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Policy-based initiatives on promoting China's affordable housing: Challenges and opportunities

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ABSTRACT

The construction industry's commitment to achieving carbon neutrality has underscored the urgency of promoting green and low-carbon sustainable affordable housing. However, the development process has encountered several challenges, including conflicts between the central and local governments arising from differences in value preferences, financial constraints faced by local governments, inadequate access mechanisms, lenient screening processes, insufficient funding, and remote locations. Despite its significance, the policies related to affordable housing, especially in the context of assembly affordable housing, have received limited systematic examination. To address this research gap, this paper presents a comprehensive review and analysis of China's affordable housing policies. Firstly, it compiles and compares recent affordable housing policies in China, serving as a valuable reference for future affordable housing construction endeavors. Secondly, it conducts an in-depth analysis of the barriers and challenges obstructing affordable housing development in China, and proposing corresponding measures for improvement. Moreover, this paper identifies significant opportunities for affordable housing development in the country and explores the potential synergy between the development of assembly buildings and affordable housing by leveraging their respective attributes. By illuminating pertinent policies and associated issues, this research aims to inform policymakers, practitioners, and stakeholders involved in the affordable housing sector. Additionally, it aims to stimulate further research and innovation in the field, contributing to effective and sustainable housing solutions for low-income communities and society at large. This paper systematically analyzes the current status of affordable housing policies, challenges and opportunities. It also discusses the application of assembly building techniques in the realm of affordable housing, proving valuable insights to address traditional housing issues.

1. Introduction

Housing, being a fundamental human demands, holds a pivotal role in determining the overall quality of life (Winston and Eastaway, 2008; Li et al., 2021, 2023; Tusell, 2017). In recent years, rent levels in some countries have risen more rapidly than incomes, and housing has become increasingly unaffordable, especially for low-income groups (Guzikova and Plotnikova, 2018) (Corlett et al., 2019). Meanwhile, in the context of developing countries, the issue of housing scarcity remains both widespread and intricate (Kamruzzaman and Ogura, 2009). A standout example is China, which has seen a significant surge in urban

commercial housing prices since 2004. This surge has outstripped the growth rate of urban household incomes, thereby making suitable housing increasingly unattainable for many low- and middle-income households (Zhang, 2015; Li, 2023; Li et al., 2022). The process of rapid urbanization has only heightened the demand for housing in cities, warranting concentrated efforts to address housing conditions for various groups, including low-income individuals, new residents, and young people (Yao et al., 2014; Jin et al., 2023). Recognizing the importance of social welfare policies, China has identified social housing, including affordable housing, as a pivotal solution to tackle housing challenges (Adema et al., 2020). Notably, the December 2020 Central Economic Work Conference emphasized the significance of affordable

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Abbreviations

EU	European Union
WOS	Web of Science
GDP	Gross domestic product
PPP	Public-private partnership
HDB	Housing development board
SAR	Special administrative region

housing construction as a measure to alleviate housing pressures in major cities (Li, 2023). During the “14th Five-Year Plan” period, affordable housing has emerged as a central pillar of China’s housing security system, attracting considerable attention in the nation’s housing development initiatives. Amidst the backdrop of the “double carbon” strategy aimed at carbon peak and carbon neutrality, affordable

housing, as a government-led initiative, assumes a pivotal role in proactively addressing the national push for promoting green building practices for promoting green building practices (Sales, 2022).

The development of affordable housing in China is characterized by a significant supply-demand imbalance (Torab, 2018). Yang (2014) reported that approximately 30% of urban families were supposed to be eligible for affordable housing, leaving a large proportion of disadvantaged families without guaranteed housing conditions. In the absence of an adequate supply of affordable housing in the market, low-income households often find themselves in the predicament of sacrificing essential needs like food and healthcare to afford rent payments (Anderson et al., 2003). Furthermore, public concerns regarding housing quality have been on the rise (Krieger and Higgins, 2002). As the country progresses in economic development, there is a growing demand for improved environmental standards in housing. In alignment with the “double carbon” goal, a renewed focus has emerged on the development of high-quality rental properties characterized by their green, low-carbon (Zhou, 2023b), ecologically sustainable attributes,

Table 1
Studies related to affordable housing projects.

Research Fields	Authors	Main findings
Affordable housing policy	Zhang et al. (Zhang and Wu, 2014) Raynor et al. (Raynor and Whitzman, 2021) Lucio et al. (Lucio and de la Cruz, 2012)	The evolution of China’s housing policy was reviewed, and the interaction between the actors in the policy network and their interests was studied. A longitudinal comparative analysis was conducted through interviews with members of the affordable housing policy network. This study clarified the position of public, nonprofit, and private organizations in the network of participants in the production of affordable housing in China.
Affordable housing financing model	Sun et al. (Sun and Ye, 2011) Noring et al. (Noring et al., 2022)	It analyzed the current situation of affordable housing financing, and made suggestions for the path innovation of affordable housing financing in China. It examined the governance and financing models of the private nonprofit housing sector in Denmark, whose private nonprofit housing system provided affordable housing at a lower level of public financing.
Challenges to policy implementation	Tan et al. (Tan et al., 2017) Han et al. (Han et al., 2021) Li et al. (Li and Tang, 2017)	The challenges faced by private housing developers in Malaysia for providing affordable housing were explored, primarily the institutional and economic issues associated with housing construction in the country. This study assessed the barriers and opportunities to the provision of affordable housing through interviews, identifying existing challenges. This study described the current situation of China’s housing security system and analyzed the obstacles encountered in the operation process.
Other challenges	Ludick et al. (Ludick et al., 2021) Scalli (Scalli, 2013) Li et al. (Li and Guo, 2022)	This study analyzed how new affordable housing development affected the location and structural value of the adjacent existing housing market. Local acceptance and avoidance of affordable housing development under the Low Income Housing Tax Credit program was explored through six cases in New York State. An analysis of the spatial concentration and average neighborhood characteristics of affordable housing revealed that affordable housing is more likely to be placed in disadvantaged neighborhoods than in market-rate housing.
Impact on the community environment	Albright et al. (Albright et al., 2013) Mueller (Mueller and Tighe, 2007)	A comparison of crime rates, property values and property taxes in Mount Laurel, New Jersey, with those in similar nearby cities showed that affordable housing development was not associated with crime, property value or tax trends. An analysis of the impact of affordable housing on health was conducted, showing that the cost of addressing housing-related health care needs was important to public health.
Impact on social life	Cheng et al. (Cheng et al., 2017)	This study investigated the main factors that prevented the effective adoption of assembly buildings in different types of public housing in China from the perspective of developers.
The application of assembly building in public rental housing	Chen et al. (Chen et al., 2010) Esruq-Labin et al. (Esruq-Labin et al., 2014) Chan et al. (Chan and Adabre, 2019)	The performance of the affordable housing was evaluated, and a model was established to satisfy the objective 0–1 planning optimization for the allocation of affordable housing. Six affordable housing performance measurement elements were identified, which were considered to be the main factors directly affecting the performance of affordable housing. By identifying and classifying various critical success factors, the analysis showed that the various factors could be categorized into six components.
Evaluation of affordable housing projects	Li (Li et al., 2021)	By analyzing the satisfaction of public services in the affordable housing communities in Nanjing, China, this study ultimately aimed to optimize the supply and demand of affordable housing community services.
Implementation of supporting services	Zhang et al. (Zhang et al., 2018)	A study of the degree of adaptation of basic service facilities for the elderly population in Shijiazhuang, China, revealed that there are some problems such as low quality and insufficient number of basic service facilities allocated in affordable housing settlements.
Profit-driven construction of affordable housing	Nguyen (Nguyen, 2005) Olanrewaju et al. (Olanrewaju et al., 2018) Chegut et al. (Chegut et al., 2016)	The impact of affordable housing on property values was studied, and the analysis showed that the degree of property value reduction depends on a variety of factors: the design and management of the affordable housing, etc. Housing providers’ insights into the potential benefits of sustainable and affordable housing were investigated. The value effect of energy efficiency in the Dutch affordable housing market was analyzed, using energy performance certificates to determine the value of energy efficiency in these transactions.

and capacity to provide comfortable living conditions (Sales, 2022; Liu et al., 2023a; Song et al., 2022; Zhou et al., 2021). Consequently, it becomes essential to evaluate the present status of affordable housing policies, scrutinize prevailing challenges and implementation impediments, and provide policy suggestions to secure the sustainable progression of affordable housing in China. This research holds immense significance in addressing the welfare requirements of Chinese citizens while facilitating the transformation and upgrading of the real estate industry (Song and Zhou, 2023a, 2023b) towards high-quality green development.

Numerous studies have been conducted, covering various aspects of affordable housing projects, including policy analysis (Zhang and Wu, 2014; Raynor and Whitzman, 2021; Lucio and de la Cruz, 2012), financing models (Sun and Ye, 2011; Noring et al., 2022), implementation challenges (Tan et al., 2017; Han et al., 2021; Li and Tang, 2017), community environment impacts (Ludick et al., 2021; Scally, 2013; Li and Guo, 2022), social implications (Albright et al., 2013; Jin et al., 2022; Li, 2023; Mueller and Tighe, 2007), barriers to using assembly buildings in public rental housing (Cheng et al., 2017), affordable housing initiatives (Chen et al., 2010; Esruq-Labin et al., 2014; Chan and Adabre, 2019), provision of support services (Li et al., 2021; Zhang et al., 2018), and profit-driven approaches (Nguyen, 2005; Olanrewaju et al., 2018; Chegut et al., 2016). A summary of these studies is presented in Table 1.

In summary, while scholars have extensively researched various aspects of affordable housing from diverse perspectives, several research gaps persist, encompassing: 1) A dearth of comprehensive analysis of China's affordable housing policy, overlooking essential systematic examinations of obstacles, challenges, issues, and opportunities encountered during policy implementation; 2) Insufficient systematic summarization and analysis of assembly building's practical applications in affordable housing, coupled with a deficiency of in organized, comprehensive policy analysis concerning their integration; 3) A scarcity of studies investigating the viability and promotion of the relationship between affordable housing and assembly buildings, necessitating the development of a systematic framework offering practical and feasible policy recommendations for the integration of assembly building methods into affordable housing initiatives.

This study aims to bridge these research gaps and contribute to the sustainable and high-quality advancement of affordable housing in China. The paper's innovations lie in its systematic organization of China's affordable housing policy evolution, accentuating the encountered implementation challenges within key representative cities, and identifying significant prospects inherent in the integration of affordable housing and assembly buildings. Furthermore, this study comprehensively compiles and analyzes policy documents pertinent to assembly buildings in affordable housing. It scrutinizes the current implementation status and appraises recent instances of assembly-based affordable housing in specific Chinese regions. Additionally, by analyzing the compatibility between assembly buildings and affordable housing, considering their attributes, benefits, and mutual enhancement impacts, this study formulates corresponding policy recommendations for the growth of assembly-based affordable housing. The proposed comprehensive policy framework and blueprint for the development of assembly-based affordable housing are anticipated to vigorously foster the synergistic advancement of both affordable housing and assembly building domains.

2. Methodology

The research methodology employed in this study encompasses a comprehensive review and analysis of publicly available articles and information on affordable housing sourced from official government websites. The study primarily adopts a literature review approach to dissect the policies, existing landscape, challenges, and prospects within the domain of affordable housing. Additionally, the research

incorporates a case analysis method to juxtapose and dissect the policies and present status of affordable housing development across select representative cities in China. Given the diverse urban development scenarios in China, this study strategically selects two categories of cities as representatives for analysis: prominent first-tier cities and emerging new first-tier cities. These two categories allow for an examination of distinct measures adopted for affordable housing development. The research process comprises four fundamental steps: identification of research content, retrieval and refinement of pertinent papers, extraction and synthesis of relevant content, and a comprehensive analysis of outcomes to formulate a framework for policy recommendations.

In the first step, the research proposal was developed. Firstly, the scope of this study needs to be defined: i) Definition of Affordable Housing: Affordable housing refers to housing that is planned and coordinated by the government, provided for use by specific groups of people, which limits construction standards and sales prices or rental standards, and plays a social security role (Feng et al., 2007); ii) Contents included in the affordable housing policy: ① Group involved in affordable housing: affordable housing is mainly for the middle- and low-income groups. ② Affordable housing financing model, access standards, and operation management, etc. iii) Key influencing factors of the implementation of the affordable housing policy: analyzed from three perspectives of government, developers and users. Secondly, two main questions of the study were defined: i) What is the current status of the implementation of affordable housing policies in China? ii) What are the challenges and opportunities associated with the implementation of affordable housing related policies in China?

The second step involved identifying keywords and relevant databases for paper retrieval. The relevant papers were searched in widely used databases such as Web of Science (WOS), ScienceDirect, etc. Chinese literature was retrieved from sources like China Knowledge Network (<https://www.cnki.net/>), Wanfang Data Knowledge Service Platform (<https://www.wanfangdata.com.cn>), etc. Typically, review studies used keyword to identify journal articles that are relevant to their research objectives (Darko and Chan, 2016; Deng and Smyth, 2013; Osei-Kyei and Chan, 2015). Since affordable housing projects are public housing projects, papers related to public housing projects, housing, and public-private partnership (PPP) projects were also reviewed in terms of policies and barriers (Adabre and Chan, 2019). To identify relevant papers, separate searches were conducted using the following keywords: “affordable housing”, “policy”, “public housing”, “low cost housing”, and “China affordable housing”. For the specific aspects related to assembly housing in China and Chinese-language information, relevant keywords were searched on China Knowledge Network, Wanfang Data Knowledge Service Platform, and other Chinese databases. Additionally, information was gathered from official Chinese government websites, with the main website sources indicated in Table 2. Due to the broad range of keywords used, the search results needed to be filtered based on the study's content (Cattan et al., 2005).

Table 2

Statistics of representative official websites involved in this study.

Full name of the website		Related Links
Local Governments	China Government Website	https://www.gov.cn/
	Ministry of Housing and Urban-Rural Development of the People's Republic of China	https://www.mohurd.gov.cn/
	Ministry of Natural Resources of the People's Republic of China	https://www.mnr.gov.cn/
	the People's Government of Beijing Municipal	http://www.beijing.gov.cn/
	the People's Government of Shanghai Municipal	https://www.shanghai.gov.cn/
	the People's Government of Guangzhou Municipal	https://www.gz.gov.cn/
	-	-

Note: The corresponding reference websites and links will be listed after the corresponding contents.

Screening was performed by reviewing the titles and abstracts of articles to identify the most relevant literature. Finally, 156 articles relevant to the study were selected for thorough examination.

In the third step, the relevant content for this study was extracted and summarized through a thorough reading of the papers obtained using the aforementioned keywords. In the fourth step, the summarized content was analyzed and synthesized, leading to the formulation of a policy recommendation framework for the development of affordable housing and assembly affordable housing. The research methodology flow of this paper is illustrated in Fig. 1.

3. Overview on policy-based initiatives of China's affordable housing

3.1. Evolution of China's affordable housing policies

This section presents a chronological comparison of China's affordable housing policies, delineating focal points and corresponding development statuses across various periods, as illustrated in Fig. 2. Simultaneously with the impetus to advance affordable housing construction, China has accorded paramount significance to guaranteeing its quality and environmental impact. Consequently, existing policy documents encompass provisions like the establishment of dedicated material and component procurement platforms tailored to affordable housing construction. Additionally, these policies actively promote and implement new technologies, materials, and methodologies that align with energy preservation and environmental safeguarding standards. Furthermore, deliberate endeavors are undertaken to elevate the construction quality and overall performance of affordable housing projects.

3.2. Main aspects of China's affordable housing policy

This section delves into an in-depth analysis of China's affordable housing policy, focusing on several key aspects. These include: 1) Prevalent Financing Models for Housing Construction: This aspect examines the various financing models utilized in the construction of affordable housing projects. 2) Primary Criteria for Determining Affordability: The section explores the key criteria and parameters used to assess the affordability of housing for low and middle-income households. 3) Influence of Land Finance on Affordable Housing: This aspect delves into the impact of land finance policies and practices on the development and implementation of affordable housing initiatives. 4) Motivations Driving Local Governments in Affordable Housing Initiatives: The section investigates the underlying factors and motivations that prompt local governments to actively engage in affordable housing projects. 5) Spatial Distribution Patterns of Affordable Housing: This aspect analyzes the geographical distribution and allocation of affordable housing projects across different regions. By comprehensively examining these aspects, this study aims to gain a deeper understanding of the current state of China's affordable housing policy and identify the underlying challenges. The framework illustrating the content covered in China's affordable housing policy is presented in Fig. 3.

Funding for affordable housing in China primarily originates from the following sources: financial allocations (Mao and Wang, 2012), net income generated from land leases (Mao and Wang, 2012), appreciation income from housing provident funds (Mao and Wang, 2012), bank loans (Chen, 2010). Firstly, financial allocation plays a crucial role due to the public nature and positive externalities associated with affordable housing, which limits private sector investment in this sector. Secondly, the net income obtained from land leases is a significant source of funding. According to the Opinions of the State Council on Solving the Housing Difficulties of Low-income Families, a minimum of 10% of the

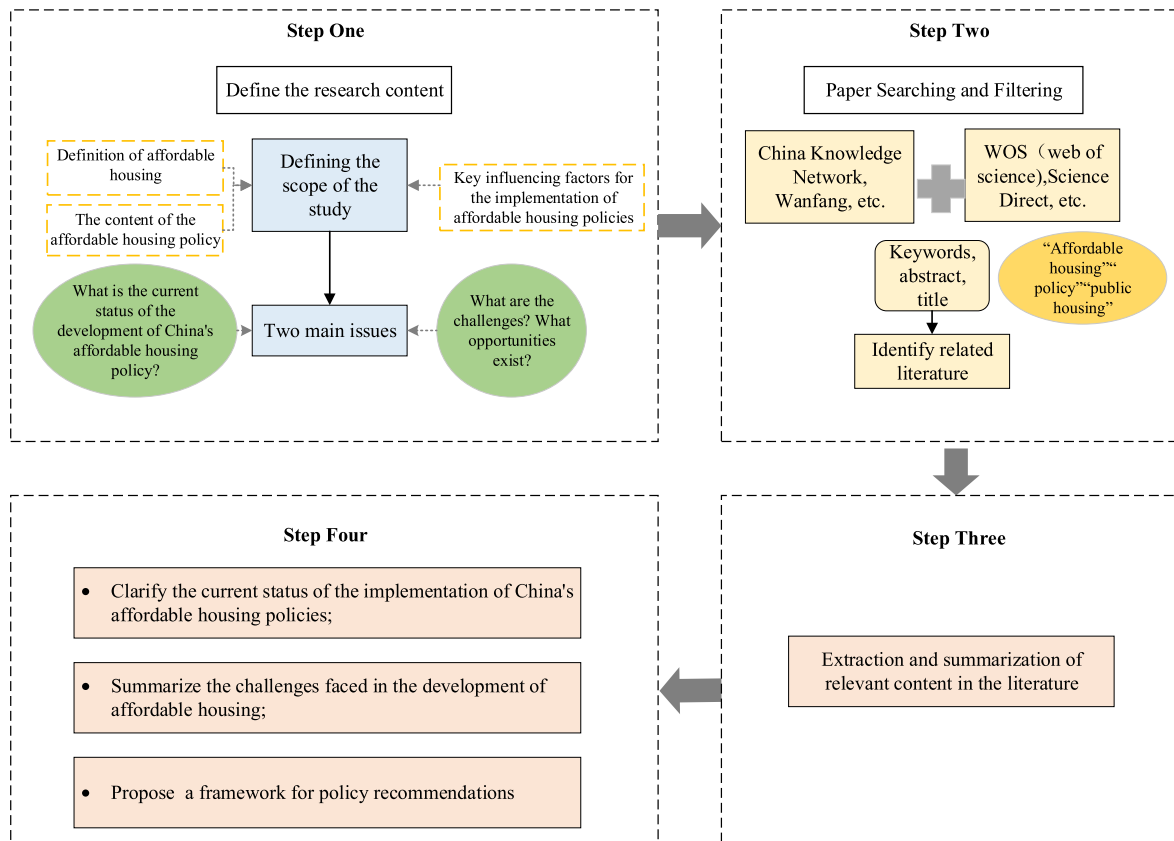


Fig. 1. Flow chart of research method.

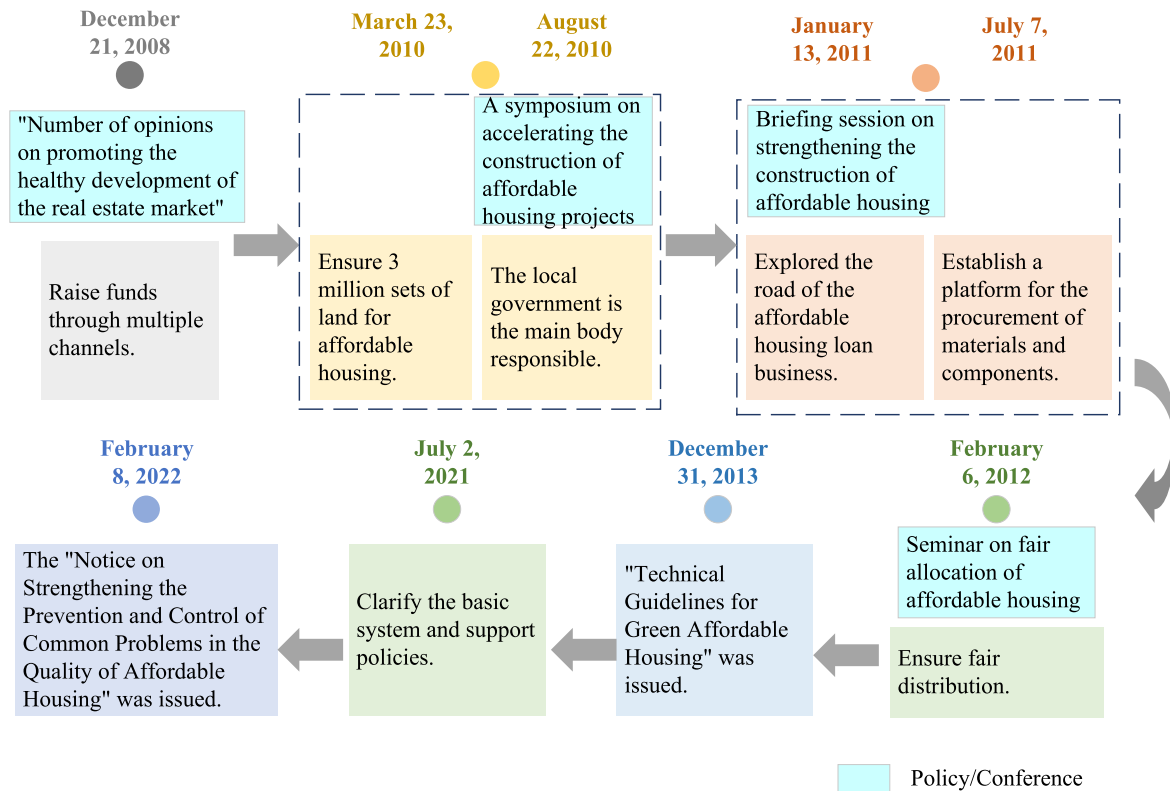


Fig. 2. Evolution of China's Affordable Housing Policy (The summarized content information in this figure is derived from references of (China M.o.H.a.U.-R.D.o.t.P.s.R.o, 2008; China M.o.H.a.U.-R.D.o.t.P.s.R.o, 2010a; China M.o.H.a.U.-R.D.o.t.P.s.R.o, 2010b; China M.o.H.a.U.-R.D.o.t.P.s.R.o, 2011a; China M.o.H.a.U.-R.D.o.t.P.s.R.o, 2011b; China M.o.H.a.U.-R.D.o.t.P.s.R.o, 2012; China M.o.H.a.U.-R.D.o.t.P.s.R.o, 2013; China C.P.s.G.o.t.P.s.R.o, 2021a; China M.o.H.a.U.-R.D.o.t.P.s.R.o, 2022a)).

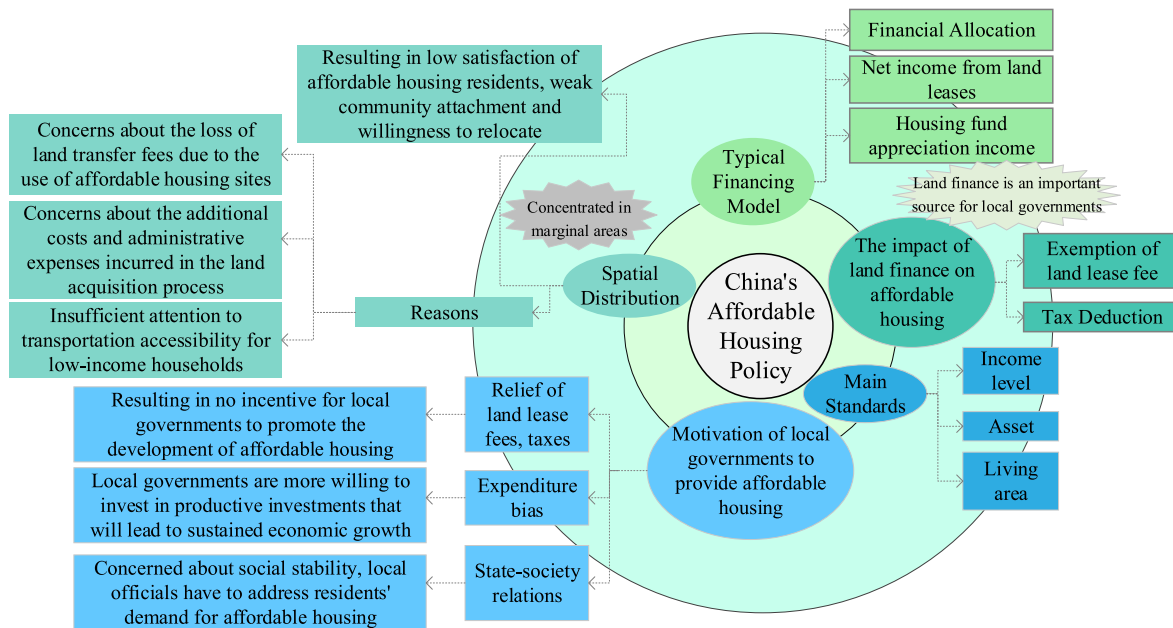


Fig. 3. Framework of content involved in China's affordable housing policy (The summarized content information in this figure is derived from references of (Mao and Wang, 2012; Chen, 2010; Cai et al., 2017; Hu and Qian, 2017; Dang et al., 2014; Zheng and Zhang, 2010; Zeng et al., 2019; Yang et al., 2009)).

net proceeds from land concessions is dedicated to low-rent housing guarantee funds (China C.P.s.G.o.t.P.s.R.o., 2007). Thirdly, the appreciation income of housing provident funds contributes to affordable housing financing. The housing provident fund was established during China's urban housing system reform (Li et al., 2009). The Ministry of

Housing and Urban-Rural Development and other relevant authorities have issued the "Implementation Opinions on the Use of Housing Provident Fund Loans to Support the Construction of Affordable Housing," enabling the utilization of a portion of the housing provident fund balance loans to support affordable housing projects (China C.P.s.G.o.t.

P.s.R.o, 2009). Fourthly, bank loans also serve as a funding source. The People's Bank of China and the China Banking and Insurance Regulatory Commission issued a notice stating that loans associated with affordable housing projects should not be classified as real estate loans (China C.P. s.G.o.t.P.s.R.o, 2022a). The motivations behind local governments' provision of affordable housing encompass concerns related to urban management, social stability, and revenue generation (Hu and Qian, 2017). Fig. 4 provides a detailed illustration of these motivations. Among these, the pursuit of revenue maximization is the primary factor influencing the land allocation decisions of Chinese urban governments.

3.3. Current development status of affordable housing in representative cities

Having gained insights into the evolution and key components of China's affordable housing policies, this section delves into present state of policy development in affordable housing across selected representative cities. To dissect the development strategies of these cities, reference is made to the "2019 City Business Attractiveness Ranking" published by the New Tier One Cities Research Institute, a project focused on urban data research conducted in Shanghai (HERALD, 2019). This ranking incorporates five key indicators: concentration of business resources, urban centrality, civic engagement, diversity of lifestyles, and future adaptability. Among the 337 assessed cities, the first-tier cities include Beijing, Shanghai, Guangzhou, and Shenzhen, whereas the 15 new first-tier cities are Chengdu, Hangzhou, Chongqing, Wuhan, Xi'an, Suzhou, Tianjin, Nanjing, Changsha, Zhengzhou, Dongguan, Qingdao, Shenyang, Ningbo, and Kunming, in that respective order.

Acknowledging the diverse developmental trajectories of cities in China, this study focuses on two distinct categories of cities to exemplify the approaches they've adopted in advancing affordable housing initiatives. The chosen first-tier cities encompass Beijing, Shanghai, and Guangzhou, while the new first-tier cities comprise Chengdu, Chongqing, Hangzhou, Wuhan, Xi'an, Nanjing, and Changsha. The specific measures outlined in the development plans of these ten representative cities, with the intent of accelerating affordable housing initiatives, are summarized in Table 3.

Informed by a comprehensive grasp of China's affordable housing policies, this study proceeds to conduct an analysis of the contemporary status of affordable housing development within specific regions of the country. The focus is specifically directed towards two categories of regions, each in distinct developmental stages. The first group includes four cities: Beijing, Guangzhou, Tianjin, and Nanjing. Within this group, Beijing and Guangzhou hold the status of first-tier cities, while Tianjin

and Nanjing belong to the category of new first-tier cities. A comprehensive overview of the current developmental statuses of affordable housing within these cities, along with the challenges they confront, is provided in Table 4.

Upon scrutinizing the ongoing development status of these cities, a recurring issue surfaces across nearly all of them: the inadequate positioning of affordable housing. Furthermore, the remote placement of these housing projects may contribute to a spectrum of social challenges, including heightened crime rates and reduced levels of business investment (Cai et al., 2017; Ma et al., 2018).

4. Challenges and opportunities on promoting affordable housing

4.1. Challenges on promoting affordable housing

The advancement of affordable housing construction in recent years has witnessed commendable progress in affordable housing system. However, several pressing challenges persist and need to be addressed. This section aims to succinctly delineate and analyze these challenges prevalent in China's ongoing affordable housing development. A primary challenge resides in the tensions between central government directives and local governments (Mao and Wang, 2012; Cai et al., 2017; Zou, 2014), impeding the seamless implementation of affordable housing policies. Another challenge arises from divergent value preferences (Tan and Lou, 2012), hampering consensus and collaboration among stakeholders engaged in the affordable housing domain. Inadequate access mechanisms and lenient scrutiny processes concerning affordable housing applications constitute an additional hurdle (Fan and Zhang, 2014). These issues can lead to inefficiencies and potential abuse in the allocation and management of affordable housing resources. Furthermore, certain behaviors that undermine the normal operation of the system, particularly in the areas of construction, distribution, and exit of affordable housing, present significant challenges (Li and Ieee, 2015). The dependence on local government investment is an additional challenge that needs to be addressed (Mao and Wang, 2012; Gan et al., 2017). Over-reliance on local government funding may hinder the long-term sustainability and scalability of affordable housing initiatives. Moreover, the remote locations of some affordable housing projects limit residents' opportunities for social interaction and access to services (Dang et al., 2014; Zeng et al., 2019; Ma et al., 2018), which can adversely affect the livability and community integration aspects of these developments. Furthermore, remote locations can give rise to societal issues (Cai et al., 2017; Ma et al., 2018), exacerbating issues such

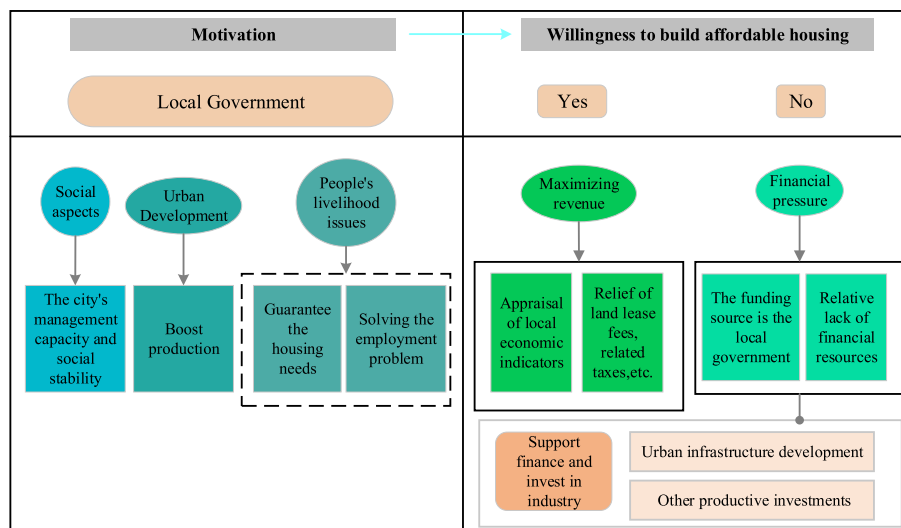


Fig. 4. Motivation of local governments to provide affordable housing.

Table 3
Detailed measures to accelerate the development of affordable housing in selected representative cities in China.

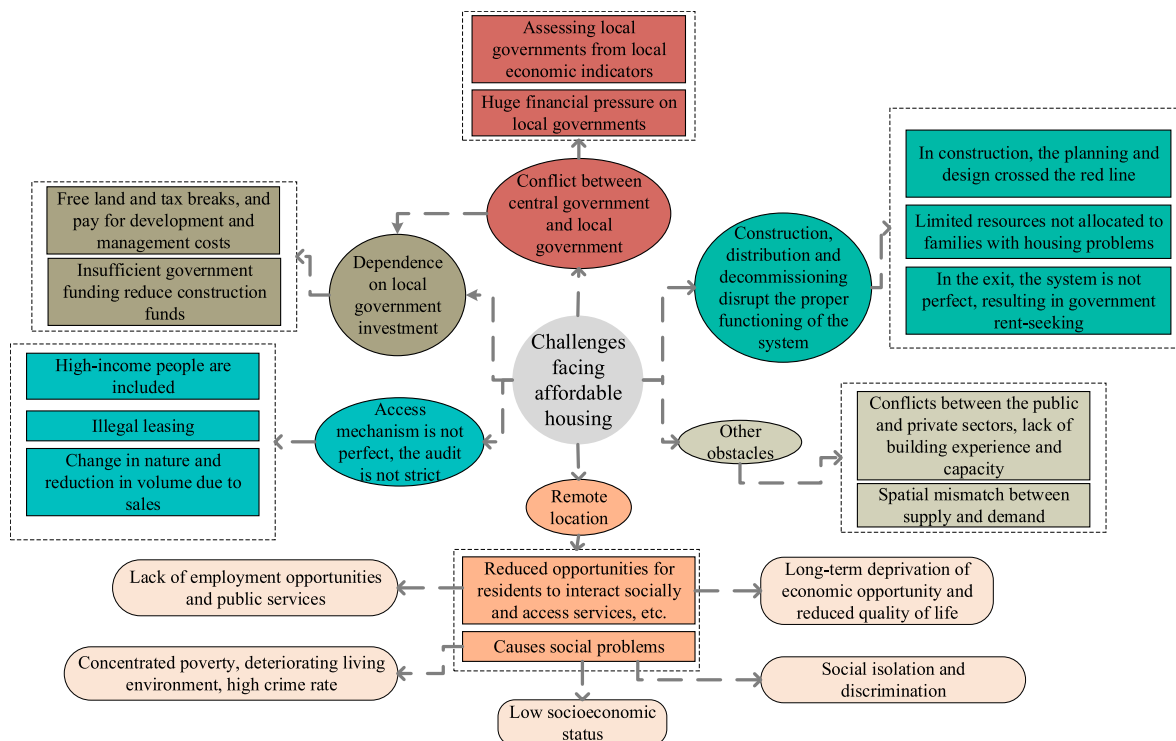
Policies/Key Cities		Beijing (Municipality T. P.s.G.o.B, 2022a)	Shanghai (Municipality T. P.s.G.o.S, 2021)	Guangzhou (Municipality T. P.s.G.o.G, 2021)	Chengdu (Municipality T. P.s.G.o.C, 2021)	Chongqing (Municipality T. P.s.G.o.C, 2022a)	Hangzhou (Municipality T. P.s.G.o.H, 2021)	Wuhan (Housing, 2021)	Nanjing (Municipality T. P.s.G.o.N, 2022)	Xi'an (Municipality T. P.s.G.o.X.a, 2022)	Changsha (Municipality T. P.s.G.o.C, 2022b)
Basic Systems	Multi-channel construction	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Construction Standards	✓	✓	/	✓	✓	✓	✓	✓	✓	✓
	Strengthen the spatial planning	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Scientific determination of objectives	✓	/	✓	✓	/	✓	✓	✓	✓	✓
	Lead the participation of multiple parties	✓	/	/	✓	✓	/	✓	✓	✓	✓
	Simplify the approval process	✓	/	✓	/	✓	✓	✓	✓	✓	✓
Support Policies	Land Support Policies	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Financial and Tax Support Policies	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Electricity, water and gas pricing policies	✓	✓	/	✓	✓	✓	✓	✓	✓	✓
	Financial Support Policies	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Matching public service support policies	/	✓	/	✓	✓	/	/	✓	/	✓
	Establish a project identification mechanism	/	/	/	/	/	✓	/	✓	/	/
Operations	Clarify the criteria for protection objects	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Management	Reasonable determination of rent	✓	✓	/	✓	✓	✓	✓	✓	✓	✓
	Strict supervision and management	✓	✓	/	✓	✓	✓	✓	✓	✓	✓
	Operation and management units perform tasks	/	/	✓	/	/	✓	/	✓	/	/
	Strengthen the construction of housing security information platform	/	✓	✓	✓	/	✓	✓	✓	✓	✓

Note: “/” indicates that the city has not formulated the policy; “✓” indicates that the city has formulated the policy.

Table 4

Comparison of the development status of affordable housing in key cities in China.

Cities	Finance Source	Price of affordable housing	Property rights of houses	Property Management Prices	Number of affordable housing	Building area	Space Location	Allocated objects	Problems	References
Beijing	Granted by the local government to the developer with no cost.	Development costs plus taxes and a 3% profit cap from developers.	Ownership of affordable housing is restricted.	Its price is much lower than the market price of housing.			Municipalities use profitable land for commercial housing.		1. The number of housing decreases when the housing area is large; 2. The income limits for eligible households are unclear;	(Cai et al., 2017; Dang et al., 2014)
Tianjin					Significantly expand its coverage.		Located in suburban or developing areas.		1. Mostly located in developing areas; 2. Population concentrations are likely to lead to social problems.	Cai et al. (2017)
Guangzhou			Trading on the market is not allowed for five years.		Limited coverage of affordable housing	Limited to 60–65 square meters			1. There are insufficient funding sources; 2. The supply of land is far from enough.	Cai et al. (2017)
Nanjing					4535 households received in 2010.		Located at the edge of the city.	5% was allocated to low- and middle-income families.	Residents have difficulty accessing services such as shopping, education, medical.	(Zeng et al., 2019; Hu et al., 2015)

**Fig. 5.** Challenges to the development of affordable housing in China.

as crime rates and limited economic opportunities in these areas. Additionally, various other barriers impede the effective implementation and widespread adoption of affordable housing policies (Cai et al., 2017; Hu and Qian, 2017). For a visual representation of these challenges, refer to Fig. 5. Addressing these challenges is crucial to further improve the affordability, accessibility, and overall impact of affordable housing in China.

4.2. Opportunities on promoting affordable housing

To facilitate the implementation of the Opinions of the General Office of the State Council on Accelerating the Development of Affordable Housing, Chinese cities have issued policy documents to promote the growth of affordable housing. In January 2022, the Ministry of Housing and Construction emphasized the need to enhance policy support to expand the supply of affordable housing in the 14th Five-Year Public Service Plan for the National Economic and Social Development of the People's Republic of China. An integral part of the preliminary scheme for the 14th Five-Year Plan is the target for 40 key cities across China to augment the affordable housing inventory by 6.5 million units (China M.o.H.a.U.-R.D.o.t.P.s.R.o., 2022b).

During the “14th Five-Year Plan” period, the government has established construction targets for affordable housing, leading to a significant demand for affordable housing across the country. This increased demand presents an opportunity for the utilization of assembly-type construction methods, also including using the advanced renewable energy technologies or systems (e.g., solar energy (He et al., 2022; He et al., 2021a; He et al., 2021b; Zhou et al., 2018), geothermal energy (Liu et al., 2017, 2019a, 2019b, 2022a), wind energy (Liu et al., 2022b; Zhou, 2022a), ocean energy (Liu et al., 2023b; Zhou, 2022b), etc.), battery (Song and Zhou, 2023a, 2023b), energy sharing (Zhou, 2023a, 2023d; Zhou and Lund, 2023), artificial intelligence (Zhou, 2022c; Zhou and Zheng, 2020a, 2020b, 2020c, 2020d), to achieve sustainable green construction practices. Prominent regions like Beijing, Shanghai, Tianjin, Shenzhen, Zhejiang, and Shanxi have issued targeted policies to guide the assimilation of assembly building techniques within affordable housing projects. Illustrated in Fig. 6 are policies pertaining to affordable housing from selected Chinese cities (Municipality T.P.s.G.o.B., 2022a; Municipality T.P.s.G.o.S., 2021; Municipality T.P.s.G.o.G., 2021; Municipality T.P.s.G.o.C., 2021; Municipality T.P.s.G.o.C., 2022a; Municipality T.P.s.G.o.H., 2021; Housing, 2021; Municipality T.P.s.G.o.N., 2022; Municipality T.P.s.G.o.X.a., 2022; Municipality T.P.s.G.o.C., 2022b; Province P.s.G.o.G., 2022) and the affordable housing development goals of specific provinces and cities during the 14th Five-Year

Plan (Municipality T.P.s.G.o.B., 2022b; China C.P.s.G.o.t.P.s.R.o., 2021b; China C.P.s.G.o.t.P.s.R.o., 2021c; Municipality T.P.s.G.o.C., 2022c; Municipality T.P.s.G.o.H., 2022; Municipality T.P.s.G.o.W., 2021; China C.P.s.G.o.t.P.s.R.o., 2022b; District T.P.s.G.o.N.L., 2022; Municipality T.P.s.G.o.X.a., 2021; China C.P.s.G.o.t.P.s.R.o., 2021d).

On this basis, China has introduced some policies on the combination of assembly building concepts and affordable housing endeavors. This dynamic aims to advance assembly building developments while vigorously propelling affordable housing construction. The specific policies are shown in Fig. 7.

Aligned with the overarching trajectory of affordable housing development, the Chinese government has proactively championed the concurrent deployment of assembly building techniques alongside affordable housing endeavors. During the 14th Five-Year Plan period, the Ministry of Housing and Urban-Rural Development issued the “14th Five-Year Development Plan,” which emphasizes the robust advancement of assembly building practices. This roadmap underscores the establishment of a standardized design and production system, the amplification of standardized component and part integration, the augmentation of comprehensive benefits associated with assembly buildings, and the specification that assembly building integration in new constructions should surpass 30% (China M.o.H.a.U.-R.D.o.t.P.s.R.o., 2022c).

The ambitiously charted affordable housing development scheme delineated within the 14th Five-Year Plan presents an ample opportunity for the assimilation of assembly building methods. The extensive scale of affordable housing construction furnishes fertile ground for the proliferation of assembly building techniques, with many regions aiming to leverage affordable housing projects to boost the penetration rate of assembly building (China, B. N., 2022). As a pivotal venture indelibly affecting the lives of Chinese citizens, affordable housing possesses distinct construction characteristics (Wu and Shen, 2011; Wang, 2017; Yin, 2015; Wu, 2012; Pan et al., 2020; Lu, 2011; Li, 2019; Dong et al., 2018; Ge et al., 2020), while assembly buildings confer a multitude of advantages (Dong et al., 2018; Ye and Chen, 2019; Zhang, 2012).

Upon dissecting the merits and unique attributes of assembly building and affordable housing, it becomes manifest that the assembly building framework inherently catalyzes the advancement of affordable housing construction. The convergence of assembly assembled housing with affordable housing initiatives paves the way for China's affordable housing projects into the realm of industrialization (Huang et al., 2012). Promoting the modernization of residential sector within the context of affordable housing construction holds the potential to significantly enhance overall quality, expedite housing supply, and reduce

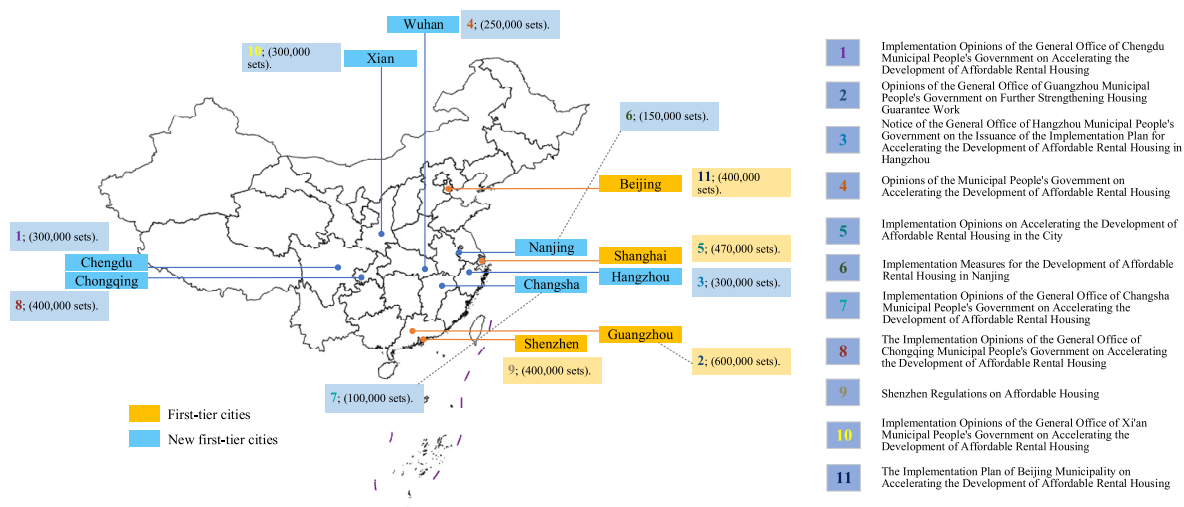


Fig. 6. Policies related to affordable housing in some cities in China and the development target of affordable housing during the 14th Five-Year Plan.

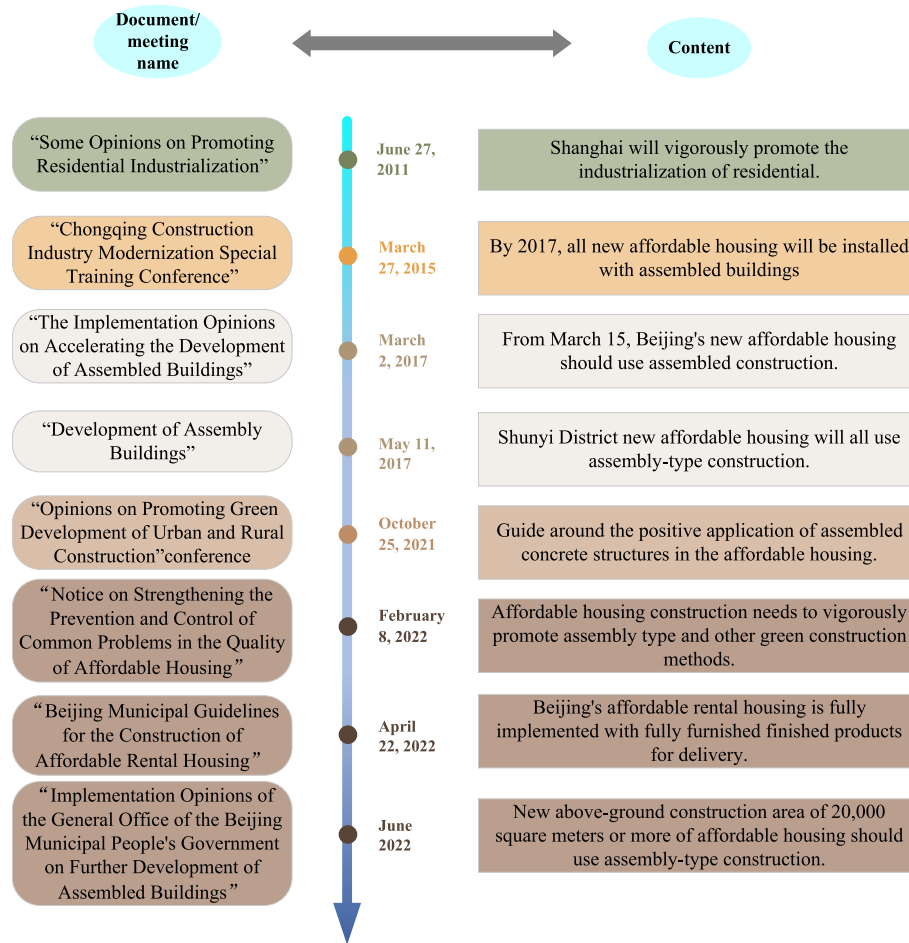


Fig. 7. Policies related to the combined development of assembly buildings and affordable housing (The summarized content information in this figure is derived from references of [Government, 2017](#); [Ministry of Housing and Construction, 2021](#))).

construction costs. These endeavors align seamlessly with China's residential construction strategy, characterized by land conservation, energy efficiency, and environmental sustainability ([Liu et al., 2010](#)). The specific outcomes of this promotion effects are outlined in [Table 5](#).

Assembly housing emerges as a formidable ally for propelling the sustainable expansion of affordable housing, addressing challenges related to cost-effectiveness, elevated quality standards, streamlined timelines, and ambitious objectives ([Wang, 2015](#)). The theoretical advantages of assembly building are significant, nevertheless, certain hindrances persist, including an incipient industrial chain, inadequate policy support, and challenges in policy implementation. Nevertheless, the strides taken in affordable housing initiatives have demonstrated a positive influence on the promotion and advancement of assembly building practices ([Zhang, 2012](#); [Chang et al., 2015](#); [Wang, 2015](#)). For a more comprehensive insight, please refer to [Fig. 8](#).

For affordable housing, the integration of assembly-type construction presents substantial development opportunities. During the "14th Five-Year Plan" period, China is poised to experience a marked upsurge in affordable housing construction. Integrating assembly building techniques into affordable housing projects not only enhances construction capacity and ensures project completion, but also reduces construction costs and effectively addresses the funding challenges faced by local governments amidst the widespread adoption of assembly building. This strategic alignment dovetails seamlessly with the "double carbon" goal, fast-tracking the trajectory of affordable housing construction while safeguarding construction quality and optimal living conditions. Affordable housing serves as an auspicious launchpad for propelling assembly buildings forward and provides a policy scaffold for

their enactment. Consequently, the combination of assembly building and affordable housing represents a significant opportunity within the ambit of affordable housing development.

4.3. Necessity and feasibility of assembly building to promote affordable housing

The construction industry, being one of the largest contributors to carbon emissions ([Lai et al., 2019](#)), plays a critical role in achieving the "double carbon" goal ([Liu et al., 2023a, 2023c](#); [Pan et al., 2023](#)). In recent years, there has been a strong emphasis on promoting green buildings in the construction industry to reduce carbon emissions ([Zuo and Zhao, 2014](#); [Xie et al., 2022a](#)). Numerous studies have focused on the development and evaluation of green buildings ([Qiu, 2012](#); [Zhang and Gu, 2012](#); [Qin et al., 2017](#); [GhaffarianHoseini et al., 2013](#)), which offer environmentally friendly, energy-efficient, and comfortable living environments that align with the objectives of the "double carbon" goal ([Liu et al., 2023d](#); [Zhou and Liu, 2023](#); [Xie et al., 2022b](#)).

Assembly building, boasting green advantages, swift construction timelines, economical costs, augmented value, and ease of upkeep and repair, has gained significant traction in promoting the development of green buildings. On June 30, 2016, the General Office of the State Council of China issued the "Guidance on Vigorously Developing Assembly Buildings," aiming to achieve a target of 30% of new construction area using assembly buildings within 10 years ([China C.P.s.G.o.t.P.s.R.o., 2016](#)). Building upon this objective, on June 30, 2022, the Ministry of Housing and Construction and the Development and Reform Commission released the "Implementation Plan for Carbon Emission

Table 5
Promotion mechanism of assembly building for the construction of affordable housing.

Index	Promotional role	References
Architectural design	The design facade of affordable housing is relatively simple, and the floor area and household type are basically fixed. The components of the assembly building are produced by industrialization with certain modules, and the assembly building is introduced into the construction of the affordable housing in China, which adapts to the requirements of the affordable housing construction.	Huang et al. (2012)
Engineering Quality	The quality of the components affects the quality of the housing to a certain extent. The components of the assembly building are processed in the factory and the precision can meet the factory acceptance standards. Applying the production method of assembly building to the construction of affordable housing can effectively solve the quality problems arising in the construction of affordable housing.	Huang et al. (2012); Chang et al. (2015)
Construction duration	The assembly building can shorten the time of on-site construction and accelerate the construction speed, as most of the components of assembly buildings are produced and finished in factories.	Zhang (2012); Chang et al. (2015)
Cost	The construction cost of assembly houses is higher than that of traditional construction methods now. But after the large-scale promotion and implementation, it can reduce the construction cost of affordable housing in general; the government's preferential policies for assembly buildings have increased, which also creates more space for the development of affordable housing.	Dong et al. (2018); Chang et al. (2015)
Resource and Environment	The assembly building can greatly reduce the burden on the environment during the building construction process. The construction process produces almost no dust, and the amount of cement mortar used on site is significantly reduced. The noise generated by on-site operations is significantly reduced; manual work and on-site wet work are reduced, and the amount of waste water is also significantly reduced.	Zhang (2012); Chang et al. (2015); Liu (2016)

Reduction in Urban and Rural Construction,” explicitly stating that the proportion of assembly buildings in new urban constructions should reach 40% by 2030 (China M.o.H.a.U.-R.D.o.t.P.s.R.o., 2022d).

In tandem with this, the construction of affordable housing assumes paramount significance for the government in its commitment to addressing livelihood challenges. Thus, within the ambit of the “double carbon” goal, the construction of affordable housing should consider the adoption of assembly building methods to provide low-carbon, environmentally friendly, comfortable, and healthy living environments for low-income individuals while meeting their housing requisites.

The integration of assembly building practices in affordable housing is a long-standing tradition, as exemplified by global examples like Singapore. The affordable housing landscape in Singapore encompasses public apartment flats and a limited number of low-cost housing units. The impetus for industrialized construction was launched in 1981, and presently, approximately 79% of Housing Development Board (HDB) flats are constructed using assembled technology (Ye and Chen, 2019). A similar trajectory was observed in Hong Kong Special Administrative Region (SAR) of China, where assembly buildings have been employed for affordable housing over an extended period. The Hong Kong government initiated a public housing program in 1953 to tackle escalating housing challenges (Ye and Chen, 2019). In 2002, assembled components accounted for roughly 17% of the total volume of reinforced concrete used in public housing construction (Chiang et al., 2006). This proportion surged to 65% by 2007, encompassing monolithic kitchens, bathrooms, and structural walls (Ye and Chen, 2019). In recent years, mainland China has introduced a series of policies advocating for the integration of assembly building techniques in affordable housing projects. This has borne fruit in regions like Beijing, Shanghai, Guangzhou, Shenzhen, Nanjing, Jinan, Tianjin, and Shenyang, where assembly building methods harmoniously melded with affordable housing endeavors to achieve energy-efficient, environmentally friendly, and comfortable buildings. Fig. 9 showcases examples of assembly affordable housing projects in select regions of China.

It is evident that certain regions in China have already embarked on the incorporation of assembly techniques in affordable housing projects, achieving commendable results with assembly rates scaling heights of 86% (Ji et al., 2015). These successful examples of assembly affordable housing serve as venlightening case studies for other locales eager to embark on similar trajectories. Based on current policy documents and real-world cases showcased, China has enthusiastically embraced the assimilation of assembly-type construction in affordable housing, injecting new vigor into the construction and advancement of assembly methods, especially considering the significant volume of affordable housing projects. The utilization of assembly techniques ensures the swift construction of affordable housing while concurrently promoting

environmentally friendly and healthy living environments. These observations crystallize the feasibility and necessity of synergizing assembly building with affordable housing initiatives.

5. Recommendations for implementing affordable housing

5.1. Recommendations to promote affordable housing policy implementation

Building upon the challenges and opportunities identified in the previous section regarding affordable housing construction, this section presents a set of policy recommendations. These recommendations are tailored to foster a sustainable and high-quality development of affordable housing, considering the viewpoints of local administrations, developers, and residents. They encompass various aspects, such as securing construction funding (Mao and Wang, 2012; Zou, 2014), strengthening incentives for local governments (Ma et al., 2018; Israel et al., 2003), enhancing the stability of local governments' financial resources (Mao and Wang, 2012), introducing the PPP model (Mao and Wang, 2012), requiring developers to share the burden of land supply (Zou, 2014), strengthening government intervention in policy (Ma et al., 2018), weakening local governments' reliance on urban land interests (Hu and Qian, 2017), considering spatial location (Zeng et al., 2019), and implementing other relevant measures (Fan and Zhang, 2014; Shi et al., 2016; Wei, 2018). Fig. 10 graphically outlines the specific recommendations for advancing affordable housing policy implementation, spotlighting the proposed strategies from the aforementioned vantage points.

5.2. Policy recommendations and paths for promoting the implementation of assembly buildings in affordable housing

Based on the preceding discussion, the integration of assembly building into affordable housing assumes pivotal significance within the ambit of “double carbon” goals. This mutualistic synergy ensures the triumphant realization, quality assurance, and swift execution of affordable housing ventures. This section presents a set of policy recommendations aimed at fostering the long-term and sustainable development of assembly affordable housing. These policy recommendations encompass six key areas: policy, technology, talent, market, management, and publicity.

In terms of policy, it is recommended to institute favorable fiscal and tax policies, refine preexisting policies, and elevate industry standards. Additionally, it is crucial to develop specialized technical systems (Ji et al., 2017; Deng, 2014), establish demonstration bases, and initiate pilot demonstration projects. Furthermore, enhancing the market

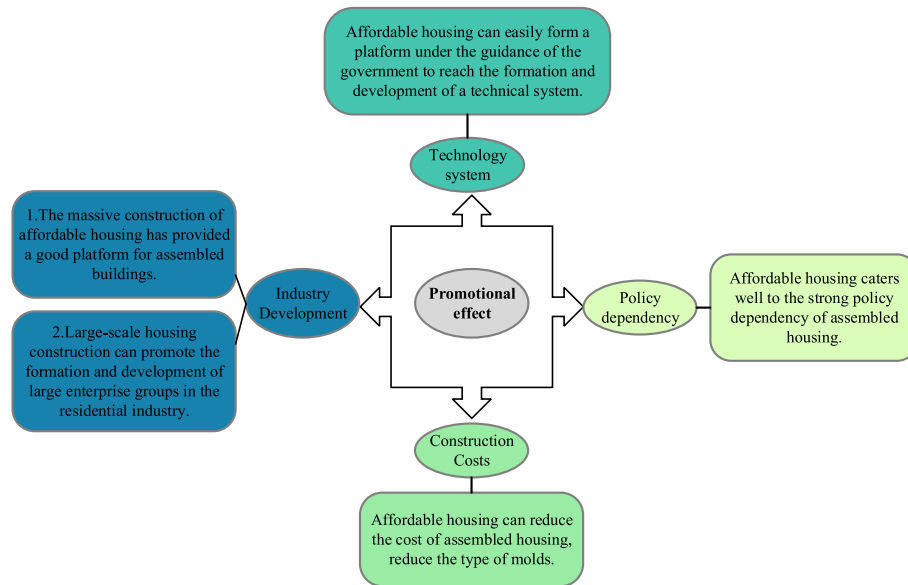


Fig. 8. The promotion of assembly buildings by affordable housing.

	Project Name	Project Profile
Beijing	Tongzhou Taihu Affordable Housing	The prefabrication rate is 42.76%~52.63%.
Guangzhou	Shi Feng Road Affordable Housing	Combining prefabricated components with cast-in-place concrete for some parts.
Shenzhen	Long Yueju Phase III Affordable Housing	China's first one-time development of industrialized affordable housing projects.
	Yujing Happy Home	It is the first pilot project of EPC general contracting for assembled affordable housing launched in Shenzhen.
	Changshen Project	The corresponding assembly building technology system according to different types and heights.
	Huaruncheng Runfu Phase III Project	The tallest assembled house currently under construction in Shenzhen.
Shanghai	Minhang Pujiang Township Base	Shanghai's first fully furnished assembled housing project.
	Rainbow Bay Affordable Housing Base Phase III Relocation Housing	Located in Hongkou District, Shanghai, with a 30% assembly rate.
Jinan	Qinghe-Xinju Affordable Housing	The prefabrication rate of the whole project reached 86%.
Nanjing	Qixia District Dingjiazhuang Phase II Affordable Housing	The pre-fabricated assembly rate has reached 67.5%, and the pre-fabricated concrete rate is over 30%.
Tianjin	Shuangqing New Home	Achieving a maximum prefabricated assembly rate of 80%.
Shenyang	Metro Lishui New Town Phase I (Public Housing)	Constructed with assembly technology.

Fig. 9. Assembly affordable housing projects in some regions of China (The summarized content information in this figure is derived from references of (Yin, 2015; Pan et al., 2020; Ye and Chen, 2019; Council, S.-o.A.S.a.A.C.o.t.S, 2023; Pan and Zhu, 2018; Ji et al., 2015; China, 2019; Peng et al., 2013)). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

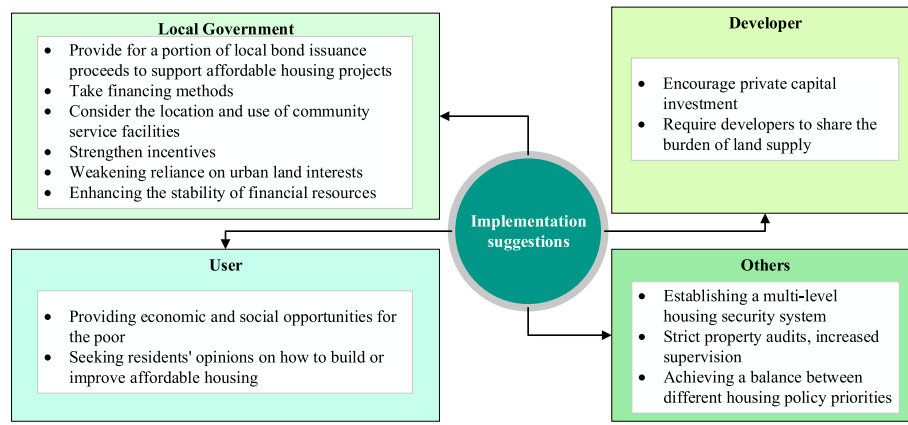


Fig. 10. Recommendations for the implementation of affordable housing policy promotion.

environment, adopting PPP management modes (Jiao et al., 2021), and introducing comprehensive talent development initiatives are imperative. Lastly, it is essential to strengthen public opinion guidance to create a positive narrative surrounding assembly affordable housing. Please refer to Fig. 11 for a holistic panorama of these policy recommendations, which serve as a valuable reference for the long-term and favorable development of assembly affordable housing.

The detailed implementation strategy for promoting assembly building in affordable housing is outlined as follows.

- 1) **Policy:** To effectively address housing challenges faced by middle and low-income families, the government has taken the initiative to construct affordable housing through assembly building methods. However, this approach initially raises construction costs and dampens industry engagement (Nasereddin et al., 2007). In response, the government should institute targeted economic incentives to encourage enterprise participation. Specifically, the government could offer financial and tax benefits to companies adopting assembly construction techniques. To foster developer and user involvement, incentive policies must be established. Furthermore, punitive measures should be defined in advance for companies failing to meet predetermined assembly building standards. Improvement of policies relating to supporting infrastructure for assembly affordable housing is also essential.
- 2) **Technology:** Improving standards and specialized technical systems is paramount. The standardized system is at the core of advancing assembly building construction and is a foundational guarantee for assembly affordable housing. This involves refining industry

standards for assembly construction and bolstering the technical framework for industrialized construction of affordable housing. These improvements encompass streamlining design processes, industrializing component production, integrating supporting facilities, and so on. It is also important to improve the overall standard system covering the entire process of planning, production, construction, and application of industrialized construction in affordable housing.

- 3) **Talent:** Establishing a talent recruitment system and importing expertise from developed countries or regions within China can address workforce shortages. Enterprises can cooperate with vocational colleges to cultivate professional and skilled talents. Additionally, reforms in the talent management system should be promoted to attract and retain talent in the assembly affordable housing sector.
- 4) **Market:** Strengthening quality supervision and review processes for assembly housing is vital. The implementation of a project evaluation and inspection mechanism guarantees adherence to quality benchmarks. Furthermore, implementing a robust government supervision system is necessary to monitor and regulate the market.
- 5) **Management mode:** Promoting the PPP management mode can address financing challenges by sharing risks between the government and private investors. This collaborative approach can facilitate the implementation of assembly affordable housing projects.
- 6) **Publicity:** Currently, assembly building techniques are not widely recognized by the public. To reshape traditional perceptions and foster a conducive market environment, government-led awareness campaigns are vital (Yang and Liu, 2018). Government initiatives

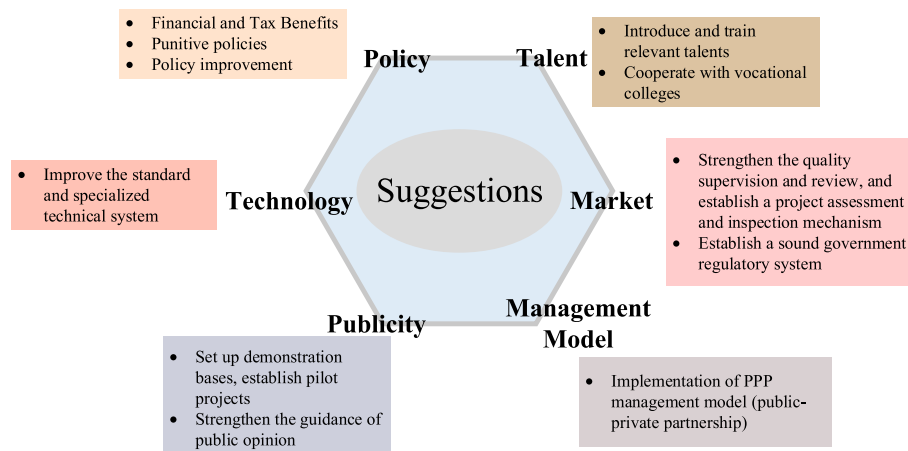


Fig. 11. Framework of policy proposals for the development of assembly affordable housing.

should include creating demonstration sites and launching pilot projects to showcase the benefits and effectiveness of assembly affordable housing. Additionally, proactive communication and public awareness campaigns should guide public opinion to cultivate a positive perception of assembly housing.

By following this comprehensive implementation strategy, the promotion of assembly building in affordable housing can be facilitated, leading to sustainable and high-quality development in this sector. The combination of supportive policies, technical advancements, skilled workforce, quality assurance, efficient management, and positive public perception will pave the way for the successful integration of assembly building in affordable housing projects across China.

6. Conclusions and future studies

This study underscores the imperative of embracing green and low-carbon development within China's affordable housing sector, considering the nation's substantial carbon emissions and global imperative to combat climate change. Despite the growing attention towards affordable housing, there remains a scarcity of studies specifically analyzing the policy development trends, challenges, and opportunities in China's affordable housing, particularly concerning assembly affordable housing. The principal findings of this study can be summarized as follows.

- 1) The paper delves into the historical development of China's affordable housing policy and succinctly outlines the contemporary status of such policies across distinct time periods. A recurring concern noted across diverse cities pertains to the suboptimal location of affordable housing, which carries the potential to engender issues like social segregation and broader societal challenges.
- 2) A multitude of challenges have been pinpointed in the pursuit of promoting affordable housing policies. These hurdles encompass discord between central and local governments, inadequacies in access mechanisms, the absence of robust auditing processes, disruptions in the construction and allocation of affordable housing, undue dependence on local government funding, and the remote siting of housing projects.
- 3) Recent national-level policies and directives have been introduced to stimulate affordable housing development, and various regions have taken measures to align with these mandates. The emergence of assembly building techniques introduces avenues for affordable housing development, entailing substantial benefits for the sector.
- 4) The pertinent policies associated with assembly building in the context of affordable housing have been meticulously dissected and analyzed. The implementation status of extant policies related to assembly affordable housing has been critically appraised, and current instances of assembly affordable housing within specific regions of China have been summarized and evaluated.
- 5) Building on the foundation of ongoing affordable housing development and the thrust towards assembly building, this study furnishes practical suggestions for the execution of affordable housing initiatives in China. Additionally, policy recommendations are proffered to galvanize the industrialized construction of affordable housing.

This study constitutes a meaningful contribution towards comprehending China's affordable housing policies, addressing the stumbling blocks encountered in its evolution, and presenting viable strategies for enhancement. It underscores the potential of assembly building in the affordable housing domain and furnishes policy insights for its future progression. Future research avenues should delve deeper into the perspectives of varied stakeholders, including governmental bodies, developers, and residents, to grasp the motivations and obstacles inherent in affordable housing construction. A deeper exploration into the technical intricacies of prefabricated affordable housing construction, combined with diverse research methodologies, could refine the formulation

of policy measures to promote its development. Moreover, strategies for the optimal siting of affordable housing, such as integrating these communities with commercial housing, could foster harmonious living environments. Conducting a comprehensive evaluation of the socio-economic advantages of assembly affordable housing, encompassing factors like cost-efficiency, societal and economic benefits, can furnish a scientific foundation for governmental decision-making. The incorporation of theoretical frameworks like transaction cost theory or dynamic game evolution could further enrich the analysis and promotion of assembly affordable housing within the complex interplay of distinct stakeholders. Addressing these research gaps will steer China's affordable housing sector towards a sustainable and environmentally conscious trajectory, aligned with the global drive towards carbon neutrality.

Credit author statement

Guoqiang Zhang: Formal analysis; Investigation; Methodology; Writing - original draft; Writing - review & editing. Keyi Xu: Investigation; Methodology; Writing - original draft; Writing - review & editing. Zhengxuan Liu: Conceptualization; Formal analysis; Investigation; Methodology; Resources; Supervision; Writing - original draft; Writing - review & editing. Ruopeng Huang: Investigation; Methodology; Roles/Writing - original draft; Writing - review & editing. Bo Li: Investigation; Methodology; Roles/Writing - original draft; Writing - review & editing. Ran Wang: Investigation; Methodology; Resources; Roles/Writing - original draft; Writing - review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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