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Predicting Renovation Waste Generation Based on Grey System Theory: A Case Study of Shenzhen

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Abstract: With the rapid development of urbanization, more and more people are willing to improve their living conditions, thus substantial attention has been paid to residential renovation in China. As a result, large quantities of renovation waste are generated annually which seriously challenge sustainable urban development. To effectively manage renovation waste, accurate prediction of waste generation rates is a prerequisite. However, in the literature, few attempts have been made for predicting renovation waste as renovation activities vary significantly in different cases. This study offers an approach to estimate the amount of renovation waste based on the vacancy rate and renovation waste generation rates at a city level. The grey system theory was applied to predict the amount of renovation waste in Shenzhen. Results showed that the amount of renovation waste would reach 135,620 tons in 2023. The research findings can provide supportive information to relevant stakeholders for developing a renovation waste management framework.

Keywords: renovation waste; generation prediction; management; grey system theory

1. Introduction

The real estate market in China has substantially developed due to the rapid development of urbanization. In recent years, there has been fast-growing sales of commercial housing. As a result, increasing attention has been paid to the living quality of and the renovation of houses. According to the statistics provided by the China Building Decoration Association (CBDA), the area of housing sales and the renovation output value increased very fast in recent years. What is more, the total value of residential renovation projects escalated from 1140 billion yuan (about US$ 165 billion) in 2005 to 2100 billion yuan (about US$ 305 billion) in 2010, and then to 3940 billion yuan (about US$ 573 billion) in 2017 [1]. These data illustrate the increasing trend in renovation of residential buildings in China.

The stream of construction and demolition (C&D) waste generally results from the construction, renovation, and demolition of buildings, roads, bridges, and other structures [2,3]. According to its generation phase, construction and demolition waste can be divided into three categories: construction waste, renovation waste, and demolition waste [4]. The modification or improvement of residential building is considered as renovation in this research study. According to Woodson [5], renovation is defined as the modification of any existing structure, or portion of a structure, that results in the disturbance of painted surfaces. Renovation waste includes bricks, concrete blocks, wood blocks, shavings, ash, waste ceramics, scrap metal, waste material, and others [6]. Nowadays, the majority of newly-built buildings in China are roughcast (i.e., without interior renovation) when they are delivered to the clients. Thus, a mass of waste is generated in the renovation phase of a project because of the individual renovation of roughcast housing. Even in cases where the buildings are delivered to the clients with renovation, the wall layout, as well as window and door facilities of the original buildings are usually rebuilt by the owners. Different from roughcast buildings in China, hardbound buildings are widely used in the United States and Japan [7]. It is easy to achieve intensification and high efficiency in the management and treatment of interior renovation waste [8]. The German and Japanese government have prohibited second renovation and require newly developed properties to be renovated before market sale [7]. Obviously, there is a clear lack of regulations directly focusing on renovation in China.

At present, the disposal of renovation waste in China is mainly based on simple landfilling [9], which causes low recycling rate and pollution to the environment [10]. It is reported that China is the largest producer who contributes over 2 billion tons of construction and demolition waste annually [11]. However, the average recycling rate of C&D waste in most cities in China is just between 3% and 10% [12], much lower than some developed countries (e.g., 93.8% for Japan [13], 94% for the Netherlands [14]). Due to the limited landfill disposal capacity and high price of land resources in developed cities (e.g., Shenzhen), it is not unusual that C&D waste is transferred to less-developed neighboring regions in China [11]. Even worse, illegal dumping may happen; waste might be discharged at unpermitted areas, such as farm lands, abandoned residential lands, borrow pits, river sides, and low-lying areas. Though illegal dumping in Shenzhen is not normal due to strict governmental supervision, it is unavoidable that waste producers may illegally dump waste at nearby cities.

As the urbanization in Shenzhen is developing very fast and the area of this city is comparatively limited [15], there is a serious situation of tremendous waste generation [16]. Specifically, 509 urban renewal projects were scheduled to be demolished in Shenzhen from 2010 to 2017 with an area of 3731.13 ha released [15]. According to the official statistics from the Human Settlements and Environment Commission of Shenzhen Municipality (HSECSM), the total amount of C&D waste generated in 2016 was about 70 million m^3 (about 102 million tons) in Shenzhen [17]. On the other hand, the components included in renovation waste have great reuse/recycling potentials and successful actions have been made in Xi'an, China [18]. Therefore, effective management of renovation waste has become an important issue for the city of Shenzhen.

Predicting with accuracy the generation rates of renovation waste is essential for effective waste management. As such, it is significant to develop a reliable model for predicting renovation waste generation. This paper aims to provide a methodology which can predict the amount of waste generated from renovation activities. Firstly, the renovation area was estimated based on the efficiency rate and vacancy rate. Then, the researchers used interviews with the experts working in the industry to investigate the renovation waste generation rates in different renovation processes. Finally, the grey theory was applied to predict the amount of renovation waste. It is significant for government, project managers, and site managers to quantify the renovation waste generated from refurbished construction sites and develop a renovation waste management framework.

2. Literature Review

The amount of waste generated from construction projects is enormous [19]. Many countries in the world are facing the issues caused by construction and demolition waste. For example, Seror et al. [20] investigated the illegal dumping problem in Israel. Mihai [21] also found that illegal dumping and poor monitoring of construction and demolition waste exists across the Romanian counties. Rosado et al. [22] addressed the environmental impacts caused by the construction and demolition waste, and evaluated the performance of several alternative scenarios.

To perform effective waste management, the waste generation in construction projects has been investigated extensively in previous studies. Poon et al. [23] utilized truck load records to estimate the generation of on-site produced waste. Lu et al. [24] empirically investigated the waste generation rates in the construction and demolition phases in Shenzhen, revealing that the generation rates of construction and demolition waste ranged from 3.275 to 8.791 kg/m^2, of which miscellaneous waste, timer, and concrete accounted for the three biggest proportions. Lau et al. [25] measured the volume of on-site construction waste by categorizing the piling of waste into four types, such as stockpiled, gathered, scattered, or stacked; corresponding equations were proposed for different types of piling shapes, revealing that the generation rate of construction waste on these sites ranged from 86.34 to 229.72 tons per hectare. The collected waste generation rates can provide useful references for estimating waste generation at a project level.

To estimate waste generation at a project level, many attempts have been made. Llatas [26] proposed a model to quantify construction waste based on the European Waste List. It is in view of two primary variables: (1) the number of engineering elements in the building/site and building materials as well as building components; (2) the changes that these building materials and their packaging undergo during the entire construction process [27]. The model could provide the expected amount of waste for engineering elements in each building/site due to the addition and residues of packaging waste, and soil coding. Other researchers have also attempted to evaluate waste generation based on a classification system, such as Solis-Guzman et al. [28], and Coelho and de Brito [29].

Understanding waste generation can provide valuable information that is fundamental for project waste management; however, such information is not adequate for making management strategies at a city level. Wu et al. [4] stated that forecasting future waste generation amount is more important than just understanding the existing waste generation situations for implementing strategies at a city level, and variable modelling is the mainstream method for forecasting future waste generation. In Norway, Bergsdal et al. [30] used Monte Carlo simulation to analyze the uncertainty of input variables and concluded that construction waste (especially bricks, wood, etc.) will gradually increase in the coming years. Fatta et al. [31] estimated the amount of construction waste generated in Greece by using some data which included the amount of construction waste produced per unit area, the demolition and construction area of existing buildings. Katz and Baum [32] proposed a model to predict the flow of construction waste from the beginning of the production phase to the end of the new building. The construction phase is divided into structural elements, initial finishing (concurrent), and final finishing. Banias et al. [33] developed a web-based decision support system to optimize the management of construction waste. Wu et al. [34] forecasted the construction waste amount using gene expression programming. Lee et al. [35] developed a hybrid model which combines artificial neural networks and ant colony optimization for multifamily residential buildings. Au et al. [36] used the amount of C&D waste as one of the key factors to propose a system dynamics (SD) model that can help to predict C&D waste disposal charges, and environmental implications, as well as its financial implications.

From the literature review, it can be found that waste management is based on the waste quantification at both project and city level. The collected waste generation rates can provide useful references for estimating waste generation at a project level. However, the current research focused more on waste generated from construction and demolition phases, and proper methods on forecasting waste amount produced from renovation has not been sufficiently developed. Thus, this paper attempts to bridge this research gap.

3. Research Methodology

To forecast waste generation amount, this study developed a prediction model based on grey system theory. Grey system theory was selected because it has the advantage of utilizing the known information of a system to study the unknown, and the grey model based on grey system theory focuses on the analysis and understanding of uncertainty and inadequate [37]. It is the creation function based on the standpoints and methods of the conjunction-degree convergence principle, creation number, grey differential coefficient, and grey differential equation. A typical advantage of the grey model is that it can handle prediction problems with less data, which is very suitable for the prediction of the amount of renovation waste.

The main feature of grey prediction is that the model does not use the original data sequence but the generated data sequence. Its core system contains a grey model (GM) and a modeling method that accumulate raw data (or other methods) to generate the law using approximate match. The index law is then modeled again. It can use differential equations to fully exploit the nature of the system with high accuracy. Furthermore, erratic raw data is employed to generate a sequence with strong regularity. The operation is simple and easy to test without taking the distribution rules and trend change into account. The grey model is a practical prediction method with better accuracy than the one-dimensional linear regression prediction in some specific cases [38]. However, it is only available on short-term and medium-term forecasts and suitable for the forecast of exponential growth. Many factors can influence the renovation waste generation data. The most significant is the real estate policies, but the real estate policy factors are unpredictable. A potential solution of this problem is using information processing methods such as correlation analysis, grey number generation, and grey model to explore the interrelationships between data and to predict the future generation of renovation waste. Considering exponential growth and little data, this paper forecasts the residential renovation waste for the next five years by establishing a grey model, namely GM (1, 1).

3.1. The GM (1, 1)

The aims of Grey System theory are to provide theory, techniques, notions, and ideas for resolving (analyzing) latent and intricate systems [39]. The Grey Model is based on the theory of Grey System:

1. A stochastic process whose amplitudes vary with time is referred to as a grey process;
2. The grey modelling is based on the generating series rather than on the raw one;
3. The grey differential equations are defined in order to build a GM;
4. To build a GM model, only a few data (as few as four) are needed to distinguish it.

A grey model with n variables is called GM (1, n), that reflects the effect of (n − 1) variables on the first derivative of a variable. As the core of the grey theory, GM (1, 1) is a first-order linear differential equation of a single variable. In addition, the discrete time response function which can be viewed as index predictive model naturally is acquired by the solution of the differential equation [39]. Under these conditions, the GM (1, 1) is selected to simulate the residential renovation waste for the next five years.

In the first step, use 1-AGO (Accumulated Generation Operation) to generate a one-accumulate sequence, for weakening the randomness of the original time series.

Set $X^{(0)}$ as a non-negative sequence:

$$X^{(0)} = [x^{(0)}(1), x^{(0)}(2), \ldots x^{(0)}(n)]. \quad (1)$$

$X^{(1)}$ is the one-accumulate of the time-series data of $X^{(0)}$:

$$X^{(1)} = [x^{(1)}(1), x^{(2)}(2), \ldots, x^{(1)}(n)], x^{(1)}(k) = \Sigma_{i=1}^{k} x^{(0)}(i);\ k = 1, 2, \ldots, n. \quad (2)$$

In the second step, perform quasi-smooth verification on $X^{(0)}$ and quasi-exponential verification.

$$\text{Set } \rho(k) = x^{(0)}(k)/x^{(1)}(k-1);\ k = 2, 3, \ldots, n. \quad (3)$$

The following conditions:

1) $\rho(k) < 1, k > 2$;
2) $\rho(k) \in [0, \varepsilon]$ $(\varepsilon < 0.5)$, $k > 4$

Then $X^{(0)}$ is called quasi-smooth sequence and $X^{(1)}$ has quasi-exponential law.

In the third step, since $X^{(1)}$ has the law of approximate exponential growth, $X^{(1)}$ satisfies the differential equations of the first order as flowing.

Then the following Equation (4)

$$X^{(0)} + az^{(1)}(k) = b, k = 1,2, \ldots ,n. \quad (4)$$

It is a grey differential model, called GM (1, 1) as it includes only one variable $X^{(0)}$, where

$$z^{(1)}(k) = 0.5x^{(1)}(k) + 0.5x^{(1)}(k-1), k = 1,2, \ldots ,n. \quad (5)$$

a, b, are the coefficients; in Grey System theory terms, a is said to be a developing coefficient and b the grey input, $X^{(0)}$ is a grey derivative which maximizes the information density for a given series to be modelled.

According to the least square method, we have

$$\hat{a} = (B^TB)^{-1}B^TY_n. \quad (6)$$

There,

$$Y_n = \begin{bmatrix} x^{(0)}(2) \\ x^{(0)}(3) \\ \vdots \\ x^{(0)}(n) \end{bmatrix}, B = \begin{bmatrix} -z(2) & 1 \\ -z(3) & 1 \\ \vdots & \vdots \\ -z(n) & 1 \end{bmatrix}. \quad (7)$$

Here B is called a data matrix.

By regarding the following Equation (8):

$$\frac{dx^{(1)}}{dt} + \hat{a}x^{(1)} = \hat{b} \quad (8)$$

In the fourth step, the discrete time response function can be represented as Equation (9):

$$\hat{x}^{(1)}(k+1) = [x^{(1)}(1) - \frac{\hat{b}}{\hat{a}}]e^{-\hat{a}k};\ k = 0,1,2, \ldots, n. \quad (9)$$

Finally, perform residual analysis on prediction results. Set $\varepsilon(k)$ as residual test by regarding the following Equation (10):

$$\varepsilon(k) = \frac{x^{(0)}(k) - \hat{x}^{(0)}(k)}{x^{(0)}(k)}, k = 2, 3, \ldots, n. \quad (10)$$

If $\varepsilon(k) < 0.2$, then $\varepsilon(k)$ is considered to meet the general requirements; and if $\varepsilon(k) < 0.1$, then $\varepsilon(k)$ is considered to meet higher requirements.

3.2. Data Collection and Process

To estimate the renovation waste amount, three steps were implemented. Firstly, the data of marketable housing area (i.e., sales area) in Shenzhen from 2008 to 2018 was obtained based on the Shenzhen Statistical Yearbook [40]. Shenzhen Statistical Yearbook is an informative annual publication which is issued by the Statistics Bureau of Shenzhen (SBS) in cooperation with the National Bureau of Statistic Survey Office in Shenzhen; it is a governmental official publication which contains comprehensive statistics concerning the social and economic development in Shenzhen. Subsequently, the data were processed with the aid of two factors (i.e., efficiency rate and vacancy rate) to convert the sales area into the renovation area. The efficiency rate of house is the ratio of the area available for household control (sales area—public area) to sales area, while the vacancy rate of buildings refers to the ratio of vacant housing area to the total housing area at a certain time. Based on the above data, the renovation waste amount was estimated by considering the waste generation coefficient obtained in the survey and the renovation area. The details of these three steps are explained as follows.

3.2.1. Renovation Area

As explained above, the renovation area was estimated by considering two factors, such as efficiency rate and vacancy rate. In China, the general efficiency rate for buildings is around 80%, of which 88% for multi-stored buildings, 72% for high-rise buildings, and 55% for office buildings [41]. In this study, based on the understanding of the real estate market in Shenzhen, the efficiency rate was assumed as 80%. As a result, the area of renovation is approximately 80% of the marketable housing area. Furthermore, according to the Investigation Report of National Urban Housing Market in May 2015, which was jointly issued by Tencent Real Estate Research Institute (TRERI) and the China Real Estate News, the vacancy rate of houses in the first-tier cities is 22% [42]. As Shenzhen is one of the four first-tier cities, the vacancy rate was assumed as 22% in this study. Thus, the area of renovation can be estimated by Equation (11). Here $S_{renovation}$ is the area of renovation, and S_{sale} is the marketable housing area of residential real estate.

$$S_{renovation} = S_{sale} \times (1 - 22\%) \times 80\%. \tag{11}$$

3.2.2. Renovation Waste Generation

Currently, roughcast and hardbound buildings are submitted in two different renovation ways in China. Roughcast buildings mainly refer to the interior decoration of the house, and the wall surface, the ground surface, and the top surface are not used for the surface layer; only the door frame, the toilet water supply, the drainage interface, and the wire joint. Compared with roughcast buildings, the batch decoration of hardbound buildings is a decoration mode that is vigorously promoted by the government, and is an effective way to reduce renovation waste. The hardbound buildings have been carefully renovated to the building's construction. For example, the wooden storage ghosts, cabinets, kitchens, toilet walls, floors, etc., have been carefully treated and decorated. In addition, the top surface has been suspended and light bulbs are installed. The difference between two renovation styles can be seen in Figure 1.

(**a**) (**b**)

Figure 1. Comparison of a roughcast building and hardbound building (authors' own). (**a**) Roughcast building; (**b**) hardbound building.

In this study, the empirical data of renovation waste generation rates were collected from interviews with five experienced professionals who have had more than four years' renovation waste management experiences in Shenzhen. Each interviewee was invited to give renovation waste generation rates based on his project experience, then the generation rates used in this study were derived from the average values of the provided data. According to the investigation, it was estimated that the renovation waste generation rate for roughcast buildings is 2.3 tons per 100 m^2, while the rate for hardbound buildings is 1.65 tons per 100 m^2. According to the statistics of real estate market in Shenzhen, the volume of roughcast buildings accounts for about 70% of the total residential area, and the hardbound buildings accounted for 30% [43]. Thus, the quantity of renovation waste can be calculated using Equation (12). Here $S_{renovation}$ is the area of renovation, and Q_{waste} is the renovation waste.

$$Q_{waste} = S_{renovation} \times (0.7 \times 2.3 + 0.3 \times 1.65). \quad (12)$$

Based on the calculations, the renovation waste in Shenzhen during 2008–2018 are shown in Table 1. From Table 1, it can be seen that the share of renovation waste for C&D waste is no more than 0.25%. However, it should be noted that the official C&D waste data in Shenzhen include excavated earth and no broken down data are available, which leads to the low percentage of renovation waste.

Table 1. Renovation waste of commodity housing in Shenzhen during 2008–2018.

Year	Sales Area (10,000 m²)	Renovation Area (10,000 m²)	Renovation Waste (100 tons)	C&D Waste (10,000 tons)	Percentage
2008	413.65	258.12	543.34	/	/
2009	717.40	447.66	942.32	3,732	0.25%
2010	413.80	258.21	543.53	8,195	0.07%
2011	469.43	292.92	616.61	3,073	0.20%
2012	488.44	304.79	641.58	3,659	0.18%
2013	527.16	328.95	692.44	5,854	0.12%
2014	474.81	296.28	623.67	3,659	0.17%
2015	747.83	466.65	982.29	6,146	0.16%
2016	660.08	411.89	867.03	10,244	0.08%
2017	671.03	418.72	881.41	13,771	0.06%
2018	722.01	450.53	948.37	14,864	0.06%

(Note: the data of C&D waste amount in 2008 is not applicable).

4. Results and Discussion

4.1. Data Analysis

Renovation waste is generated during the process of housing renovation. Therefore, the amount of renovation waste is directly affected by the size of the renovation area, and the area of renovation is more related to marketable housing area of the commodity housing. Therefore, the amount of renovation waste generated is consistent with the trend of the marketable housing area of the commodity housing. From Figure 2, both values generally show an exponential growth trend, but there was a large fluctuation during 2008–2009.

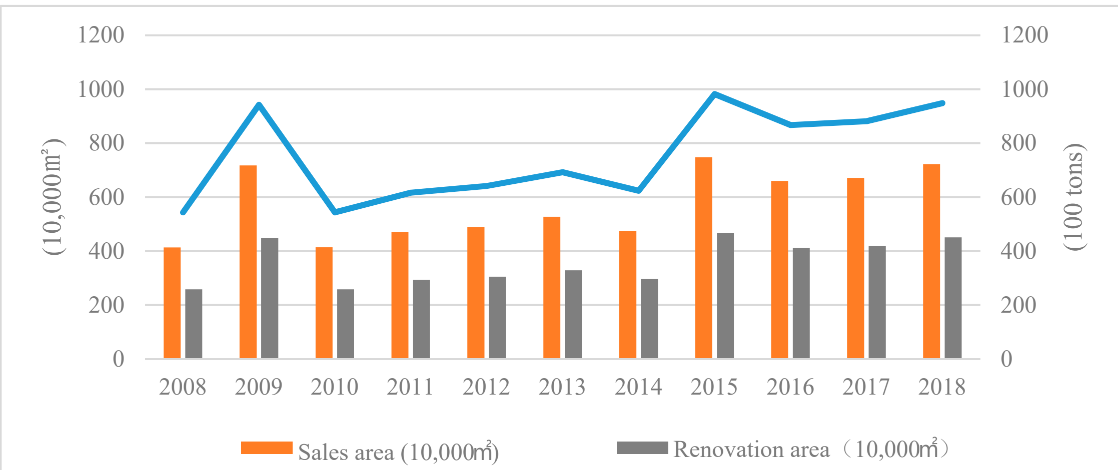


Figure 2. Renovation waste of commodity housing in Shenzhen during 2008–2018.

It is understood that, due to the influence of the international and domestic economic environment, Shenzhen's transaction of residential area has dropped for the first time in a year-on-year period since January 2008. In addition, the price of housing in Shenzhen began to decline, and the real estate industry was greatly affected in July 2008. Sales volume also declined significantly. In order to stabilize the real estate market, the Central Bank reduced the benchmark one-year deposit and lending rates as well as housing accumulation fund loan interest rate twice at the end of 2008. In addition, in order to solve the housing difficulties of the masses of people, especially low-income farmers, the relevant departments of the State Council also adopted a series of measures such as reducing real estate transaction tax, lower commercial loan interest rates, and increasing the scale of affordable housing construction and other measures. Moreover, relevant departments of Shenzhen City formulated corresponding countermeasures within a short period of time. By reducing relevant taxes and related subsidies and other promotion measures, the real estate market in Shenzhen began to pick up from the beginning of 2009.

In short, during the period from 2008 to 2018, the fluctuations in the Shenzhen's real estate market were abnormal between 2008 and 2009. After 2009, the real estate economy in China stabilized, and the amount of residential renovation waste also returned to the exponential growth trend mode. Although sales of the domestic real estate industry declined in 2014, the government adopted effective macro-control measures for the real estate industry, and the property market recovered in 2015. Therefore, it is necessary to reject some abnormal data in the time series to eliminate the impact of a large fluctuation during 2008–2009 for the forecasting model and based on optimistic forecasts of the real estate industry. This paper aims to forecast the amount of residential renovation waste generated in the next five years with the data from 2010 to 2018. Considering exponential growth and little data, GM (1, 1) was selected to forecast the renovation waste for the next five years.

4.2. Model Development and Verification

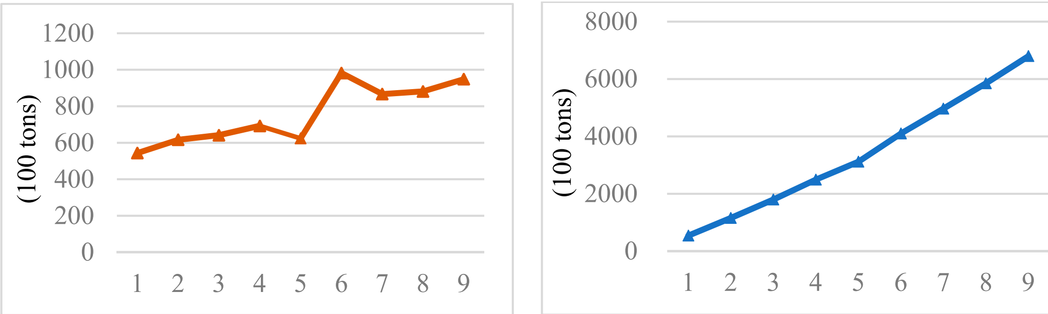
First of all, Set $X^{(0)}$ as a non-negative sequence with Equation (1).

Then, use 1-AGO to generate a one-accumulate sequence for weakening the randomness of the original time series. Table 2 shows the sequence of $X^{(1)}$ that is the one-accumulate of the time-series data of $X^{(0)}$ with Equation (2).

Table 2. The sequence of $X^{(1)}$ with equation.

k	Year	$X^{(0)}$	$X^{(1)}$
1	2010	543.53	543.53
2	2011	616.61	1160.14
3	2012	641.58	1801.72
4	2013	692.44	2494.15
5	2014	623.67	3117.82
6	2015	982.29	4100.11
7	2016	867.03	4967.14
8	2017	881.41	5848.55
9	2018	948.37	6796.93

As can be seen from Figure 3, after 1-AGO calculation, the original sequence with fluctuations becomes a smooth linear sequence.



(**a**) (**b**)

Figure 3. Comparison of non-negative sequence and 1-AGO (Accumulated Generation Operation) sequence. (**a**) $X^{(0)}$; (**b**) $X^{(1)}$.

In the second step, perform quasi-smooth verification on $X^{(0)}$ and quasi-exponential verification with Equation (3).

$$\rho(k) = (\rho(2), \rho(3), \ldots, \rho(9)) = (1.13, 0.55, 0.38, 0.25, 0.32, 0.21, 0.18, 0.16).$$

The following conditions:

1) $\rho(k) < 1, k > 2$,
2) $\rho(k) = (\rho(4), \rho(5), \ldots, \rho(9)) = (0.38, 0.25, 0.32, 0.21, 0.18, 0.16) < 0.5$.

Then, $X^{(0)}$ is called quasi-smooth sequence and $X^{(1)}$ has quasi-exponential law.

In the third step, constructing the data matrix B and vector Y, then the solution of Equation (9) is

$$\hat{x}^{(1)}(k+1) = 88955.628e0.066^{k} - 8412.093.$$

In the fourth step, the predicted value of generated sequence and restored value of the model is solved. Let k = 2, 3, 4, … ,9, the models predictive function indicates that

$$\hat{x}^{(0)} = (\hat{x}^{(0)}(2), \hat{x}^{(0)}(3), \hat{x}^{(0)}(4), \ldots, \hat{x}^{(0)}(9)) = (612.96,\ 654.92,\ 699.74,\ 747.64,\ 798.81,\ 853.48,\ 911.90,\ 974.31).$$

Finally, residual analysis. The results of calculation of the various test indexes of the model are shown in Table 3. By the formula for testing accuracy of predictive model, $\rho(k) < 0.2$, and the residual error $\varepsilon(k) < 0.2$ are obtained, which are in the allowable error range. The prediction accuracy meets the requirement.

Table 3. Model verification of GM (1, 1).

k	Year	Initial Value	Predicted Value	Absolute Error	Residuals	Relative Error
1	2010	543.53	543.53	0.0000	0.0000	/
2	2011	616.61	612.96	−3.6421	−0.0059	−0.59%
3	2012	641.58	654.92	13.3419	0.0208	2.08%
4	2013	692.44	699.74	7.3079	0.0106	1.06%
5	2014	623.67	747.64	123.9642	0.1988	19.88%
6	2015	982.29	798.81	−183.4814	−0.1868	−18.68%
7	2016	867.03	853.48	−13.5460	−0.0156	−1.56%
8	2017	881.41	911.90	30.4872	0.0346	3.46%
9	2018	948.37	974.31	25.9384	0.0274	2.74%

4.3. Discussion

The quantities of forecasted renovation waste amount were compared with the actual data, as shown in Figure 4. As can be seen from Figure 4, the absolute errors in 2014 and 2015 are higher than the others. The reason that caused the phenomenon may be related to the government's policy change. In Shenzhen, after the Third Plenary Session of the 18th CPC Central Committee, the property market was under the control of purchase of credit limit policy, therefore the volume of transactions continued to shrink in the first three quarters of 2014, and the market continued to languish. Meanwhile, the developers postponed construction plans, which made the real estate market in the doldrums and consumer hot spot cool. In the fourth quarter, the central bank issued a document setting out the criteria for determining the first mortgage loan and implementing an asymmetric rate reduction policy to make the real estate economy pick up. Furthermore, the new policy reduced the personal transfer housing business tax exemption period from 5 years to 2 years and the central bank lowered benchmark interest rate for loan and deposit rate in 2015. The real estate market is taking a gradual turn for the better. Under the overall impact, the sales of real estate declined and increased during 2014–2015. In 2014, the amount of renovation waste decreased from 69,244 tons (in 2013) to 62,367 tons and increased to 98,229 tons. The relative errors corresponding with the predicted value are 19.88% and 18.68%. According to the grey system theory, the acceptable error range is 0–0.2 [44], thus the prediction accuracy met the requirement.

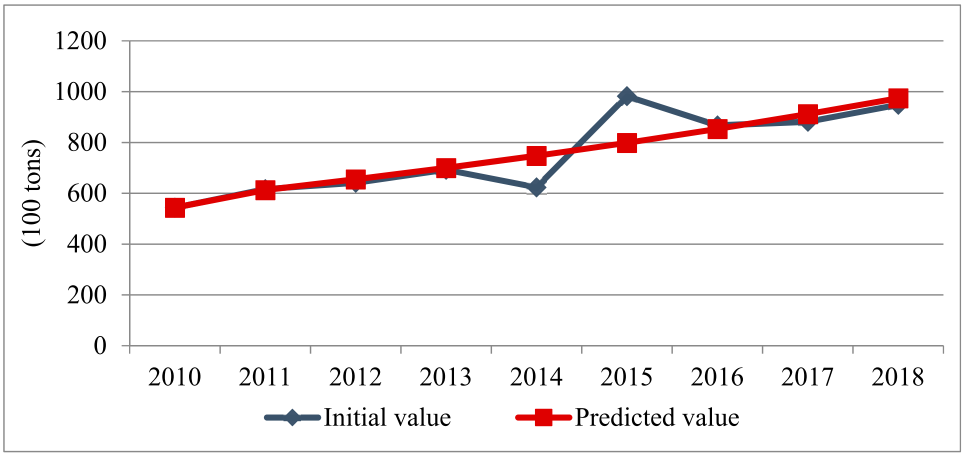


Figure 4. Comparison of actual and forecasting quantities of renovation waste.

Consequently, the predicted amount of renovation waste produced during 2019–2023 can be seen in Table 4. In the next five years, if there are no rigid macroeconomic control policies for the real estate market and the economy keeps growing, the average growth rate of renovation waste in Shenzhen will reach 8.61%. The amount of renovation waste in Shenzhen is expected to reach 135,620 tons in 2023.

Table 4. The amount of renovation waste in Shenzhen from 2019 to 2023.

Order Number	Year	Forecast Amount (100 tons)
1	2019	1041.00
2	2020	1112.25
3	2011	1188.38
4	2022	1269.72
5	2023	1356.62

Obviously, a mass amount of renovation waste will be generated without effective management. Compared with roughcast buildings, the batch decoration of hardbound buildings is a decoration mode that is an effective way to reduce the renovation waste. However, the majority of newly-built buildings in China are roughcast when they are delivered to the clients. It is suggested that the government should prohibit second renovation and require the new developed properties to be renovated before market sale. What is more, the formulation of relevant laws and standards for source classification of renovation waste, waste collection management, resource utilization, incentive policy, and finance subsidy should be initiated and accelerated as soon as possible. At the same time, it is a necessity to look into the owner's requirements and the carry out a suitable design which will minimize the renovation waste reduction to a greater extent.

5. Conclusions

An accurate forecast of waste generation is a prerequisite for effective waste management. This study investigated the renovation waste generation in Shenzhen and forecasted the future renovation waste amount based on the grey system theory. Results showed that the GM (1, 1) model is valid for forecasting renovation waste generation. Furthermore, it is forecasted that the amount of renovation waste in Shenzhen is expected to reach 135,620 tons in 2023 if there are no rigid macroeconomic control policies for the real estate market, and the average growth rate of renovation waste in Shenzhen would reach 8.61%. In this circumstance, it is suggested that the local government should make corresponding policies on extending the area of landfills or introduce management measures on reducing renovation waste and increasing its recycling rate.

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