Exploring spatial heterogeneity and factors influencing construction and demolition waste in China

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Abstract
Natural disasters, new urbanization, and urban renewal activities generated a large amount of construction and demolition waste (C&DW), and managing C&DW has become an urgent problem to be solved in the construction of “Zero-waste cities.” Based on the calculation of C&DW generation in China from 2005 to 2019, this study explored spatial heterogeneity and factors influencing C&DW in China by Exploratory Spatial Data Analysis (ESDA) and Geographically Weighted Regression (GWR) method. The results showed that C&DW generation in China increased every year, and the overall distribution was characterized as “high in the east and low in the west,” with distinct regional differences. The generation intensity of C&DW in China showed a decreasing trend every year. The regions with rapid growth of C&DW generation were concentrated in the eastern coastal areas, and there was significant spatial heterogeneity in the growth trend. There is a significant spatial autocorrelation in C&DW generation in China. The factors of population size, per capita gross domestic product, and the scale of the construction industry played a positive role in promoting C&DW generation in each province, whereas labor efficiency played a negative role inhibiting C&DW generation, which has a significant temporal and spatial heterogeneity. The results extend C&DW management theory and help the policy maker to formulate regional differentiation policies as China and developing country.

Keywords Construction and demolition waste · Slope value · ESDA method · GWR model · STIRPAT model

Introduction
In recent years, with the promotion of new urbanization and urban renewal activities, as well as the impact of natural disasters such as earthquakes, C&DW generation has increased. The annual C&DW generation worldwide is approximately 3 billion tons (Akhtar and Sarmah 2018). It was estimated that the total amount of C&DW generated in China every year was approximately 2 billion tons, accounting for approximately 30 ~ 40% of the total amount of urban waste, and the environmental problem of C&DW has become increasingly prominent (Wang et al. 2021a, b, c). Recycling of C&DW was the key to solving this problem (Liu et al. 2020). At present, the recycling rate of C&DW in China is still less than 5% (NDRC 2014), and C&DW generation is increasing year by year. The Chinese government proposed “strengthening the disposal of solid waste and C&DW,” and the reduction management of C&DW is highly important (Wang et al. 2021a). Reducing greenhouse gas emissions and reducing the growth rate of global warming has become a common goal in all countries (Khan 2019). China has become the country with the largest CO2 emissions and has been in a period of rapid industrialization and urbanization, which led to an increase in CO2 emissions (Guo et al. 2019). The implementation of C&DW reduction management and the reduction of CO2 emissions from the construction industry have become the focus of the international community (Hossain et al. 2017; Lv et al. 2020). To reduce C&DW generation, it was necessary to clarify the spatial heterogeneity and influence of various factors on C&DW generation, to provide a basis for designating scientific and
reasonable waste generation reduction policies. The spatial and temporal distribution of C&DW generation and its influencing factors are important issues in the management of C&DW reduction. How to identify regional differences in the degree of influence of individual factors on C&DW and then proposed differential regional reduction measures and collaborative regional reduction strategies is an urgent problem requiring attention in current C&DW management (C&DWM). The reduction management of C&DW has been widely studied (Duran et al. 2006; Li et al. 2020; Yuan et al. 2012; Zheng et al. 2017). In existing studies, research on influencing factors was mostly conducted from an overall perspective (Ding and Xiao 2014; Wu et al. 2019; Ye and Yuan 2014), ignoring the spatial heterogeneity of the factors influencing regional C&DW generation. However, China is a vast territory, and there were significant differences in social and economic development, population distribution, and natural conditions among different provinces. C&DW generation exhibited strong spatial differences. For example, Zhao et al. (2013) investigated the annual generation of C&DW in Beijing, Shanghai, and Shenzhen and found that the production of C&DW was higher than the national average in all three. Wang et al. (2021a) found that the proportion of C&DW generation in eastern China was the largest, while that in northeast China was the smallest. Therefore, exploring the spatial heterogeneity and factors influencing C&DW is key issue. In the past, the management of C&DW was primarily concentrated in projects and individual areas and did not consider the spatial differences in C&DW (Wang et al. 2021a; Zhang 2016). The research on influencing factors assumes that the variables are independent and homogeneous in geographical space, and the spatial heterogeneity has not been deeply studied.

To compensate for these limitations, this study used a GWR model to explore the influence intensity and direction of each factor on C&DW generation in different provinces in China and revealed the spatial heterogeneity of the influencing factors to provide a reference for the government to formulate targeted and differentiated C&DW reduction management countermeasures based on identifying the leading factors driving regional C&DW pollution and indirectly reducing carbon emissions. Moreover, new strategies could protect the ecology and promote economic development, which is of great significance to the development of a circular economy and sustainable development of the construction industry. The results may aid in formulating more targeted and effective policies for the mitigation of C&DW generation in the construction industry. It can provide the basis for the construction and governance of regional “zero-waste cities,” offer a reference for enterprise investors and enterprise development planning, and improve and further promote the theory of C&DW reduction management as China and developing country.

This paper contains five parts. After the introduction part was the literature review section, primarily introduces the research progress of construction waste reduction management. The third part includes the research plan, data sources, and analysis methods, whereas the fourth part is an empirical analysis and the fifth part presents the conclusion and countermeasures.

### Literature review

The reduction management of C&DW has been widely studied and related research can be summarized as follows.

### Measurement of C&DW generation

To reduce the harm caused by C&DW, it was necessary to consider C&DW generation in each province of China. At present, many scholars at home and abroad have studied the calculation of C&DW generation. Bernardo et al. (2016), to accurately calculate C&DW generation in a specific area, established relationships that could be used to determine the C&DW generation in a given area using the data collected from real demolition works and the statistical information of the studied geographical area and provided and explained the derived model. This model can be applied to any region of the world. Ding and Xiao (2014) proposed a method for estimating the amount and composition of C&DW, taking into account the impact of building design and structure codes in different decades on the types of building structures and the intensity of C&DW, and the analysis in this study can be applied to promote the responsibility of C&DW managers and researchers to formulate accurate policies and specifications. To accurately estimate the amount of residential C&DW, Maués et al. (2020) established a C&DW generation estimation model based on fuzzy set theory and assessed 23 residential buildings constructed in the Brazilian Amazon as a case study to further verify the accuracy of the model. Lam et al. (2019) provided a comprehensive and practical approach to estimate the C&DW of building projects after detailed design of new buildings or major retrofitting works, according to the actual design information provided by the tender or contract documentation of the project at the upstream stage. Li et al. (2015) used the area estimation method to analyze the temporal and spatial variation characteristics of C&DW generation from 1995 to 2013.

### Factors influencing of C&DW generation

The composition of C&DW is relatively complex, and there are many internal and external factors that affect C&DW
generation. The internal factors of the building are primarily the type of building structure, building area, and use type (residential or commercial). The external factors of construction primarily include the influence of population size, economic development, construction technology, construction scheme, construction management, and other technical levels (Nixon et al., 1997). Through an extensive literature review, Luangcharoenrat et al. (2019) found that C&DW had the following causes: design change, inattentive working attitudes and behaviors, ineffective planning and scheduling, and material storage, which was helpful for industry stakeholders in building suitable strategies to manage C&DW more effectively. Due to the shortage of houses in India, Patil and Manjarekar (2021) proposed a technology to reduce C&DW generation, define the C&DW and its types, and identify the causative factors responsible for C&DW generation and its common sources. By reviewing different case studies and papers and carrying out surveys, it was found that the most important factors contributing to C&DW were frequent design changes, wrong material storage, workers’ mistakes, waste management plans, procurement, and the effect of weather. Liu et al. (2020) believed that there were many factors leading to C&DW generation, and it was necessary to identify the key factors and analyze their importance. After analyzing the formation mechanism of various indicators involved in the literature review, the theoretical hypothesis was tested using the questionnaire survey data and structural equation modeling (SEM). It was found that, in incentive policies and source plans for C&DWM, the nine key factors that have positive and significant impacts on the reduction of C&DW were professional ethics of stakeholders, waste management behavior, waste sustainability, government subsidy, construction contract, construction material transportation, construction material site management planning, construction material storage, and construction site operation.

**Policies of C&DW reduction management**

At present, research on C&DW treatment technology at home and abroad had been relatively mature. Through the research on reverse logistics in the construction industry, relevant scholars have provided a model that can effectively recycle C&DW for the location planning and capacity expansion planning of C&DW treatment plants, and this model has been used in many research fields to study the variation in the degree of influence of variables in different regions. Zhang et al. (2020) used a spatial econometric model and GWR model to evaluate the spatial spillover effects of inter-provincial wastewater discharge from 2004 to 2015 and identified the driving forces of inter-provincial wastewater discharge. Zhou et al. (2019) combined the stochastic impacts by regression on population, affluence, and technology (STIRPAT) model and environmental Kuznets curve hypothesis and used a GWR model to evaluate the influence of different factors on haze pollution in different regions. Dziauddin (2019) used GWR to explain spatial heterogeneity and spatial dependence, and the results provided spatial variation information about the impact of a light rail transit system on residential property values. Trigueiro et al. (2020) believed that deforestation has a strong spatial structure,
resulting in different effects of drivers on deforestation in different regions. Hosseinzadeh et al. (2021) used GWR to explore how factors related to demographics, density, diversity, design, urbanism scores, distance to transit, and other transportation-related variables influence e-scooter trips in Louisville, KY, and the findings can help governments and e-scooter sharing companies develop policies to maximize e-scooter use, equity, and accessibility, while improving the mobility in cities. However, current research on C&DW reduction ignores the spatial heterogeneity of the distribution of construction waste generation.

From the above analysis, the research on C&DW generation management has primarily focused on the measurement and generation reduction management of C&DW generation, but there is a lack of research on the spatial heterogeneity of C&DW generation. Starting from the spatial heterogeneity of C&DW generation, this study used exploratory spatial data analysis (ESDA) to study the spatial distribution characteristics of C&DW generation and used GWR method to establish the relevant GWR model to study the differences in the degree of influence of various factors on C&DW generation in different regions to provide differentiated C&DW reduction management strategies for various provinces in China. The results can effectively help China’s provinces formulate differentiated generation reduction strategies and governance policies. It is an important reference for China’s ecological civilization construction and “zero-waste cities” governance in the new era.

Methodology

Research design

The study was divided into four steps. The first step was to use the area estimation method to calculate C&DW generation. The second step was to calculate Slope value and analyze the development trend of C&DW generation differences among different regions in China. The third step was to study the spatial agglomeration type of C&DW using the ESDA. The fourth step was to study the spatial consistency of the influencing factors of C&DW generation based on the STIRPAT analysis framework and GWR analysis method. The specific research framework is illustrated in Fig. 1.

Calculation of C&DW

At present, there are a lack of consensus on the definition and relevant statistical data on the accounting of C&DW. Methods such as material flow analysis, unit output, and field investigation methods are generally used to estimate C&DW generation (Li and Zhang 2013; Wu et al. 2019). In this investigation, C&DW can be divided into construction waste (CW), renovation waste (RW), and demolition waste (DW), based on the generation phase and previous studies (Yuan 2013). Thus, the C&DW generation in China and all provinces from 2005 to 2019 were calculated by the area estimation method (Li et al. 2016; Wang et al. 2021a). The specific calculation formula is as follows:

\[ q = m_1 \times i_1 + m_2 \times i_2 + m_3 \times i_3 \] (1)
where \( q \) is the annual C&DW generation in China; \( m_1 \), \( m_2 \), and \( m_3 \) are the annual construction area (m\(^2\)), demolition area (m\(^2\)), and decoration area (m\(^2\)) of the building, respectively; \( i_1 \), \( i_2 \), and \( i_3 \) refer to the generation amount of C&DW per unit area in the process of construction, demolition, and decoration, respectively. The generation amount of construction waste per unit construction area, demolition area, and decoration area were 550t/ten thousand m\(^2\), 1.3t/m\(^2\), and 0.1t/m\(^2\), respectively (Li et al. 2015; Wang et al. 2021a, b).

**Slope analysis**

To show the changing trend of C&DW generation in China’s provinces, this study used the C&DW generation data for each year to calculate the slope value of inter-provincial C&DW generation from 2005 to 2019. The calculation formula is as follows (Gao et al. 2021):

\[
Slope = \frac{n \times \sum_{i=1}^{n} x_i L_i - \sum_{i=1}^{n} x_i \sum_{i=1}^{n} L_i}{n \times \sum_{i=1}^{n} x_i^2 - (\sum_{i=1}^{n} x_i)^2} \tag{2}
\]

where \( n \) represents the total number of years from 2005 to 2019, which was 15; \( x_i \) is the year \( i \) (2005 was the first year), and \( L_i \) represents the corresponding C&DW generation in year \( i \). If \( Slope > 0 \), it indicates that the C&DW generation showed an increasing trend with the increase in time; if \( Slope < 0 \), C&DW generation showed a decreasing trend. The size of the slope reflects the rate of increase or decrease of C&DW generation, the tendency degree of increase or decrease. To classify the growth rate in C&DW generation, the growth trend of C&DW generation in each province was divided into four types by standard deviation classification (Table 1).

**ESDA method**

The ESDA method combines statistical principles and forms such as graphs and charts to describe and visualize the spatial distribution characteristics of research variables and detect spatial agglomeration and spatial anomalies (Wan and Su 2017; Sun and Wang 2021). It shows the spatial interaction mechanism of the research objects. The core of the technology lies in the measurement of spatial autocorrelation, including global spatial autocorrelation and local spatial autocorrelation.

1. **Global spatial autocorrelation**
   Global spatial autocorrelation was used to describe the overall spatial distribution characteristics of the research variables in the region and determine their spatial aggregation degree. It is commonly measured using the global Moran’s I index. The calculation formula is as follows:
   \[
   I = \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} w_{ij}(x_i - \bar{x})(x_j - \bar{x})}{S^2 \sum_{i=1}^{n} \sum_{j=1}^{n} w_{ij}} \tag{3}
   \]
   where \( S^2 = \frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n} \) is the sample variance, \( n \) is the number of spatial units in the study area, \( x_i \) is the observed value of area \( i \), \( \bar{x} \) is the average of the observed values, and \( w_{ij} \) is the spatial weight matrix. If spatial unit \( i \) is adjacent to spatial unit \( j \), \( w_{ij} = 1 \), otherwise, \( w_{ij} = 0 \). In this study, \( n = 30 \), \( w_{ij} \) is a first-order spatial weight matrix generated based on the Queen standard. The value range of the global Moran’s I index was between \([-1, 1]\). If Moran’s \( I > 0 \), there is positive spatial autocorrelation. The larger the value, the higher the degree of agglomeration of regions with similar observed values. When Moran’s \( I < 0 \), there is a negative spatial autocorrelation, and the smaller the value, the higher the degree of agglomeration of regions with different observed values. If Moran’s \( I = 0 \), the space is randomly distributed, and the observed values were independent of each other (Sun and Wang 2021).

2. **Local spatial autocorrelation**
   The global Moran’s I index can only reflect the spatial distribution characteristics of variables in the region as a whole, but cannot represent the spatial dependence of local regions. To measure the degree and significance of the spatial differences between a certain region and its surrounding areas, Anselin proposed the local spatial autocorrelation method to calculate the local Moran’s I index and intuitively displayed it in the form of a Moran scatter diagram to study the local spatial distribution. The formula for calculating local Moran’s I is as follows:
   \[
   I_i = \frac{(x_i - \bar{x})}{S^2} \sum_{j=1}^{n} w_{ij}(x_j - \bar{x}) \tag{4}
   \]
   The meanings of the indicators were the same as above.

**GWR method**

GWR is a commonly used model in the study of spatial heterogeneity, which can introduce the geographical location of
the research area into the regression parameters, and conduct local regression estimation by assigning different weights to sample points (Yang et al. 2021; Han et al. 2021). In other words, the regression parameters change with different geographical locations, which overcomes the defects of OLS in estimating regression coefficients based on the mean value of regional variables and ignoring spatial effects. The model form was set as follows:

$$y_i = \beta_0(u_i, v_i) + \sum_{k} \beta_k(u_i, v_i)x_{ik} + \epsilon_i \quad (5)$$

In Eq. (5), $\left(u_i, v_i\right)$ is the geographic center coordinate of the i-th sample point, $y_i$ is the dependent variable value at the geographic location $\left(u_i, v_i\right)$, $\beta_0(u_i, v_i)$ is the constant value at the geographic location $\left(u_i, v_i\right)$, $\beta_k(u_i, v_i)$ is the value of the function $\beta_k(u, v)$ in the location of the sample space $i$, $k$ is the number of independent variables, and $\epsilon_i$ is the spatial random residual.

**Index selection of influencing factors on C&DW**

The IPAT equation is a well-known formula for assessing environmental pressure, showing that environmental impacts are the result of factors such as population, affluence, and technology (Ehrlich and Holdren 1971). However, the IPAT equation only considers a limited number of variables. To overcome this shortcoming, Dietz and Rosa (1994) developed the STIRPAT model. Since the STIRPAT model allowed for further addition of factors, it was often used to explore multiple drivers of environmental pressure, which can be extended to various factors such as resource structure, cultural background, government type, and consumption concept (Vélez-Henao et al. 2019). Based on the existing research, this paper introduces the factors related to the social economy and natural environment, constructed the influence index system of C&DW in China, and analyzed its important influence on C&DW generation.

To study the factors influencing C&DW generation and regional differences in the degree of influence, under the framework of the STIRPAT model, this study adopted the GWR method, selected the C&DW generation of each province as the dependent variable, and considered the population size (POP) (Sadorsky 2008), per capita GDP (PGDP) (Mazzanti and Zoboli 2009a, b), efficiency of labor (EL) (Wang et al. 2021a), and scale of construction industry (SC) (Wang et al. 2021a, b, c) as the independent variables. The population size is the total population of each province at the end of the year, ten thousand people; the PGDP is the ratio of the GDP of each province to the total population at the end of the year, yuan per person; the labor efficiency is the ratio of the GDP of each province’s construction industry to the number of employees in the construction industry, yuan per person; the scale of the construction industry was the ratio of the GDP of each province’s construction industry to the GDP of each province. All variables were normalized to construct a GWR model in the following form:

$$C&DW = aPOP + bPGDP + cEL + dSC + \epsilon_i \quad (6)$$

**Data sources and regional division**

The research object of this study was the C&DW generation of 30 provinces in China from 2005 to 2019. Tibet, Hong Kong, Macao, and Taiwan were not considered because of the lack of data in the yearbooks. The data required for the study, such as the area covered by the construction industry, the GDP of the construction industry, and the number of employees, were obtained from the China Statistical Yearbook on Construction in the corresponding year, and the GDP, population at the end of the year, and PGDP of each province were obtained from the China Statistical Yearbook.

**Results and discussion**

**C&DW generation results**

From 2005 to 2019, C&DW generation in China showed an increasing trend, with significant regional differences. The overall distribution showed the characteristics of “high in the east and low in the west” as shown in Fig. 2. C&DW generation in 2005 was 561.91 million tons, increasing to 2134.87 million tons in 2019, with an average annual growth rate of 10%. Provinces that generated more C&DW were mostly concentrated in coastal areas in southeast China, such as Shandong, Jiangsu, Zhejiang, Fujian, and Guangdong. This was primarily because there were differences in population size and economic development basis in different provinces, which led to different growth rates of C&DW generation. Coastal areas had superior geographical location, convenient transportation, rapid economic development, large population density and high urbanization rate, and C&DW generation also increased. As shown in Fig. 2, Jiangsu and Zhejiang provinces were in the leading position with respect to C&DW generation. These provinces were located in the Yangtze River Delta region, with rapid economic development, strong urban innovation vitality, and increasing population inflow. All these factors led to an increase in C&DW generation. From 2007 to 2017, with the continuous promotion of the overall strategy of regional development, the location of China’s economic industries showed an overall trend of transferring from the east to the central and western regions (Wang and He 2020), and the share of C&DW generation in the central region also increased.
Fig. 2 Distribution map of China's inter-provincial C&DW generation in representative year (ten thousand tons)
Most of the C&DW generated in the northern inland regions was at a relatively low level, and C&DW generation in Liaoning province has shown a downward trend since 2014. The transportation in these areas was inconvenient, and the population size was relatively small; in particular, the population in northeast China had a negative growth (Liu et al. 2020), and C&DW generation was low, and the change range of each year was small.

The per capita C&DW generation in China’s provinces from 2005 to 2019 is shown in Table 2. It can be seen from Table 2 that the change trend of per capita generation was consistent with that of C&DW generation. The provinces with higher per capita C&DW generation were Zhejiang, Jiangsu, Beijing, Shanghai, and Fujian. Among them, the per capita C&DW generation in Jiangsu and Zhejiang was high, and the pressure of C&DW generation reduction was large. While maintaining the steady development of the construction industry, the local government should take measures to slow down C&DW generation, strengthen the construction and management of waste recycling, and reduce C&DW generation. The per capita generation of Hainan, Heilongjiang and Qinghai provinces was relatively low. While developing the economy, C&DW should be properly treated to avoid environmental damage.

Guangdong, Shandong, Henan, and other provinces had a large population, and their C&DW generation was in the forefront among Chinese provinces, but the per capita C&DW generation was not prominent. Guangdong province had superior geographical location and rapid economic development. Since 2009, the population of Guangdong Province has reached 100 million, and the per capita annual C&DW generation has been less than 1 ton/person, ranking 16th in China. In the process of rapid economic development, Guangdong Province focused on the reduction management of C&DW (Wu et al. 2016). To weaken the negative impact of C&DW on economic and social development,
local governments should formulate appropriate management plans according to the local population and economic development, strengthen the reduction management of C&DW, and promote the recycling of construction waste.

Table 3 shows the calculation results of the construction waste generation intensity of China’s provinces from 2005 to 2019. It can be seen that with the annual increase in the output value of China’s construction industry, the C&DW generation intensity showed a downward trend year by year, indicating that with rapid economic development, the level of green building technology has improved. In 2005, the C&DW generation intensity in Jiangxi, Guangxi, and Chongqing exceeded 2 tons/ten thousand CNY. The C&DW generation of the three provinces was not among the top in China, but the output value of the construction industry was low, resulting in high C&DW generation intensity. From 2005 to 2019, the C&DW generation intensity in Hainan, Jilin, and Inner Mongolia fluctuated, which was due to the excessive real estate investment in these provinces and the large C&DW generation. To steadily develop the economy and construction industry of the provinces, the supervision of C&DW generation cannot be ignored at any time. With the strengthening of economic cooperation among provinces, the gap in inter-provincial generation intensity continued to decrease. By 2019, except for Jiangsu and Zhejiang, the C&DW generation intensity in other provinces did not exceed 1 ton/ten thousand CNY. There was a certain gap in the total output value of the construction industry in other provinces, while the generation intensity values were mostly concentrated in the range of 0.4 – 1 ton/ten thousand CNY. Although Jiangsu and Zhejiang had high generation, the output value of their construction industry was twice as much as that of other provinces.
which maintained the steady decline in the generation intensity, reaching about 1.2 tons/ten thousand CNY in 2019. It can be seen that although these provinces had a high level of construction industry development, they had also effectively controlled the C&DW generation. Guangdong, Fujian, and Beijing had high output value and generation intensity of the construction industry at the same time, because these provinces were located in the southeastern coastal area of China; rapid economic development promoted the development of the construction industry and produced a certain amount of C&DW generation at the same time. The output value of the construction industry in Qinghai, Heilongjiang, and Tianjin was relatively low, and the generation intensity was also relatively low, indicating that the construction industry in these provinces had ample development space, and funds should be invested to expand the scale of the construction industry. In Hainan, Gansu, and Inner Mongolia, the C&DW generation and output value of the construction industry were both low, but the generation intensity was close to 1 ton/ten thousand CNY. It can be seen that the development speed of Hainan, Gansu, and Inner Mongolia was vulnerable to the impact of C&DW generation when the production capacity was low; therefore, measures should be taken to improve and control this in a timely manner. It can be seen that compared with 2005, the macro-control of the Chinese government played a leading role in promoting the development of the construction industry in all provinces and also affected the control of C&DW generation.

Table 4  Slope values and change trend types of provinces

| Province       | Slope value | Growth type    | Province       | Slope value | Growth type    | Province       | Slope value | Growth type |
|---------------|-------------|----------------|---------------|-------------|----------------|---------------|-------------|-------------|
| Beijing       | 669.57      | Fast growth type| Zhejiang      | 1559.27     | Rapid growth type| Hainan        | 17.54       | Slow growth type |
| Tianjin       | 131.65      | Slow growth type | Anhui         | 441.13      | Medium growth type| Chongqing     | 308.43      | Slow growth type |
| Hebei         | 287.75      | Medium growth type | Fujian        | 728.01      | Fast growth type | Sichuan       | 543.59      | Medium growth type |
| Shanxi        | 146.97      | Slow growth type | Jiangxi       | 343.63      | Medium growth type| Guizhou       | 184.98      | Medium growth type |
| Inner Mongolia| 15.66       | Slow growth type | Shandong      | 625.28      | Medium growth type| Yunnan        | 178.67      | Medium growth type |
| Liaoning      | 74.89       | Slow growth type | Henan         | 597.30      | Medium growth type| Shaanxi       | 308.74      | Medium growth type |
| Jilin         | 78.72       | Slow growth type | Hubei         | 954.89      | Fast growth type | Gansu         | 97.57       | Slow growth type |
| Heilongjiang  | -8.26       | Slow growth type | Hunan         | 555.30      | Medium growth type| Qinghai       | 7.48        | Slow growth type |
| Shanghai      | 350.92      | Medium growth type | Guangdong     | 522.00      | Medium growth type| Ningxia       | 17.50       | Slow growth type |
| Jiangsu       | 2317.02     | Rapid growth type | Guangxi       | 272.91      | Medium growth type| Xinjiang      | 92.16       | Slow growth type |

Formula (2) was used for calculation, and the slope value and corresponding growth trend types of each province are as follows (Wang et al. 2015).

It can be seen from Table 4 that the growth trend of C&DW generation in Jiangsu and Zhejiang was the most rapid. The growth rates of Beijing, Fujian, and Hubei were also relatively fast, and there were many provinces with medium and slow growth. The C&DW generation in Jiangsu and Zhejiang has been in the forefront of China over the years. The rapid development of the construction industry in Jiangsu and Zhejiang has led to a rapid increase in C&DW generation. Although the C&DW generation in Beijing and Fujian was higher than that in China, it was not very prominent. The rapid growth of C&DW generation indicates that measures should be taken to slow down C&DW generation. The economy and construction industry in Hebei, Anhui, Shandong, and Guangdong provinces were developing at a medium speed, and there was room for improvement. The growth rate of C&DW generation was at a medium level, which could be effectively treated in time. The development of the construction industry in Qinghai, Ningxia, Hainan, and Heilongjiang was relatively slow, and the C&DW was low, and the change trend was also very small. Overall, the growth rate of China’s C&DW generation has been well controlled. Most of the regions with fast and rapid growth in China’s C&DW generation were concentrated on the eastern coast, with distinct differences between the east and the west, and there was great spatial heterogeneity in the growth trend.
**ESDA of C&DW generation**

**Global spatial autocorrelation analysis**

The global spatial autocorrelation analysis was conducted for the C&DW generation of provinces in China from 2005 to 2019, and the calculated Moran’s I index and the corresponding p value and Z-score are shown in Table 5. It can be seen from the table that the Moran’s I index of C&DW generation in each year was significantly positive, and the p value passed the significance test with a significance level of 5%. China’s C&DW generation showed a spatially positive correlation trend. The C&DW generation in each province was affected not only by local factors, but also by adjacent areas. The C&DW generation was spatially correlated.

From 2005 to 2011, the Moran’s I index fluctuated up and down, reaching its lowest value in 2013. Since 2014, Moran’s I index has shown a distinct upward trend. Overall, the global Moran’s I index of C&DW generation showed a trend of fluctuation first and then a continuous rise during the sample investigation period, and the agglomeration characteristics of C&DW generation fluctuated. After 2016, the agglomeration characteristics of C&DW generation increased year by year, and the C&DW generation had a strong spatial correlation.

**Local spatial autocorrelation analysis**

The global Moran’s I index can only describe the overall spatial agglomeration of a certain phenomenon in a region, but cannot analyze the spatial autocorrelation and specific agglomeration location of each individual. To further study the spatial correlation of C&DW generation between China’s provinces and surrounding provinces, the local spatial autocorrelation Moran’s I index was used for analysis, as shown in Fig. 3.

In the Moran scatter diagram, the central province and its adjacent provinces in the first quadrant (HH) had high C&DW generation. In the second quadrant (LH), the central province had low C&DW generation, whereas its adjacent provinces had high C&DW generation. In the third quadrant (LL), the central province and adjacent provinces had low C&DW generation. In the fourth quadrant (HL), the central province had a high C&DW generation, while its adjacent provinces had a low generation. Among them, the provincial C&DW generation in the first and third quadrants showed a strong spatial positive correlation, i.e., homogeneity. In the second and fourth quadrants, there was a strong negative correlation, i.e., heterogeneity. The provinces in the four quadrants are summarized as follows (Table 6):

In the quadrant distribution of each year, the number of provinces in the third quadrant was the largest, accounting for approximately 50% of the total number of provinces. Among them, Heilongjiang, Inner Mongolia, Jilin, Shanxi, Qinghai, and other provinces have long shown the characteristics of low-low agglomeration. Most of them are located in the northern and central regions of China and do not have strong geographical advantages. These provinces rarely communicated or cooperated with the surrounding provinces in the development of the construction industry, resulting in low generation from themselves and nearby regions. Jiangsu, Zhejiang, and Shandong were the top three provinces in C&DW generation in China and have been in the first quadrant for a long time, indicating that while their construction industry is developing rapidly, they have effectively driven the development of the construction industry in surrounding provinces, resulting in generation in their own and neighboring provinces. Urbanization has promoted urban construction and increased carbon emissions from the construction industry. The siphon effect of population in eastern China was significant, and the increase in population propelled the demand for a large number of construction industries, which intensified the C&DW generation. Beijing, Sichuan, and Guangdong in the fourth quadrant were the provinces with high generation, and there was ample scope for the development of the construction industry in the surrounding provinces. Based on their development in the construction industry, these provinces can lead nearby provinces to expand the scale of the construction industry together. Tianjin, Jiangxi, Shanghai, and other provinces have long shown the characteristics of low–high agglomeration. These provinces can take advantage of the relatively developed construction industry of surrounding provinces and actively participate in inter-provincial cooperation to accelerate their own economic construction and the development of the construction

| Year | Moran’s I | p value | Z-score |
|------|-----------|---------|---------|
| 2005 | 0.270     | 0.004   | 2.849   |
| 2006 | 0.288     | 0.002   | 3.039   |
| 2007 | 0.275     | 0.003   | 2.963   |
| 2008 | 0.291     | 0.002   | 3.147   |
| 2009 | 0.285     | 0.002   | 3.101   |
| 2010 | 0.291     | 0.002   | 3.154   |
| 2011 | 0.272     | 0.003   | 2.985   |
| 2012 | 0.273     | 0.003   | 2.996   |
| 2013 | 0.261     | 0.004   | 2.877   |
| 2014 | 0.273     | 0.003   | 2.977   |
| 2015 | 0.296     | 0.001   | 3.198   |
| 2016 | 0.293     | 0.002   | 3.139   |
| 2017 | 0.311     | 0.001   | 3.293   |
| 2018 | 0.312     | 0.001   | 3.316   |
| 2019 | 0.317     | 0.001   | 3.340   |
industry. From 2005 to 2019, Henan, Anhui, Hubei, Hunan, and Fujian were newly added as hot spots for C&DW. With the acceleration of China’s urbanization process, provincial (municipal and district) governments, driven by the assessment of GDP indicators, invested a large amount of government funds in large-scale urban construction and infrastructure construction. Although this has increased the output value of the construction industry and hence the GDP, it also increased the related C&DW generation.

During the sample period, Anhui bounced repeatedly between the first and second quadrants. The C&DW generation of the surrounding provinces of Anhui such as Jiangsu,
Zhejiang, and Shandong was high for a long time, while the generation of Anhui was low. After a period of stable growth, the generation of Anhui decreased slightly in 2016 and continued to increase until 2019, resulting in changes in its agglomeration characteristics. The growth rate of C&DW generation in Liaoning province began to decline in 2011, and the generation decreased significantly in 2015, situating it in the fourth quadrant of high-low concentration in 2011 and 2014, but it returned to the third quadrant in 2017. Due to the long-term low C&DW generation in the provinces surrounding Liaoning, it was affected by spatial correlation and gradually decreased to a lower level after the increase in C&DW generation. It can be seen that the spatial agglomeration effect of waste generation in China’s provinces was very evident, which can greatly affect the development of the construction industry and the change trend of C&DW generation in each province. The government should formulate policies based on spatial agglomeration characteristics (Zhang et al. 2015). C&DW should focus on high-high concentration areas, reduce the C&DW generation from the source, and resolve the dilemma of waste siege.

**GWR analysis**

GWR was used for local regression. In a short interval year, the spatial aggregation characteristics of C&DW generation did not change significantly, and 2005, 2008, 2011, 2014, 2017, and 2019 were selected as representative years. The overall estimation results of the GWR model are shown in Table 7.

Considering the difference of C&DW generation in spatial geographical location in each province, a regression equation can be obtained for each province in each year. The fitting coefficients of the regression equations in each region are approximately 0.7, indicating that the explanatory ability of the model is strong. There were some differences in the fitting coefficient of each equation and the regression coefficients of each factor, indicating that there was spatial

| Year | Quadrant | Quantity | Province |
|------|----------|----------|----------|
| 2005 | I (HH)   | 4        | Shandong, Jiangsu, Shanghai, and Zhejiang |
|      | II (LH)  | 5        | Tianjin, Anhui, Jiangxi, Fujian, and Hainan |
|      | III (LL) | 16       | Heilongjiang, Inner Mongolia, Xinjiang, Jilin, Liaoning, Gansu, Hebei, Shanxi, Shaanxi, Ningxia, Qinghai, Henan, Chongqing, Yunnan, Guizhou, and Guangxi |
|      | IV (HL)  | 5        | Beijing, Sichuan, Hubei, Hunan, and Guangdong |
| 2008 | I (HH)   | 4        | Shandong, Jiangsu, Zhejiang and Fujian |
|      | II (LH)  | 4        | Anhui, Shanghai, Jiangxi, and Hainan |
|      | III (LL) | 16       | Heilongjiang, Inner Mongolia, Xinjiang, Jilin, Liaoning, Gansu, Hebei, Shanxi, Tianjin, Shaanxi, Ningxia, Qinghai, Chongqing, Yunnan, Guizhou, and Guangxi |
|      | IV (HL)  | 6        | Beijing, Henan, Sichuan, Hubei, Hunan, and Guangdong |
| 2011 | I (HH)   | 5        | Shandong, Jiangsu, Anhui, Zhejiang and Fujian |
|      | II (LH)  | 3        | Tianjin, Shanghai, and Jiangxi |
|      | III (LL) | 14       | Heilongjiang, Inner Mongolia, Xinjiang, Jilin, Gansu, Shanxi, Shaanxi, Ningxia, Qinghai, Chongqing, Yunnan, Guizhou, Guangxi, and Hainan |
|      | IV (HL)  | 8        | Liaoning, Hebei, Beijing, Henan, Sichuan, Hubei, Hunan, and Guangdong |
| 2014 | I (HH)   | 4        | Shandong, Jiangsu, Zhejiang and Fujian |
|      | II (LH)  | 4        | Tianjin, Anhui, Shanghai, and Jiangxi |
|      | III (LL) | 15       | Heilongjiang, Inner Mongolia, Xinjiang, Jilin, Gansu, Hebei, Shanxi, Shaanxi, Ningxia, Qinghai, Chongqing, Yunnan, Guizhou, Guangxi, and Hainan |
|      | IV (HL)  | 7        | Liaoning, Beijing, Henan, Sichuan, Hubei, Hunan, and Guangdong |
| 2017 | I (HH)   | 6        | Shandong, Henan, Jiangsu, Anhui, Zhejiang, and Fujian |
|      | II (LH)  | 4        | Tianjin, Chongqing, Shanghai, and Jiangxi |
|      | III (LL) | 15       | Heilongjiang, Inner Mongolia, Xinjiang, Jilin, Liaoning, Gansu, Hebei, Shanxi, Shaanxi, Ningxia, Qinghai, Yunnan, Guizhou, Guangxi, and Hainan |
|      | IV (HL)  | 5        | Beijing, Sichuan, Hubei, Hunan, and Guangdong |
| 2019 | I (HH)   | 9        | Shandong, Henan, Jiangsu, Anhui, Hubei, Shanghai, Zhejiang, Hunan and Fujian |
|      | II (LH)  | 4        | Tianjin, Chongqing, Jiangxi, and Hainan |
|      | III (LL) | 14       | Heilongjiang, Inner Mongolia, Xinjiang, Jilin, Liaoning, Gansu, Hebei, Shanxi, Shaanxi, Ningxia, Qinghai, Yunnan, Guizhou, and Guangxi |
|      | IV (HL)  | 3        | Beijing, Sichuan, and Guangdong |

Table 6 Spatial correlation evolution table of C&DW generation in each province
heterogeneity in construction waste generation in different regions.

The influence coefficients of the population size on C&DW are shown in Fig. 4. The regression coefficients of the population size for each year were positive. The regression coefficients of Anhui, Jiangsu, and Shanghai were always high, and the degree of influence of population size was centered in the eastern coastal provinces and gradually spread to the surrounding areas, while the regression coefficients of inland areas such as Xinjiang, Qinghai, and Sichuan were relatively low. The PGDP of C&DW is shown in Fig. 5. The PGDP of the southeast coastal areas was higher than that of the northwest inland areas. The productivity of these provinces has developed rapidly, and the environment and climate are comfortable, which can attract talent from various regions. With the improvement of wealth and living standards, people’s consumption quality has also improved. More people begin to buy high-quality houses and add on decoration according to their own preferences. The regression coefficients of the efficiency of labor on C&DW are shown in Fig. 6. The regression coefficients of efficiency of labor were mostly negative, but positive in individual years. Technological progress and the improvement of labor efficiency can have an overall inhibitory effect on C&DW generation to a certain extent. Regions with large coefficients from 2005 to 2019 were primarily concentrated in inland areas of western China, such as Xinjiang, Qinghai, Sichuan, and Yunnan. However, the purpose of improving labor efficiency in cities in the eastern coastal areas was mostly to pursue production efficiency, rather than considering environmental problems. Moreover, there was a significant positive correlation between regional economic development and environmental pollution, and the promotion of environmental pollution was greater than the inhibition of labor efficiency. In other words, although regional labor efficiency can improve environmental pollution, it is not enough to deal with the environmental problems caused by the economic development process. The environmental pollution in the western region was most affected by the relative effect of labor efficiency, which means that if the government of each province wants to improve the environment through labor efficiency, the western region can obtain a better implementation effect than the eastern and central regions. The eastern provinces with more developed economies should maintain the desirable current situation and continue to maintain the steady development of economy and construction industry. The regression coefficients of the scale of the construction industry on C&DW are shown in Fig. 7. The regression coefficients of the scale of the construction industry in each year were positive, and the values of these coefficients were very large, indicating that the expansion of the scale of the construction industry in each province had a direct promoting effect on C&DW generation. Economic development has driven the development of the construction industry and accelerated the process of urbanization, and the real estate fever continues to heat up, and people’s living standards have been improving day by day.

### Discussion

#### Factors influencing of C&DW

**Population size factor**

With the expansion of population size, human activities will inevitably increase the generation of construction waste, which is consistent with the conclusions of Gui et al. (2019). The spatial agglomeration of the impact of population size on C&DW showed the characteristics of temporal and spatial changes from the eastern coastal area to the central area. The economic development speed and people’s income level in coastal areas were generally higher, the regional innovation vitality was strong, the development space was large, and the attraction of cities was strong. There was a large migrant population and a high growth rate. In the process of urbanization, many rural people moved to cities, leading to an increase in the generation of urban construction waste (Yuan et al. 2018). With the increase of population, the demand for energy in urban construction, infrastructure, transportation, and entertainment were also increased, which led to the rapid development of the local construction industry, resulting in an increase in the C&DW generation. However, the climate in northwest China is poor, and the degree of economic development is low, resulting in serious population loss and slow development of the construction industry. This is related to the fact that the agglomeration effect of population urbanization in this region had not yet appeared. Henan province, a province with a large population, did not show the strongest population size effect because it had a

### Table 7 Overall estimated regression results of GWR model

| Parameter | 2005   | 2008   | 2011   | 2014   | 2017   | 2019   |
|-----------|--------|--------|--------|--------|--------|--------|
| $R^2$     | 0.869  | 0.871  | 0.856  | 0.92   | 0.878  | 0.816  |
| Adjust $R^2$ | 0.794  | 0.793  | 0.764  | 0.859  | 0.805  | 0.716  |
| Residual squares | 0.208  | 0.215  | 0.237  | 0.124  | 0.188  | 0.248  |
| AICc      | −30.394| −28.571| −23.695| −37.472| −33.159| −26.793|
Fig. 4  Comparison of regression coefficients of population size in different years
Fig. 5  Comparison of regression coefficients of per capita GDP in different years
Fig. 6  Comparison of efficiency of labor regression coefficients in different years
Fig. 7  Comparison of regression coefficients of construction industry scale in different years
large population base. During the study period, the growth rate of Henan Province was low, showing a steady growth trend. The increase in C&DW caused by an increase in population also showed a steady growth trend. In addition, the birth rate of China’s population has been at a low level in recent years, which has led to a reduction in the impact of population size on the generation of construction waste. At the same time as regional economic development and population gathering, residents’ awareness of environmental protection should be improved, the treatment system of C&DW should be improved, and the C&DW generation should be reduced through technological progress. For economically developed provinces along the eastern coast, the population inflow from other regions should be controlled to slow the expansion of population size, to reduce the promoting effect of population growth on C&DW generation. In southwest and western regions such as Yunnan, Sichuan, Qinghai, and Xinjiang, the elasticity coefficients of population size on C&DW generation were relatively small. In the process of economic development, population welfare policies should be introduced to attract talent, speed up the economic construction in these regions, make the population distribution more uniform and promote harmonious economic and societal development.

**PGDP factor**

The regression coefficients of PGDP in each year were positive; therefore, the growth of PGDP in each province will lead to an increase in C&DW generation. Aslam et al. (2020) pointed out that PGDP significantly affects the generation and management of C&DW. Income level affects consumption behavior to some extent: high-income groups have higher purchasing power and produce more waste (Gui et al. 2019; Mazzanti and Zoboli 2009a, b). Higher requirements for the comfort and functionality of housing promoted the development of the construction industry and led to a large amount of C&DW generation. The increase in PGDP was inseparable from the expansion of production (Ma et al. 2021), which led to more C&DW generation. From 2005 to 2017, the spatial aggregation of the impact of PGDP on the C&DW generation showed the characteristics of counterclockwise transfer from the south to the east coast and northeast. From 2005 to 2014, PGDP still promoted C&DW generation, but the elasticity coefficients decreased year by year. After 2014, with the construction of new urbanization and the provision of PGDP, the economic development level of eastern coastal areas had improved rapidly, and the economic vitality of northeast provinces warmed up rapidly, which can promote C&DW generation. For the southern and eastern regions with more developed productivity, such as Guangdong, Jiangsu and Zhejiang, it was necessary to increase the publicity of green buildings, promote the recycling of C&DW and reduce the C&DW generation while improving people’s living standards.

**Efficiency of labor factor**

Due to their remote geographical location and relatively slow economic development speed, the improvement of labor efficiency had a low degree of inhibition on the C&DW generation and could even promote the growth of C&DW generation to a small extent. The regression coefficients of labor efficiency in each year gradually decreased from west to east China. The efficiency of labor showed an environment-friendly trend in each city, with significant spatial differences in the degree of influence. Specifically, the regions with strong inhibition of labor efficiency were concentrated in the Beijing-Tianjin region and northeast China. The reason may be that the industrialization level of this region is relatively low, the pollution caused by generation intensity is originally small, and this region has a superior natural environment. It is a high-quality ecological environment in China, and it has strong environmental self-purification ability. In this context, the improvement of labor efficiency brought about by technological progress is more likely to play a role in improving environmental pollution (Xin and Lyu 2021), showing that the eastern region has the advantages of coastal geographical location, more convenient transportation, more developed construction industry, and higher labor efficiency, which can restrain the growth of C&DW generation to a large extent. Technological progress would improve productivity and resource use efficiency and reduce factor input in the production process, to weaken the impact of production on the natural environment. In addition, the development, use, and updating of clean technologies and the replacement of backward technologies will also effectively reduce pollution emissions (Grossman and Krueger 1995). In economically developed areas, the population density is relatively large, and the population agglomeration effect promotes regional technological progress, improves labor efficiency, and helps reduce C&DW generation. Through the cycle of buildings, through the optimization of process steps and the improvement of technical methods, the C&DW generation in the process of construction, demolition, and decoration can be effectively reduced (Liu et al. 2020). From the perspective of environmental protection technology, an increase in related R&D investment can promote the progress of environmental protection technology to a certain extent, thus inhibiting C&DW generation. In the development of the construction industry in western China, welfare policies should also be introduced to strengthen the enthusiasm of workers from other regions to participate in construction; this would decrease C&DW generation in various regions and maintain the balance between the environment and economy. With the deepening of the concept
of the green building and the maturity and promotion of energy conservation and emission reduction technology, the contribution of construction technology to the reduction of C&DW generation in the construction industry is becoming increasingly significant.

**Scale of construction industry factor**

The demand for infrastructure construction, housing construction, and commercial and industrial land construction has increased. With the expansion of the scale of the construction industry, the number of employees in the construction industry continued to increase, which promoted the agglomeration of the scale of the construction industry. Conversely, the increase in the employed population increased the demand for urban housing and infrastructure construction (Fan and Zhou 2019), which further promoted the increase in C&DW generation. The provinces with large regression coefficients were primarily concentrated in the eastern coastal areas of China. The degree of influence of the scale of the construction industry in each year was centered on Anhui, Jiangsu, Zhejiang, and Shanghai and gradually decreased in the surrounding areas. For western provinces such as Xinjiang, Qinghai, Sichuan, and Yunnan, the impact of their construction industry scale on C&DW generation was relatively low in the long term. As the economy and construction industry in various regions of China were in the process of continuous development and the construction scale was expanding, the access conditions of the construction market gradually reduced, the industrial projects of industrial surplus increased, and the industrial specifications did not improve in time, which directly led to a large amount of C&DW generation (Wang et al. 2021a, b, c). Extensive land use planning that pursued an increase in the amount of construction products for environmental benefits would inevitably accelerate the growth rate of the scale of construction products, resulting in an increase in C&DW generation. In recent years, the development of the construction industry has drawn more attention to profit-oriented construction, such as higher residential buildings, increased investment in public infrastructure construction, and the construction of high-end residential and commercial real estate, resulting in an increase in the construction industry scale and a reduction in the impact on C&DW generation in the construction industry. It can be seen that provinces in the eastern coastal areas of China should continue to maintain their relatively high scale of construction industry, steadily develop the construction industry, improve the access conditions of the construction industry market, enhance the corresponding industry norms, and improve the overall quality of the construction industry, to curb the massive C&DW generation. Xinjiang, Qinghai, Sichuan, and other western regions should take advantage of the low promotion degree of the construction industry scale to C&DW generation and strengthen the technical development of C&DW recovery and recycling to ensure that the generated C&DW can be disposed of in a timely and reasonable manner when the scale of the construction industry is expanded. Compared with the previous years, the regression coefficients in 2017 had decreased to a certain extent, which was due to the mature urbanization process and stagnation of the construction industry, which reduced C&DW generation. The construction industry scale of provinces expanded to a high level, and the inter-provincial gap narrowed.

**Suggestions**

**Balancing the population size of the provinces**

Because of the vast area of our country, the geographical location and production capacity of each province are different, which has a significant impact on the population distribution. At present, there are evident population distribution characteristics of “more in the east and less in the west” in China. The demands for construction products have promoted the generation of a large number of C&DW and also cause a burden on the land. Provinces with large populations and more developed economies should establish the conditions for population entry to control the population inflow from outside areas. In remote areas with less population, corresponding welfare policies should also be formulated to improve the living standards of local residents, to expand the population size of the province, share the population pressure with other provinces, and weaken the adverse impact of the population size on the C&DW generation.

**Encouraging the cooperative development of provincial economy**

Most of the provinces with more developed economic construction in China were concentrated in the eastern coastal areas of China. When vigorously developing their productive forces, these provinces can also make use of their geographical advantages and carry out exchanges and cooperation with surrounding provinces to promote the common development of the economy in all regions. The climate of the inland area in northwest China was poor, and transportation was inconvenient; therefore, it was difficult to trade with the surrounding provinces, which slowed economic development. The government of each province should make full use of the economic advantages of the developed regions and transfer talents and technological means to regions with slow development, to improve labor productivity and create more value. The less-developed provinces should also formulate reasonable population welfare policies according to their own environment and economic conditions to improve the
lives of local residents and stimulate the enthusiasm of the public to improve productivity. In the process of economic and technological exchanges and cooperation, all provinces worked together to improve productivity; provide sufficient impetus for the development of the construction industry and environmentally friendly construction; and improve the efficiency of recycling and treatment of C&DW, so that China can slow down the impact of C&DW generation on people’s production and life during economic development.

**Improving efficiency of labor**

The improvement of labor efficiency has a strong inhibitory effect on C&DW generation. At present, the construction technology of China’s construction industry has developed to a higher level, but there is still room for improvement. Construction industry employees should be trained and improved by scientific and effective methods, and the efficiency of the employees in the actual operation should be strengthened. The problems in the work process should be found quickly and repaired in time, to improve the work efficiency of the construction industry comprehensively. Colleges and universities should strengthen the teaching quality of majors related to the construction industry, and the construction industry should also introduce appropriate employment welfare policies, to expand the choice of talent, improve the labor efficiency of the provinces, and avoid the large amount of C&DW in the construction process. Strengthen the technological research into C&DW recycling, and strengthen the use of BIM technology, to improve labor efficiency and product quality.

**Develop the scale of the construction industry**

With the rapid development of China’s economy and productivity, the scale of the construction industry has also expanded. However, due to the low access conditions of the construction industry market, industrial surplus projects have gradually appeared. It can be seen that the development of the construction industry should not only pursue speed, but also ensure the quality of the industry. Local governments should provide subsidies or establish preferential tax policies to support the development of the C&DW treatment industry. Find enterprises with high C&DW generation and charge higher construction waste disposal fees to restrain the generation of construction waste. The incentive mechanism would further strengthen the classification and effective treatment of construction waste to promote C&DW recycling to form a complete industrial chain and gradually establishing a C&DW treatment system in line with China’s national conditions. At the same time, the government of each province should improve and implement the housing rental market system, timely control of excessive speculation, and vacant housing problems in the real estate market. It prevents the excessive growth of construction housing and control the expansion speed of the construction industry.

**Conclusions**

C&DW generation is the main component for formal solid waste in China. This study identified the regional differences and influencing factors of C&DW, which was conducive to the sustainable development of the economy and society and the formulation of environmental protection policies. Based on the analysis of regional differences in construction waste, this study explored the spatial heterogeneity of influencing factors of C&DW generation using the GWR model. The main conclusions are as follows.

First, from 2005 to 2019, C&DW generation in China’s provinces mostly increased year by year, and the overall distribution showed the characteristics of “high in the east and low in the west.” Most of the provinces with high C&DW generation were concentrated in the coastal areas of southeast China, with significant regional differences. Zhejiang, Jiangsu, Beijing, Shanghai, and Fujian were the provinces with higher per capita C&DW generation. The C&DW generation intensity in China and the provinces showed a decreasing trend each year. Guangdong, Fujian, and Beijing had high output values for the construction industry and C&DW generation intensity at the same time, while Qinghai, Heilongjiang, and Tianjin had relatively lower construction industry output values and low C&DW generation intensity. Jiangsu and Zhejiang had the fastest growth rate of C&DW generation, and Beijing, Fujian, and Hubei also had high growth rates. Most provinces belonged to the medium and slow-growth types.

Second, the global Moran’s I index of C&DW generation was unstable from 2005 to 2011 and reached its lowest value in 2013. Since 2014, Moran’s I index has shown distinct upward trend and reached a high level in 2019. Overall, the global Moran’s I index of C&DW generation showed a trend of first fluctuation followed by a continuous rise during the sample investigation period, with significant agglomeration characteristics. In the local Moran analysis, the number of provinces showing low-low agglomeration in the third quadrant was the largest, and the provinces showing low-low agglomeration over an extended period were Heilongjiang, Inner Mongolia, Jilin, Shaanxi, and Qinghai. Jiangsu, Zhejiang, and Shandong were the top three provinces in C&DW generation in China, which have long been located in the first quadrant with high agglomeration characteristics. It can be seen from the change range of the Anhui and Liaoning provinces that the spatial agglomeration effect of C&DW generation in each province was very evident, which can
greatly affect the development of the construction industry and the change trend of C&DW generation in each province. Third, from the GWR results, it can be seen that the impact of population size, PGDP, efficiency of labor, and scale of the construction industry on C&DW generation showed distinct spatial heterogeneity. Among them, population size, PGDP, and scale of the construction industry played a positive role in promoting C&DW generation in each province, while the efficiency of labor played a negative role in restraining C&DW generation. From the perspective of influence intensity, the scale of the construction industry had the strongest promoting effect, but with the rapid development of China’s economy and construction industry, the impact of the scale of construction industry factors has decreased to a certain extent. Most of the provinces affected by these factors were concentrated in economically developed coastal areas in southeast China. The formulation of C&DWM policies should focus on the spatial differences in the degree of influence construction industry-scale factors.

Author contribution Zhenshuang Wang contributed to the conception of the study and contributed significantly to analysis and manuscript preparation. Zhongsheng Zhang performed the data analyses and wrote the manuscript. Jingkuang Liu contributed to the conception of the study and helped perform the analysis with constructive discussions.

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Data availability The datasets used and/or analyzed during the current study are available from the first author on request (Zhenshuang Wang).

Declarations

Research involving human participants and/or animals Not applicable.

Ethical approval and consent to participate. Not applicable.

Consent to publish The authors consent to publish.

Conflict of interest The authors declare no competing interests.

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