Dynamic Simulation of Construction Waste in Macao

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Abstract: *This paper is the analysis for the behavioral tendency of the construction waste (CW) volume in Macao from 2006 to 2025. Four sources of CW are selected to be the objects of study, which are assumed to constitute all the CW in Macao. Some related factors, such as area of Macao, the average stay time of tourists, population density are also taken into consideration. STELLA 8 is used to perform the analysis, and correlation analysis of parameters will be carried out by a statistic software SPSS (SPSS Inc., Chicago, Ill.). The simulation result shows that the total CW will reach 530128 cubic meters in 2025. The sum of total CW from 2006 to 2025 will have a volume of 13,818,250 cubic meters. From the results of the simulation, the largest portion of CW is generated by casino and hotel projects, which is the main source of CW in the entire simulation period.*
Keywords: *Macao; Construction Waste; Systems Dynamics; Simulation; Stalla; SPSS.*

1. Introduction

Macao is strategically located at the Pearl River Delta of the southeastern coast of Mainland China. With its long association with Portugal, Macao has been playing a vital role as the cultural and economic platform linking China and the Portuguese speaking countries (Fig.1).Macao consists of the Macao Peninsula, Taipa Island, Coloane Island, and some reclaimed land (Cotai). In total, it covers an area of 28.2 km^2 (DSEC, 2006).

The construction industry began to thrive in the late 1980s and early 1990s. The construction industry continued to prosper from that time until 1995. However, from 1995, the construction industry began to slip constantly until 2002 when the liberalization of gambling industry was realized and the regional economic situation became stable again. With such positive factors, the construction industry in Macao managed to rebound from the seven-year-long down trend.

In 2002, the construction industry began to soar largely due to the liberalization of gambling industry. CW includes the construction and demolition wastes (abbreviated as CW behind), it was positively proportional to the development of a city. In recent years, the construction industry is developing by leaps and bounds due to the casinos and hotel projects in Macao, in contrast to 2000 and 2001 when the construction industry slipped. The casinos and hotel projects make the construction industry in Macao bloom, and therefore construction sites are seen everywhere when traveling in Macao. Besides, the infrastructure, such as roads, car parks, public parks and other social facilities must be built in order to satisfy the overall development of the city. As a result, the waste generated during construction is increasing isochronously. Since most of the CW can not be incinerated, it has to be dumped in designated areas of Macao. For environmental concern, the volume of the CW are taking up more and more spaces and new places for dumping CW need to be found since the current dumping areas will soon reach their capacity limits.

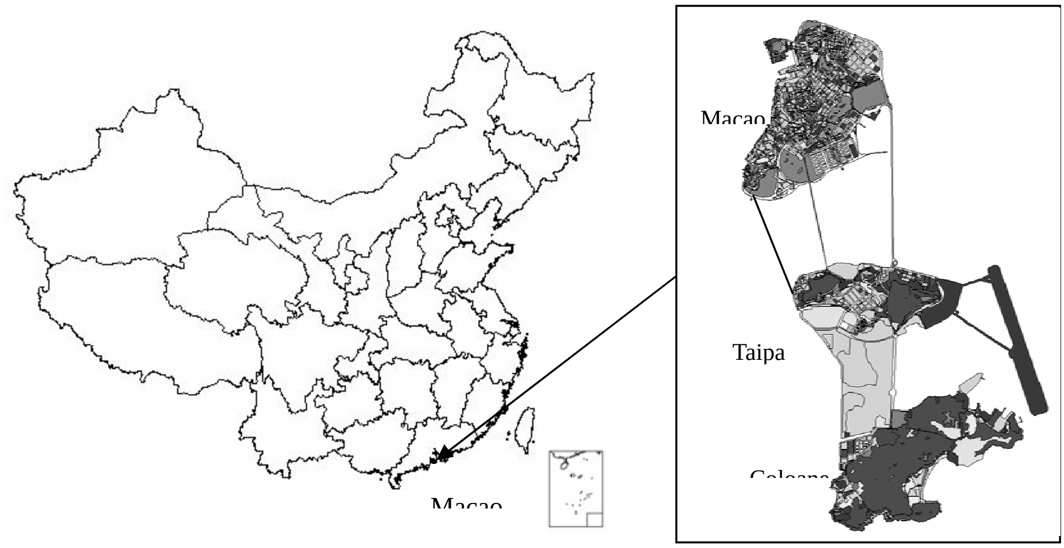


Fig. 1 The location of Macao.

Hence, the cause of CW and the prediction of it are of great significance to environmental protection and urban planning. The Macao government needs to foresee this environmental problem in order to tackle it in advance (The Environment Council, 2006). System dynamics is a powerful methodology and computer simulation modeling technique for framing, understanding, and discussing complex issues and problems.

According to the data published by DSEC of Macao government, the volume of CW in 2003 began to soar due to the commencement of some large-scale casino projects. According to the table published by DSEC (2006), the amount of CW in 2005 is 1294863 m^3, which is over 2 times that quantity of 2004. The yearly increasing rate of CW is 122 % (table1). With this dramatic increasing rate, we believe that the CW is speedily posing an environmental problem to Macao.

Table 1 the quantity of different kinds of solid waste in Macao from 2000 to 2005

Solid wastes(ton)	2000	2001	2002	2003	2004	2005
Domestic(ton)	138 290	138 111	146 642	154 067	154 527	162 131
Commercial & industrial	41 307	41 254	46 308	46 019	51 508	55 456
CW (m^3)	296 860	217 252	244 930	349 090	583 380	1 294 863
Waste collected in sea (m^3)	1 914	2 472	4 188	3 678	3 894	3 612

Most traditional statistical forecasting models, such as the geometry average method, saturation curve method, least-squares regression method, and the curve extension method, are designed based on the configuration of semi-empirical mathematical models. The structure of these models is simply an expression of cause-effect or an illustration of trend extension in order to verify the inherent systematic features that are recognized as related to the observed database (Dyson, 2005). Stella has previous been succeeded to simulate the dynamical trend of Macao' population (Lei and Wang, 2006), tap water consumptions (Lei et al., 2006) and the reclaim projections (Lei and Wang, 2008) since 2004. Case study of municipal solid wastes with Stella can be found in previous study in Texas (Dyson and Chang, 2005), Dhaka (Bala and Sufian, 2007). Furthermore, Hsiao et al. (2002) had employed it to forecast the change of CW in Taiwan, here our research presents the trends of CW generation associated with four different subsystems models using a system dynamics simulation with the software – Stella 8.

2. Methodology

Modeling has been used for years to help scientists and policy makers to find solutions to complex problems. It is one of the most valuable and useful applications of mathematics. Modeling and simulation are intellectually creative and quantitatively rigorous, and it is a ways of connecting ideas with reality. To simplify the explanation, we definite the nomenclature of the CW in Macao as (Fig. 2):

CWCH: CW generated by construction of new casinos and hotels
CWIR: CW generated by interior renovation of residence
CWCP: CW generated by Civil infrastructures and private construction project
CWRO: CW generated by reconstruction of old zones in Macao

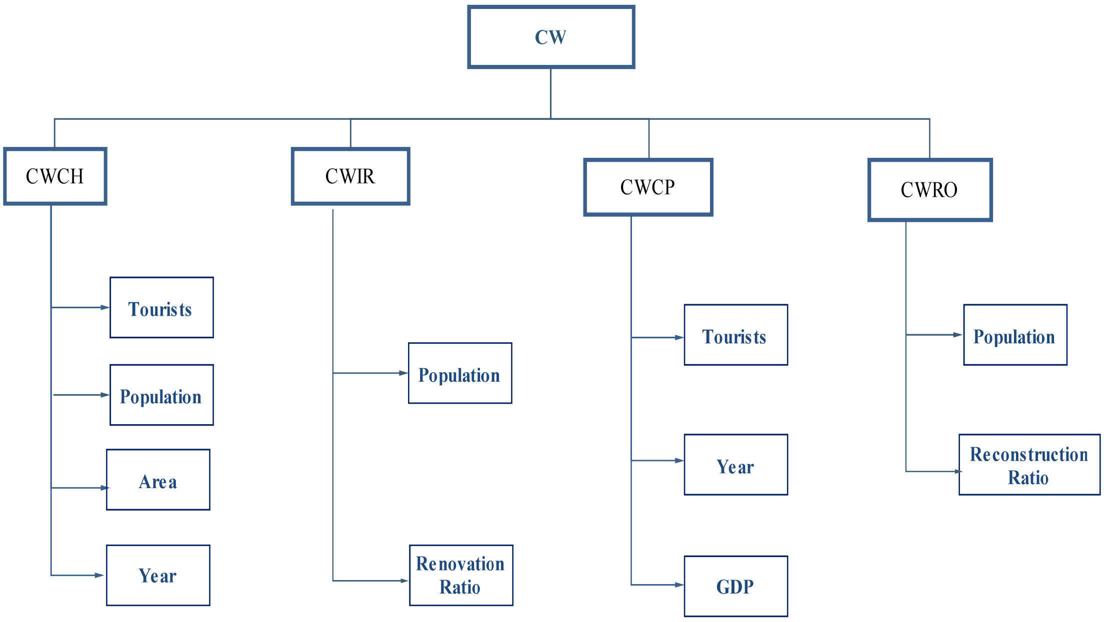


Fig. 2 Components and its correlative parameters in Simulation the CW for Macao

2.1 Dynamic Simulation Tool of CW

Correlation analysis will be performed between various parameters in the relevant ecological system in Macao, such as CW, population, *GDP*, tourists, wastes, time. As for those correlation coefficients which is bigger than 0.9, it is assumed that the level of correlation is high and therefore reliable. All the statistic data are from DSEC. The following equation shows the relations in the generation of CW.

$$CW=f(Popuoation,GDP,Tourist,Wastes,\ time,\ldots)=\sum(CWCH,CWIR,CWCP,CWRO)$$

We let the CW be the dependant variable, and set up the corresponding regression equation by using statistics software. A system dynamics simulation tool – STELLA will be used to perform the simulation, and correlation analysis between the parameters in the selecting the suitable equations will be carried out by statistic analysis software – SPSS (SPSS Inc., Chicago, Ill.). Most of the information about Macao CW, especially parameter values, is obtained from The Statistics and Census Service (2006).

Based on the results of the correlations between the cited data, we obtained some parameters which are run out by SPSS from the foundational statistical analysis, a set of the potential formula were listed. Then we selected out the most suitable equations through the comparison of the real data and the simulated data. Finally, by linked up the relative equations, the model for simulating the entire volume of Macao CW is formed, and a graph for the generation of Macao CW from 2006 to 2025 is derived by running the model.

Sensitivity tests are conducted to ensure the dynamic model to be stable and responsible, so that the simulation results will not change considerably upon high uncertainty of parameter values. Important parameters including tourist normal growth rate, city area in 2025, maximum value for population density and the money spent to generate $1m^3$ CW, are chosen to perform sensitivity tests. The sensitivity tests results are satisfactory and do not show any substantial change of the basic patterns.

2.2 The Modeling Process

Steps of modeling in this research are summarized as Fig.3 (Andrew, 1999). In this research, the model comprises mainly five parts as showed below: Population, CWCH, CWIR, CWCP and CWRO (Fig.4). The STELLA software (Costanza and Gottlieb,1998 (a); 1998 (b); Odum and Odum, 2000) offers an opportunity to create dynamic visual models for studying a wide variety of problems. We used a dynamic model created in STELLA and regression analysis performed using the SPSS statistical software (SPSS Inc., Chicago, IL) to simulate the emergy trends for Macao. For this analysis, we used curve and random methods regression. The suitable regression equations were selected according to two criteria: 1) the equation had to be logical (i.e., it had to provide a causal explanation for an observed trend), and 2) it had to have a high goodness of fit (i.e., R^2). Details of the modeling process of are 5 subsystems were shown in the following section 3.

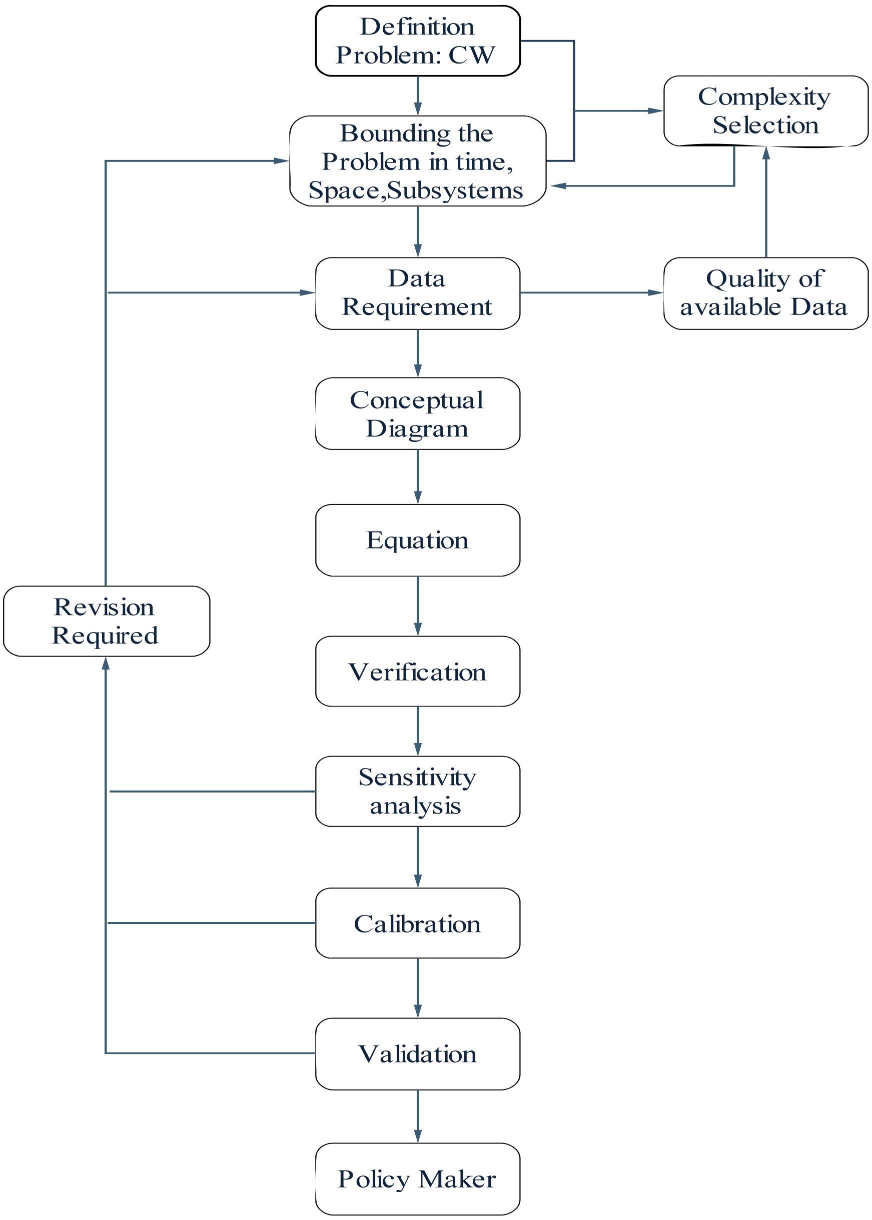


Fig. 3 Flow chart of modeling process of the CW for Macao

3. Simulation of the Subsystems of CW for Macao

For calculating the total CW, we will connect the five sub-systems together to aggregate the generation of CW in Macao from 2006 to 2025. The integrated model is shown in Fig.4. The five sub-systems are put closely and connected by connectors, Population subsystem was the foundational block of the all other subsystems. The 4 components of the CW were connected to form the total CW. Total CW of Macao was the summing result of the four subsystems, *i. e,* CWCH,CWIR,CWCP,CWRO.

3.1 System Dynamics Modeling of Macao population

The population is the fundamental element of a city's growth. It has great effect on the development of a city. Population growth is a complicated dynamic process, which is determined by various factors. In this way, we find out the key factors that have close relation with the growth of population.

These factors are the birth rate, death rate, natural growth rate and immigration. We use STELLA to set up a dynamic model to simulate the dynamic change, including the statistic data of birth rate, death rate and immigration in 1983 to 2007. We assume that the birth rate will fluctuate between the rate of 0.0075 and 0.009; death rate will range from 0.003 to 0.0025. As for the immigrants, we set 3335 people for 2005, which are obtained from the official website. And we assume the immigrants will range between 2000 and 4000 people a year from 2006 due to the outstanding labor importing policy from the authorities, when Macao face the human resource lack when the tourism industry was boomed in the past five years (DSEC, 2006). We also assume that these parameters were random in the simulating processes.

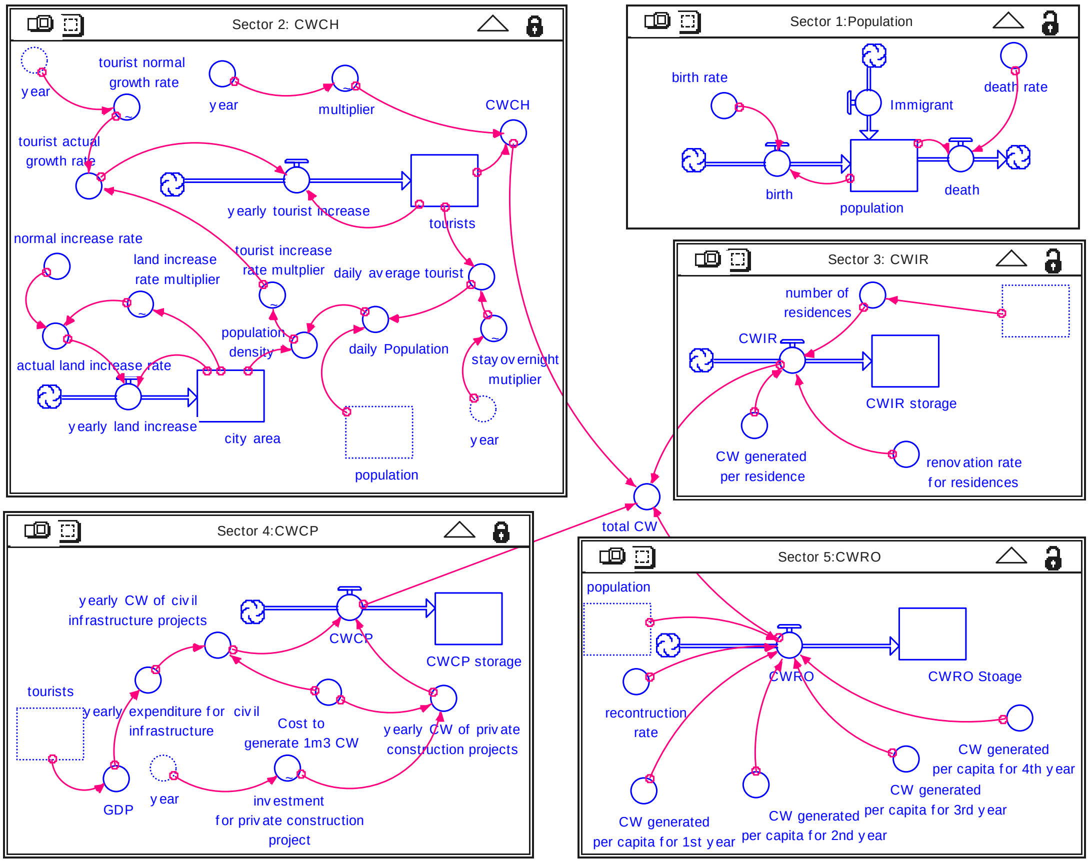


Fig. 4 Model components and its correlative parameters in Simulation the CW for Macao

The simulation equations adopted in the population subsystem was listed as:

Sector 1: Population

population(t) = population(t - dt) + (birth + Immigrant - death) × dt

INIT population = 488.144

INFLOWS:

birth = birth_rate×population

Immigrant = if time=2005 then 2.0755 else if time=2006 then 2.6658 else if time=2007 then 2.17 else if time>2007 then random (2, 4) else 0
OUTFLOWS:
death = death_rate×population
birth_rate = random(0.0075,0.009)
death_rate = random(0.003,0.0025)

The simulated result was shown in Fig. 4.

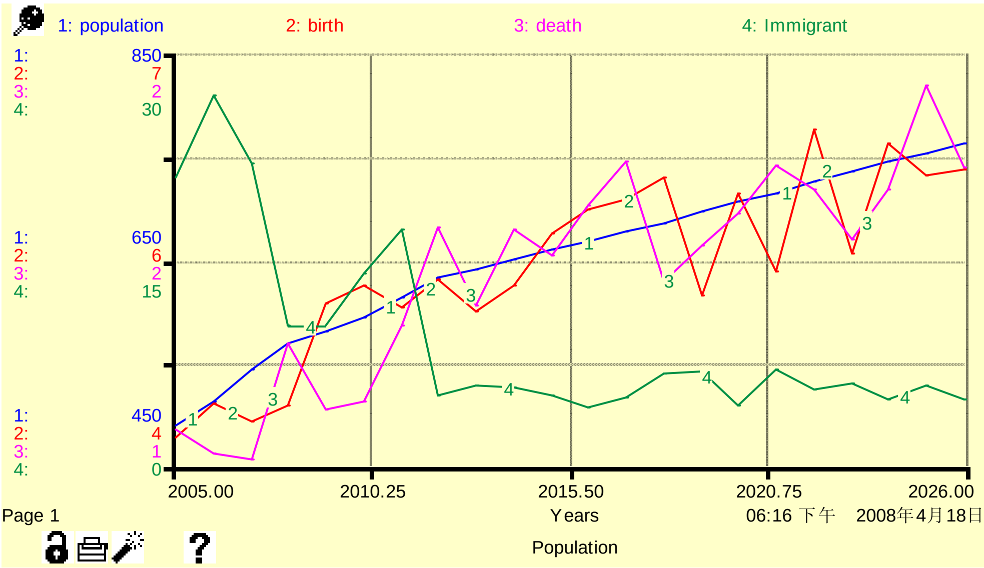


Fig. 5 Simulation graphs of Macao population from 2006 to 2025

In the next 20 years, the births and deaths in Macao will decrease but we expect it to be stable by the fact that better economy will help to ease the burden of raising children. The population of immigration will range from 2000 to 4000 people a year to prevent excessive population expansion while emigration can be neglected for the number is small to the increase of population (Fig.5). In 2025, the total population of Macao will be 608500.

3.2. CW generated by casino and hotel projects (CWCH)

The main force for building new casinos and hotel are the gambling company who want to provide more gambling table and equipment to the tourists, so as to get more profit. In fact, with the liberalization of gambling industry, the quantity of CW will surely increase to some extent. Before finding out the results, necessary information is collected to perform the analysis. As for the CWCH, some reasonable assumption should be made since the Macao government only provides information about the overall CW quantities from 2001 to 2005.

In the first place, we try to find out the tendency of CW growth if the liberalization of casino industry were not carried out. We believe that in such a case the CW in Macao will only grow in a moderate way. Now, we take a look in the CW generation in 2001 to 2005 in the neighboring area, like Hong Kong, as a reference. The data that we obtain in table 2 are from the environmental bureau of Hong Kong (EPD, 2006).

Table 2 CW in Hong Kong (2001-2005)

year	2001	2002	2003	2004	2005
CW(×1000 ton)	6408	10202	6728	6595	6556

From the data, we notice that the generation of CW in Hong Kong remained steady from 2001 to 2005 except for the year 2002. Since Macao was very similar in the city development style, so we may guess that the construction industry in Macao would be performing like Hong Kong without the liberalization of gambling industry.

In this way, we assume that the quantity of CW in Macao from 2002 to 2005 will remain more or less the same as in 2001 if the liberalization of gambling industry were not carried out. According to the survey of the local construction company, we therefore assume that the CW will increase with a yearly increase rate of 1.5%, and 2.0%, 5.0% and 6.0% for the year from 2002 to 2005 respectively excluding the CWCH. Then we can calculate the CWCH, the calculation results are shown in Table 3.

Table 3 Estimated CW in Macao

Year	2001	2002	2003	2004	2005
Estimated CW in Macao without new casinos and hotels	217252	220511	224921	236167	250337
Actual CW in Macao	217252	345881	349090	583380	1294863
* Estimated CWCH	0	125370	124169	347213	1044526

* Estimated CWCH = Actual CW in Macao - Estimated CW in Macao without new casinos and hotels

In order to perform the correlation analysis between the CWCH and the tourists, data of tourists from 2001 to 2005 is collected (see Table 4). In this way, we are going to use SPSS to find out if tourist has reliable correlation with CWCH in recent years.

Table 4 Number of Tourists in Macao from 2001-2005

Year	2001	2002	2003	2004	2005
Tourist (×1000)	10279.0	11530.8	11887.9	16672.6	18711.2

The equation is $CW=3270806.49\text{-}532.487+0.022\ Tourists^2$

here R^2 was 0.929, which can be considered reliable. For carrying out the simulation later, we are going to find out the normal growth rate of tourists in Macao.

The equation was:

$$Tourists = 15531.8 + 2123.695 sequence - 138.802 sequence^2$$

While "*sequence*" referred the sequence numbers of relative year till the final 20. In this equation the R^2 was 1, we will use the yearly growth rate of tourist in the simulation latter. The above equation was used to simulate the CVCH.

In our assumption of the intervals of construction projects from 2005 to 2025, the principle we use is to make the intervals of construction projects continuous according to the current situation of construction industry for casinos and hotels. Generally, the construction period of a new casino and hotel is about 3 years in Macao, according to the survey of the ongoing projects data, he assumption of the construction projects interval are shown in Table 5.

Table 5 The ongoing Casino and Hotel Project from 2001 To 2012

Period	2001 -2004	2002 -2005	2003 -2006	2004 -2007	2005 -2008	2006 -2009	2007 -2010	2008 -2011	2009 -2012
Number	1	1	3	6	3	2	1	1	1

The final project is assumed to be scheduled to commence in 2009 and end in 2012, when all the casinos and hotels in the Cotai Gaming strip are supposed to be completed. New projects of casino and hotel will become less and less, and the CWCH will be mostly renovation works. Since the newly built casinos and hotels occupy large area, we can foresee that their renovation works will also generate a considerable amount of CW. From 2012, we have added a component which will generate a certain amount of CW each year. This is due to the renovation works in casinos and hotels. The first periods from 2012 to 2018 will generate 80000 to 100000 cubic meters of CW, while from 2019 to 2025 there will have 90000 to 120000 cubic meters of CW. The reason for setting two different amount of CW is that more casinos and hotel will have to do some changes for the interior environment and renovation several years after their completion. For this, we can generate a curve based on the previous assumption which indicates the relation of CW from one year to another (Fig. 6)

We will use this curve to adjust the CWCH in this chapter. The method to adjust the CW is to multiply the original CW with the multiplier. The multiplier is obtained by dividing the quantity of CW each year by the quantity in 2006. We use these multipliers to simulate the CWCH. The simulation equations adopted in the CWCH subsystem was listed as:

Sector 2: CWCH
area_of_Macao(t) = area_of_Macao(t - dt) + (yearly_land_increase) × dt
INIT area_of_Macao = 27.5
INFLOWS:
yearly_land_increase = area_of_Macao×actual_land_increase_rate
tourists(t) = tourists(t - dt) + (yearly_tourist_increase) × dt
INIT tourists = 18711
INFLOWS:
yearly_tourist_increase = tourists×tourist_actual__growth_rate

actual_land_increase_rate = land_increase__rate_multiplier×normal_increase_rate
CWCH = (3270806.5-532.487×tourists+0.022×tourists×tourists)×multiplier
daily_average_tourist = tourists/365×stay_time_mutiplier
daily_Population = population+daily_average_tourist
normal_increase_rate = 0.03
population_density = daily_Population/area_of_Macao
tourist_actual__growth_rate = tourist_normal__growth_rate×tourist_increase_rate_multplier
year = time
land_increase__rate_multiplier = GRAPH(area_of_Macao)
(27.5, 1.00), (28.1, 0.9), (28.8, 0.8), (29.4, 0.7), (30.1, 0.6), (30.7, 0.5), (31.4, 0.4), (32.0, 0.3), (32.7, 0.2), (33.3, 0.1), (34.0, 0.00)
multiplier = GRAPH(year)
(2005, 1.00), (2006, 0.815), (2007, 0.453), (2008, 0.299), (2009, 0.23), (2010, 0.103), (2011, 0.0322), (2012, 0.0394), (2013, 0.03), (2014, 0.0373), (2016, 0.0292), (2017, 0.0376), (2018, 0.0506), (2019, 0.0517), (2020, 0.0517), (2021, 0.0414), (2022, 0.05), (2023, 0.0487), (2024, 0.0474), (2025, 0.062)
stay_time_mutiplier = GRAPH(year)
(2005, 1.50), (2007, 1.54), (2009, 1.59), (2011, 1.64), (2013, 1.69), (2015, 1.74), (2017, 1.78), (2019, 1.84), (2021, 1.89), (2023, 1.94), (2025, 2.00)
tourist_increase_rate_multplier = GRAPH(population_density)
(19.8, 0.995), (20.3, 0.97), (20.8, 0.81), (21.2, 0.535), (21.7, 0.39), (22.2, 0.27), (22.7, 0.165), (23.1, 0.08), (23.6, 0.04), (24.1, 0.01), (24.6, 0.00)
tourist_normal__growth_rate = GRAPH(year)

(2005, 0.122), (2006, 0.143), (2007, 0.139), (2008, 0.134), (2009, 0.129), (2010, 0.123), (2011, 0.118), (2012, 0.113), (2013, 0.108), (2014, 0.104), (2015, 0.0995), (2016, 0.0955), (2017, 0.0917), (2018, 0.0882), (2019, 0.0848), (2020, 0.0817), (2021, 0.0788), (2022, 0.0761), (2023, 0.0735), (2024, 0.0711), (2025, 0.0688)

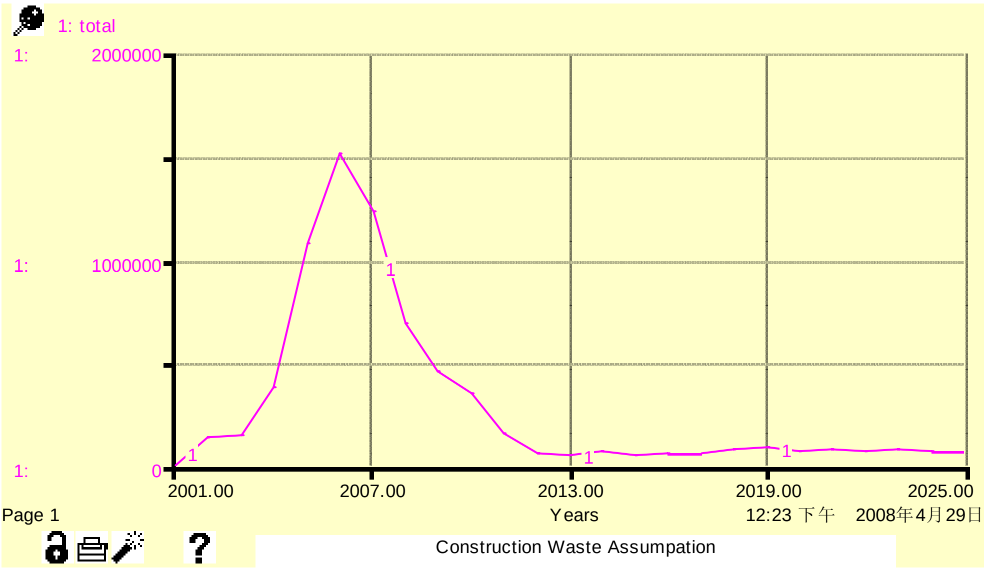


Fig. 6 The assumption of the CWCH curve

For this, we can generate a curve based on the previous assumption which indicates the relation of CWCH, and the brief result shown in Fig.7.

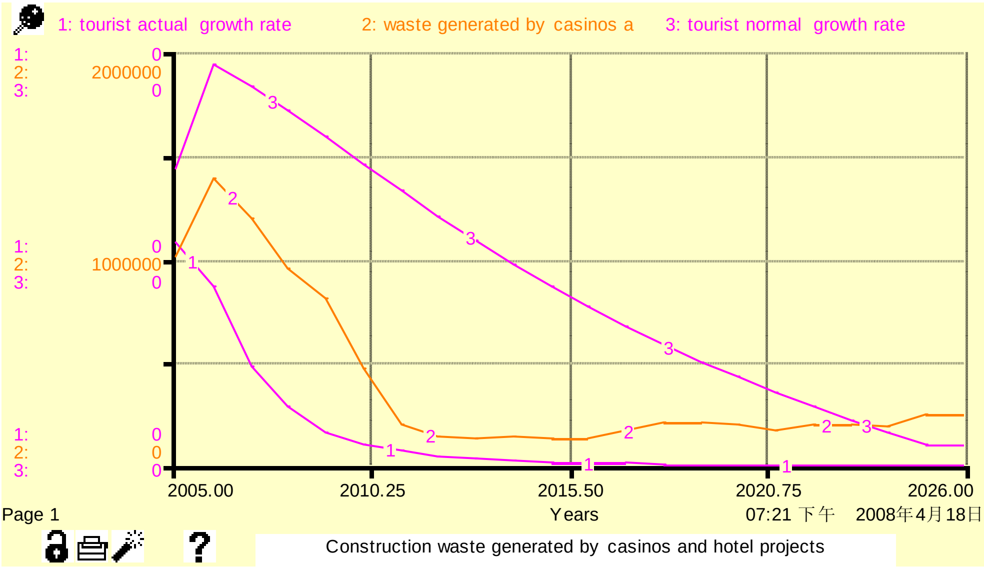


Fig. 7 Simulation results of the CWCH

3.3. CW generated by interior renovation in residences (CWIR)

This subsystem is to simulate the generation of CW from the redecoration or renovation of local residences. We suppose that two out of ten families will carry out interior redecoration every 5 years. In Macao from the statistical data that most of the family lives in the apartment with the area of about 600 square feet apartment that is composed of one parlor, two rooms, one toilet and one kitchen (Fig.8). And we assume that the family will renew the floor tiles in the parlor, the wall tiles in the kitchen and toilet.

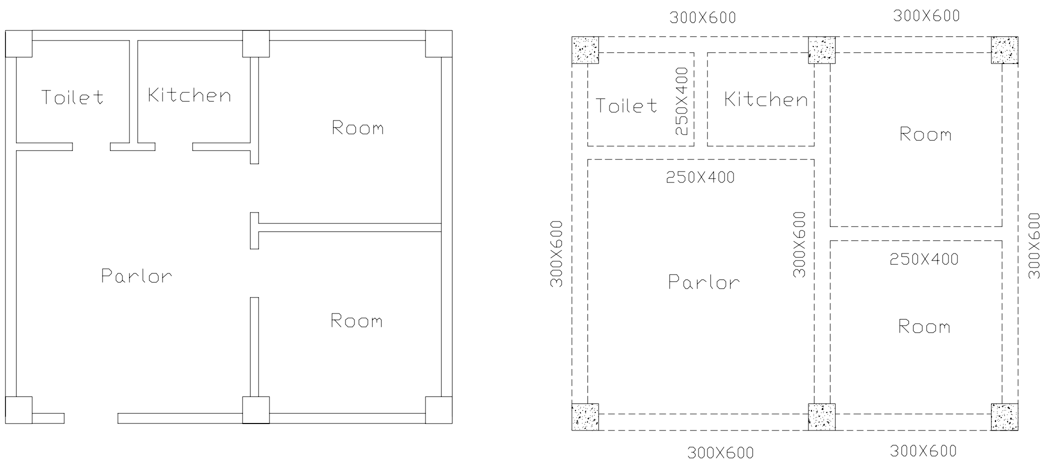


Fig.8 Apartment unit for calculating the wastes from demolition of old buildings

Table 6 Calculated of CWIR

Components	width (m)	height (m)	length (m)	volume (m^3)
Floor finishing(screeding and tiles)	7.00	0.04	8.00	2.24
Ceiling(plastering and paint)	7.00	0.01	8.00	0.56
Plastering, tiles and paint	0.02	3.00	72.60	4.36
Door,window,other indoor facilities	---	---	---	2.00
Total				9.16 m^3

From Table 6, we get the result that the unit volume of CW of the apartment is about 9.16m^3. For simplicity, we are going to use 10.0 m^3 in the following model simulation. Now we are able to calculate the yearly CW generated by the renovation works.

We make an assumption that six people constitute a family in average, and then in 2005 there are 81357 residences in Macao of the above apartment unit. Then the yearly CWIR in 2005 should be: $81357 \times 0.2 \times (1/5) \times 10 = 32543\ m^3$

The CWIR will increase with the growth of Macao's population yearly. The simulation equations adopted in the CWIR subsystem listed as:

Sector 3: CWIR

CWIR_storage(t) = CWIR_storage(t - dt) + (CWIR) × dt

INIT CWIR_storage = 150

INFLOWS:

CWIR = number_of__residences×renovation_rate ×CW_generated__per_residence

CW_generated__per_residence = 10

number_of__residences = int(population×1000/6)

renovation_rate_for_residences = 0.04

The renovation rate for residences is the factor 2/10 times 1/5=0.04. The result is an average rate. The simulation graphs and results are shown in Fig. 9, indicating that these wastes are almost linearly growing upward with the steady increase of population.

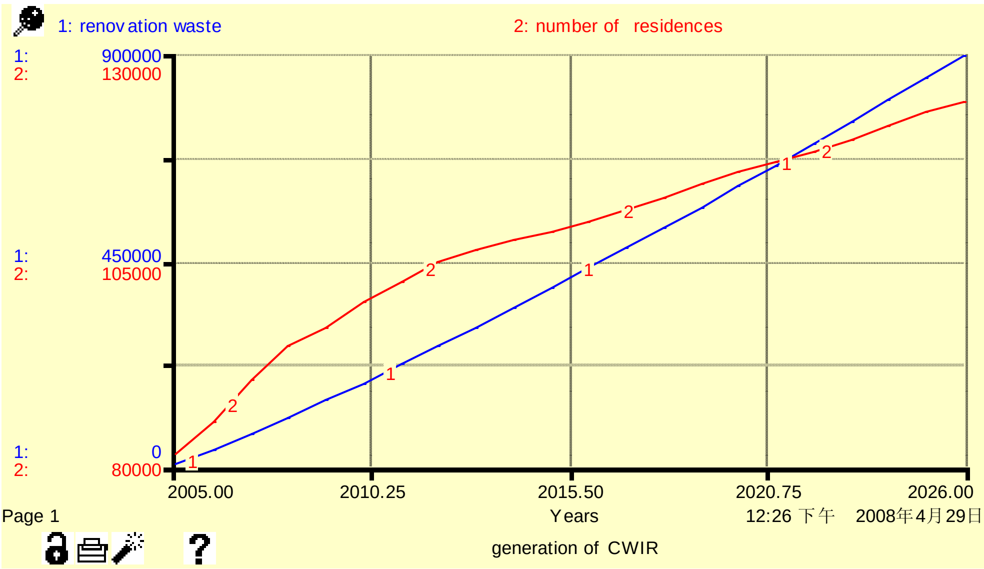


Fig. 9 Simulation results for CWIR

3.4 CW of Civil infrastructures and private construction project (CWCP)

Infrastructure is crucial to the development of a city. Infrastructure need to be planned out and set up when a city is steadily developed. In Macao, billions of MOP were invested to build various kind of civil infrastructure in order to suit the development of Macao in various aspects. Since the money spent for civil infrastructure is paid by Macao government, we try to find out the trend of the expenditure for civil infrastructure.

As the government income has close relation with Macao GDP (Unit: MOP, Macao's currency, 1 USD=8.023 MOP), so we try to establish a correlation between expenditure for civil infrastructure and Macao GDP. The GDP and Civil Infrastructure expenditure Value from 2000 to 2005 are listed in Table 7.

Table 7 GDP and Civil Infrastructure Expenditure Values from 2000 to 2005

year	GDP of Macao (×1000) MOP	Civil Infrastructure expenditure (×1000)MOP
2000	48972396	865067
2001	49704405	989804
2002	54818745	1344531
2003	63566339	2357179
2004	82899311	3386110
2005	92590984	4331432

* The Civil Infrastructure expenditure is obtained from "GOVERNMENT INVESTMENT AND DEVELOPMENT PLAN"

By using SPSS, the expenditure of civil infrastructure is found to have close correlation with Macao's GDP. The R Square value is 0.99 and we get a regression curve that shows the civil infrastructure grows almost linearly with the growth of GDP. The equation for calculation is:

$$\textit{Expenditure for infrastructure} = -4317249.792+0.123\times GDP-3.29E\text{-}010\times GDP^2$$

With the growing number of tourists in Macao, more tourists will visit the casinos and the casino income will increase accordingly, and the tax income of Macao government will increase too. As a result, GDP is affected by the number of tourists in Macao. In order to predict the Macao's GDP by the number of tourists, we carry out regression analysis between these two variables.

We use SPSS to perform the regression analysis between GDP and tourists and get the results.The R square coefficient is 0.809 which is near 0.81 and it can be considered reliable.The equation for calculation is $GDP = 13552063.828+4079.982\times Tourists$

For private projects, the investments can be calculated by the data found in the DSEC website. In the DSEC website, we have data of the area of completed private building from 1991 to 2005. We can estimate the yearly investment for private projects by multiplying the area of completed building by the unit price per square meter. Since the data of the unit prices can be obtained from 2002 to 2005, we can only work out the reference unit price in this period. The relevant data are listed in Table 8 and Table 10.

Table 8 Total area of completed buildings and transaction price from 2002 to 2005

Year	Total area of completed building (m^2)	Average price of residential units per m^2	Average price of office units per m^2	Average price of industrial units per m^2
2002	102549	6261	10759	2199
2003	243023	6377	9536	2082
2004	215108	7984	10227	2410
2005	391487	10024	13609	3347

Table 9 Area completed of various kind of units

Year	Area of completed residential units(m^2)	Area of completed office units(m^2)	Area of completed industrial units(m^2)	Area of other completed units (m^2)
2002	36387	4380	4851	56931
2003	153712	24709	14319	50283
2004	122125	18860	5187	68936
2005	161015	23395	0	207078

For calculating the general unit price per square meter, we first calculate the proportion of different kind of unit in the total completed area; the results are shown in Table 10.

Table 10 Proportion of completed units

year	Proportion of completed residential units/transaction price	Proportion of completed office units/transaction price	Proportion of completed industrial units/transaction price	Proportion of other completed units/transaction price
2002	0.3548/6261	0.0427/10759	0.0473/2199	0.4448/6406
2003	0.6325/6377	0.1017/9536	0.0589/2082	0.2069/5998
2004	0.5677/7984	0.0877/10227	0.2411/2410	0.1035/6874
2005	0.4113/10024	0.060/13609	0/3347	0.5287/8993

The transaction price of other completed unit is assumed to be the average value of the preceding three transaction prices. From Table 10, we are able to sum up the four transaction prices each year with their proportion, and we can get the general price per square meter from 2005 to 2002 is 9694, 6722, 6367, 5634 MOP respectively.

For the private investments after 2005, we assume that the investments keep increasing until 2010, then it goes down gradually from 2011 to 2025.For the simulation of CW of this kind, we use the money spent to simulate the CW. Firstly, we calculate how much money spent to generate one cubic meter of CW. Then we divide the sum of expenditure of the infrastructure and private projects by the CW of this kind. In the simulation, the value of general unit price for private building in 2005 (9694 MOP) will be used in the entire modeling process. The simulation result is shown in Fig. 10.The simulation equations adopted in the CWCP subsystem listed as:

Sector 4:CWCP

CWCP_storage(t) = CWCP_storage(t - dt) + (CWCP) × dt

INIT CWCP_storage = 221630000

INFLOWS:

CWCP= yearly_CW_of_civil__infrastructure_projects + yearly_CW_of_private_construction_projects

Cost_to__generate_1m3_CW = 32462

GDP = 4079.982×tourists+13552063.828

yearly_CW_of_civil__infrastructure_projects = yearly_expenditure_for__civil__infrastructure / Cost_to__generate_1m^3_CW

yearly_CW_of_private_construction_projects = investment_for_private_construction_project/Cost_to__generate_1m^3_CW

yearly_expenditure_for__civil__infrastructure = (0.123×GDP-(3.29E-10)×GDP×GDP-4317249.792)×1000

investment_for_private_construction_project = GRAPH(year)

(2005, 3.8e+009), (2007, 4.2e+009), (2009, 4.4e+009), (2011, 4.4e+009), (2013, 4.4e+009), (2015, 4e+009), (2017, 3.3e+009), (2019, 2.9e+009), (2021, 2.5e+009), (2023, 2.3e+009), (2025, 2.3e+009)

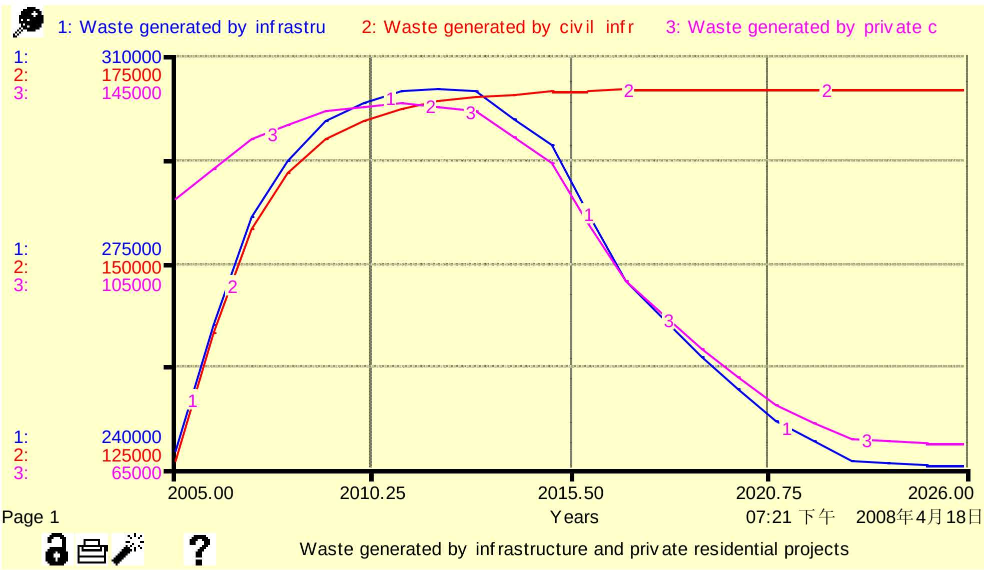


Fig. 10 Simulation graphs result for CWIP

3.5 CW generated by reconstruction of old zones in Macao (CWRO)

CWRO in Macao locates in the old district in the North of Macao peninsula. The

CWRO has also a large quantity. We assume that the speed of reconstruction of old buildings depends on the growth of total population of Macao in that almost all the old buildings in the old district are not more than 5 storey high, which can not accommodate as much population as high buildings can do. As a result, reconstruction of old buildings can solve the dangers from deterioration of building structures, and contain more people in the newly high buildings. In this way, we assume that the rate of reconstruction is expressed in terms of percentage in population. In fact, the CW generated from reconstruction is not a steady quantity, it varies dramatically. For example, in the first stage of reconstruction is to demolish the structure of old buildings. In this stage, large volumes of concrete and brick debris will be generated and carted away. The volume of CW in this stage is much higher than the latter stages. For this reason, we assume that the construction time for reconstruction of one building needs 4 years, and the CW generated in all the latter stages is about 50% of the volume in the demolition stage.

Thus, for simple simulation, the quantity of CW generated will be expressed in cubic meter per capita yearly. We assume that in the old building for reconstruction, a department of 500 square ft. can accommodate 6 people, and the CW generated from reconstructing the apartment will be the volume of the unit as shown in Fig. 7.

This residential unit is composed of one parlor, one kitchen, one toilet and two rooms. We apply the general dimension of reinforced concrete building structure and architectural finishing to make assumption of the above residential unit. The data are assumed in Table 11.

Table 11 Assumption of configuration of the existing apartment units to be demolished

Architectural or structural configuration	Dimension
Storey height	3.0m
Thickness of floor slab	120mm
External brick wall	200mm
Internal brick wall	150mm
Primary beam	300X600mm
Secondary beam	250X400mm
Column	500X500mm
Average thickness of floor finishing	30mm
Average thickness of wall finishing	20mm

Then we use the above data to calculate the total volume of the CW of the above residential unit (Table 12) .

Table 12 Calculation of CW for one apartment unit

Components	width (m)	height (m)	length (m)	volume (m^3)
Beam	0.30	0.60	31.00	5.58
	0.25	0.40	8.30	0.83
Column	0.50	0.50	18.00	4.50
Floor slab	7.00	0.12	8.00	6.72

Brick Wall	0.20	3.00	24.10	14.46
	0.15	3.00	12.20	5.49
Floor finishing (screeding and tiles)	7.00	0.04	8.00	2.24
Ceiling(plastering and paint)	7.00	0.01	8.00	0.56
Plastering, tiles and paint	0.02	3.00	72.60	4.36
Door, window, other indoor facilities	---	---	---	5.00
Total				49.74 m^3

The total volume is 49.74m^3 . However, we have to introduce the density factor into the calculated result because the density of the CW when dumping is smaller than its original form. We assume that the total volume has to be multiplied by a density coefficient 1.3. Then the volume will become 63.93m^3 .

Since there are other public structure components in the old building, like the corridor, stairs and roof house, we will multiply the results by another correction factor 1.3 to compensate for these structure components and make the result reasonable. Then we divide the result by 6 people, and we are able to get the CW generated per capita. The value is 13.85 m^3 , and we will use for 14 m^3 simplicity.

In this subsystem, we have added a factor to dynamically simulate the CW. The factor is the population. When the population grows, it demands more spaces to take up the population. When the space is limited, one solution is to replace those low and old buildings with some higher buildings which is in line with the general city planning. In this model, we assume the reconstruction rate be 0.2% of the population. It means that 0.2% of the population, or approximately 1000 people will be involved in the reconstruction projects. When the population increases, the number of people involved in the reconstruction projects will increase also. For the initial number of people involved in the reconstruction projects, it needs about ten buildings of five-storey high to accommodate.

The CW generated per year is different from one year to the next. The CW that we calculated above is only for the demolition stage. The latter stage will also generate a certain amount of CW, but it will be relatively less than in the demolition stage. In this model, we assume that the reconstruction of one old zone in Macao will take four years. The first year will generate the most waste. In this year, the demolition and foundation works will carry out. In the second year, it will proceed with the framing works, which will produce less waste. In the third year, the construction enters into the interior partition and decoration works, which will produce more waste than the previous year. In the final year, the construction is near its end, and the waste produced in this year will become less. We assume that the wastes generated in the second and the final year is the same. And we assume that the total CW generate in the entire reconstruction period will be the total quantity in demolition stage plus its 50% volume. That means the CW per capita in the four years' reconstruction period was $14\times1.5=21$ m^3 in total.

Therefore, we assume the CW generated per capita in the reconstruction period are divided into: 1) 14 m^3 of first year, 2) 1.8 m^3 of the second year, 3) 3.6 m^3 of the third year and 4) 1.6 m^3 of the fourth year. We will use the following equations in the simulation of the CWRO.

Sector 5:CWRO
CWRO_Stoage(t) = CWRO_Stoage(t - dt) + (CWRO) × dt
INIT CWRO_Stoage = 0
INFLOWS:
CWRO = if time=2010 or time=2014 or time=2018 or time=2022 then population×1000×recontruction_rate×CW_generated__per_capita_for_1st_year else if time=2011 or time=2015 or time=2019 or time=2023 then population×1000×recontruction_rate×CW_generated__per_capita_for_2nd_year else if time=2012 or time=2016 or time=2020 or time=2024 then population×1000×recontruction_rate×CW_generated__per_capita_for_3rd_year else if time=2013 or time=2017 or time=2021 or time=2025 then population×1000×recontruction_rate×CW_generated__per_capita_for_4th_year else 0
CW_generated__per_capita_for_1st_year = 14
CW_generated__per_capita_for_2nd_year = 1.8
CW_generated__per_capita_for_3rd_year = 3.6
CW_generated__per_capita_for_4th_year = 1.6
recontruction_rate = 0.002

4 Aggregating CW in Macao

We use STELLA to simulate CW from 2006 to 2025. The results are shown in Table 13. The simulation graph is shown in Fig. 11.Since some of the data that we use in the model are uncertain to some extent; we will therefore conduct sensitivity tests to prove if this model is still robust if these data vary.

Table 13 The simulation results of CW in Macao from 2006 to 2025

Year	CWCH	CWCP	CWIR	CWRO	Total CW
2006	1386871	263921	34100	0	1684892
2007	1190476	282373	36106	0	1508955
2008	947903	292021	37776	0	1277700
2009	799581	298810	39303	0	1137694
2010	466946	301770	40325	16937	825977
2011	192164	303958	41467	2239	539828
2012	136146	304098	42540	4594	487379
2013	126351	303847	43158	2072	475428
2014	128536	299242	43716	18361	489854
2015	126493	294519	44410	2398	467820
2016	125900	283095	44904	4850	458748
2017	163780	271630	45370	2178	482959
2018	195416	265132	45929	19290	525767

2019	198281	258586	46598	2516	505981
2020	188372	253195	47277	5106	493950
2021	165223	247804	47843	2296	463166
2022	190812	244338	48322	20295	503768
2023	186157	240873	48857	2638	478525
2024	184429	240488	49471	5343	479731
2025	237680	240103	49948	2398	530128

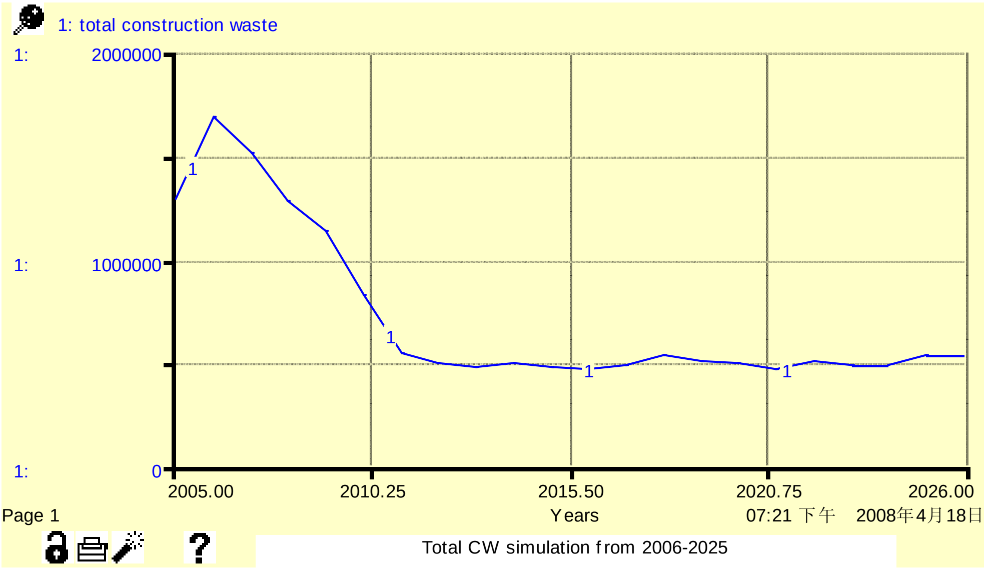


Fig. 11 Total CW simulation from 2006-2025

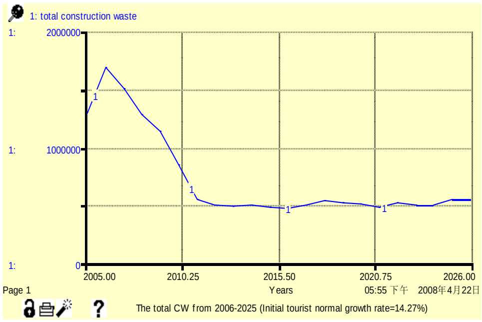
5. Sensitivity Analysis

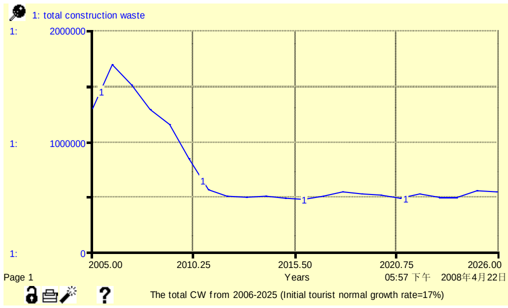
For such analysis, we choose four parameters, which are assumed to be important to the results of the simulation, to conduct the sensitivity tests. The model will be rerun by different values of the following parameters.

a) Tourist normal growth rate
b) City area in 2025
c) Maximum value for population density
d) Money spent to generate 1m^3 CW

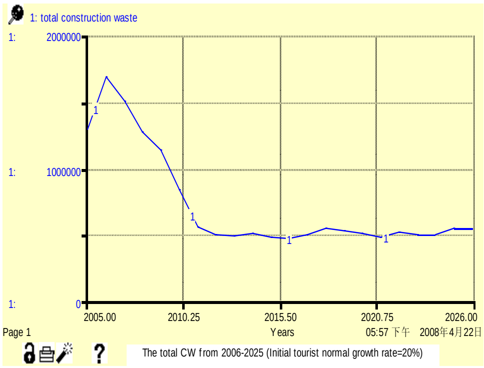
The first parameter is tourist normal growth rate. In the model, we assume that the growth rate is according to Table 4.14 with an initial growth rate of 14.27% in 2006. Now we assume that the initial value would be changed to 17%, 20% or 23%, but with the overall trend of the tourist growth rate unchanged. Because this parameter is a graphic input, we can not directly use the sensitivity function of STELLA. We will manually change the value of the parameter in the model. Then we are able to get the graphs of total CW when the tourist normal growth rate changes (Fig.12), the 4 curve shows very diffident in quantity, so this parameter was sensitivity.

a) b)





c) d)



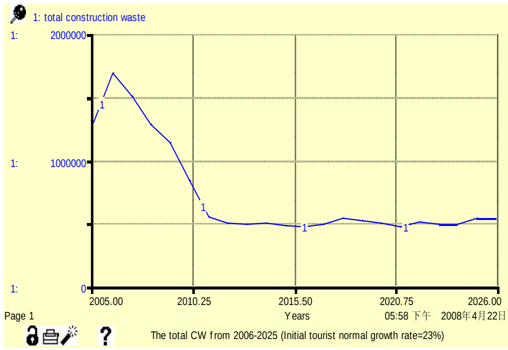
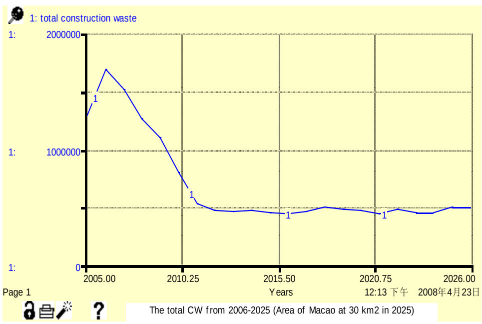


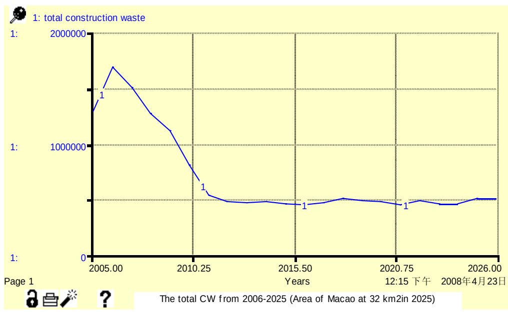
Fig. 12 The total CW from 2006-2025

(Initial tourist growth rate set as a)14.27%, b) 17% , c) 20% and d) 23%)

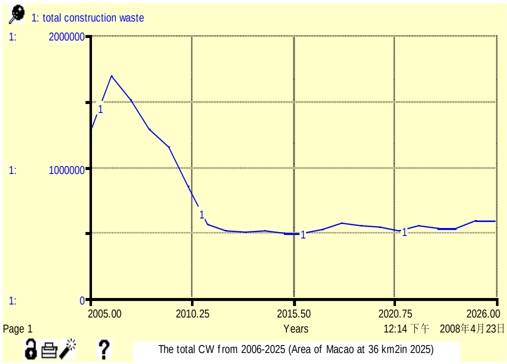
The second parameter is the city area at 2025. We assume it to be $34km^2$ earlier, now we assume that it is possible to be at $30km^2$, $32km^2$, $36km^2$ and $38km^2$, then we conduct a sensitivity test concerning this parameters. The parameter is also a graphic input, so we will simply change the value of the parameter in the model and run the simulation to get the graphs. Then we are able to get the graphs of total CW when Macao's area changes (Fig.13), the 4 curve shows very diffident in quantity, so this parameter was sensitivity.

a) b)





b) d)



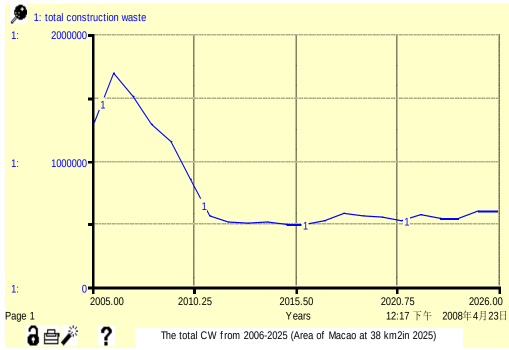
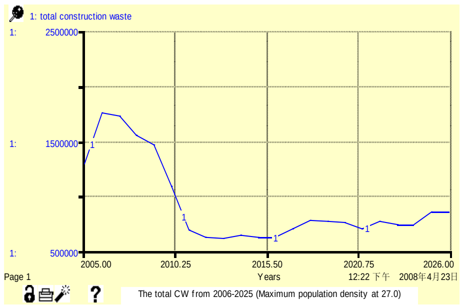


Fig. 13 The total CW from 2006-2025 when the area set as a) 30 km^2,b) 32 km^2,c) 36 km^2 and d) 38 km^2 in 2025.

The third parameter is the population density. In the model, we set the maximum density at 24.55 when the tourists can not grow any further. Now we set it at 22.0, 27.0 and 30.0. Since the parameter is also a graphic input, we will manually change the value of the parameter in the model and the get the graphs. Then we are able to get the graphs of total CW when Macao's population density changes (Fig.14), the 4 curve shows very diffident in quantity, so this parameter was sensitivity.

a) b)



c)

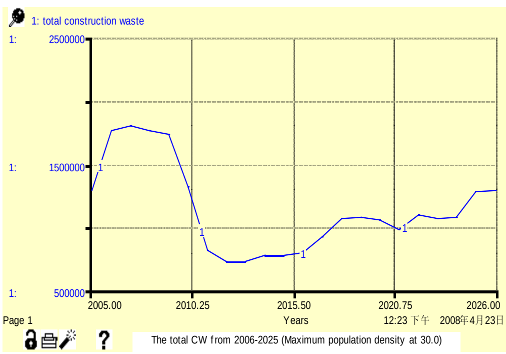


Fig. 14 The total CW from 2006-2025, (Maximum population density set at a).22000, b).27000 and c).30000 person/km^2.

The last parameter that we conduct a sensitivity test is the money spent to generate 1 cubic meters of CW in the civil infrastructure and private projects. In the model, we use the calculated value in 2005 (32462 MOP) to generate one cubic meter of CW. Since this value varies from 2002 to 2005 due to inflation, now we assume the value will range from 2000 to 5000 MOP, and then we conduct the sensitivity test by the sensitivity function in STELLA using incremental values from 2000 to 5000 MOP. The curves show very diffident in quantity, so this parameter was sensitivity.

The graph of the sensitivity test result is shown in Fig.15.

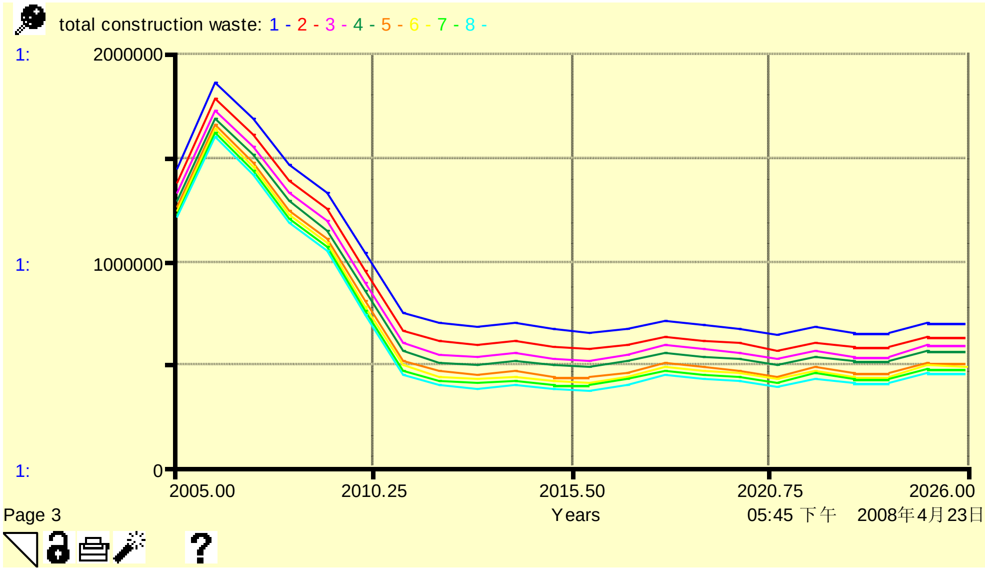


Fig. 15 Sensitivity results for the money flow to generate 1 cubic meter of CW

In summary of all above sensitivity test, the basic patterns of the graphs are all alike despite we use different parameter values to simulate the same model. That means the model is immune to the uncertain parameter values, and we can say this model is a strong, or robust model.

6. Conclusion

In the research, system dynamics models are built up for the simulation of the CW generation in Macao. The results of the simulation show that the CW will be generated in an increasing way from 2013. In 2010, 2015, 2020 and 2025 the percentage of different CW is shown in table 14.The results are summarized as follows:

1) The total CW will reach 530128 cubic meters by 2025.
2) The CWCH will reach 237680 cubic meters by 2025.
3) The CWCP will reach 240103 cubic meters by 2025.
4) The CWIR will reach 49948 cubic meters by 2025.
5) The CWRO will reach 2398 cubic meters by 2025.

Table 14 The distribution of the simulated CW in 2010, 2015, 2020 and 2025

Percentage in Total CW	2010	2015	2020	2025
CWCH	73.89%	57.75%	72.39%	77.84%
CWCP	22.77%	37.99%	24.20%	19.34%
CWIR	2.35%	4.05%	3.07%	2.69%
CWRO	0.99%	0.22%	0.33%	0.13%

The sum of total CW from 2006 to 2025 is 13,818,250 cubic meters. Its volume is equal to a cube of 240×240×240 meters.

From the results of the simulation, we know that the largest portion of CW is generated by casino and hotel projects, which are the main source of CW during the entire simulation period.

The simulation result indicates that the total CW generated in 2025 will up to around 530128 cubic metres and its peak value is counted in 2009 with a volume of 1, 684892m^3. It shows that the increasing volume of CW requires a large dumping area to accommodate such a large volume of non-incinerated waste.

From the Table 14, we notice that from 2011 to 2016, the proportion of CW from the civil infrastructure projects and the private projects increases as the construction of new casinos and hotels is near its saturation.

The CW generated by reconstruction of old zone in Macao only constitute a small portion of the total CW from 2010, the year which we assume the Macao government will commence the reconstruction of old zones. In fact, the pace of the reconstruction of old zone is still pending due to the disagreement between government and the residents in the old zone concerning the compensation issues and temporarily accommodation problems. The thriving public and private civil construction has apparently increased the amount of CW recently. Since CW is generated in great volume, Macao is experiencing immense pressure on its limited landfill capacity. Long-term solutions are therefore crucially needed.

Macao government is now facing a high pressure on improving the public transportation in the entire city, and carrying out reconstruction of old zones. New projects like extension of Macao airport, Macao overhead railway system project, Macao-Taipa submarine tunnel will be launched in the near future. The government's tax income from gambling industry provides a solid base for carrying out these projects. These projects will last for several years and push the construction industry forward. As such, we can foresee that the slowdown of building new casinos and hotels will not cause the quantity of CW to decrease in a significant way.

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