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Strategies for sustainable development of green buildings

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ABSTRACT

This study systematically analyzed the strategies and approaches for the sustainable development of green buildings (SDGB) and summarized potential driving forces of SDGB from four aspects of green buildings (GB), including market development environment, economic value, the degree of social participation, and ecological value. A structural equation modelling (SEM) technique was used to explore dynamic interactions and leading roles of driving forces of SDGB based on data collected from a questionnaires survey of 240 respondents. Based on the SEM technique, a driving structural equation model was constructed to reveal the key driving paths and forces of SDGB. SPSS (Statistical Package for Social Sciences) and AMOS (Advanced MOrtar System) were applied to analyze the data. A dynamic system of SDGB was established to explore the SDGB's driving mechanism. The results show that the market development environment and ecological value have a significant direct and comprehensive impact on SDGB. The economic value and the degree of social participation are key path nodes of SDGB. This study may provide appropriate strategies and practical guidance for better promoting SDGB.

1. Introduction

Due to increasing conflicts between the rapid development of buildings and the deterioration of ecological environment, green building (GB) has become a hot topic of study in China in recent years. GB is considered as an answer to China's urgent problem of unreasonable use of energy and resources by the construction industry, as well as the discharge of large amounts of garbage and CO_2. During the Paris Conference in 2015, China announced a goal to achieve a GB level of 50% in new urban buildings by 2020.Green building development (GBD) in China varies in different regions because of uneven economic and social development. In areas with low levels of economic and social development, the growth of GB is relatively slow (Hui-feng, Huan, Daming, Yun, & Youwei, 2012; Teng, Zhang, Wu, & Zhang, 2016). As a new type of building, GB is not readily accepted by the public due to immature technologies of green construction, long investment return time, and low public awareness (Frontczak, 2012), which are key issues in the sustainable development of green buildings (SDGB).

Previous studies have demonstrated that GBD can generate inspiring benefits, including improving the ecological environment, achieving sustainable use of land, protecting the ecosystem, facilitating the recycle and reuse of materials, improving energy efficiency, and reducing solid waste and CO_2 emission (Zuo, 2014). GBD is inseparable from the active participation of stakeholders, including government, developers, technology builders, and consumers. The social, economic and ecological behaviors of stakeholders may be the key to driving SDGB (Onuoha, Aliagha, & Rahman, 2018; Darko, Chan, Owusu-Manu, & Effah, 2017; Darko, Zhang, & Chan, 2017; Sharma, 2018; Wang, Zhang, & Pasquire, 2018; Wang et al., 2014).

Sharma (2018) developed a "Green building sustainability model" using a structural equation modelling (SEM) to study GBD in India. The author proposed that government of a country should develop 'strategic-mix', which involves combing different policies to establish a synergy between supply and demand, along with other stakeholders to pave way for GBD. Using the SEM method, Onuoha et al. (2018) proved that GBD is directly related to motivations in reducing life cost, government policies, green certification, developers' expectation on investment return, and market strategy benefit.

Wang et al. (2018) proposed that GBD is affected by the acceptance of market, the maturity of green technology, economics, the social awareness, and government policies. MacNaughton, Cao, and Buonocore, (2018) investigated the ecological benefits of GB, and found that GBD had already contributed to the mitigation of greenhouse gas emission and the improvement of health for millions of people around the world. Tian and Li (2018) found that environment awareness is closely related to GBD.

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In a summary, these previous studies have laid a solid foundation for the study of key driving factors and driving mechanisms for SDGB. Despite of those previous studies, there is still an urgent need to systematically analyze the key driving factors of SDGB comprehensively from four aspects: stakeholders (government, developers, technology builders, and consumers), social value, economic value and ecological value of GB, and to study the operational mechanisms of GB sustainability.

This study will use an SEM technique to explore dynamic interactions and leading roles of driving factors of SDGB in China. The SEM technique is a multivariate statistical technique that combines multiple regression analysis, path analysis, and factor analysis using both qualitative hypothesis and quantitative data (Berzuini, Dawid, & Beruardinelli, 2012). It is a method for establishing, estimating, and testing causality models. It can be used to analyze effects of an individual factor on the whole system, and to investigate and quantify the complicated interactions between individual factors. AMOS (Advanced MOrtar System) and SPSS (Statistical package for Social Sciences) are powerful software used in SEM (Hui & Jianting, 2012; Leung, 2018; Olanipekun, Xia, Hon, & Darko, 2018; Onuoha et al., 2018; Serdar Durdyev, Syuhaida Ismail, & Kandymov, 2018; Sharma, 2018; Shen, Zhang, & Long, 2017; Xiaowen & Yinsheng, 2014), In this study, AMOS version 24 and SPSS 19.0 were applied to analyze data.

For SDGB, there are many potential driving factors. SDGB should consider the coordination of green building development with economic, social and ecological environment, and should consider the current development status and future development potential (Liu 2016). The ultimate goal is to achieve a harmonious and sustainable development of green buildings along with the development of economic, social, and ecological environment. This study aims at providing appropriate strategies and practical guidance for better promoting the SDGB.

The paper is structured as follows. In Section 2, a methodology consisting of subsystems, framework, hypothesis, and measures is developed. In Section 3, three steps are introduced for data collection of questionnaires. In Section 4, a structural equation model is built with AMOS and verified by means of model reliability, model hypothesis, and model fitting index. In Section 5, the verified model is simulated to investigate the impact of subsystems and the impact of measures. In Section 6, strategies for SDGB are proposed and dynamic systems of SDGB are presented. The last section contains conclusions and an outlook of future works.

2. Methodology

2.1. Subsystems

Using "green building", "sustainable development", "green building and impact", "green building and driving", "green building and policy" as keywords, we conducted literature retrieval from relevant papers published in the past 5 years, with results summarized in Table 1. For the SDGB, we statistically analyzed 32 highly relevant papers and identified four subsystems of development (Table 1), including: 1) the market development environment of GB; 2) the degree of social participation of GB; 3) the economic value of GB; 4) the ecological value of GB. The percentage for each subsystem is 35.4%, 23.1%, 20.0%, and 15.4%, respectively.

Table 1 shows that the market development environment of GB has become the primary focus point, which includes behavioral trends of direct stakeholders, including developers, design architects, technology suppliers, consumers, and constructers.

The second focus point is the degree of social participation of GB. The reason is that direct stakeholders in the process of green building development are more concerned about whether GB can be sustainably supported by social and economic aspects, including the degree of participation of all parties in a society, the government policies and regulations, the public awareness, and the economic value of GB. At the same time, indirect stakeholders (governments) will focus on how to promote the sustainable development of economy and society by GBD.

The last focus point is the economic value of GB. One of the main purposes of GBD is to reduce the impact on ecological environment by the construction industry. The impact of GB on ecological sustainable development is positive, so the proportion of attention is relatively low (15.4%). However, with the continuous increase of GB, it is very important to reasonably evaluate its impact on regional ecological environment. It is important to formulate more effective development policies based on reasonable evaluations, and to promote the SDGB and ecological environment.

2.2. Framework and hypothesis

The subsystem partition for SDGB, as well as the relationship between subsystems, is shown in Fig. 1.

2.2.1. Framework

(1) Market development environment of GB (attitudes of relevant parties). The market development environment mainly refers to the structure of the main body of the green building market, the soundness of the market, the supply demand relationship of the market, and the technical environment. Achieving the goal of SDGB requires the driving and supporting for the market development environment, including the attitudes and behavioral trends of direct stakeholders (developers, design architects, technology suppliers, consumers, and constructers), the maturity of green technology, the development level of prefabricated industries (certification projects of green buildings), and other factors.
(2) Ecological value of GB. Ecological value mainly refers to the ecological benefits brought by GB, including savings on energy, water, land, material, and solid waste, and promotion on indoor health and comfort. The ecological value of GB is one of the focuses of SDGB.
(3) The economic value of GB. Economic value mainly refers to the economic benefits brought by GB. To achieve SDGB, it is inseparable from the driving and supporting by regional economies. The economic value of GB affects the SDGB.
(4) The degree of social participation of GB. The degree of social participation of GB is the key to the effective implementation and sustainable development of green buildings. It mainly refers to green building education and training, public opinion, green building reputation, government policies, regulations, and standards.

2.2.2. Hypothesis

(1) Hypotheses for the market development environment of GB

Hypothesis 1. The market development environment of GB and the economic value of GB are interrelated.

Hypothesis 2. The market development environment of GB and the degree of social participation of GB are interrelated.

Hypothesis 3. The market development environment of GB and the ecological value of GB are interrelated.

Hypothesis 4. The market development environment of GB is positively related to the SDGB.

(2) Hypotheses for the economic value of GB

Hypothesis 5. The economic value of GB and the degree of social participation of GB are interrelated.

Hypothesis 6. The economic value of GB and the ecological value of GB are interrelated.

Table 1
Key subsystems of SDGB.

Subsystems	Reference	Number of papers	Percentage
The market development environment of GB	(Darko et al., 2017; Min et al., 2014; Ling et al., 2017; Qin et al., 2018; Murtagh et al., 2016; Huang, 2017; Donghong & Zhiqiang, 2017; Yan & Junzhang, 2017; Fanyin, 2017; Yujun & Xiaochen, 2017; Baoxing et al., 2017; Huang & Mu, 2017; Kaixuan, 2016; Jia et al., 2016; ; Ping & Guogang, 2015; Xiaolong & Xiaobin, 2015; Xiaowen & Yinsheng, 2014; Xia, 2015; Olubunmi et al., 2016; Ling et al., 2017; Darko & Chan, 2018; Darko & Chan, 2017)	23	35.4%
The ecological value of GB	(Darko et al., 2017; Donghong & Zhiqiang, 2017; Fanyin, 2017; Yujun & Xiaochen, 2017; Kaixuan, 2016; Darko & Chan, 2017; Devine, 2015; Ming & Ganbin 2017; Wei et al., 2016; Jianyan & Maozhi 2016)	10	15.4%
The economic value of GB	(Darko et al., 2017; Min et al., 2014; Huang, 2017; Donghong & Zhiqiang, 2017; Fanyin, 2017; Yujun & Xiaochen, 2017; Huang & Mu, 2017; Kaixuan, 2016; Wenhao et al., 2016; Olubunmi et al., 2016; Darko & Chan, 2017; Ming & Ganbin, 2017; Jianyan & Maozhi, 2016)	13	20.0%
The degree of social participation of GB	(Darko et al., 2017; Min et al., 2014; Xiaowen & Yinsheng 2014; Donghong & Zhiqiang 2017; Yan & Junzhang, 2017; Fanyin, 2017; Yujun & Xiaochen, 2017; Kaixuan, 2016; Jia et al., 2016; Ping & Guogang, 2015; Darko & Chan, 2017; Ming & Ganbin, 2017; Wei et al., 2016; Jianyan & Maozhi, 2016; Feng, 2016)	15	23.1%
Others	(Baoxing et al., 2017; Olubunmi et al., 2016; Ling et al., 2017;)	4	6.1%

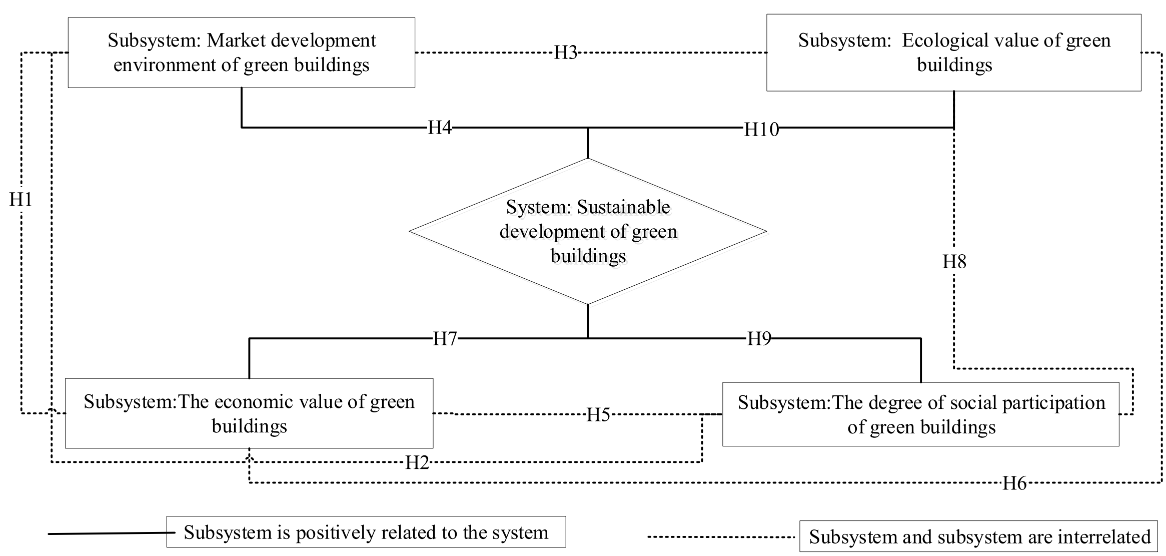


Fig. 1. System structure and its internal hypothesized diagram.

Hypothesis 7. The economic value of GB is positively related to the SDGB.

(3) Hypotheses for the degree of social participation of GB

Hypothesis 8. The degree of social participation of GB and the ecological value of GB are interrelated.

Hypothesis 9. The degree of social participation of GB is positively related to the SDGB.

(4) Hypotheses for the ecological value of GB

Hypothesis 10. The ecological value of GB is positively related to the SDGB.

2.3. Measures

Based on the review for the SDGB, the potential driving forces (measures) for the SDGB are proposed from the following four perspectives: 1) market (technology) development environment; 2) economic environment; 3) social (policy) environment, and 4) ecological environment, as shown in Table 2. These driving factors (measures) are the focus of research on the mechanism and dynamics of SDGB.

2.4. Structural equation modelling (SEM) technique

Structural Equation Modelling (SEM) technique is able to explore dynamic interactions and leading roles of driving factors (measures) for SDGB.

In this study, SEM was used to test the framework and hypotheses statistically, and to estimate all coefficients of measures (variables) in the SDGB model using data collected via a questionnaires survey of 240 respondents.

AMOS (Advanced MOrtar System) and SPSS (Statistical Package for Social Sciences) are powerful software for supporting SEM. These software were used to analyze data and obtain results.

A (standardized) structural diagram of SDGB was created by importing the data from the survey of 240 respondents to AMOS 24.0.

SPSS 19 (Statistical Package for Social Sciences) is one of the leading statistical software for quickly and conveniently analyzing Cronbach's Alpha coefficient, which is commonly used to estimates and verify the reliability of a model (Shammout, 2007). A value of Cronbach's alpha coefficient greater than 0.7 indicates a good reliability of a model (Jang, Kim, Kim, & Kim, 2011). In this study, Cronbach's alpha was used to evaluate the reliability of subsystem models.

Table 2
Potential driving factors (measures) of SDGB.

Subsystems	Measures	Descriptions	References
Market Development Environment (MDE) of GB	MDE01	Willingness for the development of green buildings. It including developers' corporate social responsibility, image, reputation, and competitive credibility, reflecting developers' willingness to develop green buildings.	(Darko et al., 2017; Min et al., 2014; Xiaowen & Yinsheng, 2014; Murtagh et al., 2016; Huang, 2017; Donghong & Zhiqiang, 2017; Yan & Junzhang, 2017; Fanyin, 2017; Xiaolong & Xiaobin, 2015; Xia, 2015; Olubunmi et al., 2016; Ling et al., 2017; Darko & Chan 2018; Darko & Chan 2017; Ming & Ganbin, 2017; Windapo, 2015; Sharma, 2018; Fan et al., 2018; Ofek et al., 2018)
	MDE02	Architects' willingness to green design. It reflecting architects' green concept and their willingness to embrace green buildings.	(Darko et al., 2017; Min et al., 2014; Feng, 2016; Ofek et al., 2018)
	MDE03	The enthusiasm of suppliers for manufacturing green materials (technology development). It indicates the enthusiasm of green material manufacturing (technology development) from suppliers, directly affecting the maturity that green technologies can achieve.	(Darko et al., 2017; Min et al., 2014; Xiaowen & Yinsheng, 2014; Ling et al., 2017; Qin et al., 2018; Donghong & Zhiqiang, 2017; Fanyin, 2017; Yujun & Xiaochen, 2017; Kaixuan, 2016; Jia et al., 2016; Wenhao et al., 2016; Ping & Guogang, 2015; Xia, 2015; Olubunmi et al., 2016; Darko & Chan, 2018; Darko & Chan, 2017; Wei et al., 2016; Jianyan & Maozhi, 2016; Jie et al., 2016; Sharma, 2018; Onuoha et al., 2018; Qin et al., 2018)
	MDE04	Consumers' desire for green building purchase.	(Darko et al., 2017; Ling et al., 2017; Xiaowen & Yinsheng, 2014; Huang, 2017; Donghong & Zhiqiang, 2017; Yan & Junzhang, 2017; Wenhao et al., 2016; Xia, 2015; Olubunmi et al., 2016; Sharma, 2018; Portnov et al., 2018; Zhang et al., 2018; Tian & Li, 2018; Jang et al., 2018; Ofek et al., 2018)
	MDE05	The capacity of constructers on green construction (management mode). It demonstrates the ability to transform green design and technology into actual green buildings.	(Darko et al., 2017; Min et al., 2014; Xiaowen & Yinsheng, 2014; Yujun & Xiaochen, 2017; Kaixuan, 2016; Wenhao et al., 2016; Xia, 2015; Olubunmi et al., 2016; Ling et al., 2017; Darko & Chan, 2018; Darko & Chan, 2017; Wei et al., 2016; Zhai et al., 2014; Ofek et al., 2018)
	MDE06	The development level of the prefabricated industry (green building certification projects). It indicates the level of development of the prefabricated industry and directly affects the total area of green buildings and the level of greenness.	(Darko et al., 2017; Ling et al., 2017; Xiaowen & Yinsheng, 2014; Qin et al., 2018; Donghong & Zhiqiang, 2017; Yan & Junzhang, 2017; Baoxing et al., 2017; Huang & Mu, 2017; Wenhao et al., 2016; Olubunmi et al., 2016; Zhai et al., 2014; Onuoha et al., 2018)
Economic Value (ENV) of GB	ENV01	The proportion of incremental investment in green building. The ratio of incremental investment per unit area of green building to investment per unit area (not using green technology) is closely related to the degree of integration design.	(Darko et al., 2017; Min et al., 2014; Xiaowen & Yinsheng, 2014; Ling et al., 2017; Qin et al., 2018; Murtagh et al., 2016; Huang, 2017; Donghong & Zhiqiang, 2017; Yujun & Xiaochen, 2017; Baoxing et al., 2017; Kaixuan, 2016; Jia et al., 2016; Wenhao et al., 2016; Wei et al., 2016; Feng, 2016; Portnov et al., 2018; Fan et al., 2018)
	ENV02	Recovery period (Return time) of green building investment.	(Darko et al., 2017; Huang, 2017; Donghong & Zhiqiang, 2017; Devine, 2015)
	ENV03	Investment income (selling price in the market of green buildings). It represents the percentage of investment income from the development of green buildings.	(Darko et al., 2017; Ling et al., 2017; Huang, 2017; Baoxing et al., 2017; Wenhao et al., 2016; Ping & Guogang, 2015; Xiaolong & Xiaobin, 2015; Darko & Chan, 2018; Darko & Chan, 2017; Devine, 2015; Onuoha et al., 2018; Marzouk et al., 2018; Portnov et al., 2018; Zhang et al., 2018; Ofek et al., 2018)
	ENV04	The reduction of construction cost in green buildings. It indicates the ratio of the reduction of construction cost per unit area of green buildings to the construction cost per unit area of traditional buildings.	(Darko et al., 2017; Qin et al., 2018; Yujun & Xiaochen, 2017; Onuoha et al., 2018; Marzouk et al., 2018; Ofek et al., 2018)
	ENV05	The ratio of cost reduction in the operation of green buildings. It represents the ratio of the reduction in operating cost per unit area of green building to the operating cost per unit area of traditional buildings.	(Darko et al., 2017; Qin et al., 2018; Onuoha et al., 2018; Dwaikat & Ali, 2018a, 2018b; Marzouk et al., 2018; Li et al., 2018; Ofek et al., 2018)
	ENV06	Vacancy rate of green buildings (demand / rental rate / occupancy rate).	(Darko et al., 2017; Min et al., 2014; Xiaowen & Yinsheng, 2014; Murtagh et al., 2016; Huang, 2017; Donghong & Zhiqiang, 2017; Wenhao et al., 2016; Xiaolong & Xiaobin, 2015; Xia, 2015; Olubunmi et al., 2016; Devine, 2015; Tian & Li, 2018; Jang et al., 2018)
The Degree of Social Participation (SCP) of GB	SCP01	The degree of participation of key stakeholders. It indicates the willingness and desire of architects, developers, and consumers involved in the design, development, and consumption of green buildings.	(Darko et al., 2017; Min et al., 2014; Ping & Guogang, 2015; Olubunmi et al., 2016)
	SCP02	Continuing education, training, and advocacy. It represents the ratio of investment of continuing education, training, and advocacy in green building to total investment in green buildings.	(Darko et al., 2017; Min et al., 2014; Xiaowen & Yinsheng, 2014; Ling et al., 2017; Murtagh et al., 2016; Donghong & Zhiqiang, 2017; Yujun & Xiaochen, 2017; Ping & Guogang, 2015; Xia, 2015; Olubunmi et al., 2016; Darko & Chan, 2018; Wei et al., 2016; Feng, 2016; Qin et al., 2018; Portnov et al., 2018; Tian & Li, 2018)
	SCP03	The competence of government policies, regulations, and standards. It indicates the competence of governmental policies, regulations, and standards in green buildings, including policies on incentives and enforcement.	(Darko et al., 2017; Min et al., 2014; Xiaowen & Yinsheng, 2014; Ling et al., 2017; Qin et al., 2018; Murtagh et al., 2016; Donghong & Zhiqiang, 2017; Yan & Junzhang, 2017; Fanyin, 2017; Yujun & Xiaochen, 2017; Baoxing et al., 2017; Kaixuan, 2016; Jia et al., 2016; Wenhao et al., 2016; Ping & Guogang, 2015; Xiaolong & Xiaobin, 2015; Xia, 2015; Olubunmi et al., 2016; Ling et al., 2017; Darko & Chan, 2018; Ming & Ganbin,

(continued on next page)

Table 2 (*continued*)

Subsystems	Measures	Descriptions	References
			2017; Wei et al., 2016; Teng, Wang, Wu, & Xu, 2016; Sharma, 2018; Onuoha et al., 2018; Qin et al., 2018; MacNaughton et al., 2018; Portnov et al., 2018; Zhang et al., 2018; Fan et al., 2018; Tian & Li, 2018; Deng, Yang, Tang, & Tang, 2018)
	SCP04	Public opinion (traditional factors). It indicates the extent to which traditional factors affect green buildings.	(Darko et al., 2017; Ling et al., 2017; Murtagh et al., 2016; Donghong & Zhiqiang, 2017; Yan & Junzhang, 2017; Fanyin, 2017; Kaixuan, 2016; Ping & Guogang, 2015; Darko & Chan, 2018; Qin et al., 2018; Portnov et al., 2018; Zhang et al., 2018; Tian & Li, 2018)
	SCP05	The reputation of green buildings. It represents consumers' evaluation of green buildings.	(Darko et al., 2017; Ling et al., 2017; Xiaowen & Yinsheng, 2014; Olubunmi et al., 2016; Devine, 2015; Windapo 2015; Portnov et al., 2018)
	SCP06	The living quality of residents. It indicates the effects of residents' income and reginal GDP.	(Darko et al., 2017; Xiaowen & Yinsheng, 2014; Qin et al., 2018; Donghong & Zhiqiang, 2017; Yan & Junzhang, 2017; Baoxing et al., 2017; Wenhao et al., 2016; Darko & Chan, 2018; Feng, 2016; Teng, Wang et al., 2016)
Ecological Value (ELV) of GB	ELV01	Energy saving per unit area (CO_2 emission reduction).	(Darko et al., 2017; Xiaowen & Yinsheng, 2014; Fanyin, 2017; Darko & Chan, 2017; Devine, 2015; Ming & Ganbin, 2017; Wei et al., 2016; Teng, Wang et al., 2016; Dwaikat & Ali, 2018a, 2018b; MacNaughton et al., 2018; Portnov et al., 2018; Ofek et al., 2018)
	ELV02	Water saving ratio per unit area.	(Darko et al., 2017; Xiaowen & Yinsheng, 2014; Fanyin, 2017; Darko & Chan, 2017; Devine, 2015; Ming & Ganbin, 2017; Wei et al., 2016; Teng, Wang et al., 2016; Portnov et al., 2018; Ofek et al., 2018)
	ELV03	Land saving ratio per unit area.	(Darko et al., 2017; Xiaowen & Yinsheng, 2014; Fanyin, 2017; Darko & Chan, 2017; Ming & Ganbin, 2017; Teng, Wang et al., 2016)
	ELV04	Solid waste reduction ratio per unit area.	(Darko et al., 2017; Fanyin, 2017; Yujun & Xiaochen, 2017; Darko & Chan, 2018; Teng, Wang et al., 2016; Portnov et al., 2018)
	ELV05	Materials saving ratio per unit area.	(Xiaowen & Yinsheng, 2014; Fanyin, 2017; Darko & Chan, 2018; Ming & Ganbin, 2017; Wei et al., 2016; Jie et al., 2016; Teng, Wang et al., 2016; Ofek et al., 2018)
	ELV06	Indoor environmental healthy and comfort. They are relevant to the living quality of residents.	(Darko et al., 2017; Min et al., 2014; Fanyin, 2017; Yujun & Xiaochen, 2017; Darko & Chan, 2018; Devine, 2015; Ming & Ganbin, 2017; Wei et al., 2016; Portnov et al., 2018; Fan et al., 2018; Cedeno-Laurent et al., 2018; Ofek et al., 2018)
Sustainable Development of Green buildings (SDGB)	SDGB01	The harmony between construction industry and economic development.	(Darko et al., 2017; Min et al., 2014; Huang, 2017; Donghong & Zhiqiang, 2017; Fanyin, 2017; Yujun & Xiaochen, 2017; Huang & Mu, 2017; Kaixuan, 2016; Wenhao et al., 2016; Olubunmi et al., 2016; Darko & Chan, 2017; Ming & Ganbin, 2017; Jianyan and Maozhi 2016; Sharma, 2018; Qin et al., 2018)
	SDGB02	The harmony between construction industry and social development.	(Darko et al., 2017; Min et al., 2014; Xiaowen & Yinsheng, 2014; Donghong & Zhiqiang, 2017; Yan & Junzhang, 2017; Fanyin, 2017; Yujun & Xiaochen, 2017; Kaixuan, 2016; Jia et al., 2016; Ping & Guogang, 2015; Darko & Chan, 2017; Ming & Ganbin, 2017; Wei et al., 2016; Jianyan and Maozhi 2016; Feng, 2016; MacNaughton et al., 2018; Cedeno-Laurent et al., 2018)
	SDGB03	The harmony between construction industry and ecological development.	(Darko et al., 2017; Donghong & Zhiqiang, 2017; Fanyin, 2017; Yujun & Xiaochen, 2017; Kaixuan, 2016; Darko & Chan, 2017; Devine, 2015; Ming & Ganbin, 2017; Wei et al., 2016; Jianyan and Maozhi 2016; MacNaughton et al., 2018; Portnov et al., 2018)

3. Data collection

The use of questionnaire survey for data collection involves three steps:

(1) With the "Questionnaire Star" online platform of China, 27 driving factors that affect the SDGB (Table 2) were used to prepare questionnaires which were distributed in the form of QR codes to professionals in the construction/real estate industry who have at least one year of experience in GB. The results of questionnaire surveys were based on a 5-point scoring method, that is, the respondents gave 5, 4, 3, 2, and 1 points from high to low according to the cognition of importance of the question.
(2) Trial research to verify the rationality of the questionnaire. 100 questionnaires were distributed and 74 questionnaires were effectively recovered, with an effective recovery rate of 74%. The collected data were processed with SPSS software for analyzing the rationality of the questionnaire. The questionnaire was subsequently improved according to the subjective opinions in those 74 questionnaires. The results showed that the Cronbach's Alpha coefficient of the whole questionnaire reached a test value of 0.964, indicating that the questionnaire was reasonably formulated.
(3) research. A total of 300 questionnaires were distributed, and 240 questionnaires were effectively recovered, with an effective recovery rate of 80%. The sample distribution is shown in Fig. 2. Fig. 2(a) shows that the constructers, architects/designers, and developers were the main respondents, accounting for 29.85%, 17.08%, and 16.67%, respectively. Fig. 2(b) shows that most respondents had green building related work experience of 1–2 years and 3–4 years, accounting for 76.25% and 14.17% respectively. Based on reliability analysis of 240 collected questionnaires by using SPSS software, the Cronbach's Alpha coefficient reached a test value of 0.974.

4. Structural equation model development and verification

4.1. Structural equation model development

Based on a model hypothesis and 24 driving factors (measures), a basic driving structure equation model of SDGB was created, with results shown in Fig. 3, which details the causal relationship between potential variables (measures).

4.2. Model verification

After being processed by SPSS, data collected from the questionnaire survey were imported into AMOS 24.0 for estimating the basic driving model.

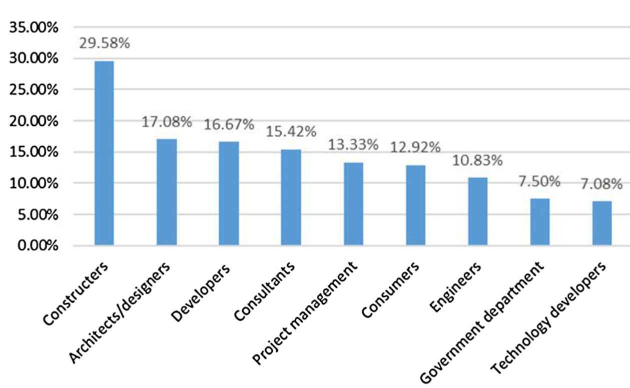
The model was verified from three aspects: model reliability, model hypothesis, and model fitting index. The verification results are as following:

(1) Model reliability verification. Based on analysis of data using SPSS software, the reliability level of the model of subsystems was tested and summarized as shown in Table 3. The Cronbach's alpha coefficient greater than 0.7 is considered to be high (Jang et al., 2011). The results indicate that the framework and the internal consistency of the subsystem models have good reliability.
(2) Model hypothesis verification. The data collected from the questionnaire survey were analyzed based on a basic driving structure equation model built by AMOS 24.0 software. Using the "Amos Output" of parameter estimation and significance test of the driving structure model, the validity of the hypothesized relationship between variables (driving forces) was evaluated by using a significance level $P < 0.05$. Table 4 shows that among the 10 hypotheses proposed in this study, two hypotheses are invalid, while other eight hypotheses are valid. The two invalid hypotheses include H2c, the economic value of GB is positively related to the SDGB, and H3b, the degree of social participation is positively related to the SDGB. Based on this result, the paths "economic value of GB → sustainable development of GB" and "the degree of social participation of GB → sustainable development of GB" were removed from the structural model, and a revised model was obtained as shown in Fig. 4, which validates that Fig. 3 after verification has theoretical basis and practical significance.
(3) Model fitting index verification. Using software AMOS 24.0, the most generally used fit indices (indicators) were used to verify the fitness of the driving structural equation model for the SDGB. The "Amos Output" values of key indicators and fitting evaluation criteria are shown in Table 5.

Table 5 shows the evaluation criteria (references) of key indicators, including the "not bad fit" and the "good fit". When the output value of GFI (goodness-of-fit index) is greater than 0.8, it indicates that the constructed model is not bad (acceptable); when the output value of GFI is greater than 0.9, it indicates that the constructed model is good. Through a comprehensive analysis of 12 "Amos Output" values of key indicators shown in Table 5, the overall fitting level of the constructed model shown in Fig. 4 is good.

4.3. Driving structural equation model

After model modification and model verification, the driving structural equation model (path relationship) for SDGB and its standardized path coefficient between its internal variables (measures) were obtained as shown in Fig. 4. This verified driving model can be



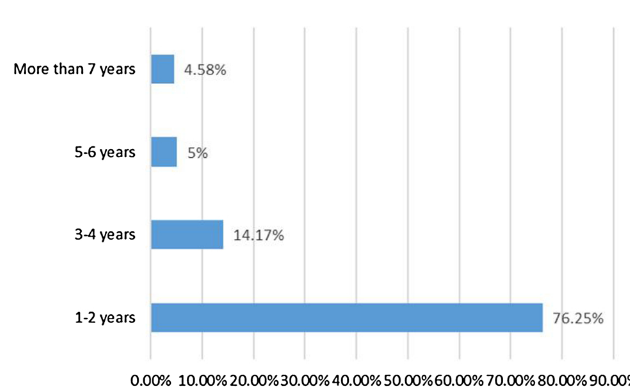


Fig. 2. The sample distribution.

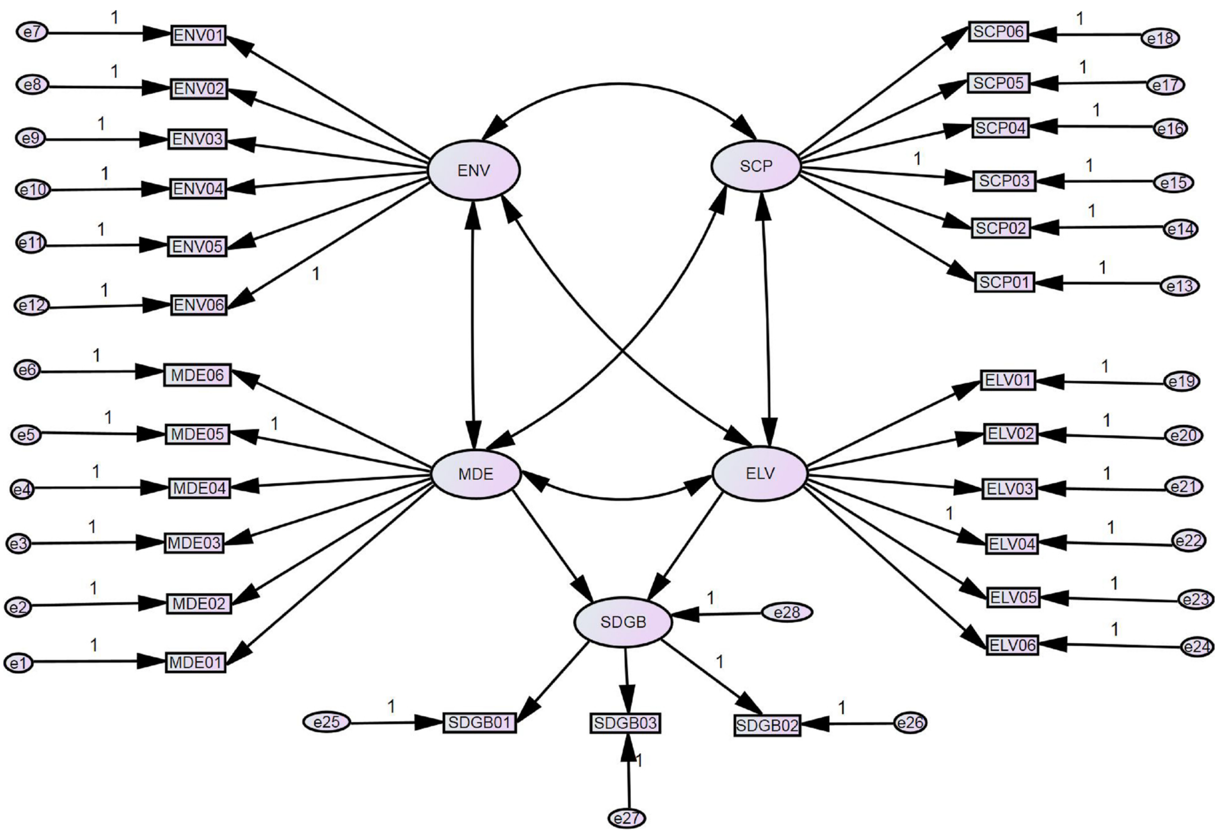


Fig. 3. The basic driving structure equation model of SDGB.

Table 3
The reliability level results of the model.
Source: Complied from SPSS output

Model of Subsystems	Cronbach's Alpha	reliability
The market development environment of GB	0.877	High
The economic value of GB	0.910	High
The degree of social participation of GB	0.896	High
The ecological value of GB	0.940	High

Table 4
The results of the model hypothesis verification.
Data Source: Amos Output

Relationships				Regression weights				Results
				Estimate	S.E.	C.R.	P	
H1	MDE	↔	ENV	.357	.060	5.936	***	supported
H2	MDE	↔	SCP	.353	.051	6.980	***	supported
H3	MDE	↔	ELV	.594	.069	8.550	***	supported
H4	MDE	→	SDGB	.452	.114	3.981	***	supported
H5	ENV	↔	SCP	.188	.037	5.115	***	supported
H6	ENV	↔	ELV	.275	.048	5.678	***	supported
H7	ENV	→	SDGB	.124	.141	.877	.380	Not be supported
H8	SCP	↔	ENV	.188	.037	50115	***	supported
H9	SCP	→	SDGB	.017	.118	.141	.888	Not be supported
H10	ELV	→	SDGB	.354	.105	3.383	***	supported

Note: S.E. represents Standard Error; C.R. represents Critical Ratio; *** indicates that P < 0.001, the significance level is high.

used to analyze driving mechanisms of SDGB.

5. Analysis of results

According to the driving structural equation model and its (non) standardized path coefficients shown in Fig. 4, quantitative analysis of the operating mechanism was carried out from two aspects including impact of subsystems and impact of measures to identify the key driving paths and factors of SDGB.

5.1. Impact of subsystems

Using AMOS software, the model parameters were evaluated based on the driving structural model shown in Fig. 4. The direct effects, indirect effects, and comprehensive effects between the total system and its subsystems were obtained, and the driving routes were comprehensively ranked according to the comprehensive effects (Table 6). The path relationship in Fig. 4 includes two types: direct path relationship and indirect path relationship. The direct path relationship is the direct correlation between two variables (measures), and the path coefficient is the direct effect between the two variables (measures). The indirect path relationship refers to that there is more than one intermediate variables (measures) in the path between start variables (measures) and final variables (measures), product of the path coefficient among these variables (measures) is the indirect effect. The sum of the absolute values of the direct effect and the indirect effect is the comprehensive effect between two variables (measures).

Table 6 shows that the market development environment of GB has the most significant direct impact and comprehensive impact on SDGB, and is a key driving path of SDGB. The second most important driving path is "Ecological Value of GB → SDGB". In addition, the degree of social participation of GB has the largest number of action paths in the driving mechanism (6 paths), and it is a key node for path propagation.

Among all the indirect paths shown in Table 6, the largest indirect effect comes from the path "ecological value of GB → market development environment of GB → SDGB" with an indirect effect of 0.32, and the following important indirect effects comes from the path "market development environment of GB → ecological value of GB →

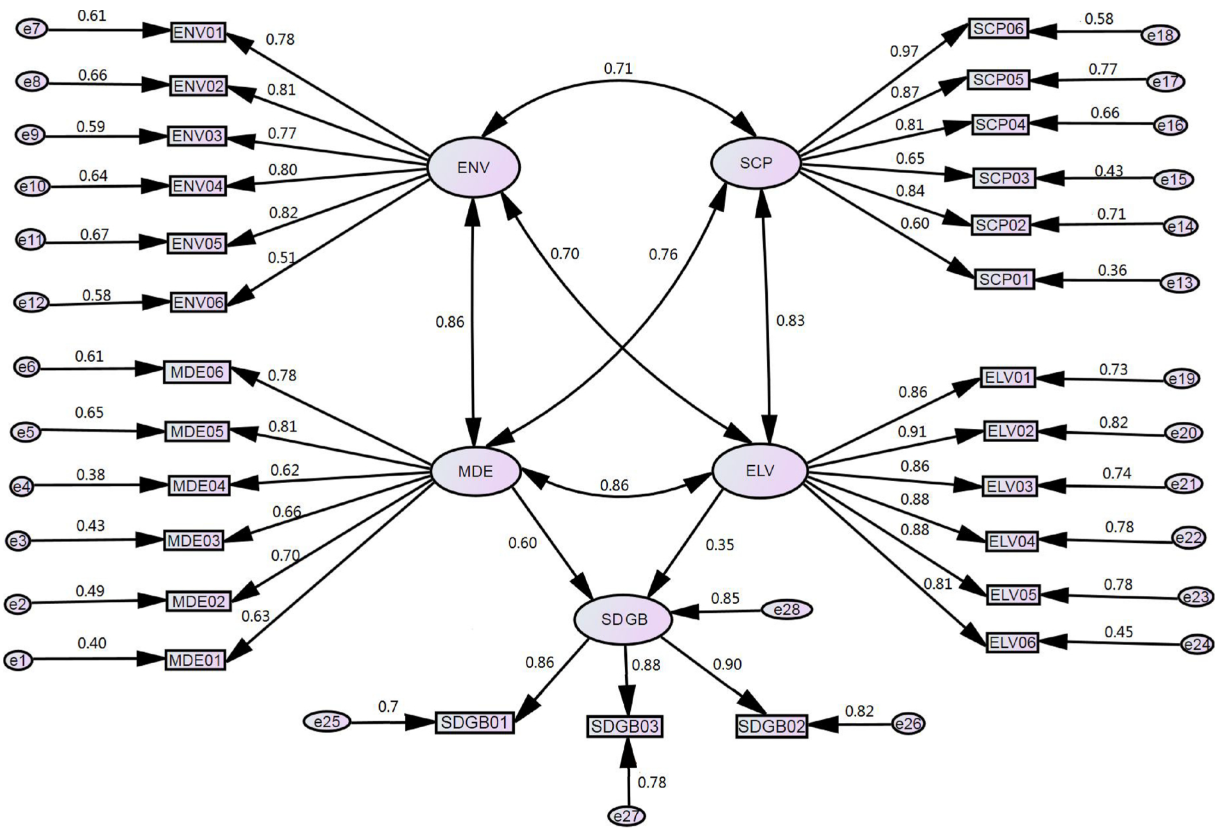


Fig. 4. Driving structural equation model (standardized parameters) of SDGB.

SDGB" with an indirect effect of 0.20, the path "economic value of GB → market development environment of GB → SDGB" with an indirect effect of 0.19, and the path "The degree of social participation of GB → market development environment of GB → SDGB" with an indirect effect of 0.19. It demonstrates that the key to the SDGB is the ecological value of GB and the market development environment of GB; the economic value and the degree of social participation directly drive (affect) the market environment of GB, and indirectly drive (affect) the SDGB.

5.2. Impact of measures

Based on results of parameter estimation for the driving structural equation model shown in Fig. 4, the contribution of driving factors (measured variables) is analyzed from four aspects, including market development environment of GB, economic value of GB, social participation degree of GB, and ecological value of GB. The greater contribution (standardized direct path coefficient) of the driving factors (measures) indicate the greater driving contribution for SDGB. The contribution of driving factors (measures) is shown in Fig. 5.

Fig. 5 shows that among the market development environment (MDE) driving factors, MDE05 (The capacity of constructers on green construction) is the only driving factor with a standardized direct benefit greater than 0.8, indicating that green construction technology and capability are key factors that directly drive the market development of GB. Among the economic value (ENV) driving factors, ENV02 (Recovery period of green building investment), ENV04 (The reduction

Table 5
The results of the model fitting index verification.
Value Source: Amos Output

Type of fit indices	Indicators	Evaluation criteria	Output Value	Test results
Absolute fit indices	χ2/df	χ2/df < 3, good fit (Sharma, 2018)	2.054	✓
	GFI	> 0.8, not bad fit; > 0.9, good fit (Onuoha et al., 2018; Hair, Anderson, Tatham, & Black, 1975)	0.845	✓
	RMR	< 0.05, good fit (Xiong, Skitmore, & Xia, 2015)	0.038	✓
	AGFI	> 0.8, not bad fit; > 0.9, good fit (Onuoha et al., 2018; Hair et al., 1975)	0.811	✓
	RMSEA	< 0.08, not bad fit; < 0.05, good fit (Hair et al., 1975)	0.066	✓
Incremental fit indices	NFI	> 0.9, good fit (Hair et al., 1975; Byrne, 2010)	0.902	✓
	IFI	> 0.9, good fit (Xiong et al., 2015)	0.947	✓
	TLI	> 0.9, good fit (Xiong et al., 2015)	0.936	✓
	CFI	> 0.9, good fit (Schreiber, Nora, Stage, Barlow, & King, 2006)	0.947	✓
Parsimonious fit indices	PGFI	> 0.5, good fit (Xiong et al., 2015)	0.658	✓
	PNFI	> 0.5, good fit (Xiong et al., 2015)	0.748	✓
	PCFI	> 0.5, good fit (Xiong et al., 2015)	0.785	✓

Note: χ2 test = Chi-square test; GFI = goodness-of-fit index; RMR = root mean square residual; AGFI = adjusted goodness-of-fit index; RMSEA = Root Mean Square Error of Approximation; NFI = normed fit index; IFI = incremental fit index; TLI = Tucker-Lewis index; CFI = comparative fit index; PGFI = parsimony goodness-of-fit index; PNFI = parsimony normed-fit index; PCFI = parsimony comparative fit index.

Table 6
(Non-standardized) path effects between subsystems and the total system.

Relationships	Direct effects	Indirect effects	Total effects	Ranking
MDE→SDGB	0.54	0.01 + 0.04 + 0.04 + **0.20** = 0.29	0.83	1
ENV→SDGB	0.00	**0.19** + 0.02 + 0.02 + 0.07 + 0.10 = 0.40	0.40	4
SCP→SDGB	0.00	0.02 + **0.19** + 0.04 + 0.02 + 0.07 + 0.12 = 0.46	0.46	3
ELV→SDGB	0.34	0.01 + 0.07 + 0.05 + **0.32** = 0.45	0.79	2

of construction cost in green buildings), and ENV05 (The ratio of cost reduction in the operation of green buildings) are the driving factors with standardized direct benefits greater than 0.8, indicating that these three factors are directly and effectively reflecting the economic value of GB, and are key factors that drive the SDGB.

Among the degree of social participation (SCP) driving factors, SCP02 (Continuing education, training, and advocacy), SCP04 (Public opinion/traditional factors)), SCP05 (The reputation of green buildings), and SCP06 (The living quality of residents) are the driving factors with standardized direct benefits greater than 0.8. It was very surprising to find out that the standardized direct benefits of SCP03 (the competence of government policies, regulations, and standards) only reached 0.65, which fully demonstrates that SDGB cannot rely solely on governments' incentive and mandatory policies. Although at the initial stage of development of GB, policies are the key forces to promote the development of GB, with the development of GB, the key to continuously drive SDGB is the living quality of residents, public awareness of environmental protection (a traditional force), public awareness of green buildings, and the reputation of green buildings.

Among the ecological value (ELV) driving factors, ELV01 (Energy saving per unit area (CO_2 emission reduction)), ELV02 (Water saving ratio per unit area), ELV03 (Land saving ratio per unit area), ELV04 (Solid waste reduction ratio per unit area), ELV05 (Materials saving ratio per unit area), and ELV06 (Indoor environmental healthy and comfort) are the driving factors with standardized direct benefits greater than 0.8. This result indicates that the key for driving SDGB is the ecological value of GB, reflected in the savings and reductions of water, materials, land, energy, solid waste, and CO_2 emission, and in the promotion of indoor environment health and comfort. This driving factor is a key prerequisite for the sustainable scale-up development of GB.

To summarize, the abovementioned 14 factors (MDE05, ENV02, ENV04, ENV05, SCP02, SCP04, SCP05, SCP06, and ELV01- ELV06) are the key driving factors of SDGB. The ultimate goal is to improve the social benefits (0.90), ecological benefits (0.88), and economic benefits (0.86) of regional green buildings.

6. Strategies and discussions

Based on the analysis of key driving paths and forces, this study proposes SDGB strategies, studies SDGB dynamics, and clarifies SDGB driving mechanisms.

6.1. Strategies of measures

The keys of SDGB are the ecological value of GB and the market development environment of GB. From these two aspects, it should be mainly focused on 7 key factors which are MDE05 (The capacity of constructers on green construction), ELV01 (Energy saving per unit area (CO_2 emission reduction)), ELV02 (Water saving ratio per unit area), ELV03 (Land saving ratio per unit area), ELV04 (Solid waste reduction ratio per unit area), and ELV05 (Materials saving ratio per unit area), ELV06 (Indoor environmental healthy and comfort) to increase the capacity of green construction technology, build a green building with high comfort, promote consumers' desire of purchase, reduce the impact of green buildings on the ecological environment, decrease the

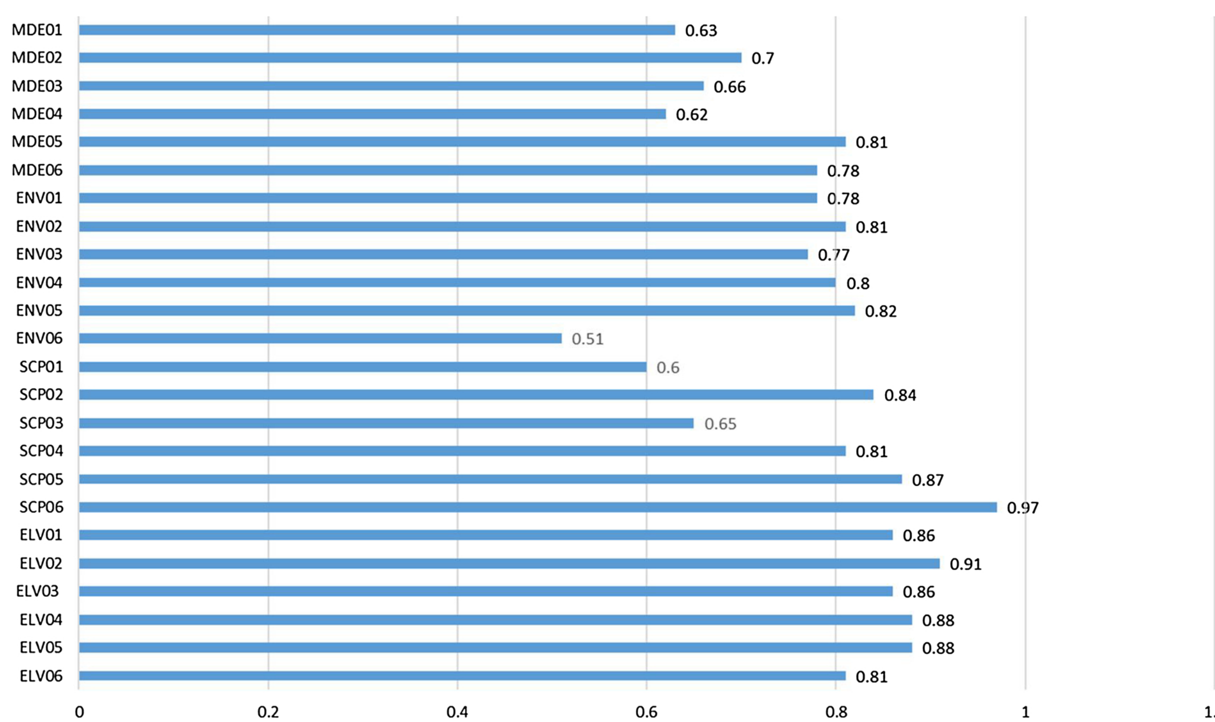


Fig. 5. Contributions of driving forces.

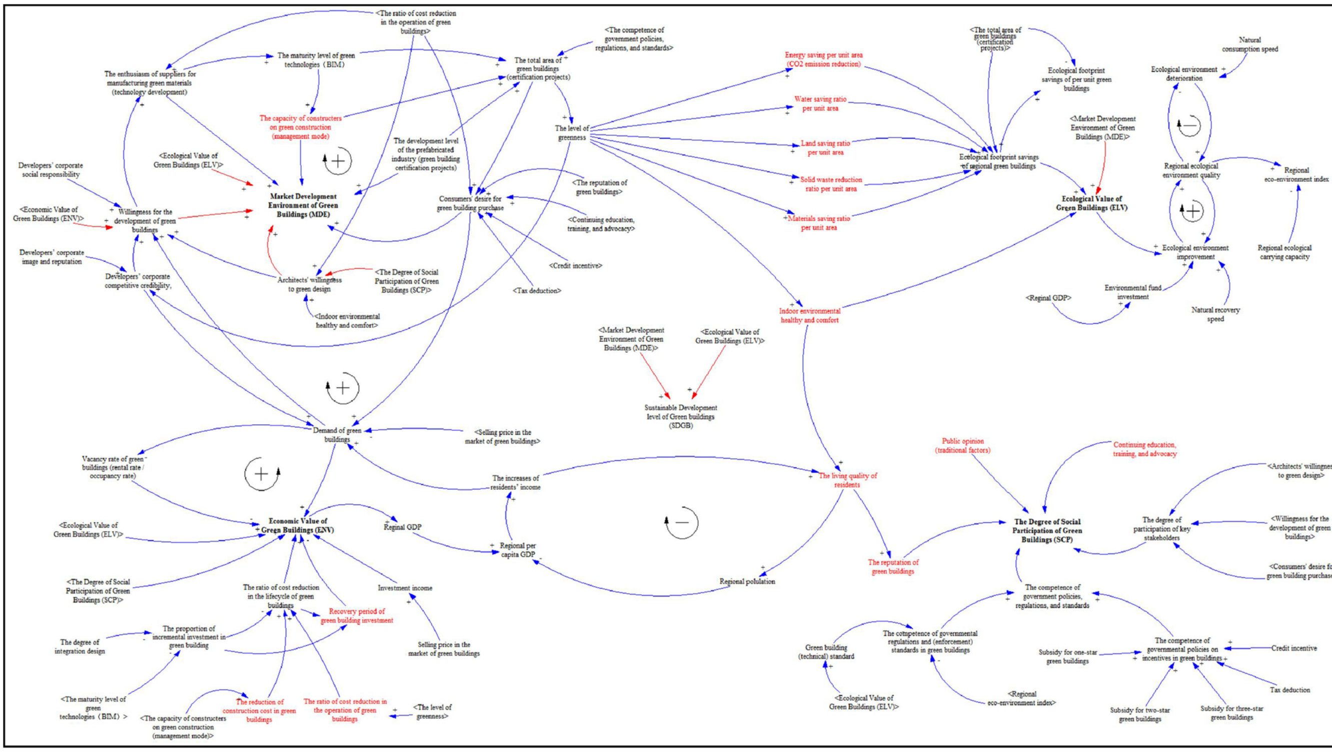


Fig. 6. The dynamic system (interactions) for the sustainable development of green buildings.

ecological footprint, enhance the ecological value of GB, stimulate the participation of stakeholders, improve the market development environment of GB, and eventually realize the sustainable development of green buildings.

Economic value of GB and social participation of GB indirectly drive (affect) SDGB. From these two aspects, it should be focused on 7 key factors which are ENV02 (Recovery period of green building investment), ENV04 (The reduction of construction cost in green buildings), ENV05 (The ratio of cost reduction in the operation of green buildings), SCP02 (Continuing education, training, and advocacy), SCP04 (Public opinion (traditional factors)), SCP05 (The reputation of green buildings), and SCP06 (The living quality of residents) to improve the economic environment and social environment of SDGB, to mitigate the problems in the development process of GB, such as higher incremental costs, long payback period, and lack of awareness of green buildings, and to promote the harmonic development between green building market, economic value, social participation, and ecological value.

6.2. Strategies of subsystems

The market development environment of GB and the ecological environment of GB are key driving paths with significant comprehensive impacts on the SDGB. The degree of social participation of GB has the largest number of paths in driving mechanisms and is the key node of path propagation. Based on this, it should be focused on effectively promoting the degree of social participation of GB, improving government policies, regulations, and standards, to continuously improve the ecological value of GB, hence better promote SDGB. In addition, the economic value of GB is a key node of path propagation which determines whether GB can be effectively promoted. Based on this, the construction industry should improve the economic value of GB, promote regional economic development, and provide a good economic environment for the market development and the sustainable development of green buildings.

The market development environment of GB has the most significant direct impact on SDGB. Based on this, in the process of promoting SDGB, it is very important to pay attention on the market development environment (stakeholders' attitude) of GB. The main body of developing GB is the stakeholders. Only when stakeholders convert green buildings into building entities with market values can they fully reflect the economic value and ecological value of GB, thus affect the degree of social participant of GB and further affect the effectiveness of SDGB.

6.3. Dynamic systems for the sustainable development of green buildings

Based on the driving structural equation model, through the analysis of critical paths and key factors, the system dynamics Vensim is used to construct the dynamic system (interactions) for the sustainable development of green buildings (Fig. 6). Fig. 6 shows the potential driving factors and causality of the sustainable development of green buildings. The red marks indicate the key factors and their critical paths. The arrows indicate the causal relationship between different factors. The symbol "+" stands for promotion, while "-" represents impediment. Fig. 6 displays the operational mechanism of the sustainable development of green buildings (between internal factors).

7. Conclusions and future works

7.1. Conclusions

(1) This study systematically analyzed the sustainable development of green buildings from four aspects (subsystems), including the market development environment of GB, economic value of GB, degree of social participation of GB, and ecological value of GB. This study clarified the internal driving forces of SDGB, and constructed a well fitted structural model for SDGB.
(2) Through the parameter estimation analysis of the driving structural equation model for SDGB, the results show that the market development environment of GB has the most significant direct impact on SDGB, and the ecological environment of GB, a key driving path, has a significant comprehensive impact on SDGB. The degree of

social participation of GB and the economic value of GB are the key nodes of path propagation. Fourteen driving factors (MDE05, ENV02, ENV04, ENV05, SCP02, SCP04, SCP05, SCP06, and ELV01-ELV06) have been identified with important roles in SDGB.

(3) Based on the analysis of key paths and factors for SDGB, driving strategies have been proposed, a dynamic system has been constructed, and operational mechanisms have been clarified. The results are beneficial in providing a reliable model for decision-making and provide practical guidance to promote SDGB.

7.2. Future works

Based on results obtained in this study, future efforts will be focused on the in-depth study of direct quantitative relationship between subsystems and their influencing factors, the construction of a dynamics-based simulation model for the sustainable development of green buildings. The suitability and reliability of the model will be verified, together with performing simulations on the status quo and policies of the sustainable development of green buildings in different regions, to provide a powerful model and practical basis for further promoting the sustainable development of green buildings.

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