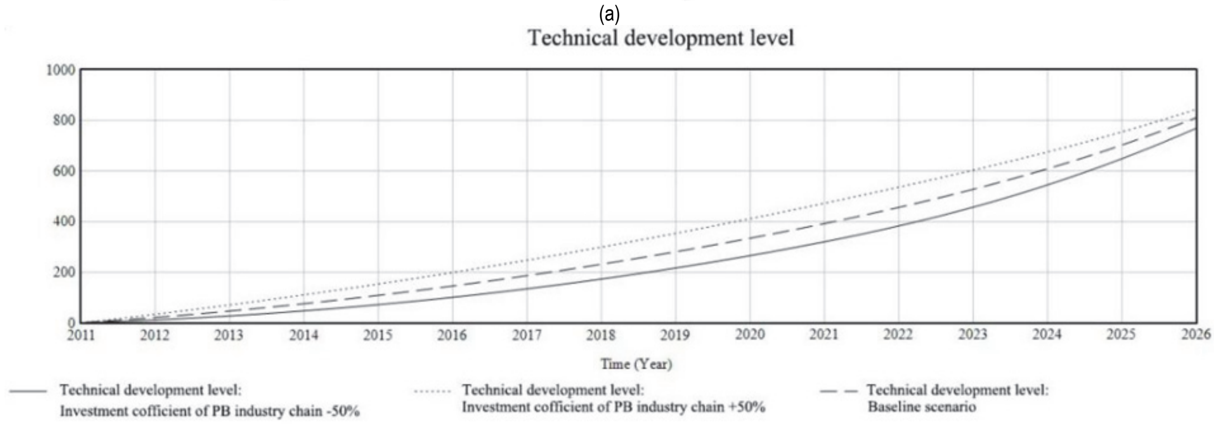
Starting from the research purpose of the article, the simulation time in the article is based on the development of time axis of the prefabricated construction industry, with 2011 as the initial time of simulation and 2026 as the end time. The unit is set to year, and the step size is 0.5; for simulation the object mainly chooses policy variables that change directly affected by changes in national policies.

3.1 Simulation Analysis of Technical Support Policy Change Scenarios

The change of technical support policy has a direct effect on the development level of the prefabricated industrial chain and the level of technological development. Assuming other policy variables remain unchanged, change the value of the variable equation Investment cofficient of PB industry chain, and set up three simulation scenarios and corresponding models: Investment cofficient of PB industry chain –50%, Investment cofficient of PB industry chain +50%, and the benchmark scenario.



(a)



(b)

Figure 4 Simulation results of technical support policy changes

The simulation results are shown in Fig. 4a and b. From Fig. 4a, it can be seen that the increase and decrease in the input coefficient of the industrial chain of prefabricated construction has a relatively large impact on the development level of the industrial chain in the initial and mid-term. Fig. 4b shows that the substantial increase in the input coefficient of the industrial chain has not greatly promoted the level of technological development, but the reduction of the input coefficient has a significant decline in the level of technological development.

In the early and mid-stage of the development of the prefabricated construction industry, the government's capital investment in prefabricated buildings was mainly used in technological research and development projects, and the improvement of the technical level directly promoted the development of the industrial chain. In the later stages of the development of the industrial chain, the investment of the industrial chain funds mainly comes from the internal fund-raising of the developers. Therefore, the government's increase or decrease of the input coefficient of the industrial chain has little effect on the development of the industrial chain. In the early stage of technological development, significantly increase the government's investment coefficient in the industrial chain, and the level of technological development will surpass the development needs of the industrial chain, so the surpassed part of the technology investment funds will flow into the construction of prefabricated building infrastructure production facilities. In the later period, enterprises gradually paid attention to the innovation and development capabilities of prefabricated buildings, and their investment willingness gradually tilted toward prefabricated building technology projects. However, the government's investment in prefabricated construction technology plays a very important role, and a good initial technological development level plays a major role in guiding the development of the entire industrial chain.

3.2 Simulation Analysis of Tax Support Policy Change Scenarios

The tax support policy mainly includes three aspects. One is the preferential tax policy for the research and development of new technologies, new products, and new processes; the other is that qualified enterprises can enjoy the preferential policy of taxation and refund of value-added tax; and the third is included in the development of the western region. Scope of tax incentives. By reducing the cost of using prefabricated buildings, the production costs of structural parts and the transaction costs of intermediate links, tax support policies act on the entire industrial chain, which will promote the participation of enterprises in the traditional construction industry in the development of prefabricated buildings. The transformation and upgrading of enterprises has a positive guiding role. Therefore, comprehensively considering the diversity of tax support policies, the simulation of corporate tax incentives increased by 50%, decreased by 50%, and the baseline scenario, the simulation results are shown in Fig. 5. The increase in corporate tax incentives will increase the level of development of the industrial chain, while, the decrease in corporate tax incentives will slow the development of the industrial chain. From the perspective of the development and change of the industrial chain and the continuity of time, the impact of corporate tax incentives on the development of the industrial chain of prefabricated construction is long-term and stable.

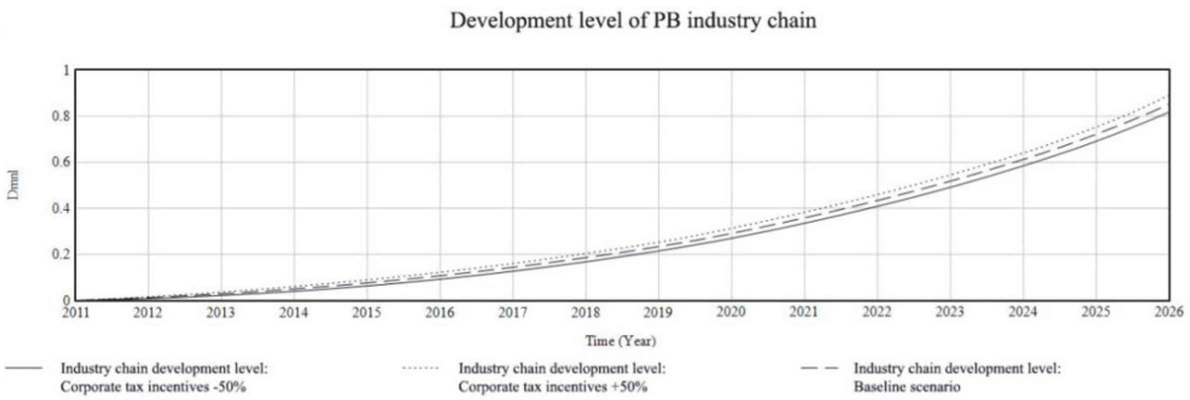
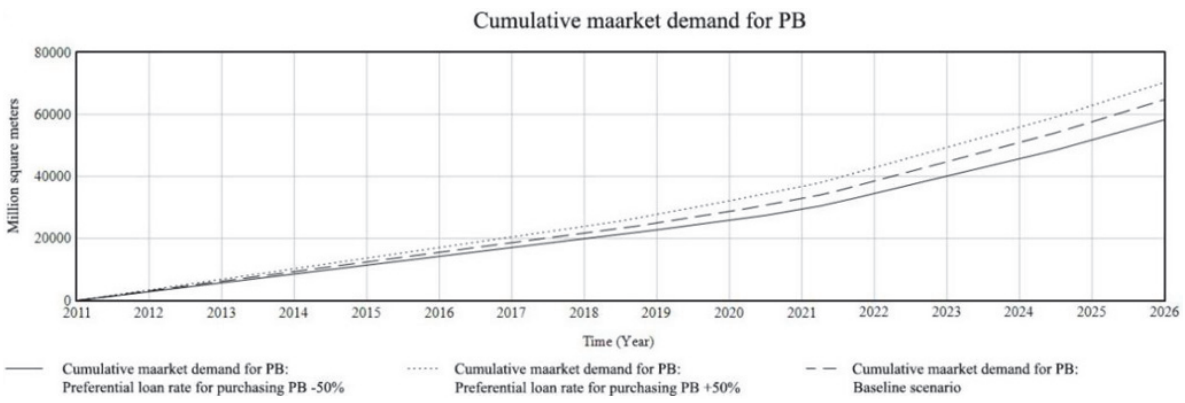


Figure 5 Simulation results of enterprise tax incentive policy change

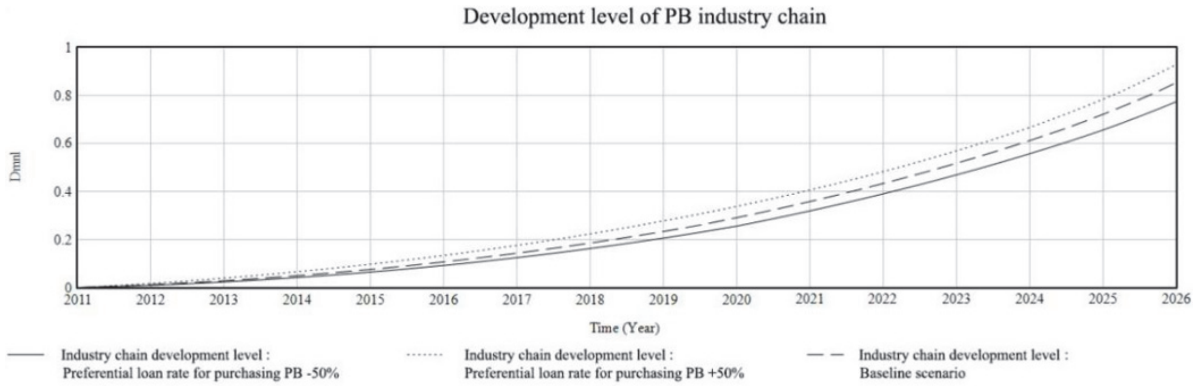
3.3 Simulation Analysis of Financial Support Policy Change Scenarios

In order to study the impact of financial support policies on the development of the prefabricated construction industry, the article selects preferential house purchase loan policies as the main financial policy variable, and discusses the changes in prefabricated building purchase loan preferences on the cumulative demand for prefabricated construction market and the development level of the industrial chain. It analyzes the impact mechanism of financial support policies.

The simulation results are shown in Fig. 6a and b. Fig. 6a shows that the change in the preferential rate of purchase loans for prefabricated buildings has little effect on the cumulative demand for prefabricated buildings before 2016, but in the mid-late-stage influence of industrial development has increased; and in the initial stage of the development of the industrial chain, the reduction in the preferential rate of purchase loans has a greater impact on the change in the market demand for prefabricated construction than the increase in the preferential rate of purchase loans.



(a)



(b)

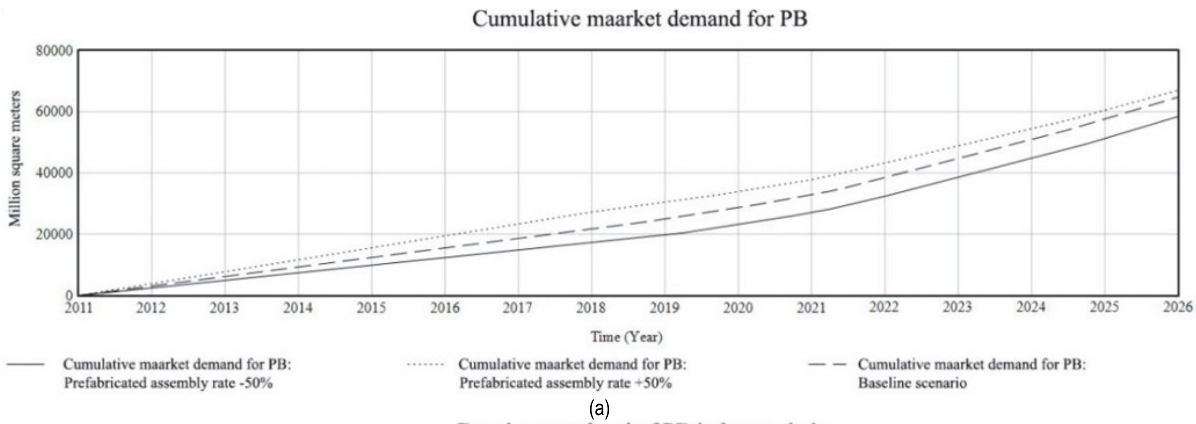
Figure 6 Simulation results of financial support policy changes

In the early stage of industrial development, consumers did not have a high degree of understanding of prefabricated building products, and their willingness to purchase was not only affected by the purchase price, but also by the nature of the building's use cost and performance. With the improvement of technology, the purchase cost became the main factors affecting consumers' choice of prefabricated buildings. The preferential rate of purchase loans has the same effect on the development level of the industrial chain. Therefore, the preferential rate of purchase loans is a long-term influencing factor for the development of the prefabricated construction industry chain.

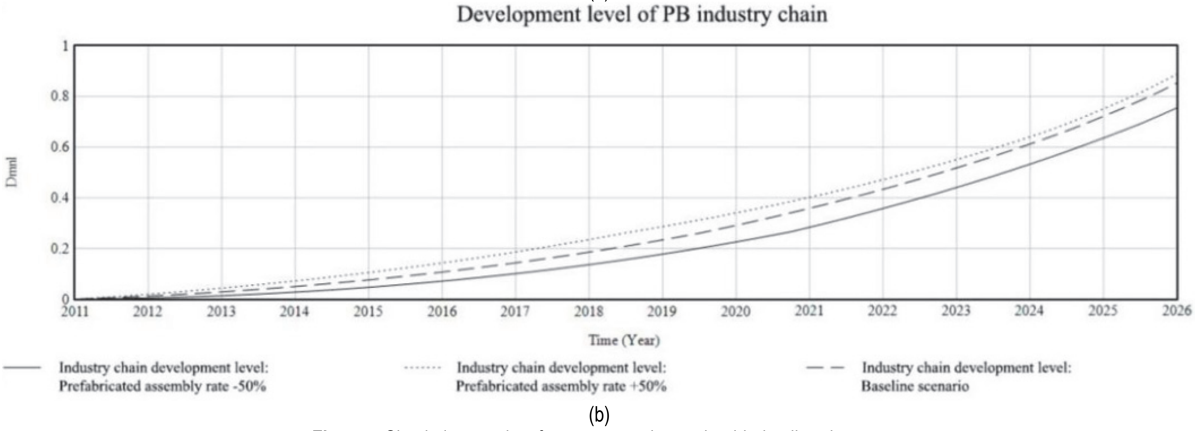
3.4 Simulation Analysis of Demand-Guided Policy Change Scenarios

Market demand plays an active role in promoting the competitive advantage of prefabricated buildings in the construction market. Therefore, government takes the lead in piloting, establishing a market mechanism, promoting the use of prefabricated buildings, formulating reasonable demand guidance policies, guiding market development, increasing consumers' attention and understanding of prefabricated buildings, and improving developers' willingness to construct prefabricated building projects. In order to explore the influence mechanism of government demand on the development of the prefabricated construction industry, the prefabricated assembly rate of government-invested construction projects was increased by 50% and decreased by 50% more than the model was simulated. The results are shown in Fig. 7a, b.

From the simulation results of Fig. 7a and b, it can be seen that increasing the prefabricated assembly rate will increase the cumulative demand in the prefabricated building market, and the increase will be greater before 2021 than after 2021. The decrease in the prefab assembly rate has a greater impact on the cumulative demand and development level of the prefabricated construction market than the increase in the prefab assembly rate.



(a)



(b)

Figure 7 Simulation results of government demand-guided policy changes

This is mainly because in the early stage of the development of prefabricated buildings, consumers did not pay much attention to understanding of prefabricated buildings, and the demand for prefabricated buildings was not high. The government's demand for prefabricated buildings is the main source of market demand, which greatly stimulates the development of the prefabricated building industry. In the later stages of the development of prefabricated buildings, consumers have become the main source of demand for prefabricated buildings, and the promotion of the increase in the prefabricated assembly rate of government-invested construction projects is very limited. However, reducing the government's demand for prefabricated buildings in the early stage is equivalent to limiting the initial motivation for the development of prefabricated buildings, and will severely restrict the subsequent development of the industrial chain.

4 CONCLUSIONS AND RECOMMENDATIONS

From the perspective of the development of the prefabricated building industry chain, this paper establishes a system dynamics model. Under different policy scenarios, the model is simulated and analyzed to study the impact of policy changes on the development of the prefabricated building industry. The results show that in the early stage of the development of the prefabricated building industry, the state's investment in the prefabricated building industry and the government's demand for prefabricated buildings played an important role in promoting the development of the prefabricated building industry; while the state has a long-term positive impact on the tax incentives for enterprises in the prefabricated construction industry and consumer prefabricated building purchase loans. At the same time, in order to reduce the cost of national incentive policies for the development of prefabricated buildings, based on the above simulation results, the following policy formulation recommendations are put forward:

(1) Formulate a reasonable capital investment policy, and adjust the proportion of technology investment and infrastructure production facility investment in a timely manner. A sound technical system through the entire industrial development process is an important foundation for advancement of the development of prefabricated buildings. In the initial stage of industrial development, the government should give full play to the supporting role of technological policies and appropriately increase technological investment, but should adjust the investment ratio according to the real-time situation of the industrial development level and technological development level. When the industrial development enters a period of relative stability, the government will appropriately reduce capital investment and increase other policy support.

(2) Expand the scope of preferential tax policies for enterprises, clarify the responsibilities of relevant departments, and promote the effective implementation of policies. As an important factor in influencing the enthusiasm of enterprises to participate in the development of prefabricated buildings, tax support policies play a long-term and stable role in promoting the development of the prefabricated building industry. For this type of policy, the policy coverage area should be increased to attract more relevant enterprises to transform to prefabricated buildings.

(3) According to local conditions, the corresponding preferential policies for the purchase of prefabricated buildings shall be promulgated in accordance with the actual conditions of each region. For example, in some areas where the development of prefabricated buildings is relatively mature, the purchase price of prefabricated buildings is not much different from that of traditional cast-in-place buildings. In order to reduce the direct cost of financial subsidies, the government can increase consumers' willingness to purchase prefabricated buildings by increasing loan lines and loan terms. For areas where the development of prefabricated buildings is still in its infancy, consumers do not know much about prefabricated buildings, and the government can increase the preferential power of loans for the purchase of prefabricated buildings, thereby increasing consumers' willingness to buy.

(4) Reasonably plan the prefabrication rate of government prefabricated buildings. Based on the simulation results of the demand policy, in the early stage of the development of the prefabricated construction industry, the government can expand the government's demand for prefabricated buildings by increasing the prefabricated assembly rate, thereby guiding and stimulating the development of the prefabricated construction industry. In the middle and late stages of the development of the prefabricated construction industry, considering the insignificant effect of government demand on the development of the prefabricated building industry and the incremental cost of the project itself brought by the excessively high prefabricated assembly rate, the government should re-plan the prefabrication rate of government-invested construction projects.

5 REFERENCES

[1] Cheng, X. K. (2021). Development of prefabricated buildings at home and abroad. *China Construction Information*, *20*, 28-33.

[2] Wang, C. J., Huang, X. L., & Feng, T. (2019). System simulation and policy optimization of the prefabricated housing market: Taking Xi'an as an example. *Mathematics in Practice and Understanding*, *49*(24), 90-99.

[3] Liu, J. & Sun, Y. L. (2018). The choice of fiscal and taxation policies for the promotion and application of low-carbon buildings - Taking prefabricated buildings as an example. *Local Financial Research*, *1*, 53-61.

[4] Luo, L., Qiping Shen, G., Xu, G., Liu, Y., & Wang, Y. (2019). Stakeholder-associated supply chain risks and their interactions in a prefabricated building project in Hong Kong. *Journal of Management in Engineering*, *35*(2), 05018015. https://doi.org/10.1061/(ASCE)ME.1943-5479.0000675

[5] Marchesi, M. & Matt, D. T. (2017). Design for mass customization: Rethinking prefabricated housing using axiomatic design. *Journal of Architectural Engineering*, *23*(3), 05017004. https://doi.org/10.1061/(ASCE)AE.1943-5568.0000260

[6] Du, J., Sugumaran, V., & Gao, B. (2017). RFID and multi-agent based architecture for information sharing in prefabricated component supply chain. *IEEE Access*, *5*, 4132-4139. https://doi.org/10.1109/ACCESS.2017.2665778

[7] Chang, C. & Han, M. (2021). Production scheduling optimization of prefabricated building components based on dde algorithm. *Mathematical Problems in Engineering*, *2021*, 1-11. https://doi.org/10.1155/2021/6672753

[8] Wang, X., Du, Q., Lu, C., & Li, J. (2022). Exploration in carbon emission reduction effect of low-carbon practices in prefabricated building supply chain. *Journal of Cleaner Production*, *368*, 133153.

https://doi.org/10.1016/j.jclepro.2022.133153
[9] Zhao, S., Wang, J., Ye, M., Huang, Q., & Si, X. (2022). An evaluation of supply chain performance of China's prefabricated building from the perspective of sustainability. *Sustainability*, *14*(3), 1299. https://doi.org/10.3390/su14031299
[10] Steinhardt, D. A. & Manley, K. (2016). Adoption of prefabricated housing - the role of country context. *Sustainable Cities and Society*, *22*, 126-135. https://doi.org/10.1016/j.scs.2016.02.008
[11] Hanna, A. S., Mikhail, G., & Iskandar, K. A. (2017). State of prefab practice in the electrical construction industry: Qualitative assessment. *Journal of Construction Engineering and Management*, *143*(2), 04016097. https://doi.org/10.1061/(ASCE)CO.1943-7862.0001236
[12] Liu, G. W., Tao, Y., Mao, C., & Xu, P. P. (2018). A quantitative study of Chinese prefabricated building policy text from the perspective of policy tools. *Journal of Chongqing University* (*Social Science Edition*), *24*(5), 56-65.
[13] Sun, Y. Q. & Tian, Y. (2020). Research on key risks of prefabricated building supply chain based on complex network theory. *Construction Economics*, *41*(11), 79-83. https://doi.org/10.14181/j.cnki.1002-851x.202011079
[14] Liu, Z. Q., Zhang, Y. N., Ouyang, H. X., & Song, L. L. (2020). Sustainability evaluation of prefabricated building supply chain based on cloud matter-element theory. *Journal of Civil Engineering and Management*, *37*(3), 109-115+122. https://doi.org/10.3969/j.issn.2095-0985.2020.03.018
[15] Qu, F. Q., Yan, W., & Chen, C. Y. (2019). Research on the construction of collaborative performance evaluation index system for prefabricated construction supply chain. *Construction Economy*, *40(*10), 97-102.
[16] Zhu, H. L. & Lin, Z. M. (2020). A QCA-based analysis of regional development influencing factors of prefabricated buildings. *Construction Economics*, *41*(2), 115-120.
[17] Liu, F., Jia, K. P. (2019). Cooperation between industry, academia and research to promote high-quality development of prefabricated building industry. *China University Science and Technology*, *S1*, 47-49.
[18] Liao, L. P. (2019). Current situation and strategies for the development of green prefabricated buildings. *Enterprise Economy*, *38*(12), 139-146. https://doi.org/10.13529/j.cnki.enterprise.economy.2019.12.017
[19] Huang, G. L., Zhang, C., & Wei, X. L. (2019). Research on green supply chain model of prefabricated buildings. *Construction Economics*, *40*(7), 48-52. https://doi.org/10.14181/j.cnki.1002-851x.201907048
[20] Wang, K., Liang, J. N., & Zhang, S. Y. (2019). The predicament of the development of prefabricated building industrialization under supply-side reform and countermeasures. *Journal of Engineering Management*, *33*(5), 7-12. https://doi.org/10.13991/j.cnki.jem.2019.05.002
[21] Zhang, Y. & Wang, J. J. (2020). A study of China's prefabricated building policy text based on content analysis method. *Journal of Engineering Management*, 1-6.
[22] Qi, Y. & Wang, Q. (2020). Research on the evaluation of regional prefabricated building development policies - based on the first-right TOPSIS method. *Construction Economics*, *41*(4), 28-33. https://doi.org/10.14181/j.cnki.1002-851x.202004028
[23] Li, L. H., Guo, Z., & Guo, C. B. (2020). Evaluation of the implementation effect of construction management policy for prefabricated buildings in Shenyang. *Construction Economics*, *41*(4), 23-27. https://doi.org/10.14181/j.cnki.1002-851x.202004023
[24] Liu, M. X., Li, W. D., Cao, Y., He, J., & Sun, F. (2022). Comparative analysis of demand guidance policies for urban district-level assembly building industry chain. *Building Structures*, *52*(13), 1-6. https://doi.org/10.19701/j.jzjg.20201453
[25] Chen, Y. L., Lin, S. Z., & Shi, Y. Z. (2018). Game theory-based incentive policies for prefabricated buildings. *Journal of Civil Engineering and Management*, *35*(2), 155-160+169. https://doi.org/10.13579/j.cnki.2095-0985.2018.02.024
[26] Shazmin, S. A. A., Sipan, I., Sapri, M., Ali, H. M., & Raji, F. (2017). Property tax assessment incentive for green building: Energy saving based-model. *Energy*, *122*, 329-339. https://doi.org/10.1016/j.energy.2016.12.078
[27] Simcoe, T. & Toffel, M. W. (2014). Government green procurement spillovers: Evidence from municipal building policies in California. *Journal of Environmental Economics and Management*, *68*(3), 411-434. https://doi.org/10.1016/j.jeem.2014.09.001
[28] Zhou, J., Qin, Y., & Fang, S. (2019). Impacts of consumers and real estate enterprises on the implementation of prefabrication in residential buildings: The moderating role of incentive policies. *Sustainability*, *11*(18), 4827. https://doi.org/10.3390/su11184827
[29] Jin, Z. Y., Qiu. X. H., Sun, J. Y., Wang, Y., & Kang, X. H. (2020). Research on economic incentives for the development of prefabricated buildings based on tripartite game. *Construction Economics*, *41*(1), 22-28.
[30] Zehawi, R. N. & Hameed, A. H. (2022). The impact of urban growth pattern on local road network: A system dynamics study. *International Journal of Design & Nature and Ecodynamics*, *17*(2), 221-231. https://doi.org/10.18280/ijdne.170208
[31] Mou, X. D., Li, X. T., Dong, J. C., & Dong, Z. (2020). Simulation study of housing demand in my country based on system dynamics. *Management Review*, *32*(6), 16-28.
[32] Jia, S. W. & Yan, G. L. (2018). Dynamic simulation of construction waste management model under combined policy. *System Engineering Theory and Practice*, *38*(11), 2966-2978.
[33] Yang, X. D. & Wu, Y. X. (2013). Simulation research on system dynamics of green housing market. *China Civil Engineering Journal*, *46*(8), 119-122.
[34] Yang, S. W., Xu, X., & Wang, S. (2016). Research on the key nodes of the industrial chain of prefabricated concrete construction and the driving force of industrial development. *Enterprise Economics*, *6*, 123-127. https://doi.org/10.13529/j.cnki.enterprise.economy.2016.06.023
[35] Cao, Y. C., Yang, J., & Li, J. W. (2020). Energy-saving research on residential gas heating system in cold area based on system dynamics. *International Journal of Heat and Technology*, *38*(2), 457-462. https://doi.org/10.18280/ijht.380222
[36] Hu, Y. M., Liu, J., Ding, H. T., & Fan, P. H. (2019). Research on energy consumption forecast of rural residential buildings in Beijing based on system dynamics. *Energy Conservation of Buildings*, *47*(9), 123-129+135.
[37] Yan, J. N. (2018). The formation mechanism of the prefabricated building industry chain from the perspective of sustainable construction. *Value Engineering*, *37*(23), 124-128.
[38] Qi, S. J., Zhang, Y. B., Zhang, T. J., & She, J. Q. (2013). Simulation study on the scale economy effect and macro-incentive policies of housing industrialization. *Construction Economy*, *7*, 89-92.

Contact information:

Jiawei LUO
(Corresponding author)
School of Civil Engineering and Architecture,
East China Jiaotong University,
Nanchang 330013, China
E-mail: ljw67056296@163.com