Application of System Dynamics model and GIS in sustainability assessment of urban residential development

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Abstract: : Considering rapid population growth and urbanization, sustainability assessment of residential development has become increasingly necessary for understanding environmental impacts and supporting urban planning. In this paper, due to the urban activities cause impacts not only on local level but also a broader scale, a simulation model, using System Dynamics (SD) methodology, was structured to quantitatively investigate the developmental tendency of housing demand and supply. And then the estimated results were displayed in ArcGIS and CityEngine. The integration of GIS and SD model can better explain the interaction and the variation with time of the sustainable indicators for residential development. Hence it's able to support the Decision Maker to view the sustainable level of urban residential areas more comprehensively.

Keywords: sustainability, residential development, System Dynamics model, GIS, 3D visualization.

1, Introduction

During the past decades, urban residential development has speed up extremely with massive population mobility in cities. In 2009, the United Nations estimated that the world's population is projected to reach 7 billion in late 2011, up from the current 6.8 billion, and surpass 9 billion people by 2050 (United Nations, 2009). Urban residential areas, facing restriction by social-economic level, environmental pressure, population pressure and traffic pressure, etc, attract growing attentions nowadays as an important component of sustainability study. Sustainability is a multi-dimensional concept that takes into account different elements of territorial development, such as economic growth, well-being of population, environmental quality, etc. (Bruntland, 1987). Since the early '90s many countries and international organizations have been working on sustainable development assessment by means of specific indicators (World Bank, 1997; OECD, 1993; Lisa, 2002). With specific reference to urban areas, the indicator approach is useful to give information about the sustainability condition of the system under examination and it can be used in order to make previsions about future sustainably trends (Bottero & Mondini, 2003; Brandon & Lombardi, 2005; Nessa & Montserrat, 2008).

This paper presents research to develop an integration of System Dynamics (SD) and GIS technology for sustainability assessment of urban residential development. The methodology presented here is capable of forecasting residential development and considered in relation to sustainability indicators of four main sectors: housing, society, economics and environment. System Dynamics is a realistic tool for sustainability assessment, utilized to better understand the sustainable development in a considered period and forecast the future trends, while GIS technology provides a consistent visualization environment for displaying the input data and results of a model which is a very useful ability in a decision-making process. Although it is a hard task to forecast the future evolution for assisting policy makers due to the hypercomplexity of the systems, it is necessary to provide the decision makers with assessments regarding the future (Brans et al. 1998). The paper attempts to provide a tool that is able to inform the Decision Maker on whether residential urban areas develop sustainably or not, and provide more information about housing equilibrium.

2, Background

Many important mathematical approaches have been widely used in the related sustainability study. A method described for analyzing urban development and for assessing the sensitivity to change by available data about city systems and a Neural Network system (Kropp 1997). Li and Yeh (2000) discussed how cellular automata (CA) can be extended and integrated with GIS to help planners to search for better urban forms for sustainable development. Sense and Toccolini (1998) applied the GIS (Geographical Information System) technology for the analysis and processing of the data acquired in the sustainable land use planning process. The use and integration of various approach to simulate and interpret the sustainability problems leads to a deeper understanding on sustainable development especially in economics, society, environment and housing.

This paper applies system dynamics theories to formulate, simulate and validate the sustainable development of urban residential areas. The system dynamics model has also been widely accepted in the study of sustainable development. The system dynamics approach is presented in the research (Saysel et al 2002) to provide an experimental simulation platform for the long-term environmental sustainability analysis of the interconnected strategic problems in their interconnected context. O'Regan and Moles (2006) examined how environmental policy affects the investment and development decisions of the mining industry within the context of sustainable development, through quantitative analysis of existing data, using system dynamics model. Georgiadis & Besiou (2008) discussed sustainable development through the management of natural resources usage and landfill availability and specifically adopted a system dynamics model to evaluate the impact of ecological motivation and technological innovations on the long-term behavior of a closed-loop supply chain with recycling activities. Shen et al (2009) used a system dynamics model on the sustainable land use and urban development in Hong Kong. The model, including five sub-systems including population, economics, housing, transport and urban/developed land, is used to test the outcomes of development policy scenarios and make forecasts.

GIS (Geographical Information System) can be thought of as a system merging of cartography, statistical analysis, and database technology and has become an useful instrument in linking and analyzing spatially resolved data. For urban development and its sustainability, GIS technology has the potential and ability to be used to “drive planning support systems, decision-making frameworks incorporating a combination of computer and information technology, urban growth models, and computer-based visualization techniques to support community-based planning” (Brail and Klosterman, 2001). Li et al 2000 discussed how cellular automata can be extended and integrated with GIS to help planners to search for better urban forms for sustainable development. Batty et al. 1999 proposed a class of urban models whose dynamics are based on theories of development associated with GIS-based cellular automata. Xiao et al. 2005 presented an integrated study of the temporal an spatial characteristics of urban expansion using GIS and remote sensing. Visualization is an integral component in GIS technology and application. New development in 3D urban data demands 3D GIS providing extended techniques for data query, visualization and interaction with 3D GIS data, as well as, user-friendly, easy-to-use, standardized Graphics User Interface (GUI) (Zlatanova and Gruber 1999) .

3, Study area and data

Stuttgart Region is one of the four administrative regions (Regierungsbezirke) of Baden-Württemberg state, located in the north-east of the state, in the southwestern part of Germany. It is sub-divided into the three regions Heilbronn-Franken, Ostwürttemberg, Stuttgart, among which Stuttgart is the capital city of the state of Baden-Württemberg and the sixth-largest city in Germany with a total of 23 city districts, 5 inner districts and 18 outer districts. As shown in Fig 1, Plieningen is a southern district of Stuttgart city and 10 kilometers from the city center with a total district area of around 13.07 square kilometers and 13.035 thousands residents. The population of Stuttgart Region rose from 3.751 million in 1991 to 4.001 million in 2009 (State Statistic Bureau of Baden-Württemberg).

The evaluation of sustainability index and housing equilibrium mainly investigated in this study is strongly related to the economic-environmental-social variables such as disposable income per capita, population density, family size, etc., we consider and analyze all the variables in the whole Stuttgart Region circumstance. All the data used in the modeling were taken from “Structural and Regional Database” (State Statistic Bureau of Baden-Württemberg), “State Database” (State Statistic Bureau of Baden-Württemberg), “Statistic report of Baden-Württemberg for housing sample” (State Statistic Bureau of Baden-Württemberg), “Economic facts and figures Baden-Württemberg 2010” (Ministry of Economy Baden-Württemberg), “Energy report 2010” (Ministry of Economy Baden-Württemberg), “Economic and social development in Baden-Württemberg” (State Statistic Bureau of Baden-Württemberg), and “State development report Baden-Württemberg (LEB) 2005” (Ministry of Economy Baden-Württemberg), etc.

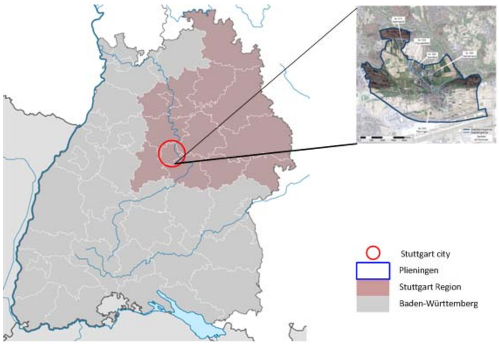

Fig 1: Location of the study area.

4, Methodology

4.1, Sustainability indicators

An indicator is a parameter which is associated with an environmental phenomenon, which can provide information on the characteristics of the event in its global form (OECD, 2003).

Many indicators are available for sustainable development assessment. Among the several indicator systems, mention can be made to the following three indicator sets related to international and European organizations that work in the field of sustainable development.

- The Organization for Economic Cooperation and Development (OECD) has been working on environmental indicators since 1989. The work of OECD mainly focuses on indicators that have to be used in national, international and global decision making; furthermore the approach may also be used to develop indicators at a sub-national or eco-system level (OECD, 2003);
- The United Nations Commission on Sustainable Development (UNCSD) produces some indicator sets in the field of sustainability assessment. UNCSD provides a very useful and timely forum for the discussion of national-level indicators with the involvement of governments, international organizations and various stakeholders. UNCSD indicators play an important role in “helping countries make informed decisions concerning sustainable development”, and they are “applied and used in many countries as the basis for the development of national indicators of sustainable development” (United Nations, 2007);
- The European System of Social Indicators (EUSI) is part of a cross-national European project which began in the late 1990s and which aims at monitoring and assessing welfare development and social change in Europe (Berger-Schmitt & Noll, 2000). The EUSI framework links sustainability to other welfare concepts, such as social cohesion, social exclusion, social capital and quality of life;

As far as residential urban areas are concerned, the above mentioned sustainability indicator systems representing indicators available for the assessment of the sustainable development of urban residence focus on different issues, such as environmental quality, well-being of the population, economic aspects, etc. According to the main dimensions that have been identified: housing, economics, environment and society, we chose the related core indicators from the three indicator systems. The availability and reliability of data and the sensitivity of indicators to reflect the underlying social and economical processes were also used as the criteria to establish the indicators system proposed in this work. Tab 1 lists all the 24 indicators selected for the application of the sustainability assessment of urban residential areas.

Table 1: indicators selected for the application

Indicator	Unit	Thematic area
• I1 Gross Domestic Product (GDP);	billion €	Economics
• I2 Disposable income per capita;	€	Economics
• I3 Investment on the residential projects completed;	€	Economics
• I4 Urban population;	million inhabits	Society
• I5 Housing demand;	million m^2	Housing
• I6 Family size;	inhabits/household	Environment
• I7 Population density;	inhabits/km^2	Society
• I8 Unemployment rate;	%	Society
• I9 Road traffic accidents.	inhabits	Society
• I10 Total motor vehicles;	million	Society
• I11 Living space per capita;	m^2	Housing
• I12 Land price per floor area	€ per one m^2	Economics
• I13 Urban housing price index;	None	Economics
• I14 rent- price index;	None	Economics
• I15 Population below the poverty line	inhabits	Society
• I16 Urban air pollution (NO2;SO2;PM10);	ton	Environment
• I17 Domestic water consumption;	m^3	Environment
• I18 Delivering quantity of domestic waste;	ton	Environment
• I19 Green coverage ratio;	%	Environment
• I20 Urban area;	km^2	Environment
• I21 Completed area of residential projects;	€	Housing
• I22 Housing supply;	million m^2	Housing
• I23 New residential projects investment;	€	Economics
• I24 Environmental regulation investment	€	Economics

4.2, SD model

In this study, a SD model designed for Stuttgart Region was employed to provide a mean of simulating the development system of urban residential areas and its internal interactions among 24 sustainability indicators.

The model has a 30-year time horizon, from 1991 to 2020, with reference to the related statistic reports published on the official website of the State Statistical Bureau of Baden-Württemberg. And the indicators are subdivided into four primary model sectors, called sub-systems, which are the Housing sector, the Economics sector, the Environment sector and the Society sector in accordance with the thematic areas in Table 1.

In the developing stage, the structure of the SD model is represented as a set of stocks and information flows, and the according stock-flow diagrams of 4 sectors shown in Fig 2 are developed using *Vensim* software. The model is composed of, in the aggregate, 58 variables including 4 stock variables, 6 rate variable and 48 convertor variables among which 24 variables are corresponding to the indicators selected to develop sustainability assessment. Each variable in the model is defined with a formula.

Housing sector

The Housing sector is of great significance in this SD model. The demand of house purchasers mainly come from 4 sources: ① the growth of nonagricultural population (natural demand); ② the growth of Stuttgart's per capita living area (initiative demand); ③ demolishment and relocation of old houses (passive demand); and ④ housing purchase of immigrated population. According to the national land use planning 2020 from German Federal Office for Building and Regional Planning (BBR), the number of households in Baden-Württemberg will has a strong rise in medium-term, while the average household size is correspondingly decrease further (Hass et al 2005). In 1994 the per capita living area in Baden-Württemberg is only 37.6 m^2, and then the number rose to 40.9 m^2 at the end of 2003 with an average annual increase of almost 0.4 m^2 between 1994 and 2003, compared to the 70s and early 80s period, of which the average annual growth is almost 0.7 m^2. In 2002 Stuttgart region has around 151 million m^2 residential buildings and 3.985 million inhabitants. By the end of 2009 the housing supply has already reached a sum of 168 million m^2 with a population of 4.001 million. That is to say, the per capita average living area increased from 37.89 m^2 in 2002 to 41.99 m^2 in 2009. However it's hard currently to foresee the end of the growth trend of per capita living area in Stuttgart region considering that it has already reached more than 50 m^2 in some other countries, such as Switzerland or the United States. For the next 10 years, Stuttgart region will still be in a developing stage of housing construction and real estate market to meet increasing housing demand. The housing sector has four indicators (I5 "The demand for housing", "I11 "Living space per capita", I21 "Completed areas of residential projects" and I22 "The supply for housing") (Table 1). It is estimated that Stuttgart will still experience a boom in residential market as the next few years. In 2009 housing supply-demand ratio stood at a 0.989:1 and then will increase to 0.991 :1 in 2020 as the estimated value simulated in SD model.

Economics sector

Baden-Württemberg's strength lies in its high economic performance. This strong export-oriented economy invests enormous amounts in research and development, as well as in innovations. Flagship branches are the technology sectors, such as automobile production, and mechanical and electrical engineering. After a historical economic decline in 2009, the economic indicators at the end of 2010 showed that it recovered much sooner than expected one year earlier in Baden-Württemberg. In 2010 the GDP of Baden-Württemberg increased by 4.75% in comparison to 7.4% in 2009. According to the economic indicators of the State Statistic Bureau, a slow GDP growth of 2.5% was predicted in 2011 (Ursula Bauer-Hailer et. al. 2010). Under these conditions the GDP at the end of 2011 will reach the level of 2008.

The GDP of Stuttgart Region rose from 96.776 billion Euros in 1991 to 145.865 billion Euros in 2008 at an annual average growth rate of 2.443%, and fell around 7.4% in 2009 then followed by a slow increase from 2010. By 2020, the GDP of Stuttgart Region is expected to exceed 160 billion Euros as calculated in the model. The economics sector has three eight indicators (I1 "GDP", I2 "Disposable income per capita", I3 "Investment on residential projects completed", I12 "Land price per floor area", I13 "Urban housing price index", I14 "rent-price index", I23 "Investment on new residential projects", and I24 "Environmental regulation investment"). "Urban housing price index" is subject to 3 variables: total construction cost, rent-price index and housing supply-demand ratio. As the stock variable, GDP depend on economic growth rate in this sector.

Society sector

The Society sector mainly refers to the quantity of population, urban traffic, unemployment rate and population below the poverty line. Population comprised of Usual Residents and Mobile Residents (immigration population and emigration population) in this paper, can cause changes of the indicators in other sectors. From 1991 to 2007, the population of Stuttgart Region stably rose from 3.751 million to 4.007 million with a positive net migration. The number of population will firstly fall below 4 million and then continue decreasing to 3.951 million at the end of 2020 according to the regional population forecast of the State Statistic Bureau. Two aspects involved in urban traffic were discussed here, “Total motor vehicles” and “Road traffic accidents”. The society sector has six indicator (I4 “Urban population”, I7 “Urban family size”, I8 “Unemployment rate”, I9 “Persons involved in road traffic accidents”, I10 “total motor vehicles”, I15 “Population below poverty line”).

Environment sector

As an important component of this SD model, the Environment sector mainly refers to six indicator (I6 “Population Density”, I16 “Urban air pollution (NO2,SO2,PM10)”, I17 “Domestic water consumption”, I18 “Delivery quantity of domestic waste”, I19 “Green coverage ratio”, and I20 “Urban areas”). Rapid economic recovery in Stuttgart Region and the state of Baden-Württemberg leads to increase in demand for environmental resources (Ursula Bauer-Hailer et. al. 2010). In residential context, the statistic data of the energy consumption and air emissions can be differentiated by two sources: households, and small residential consumers (ancillary facilities, public facilities, services, etc) according to the energy balance of Baden-Württemberg (Birgit John, 2007). In Stuttgart Region, NOx and SO2 emissions generated from households and small residential consumers separately decreased from 6099t and 6645t in 1995 to 4017t and 2337t in 2007. Domestic water supply also drop to 167.57 million m^3 in 2007 from 176.96 million m^3 in 1998. And domestic waste disposal increased to 1426t in 2009 from 1282t in 1991.

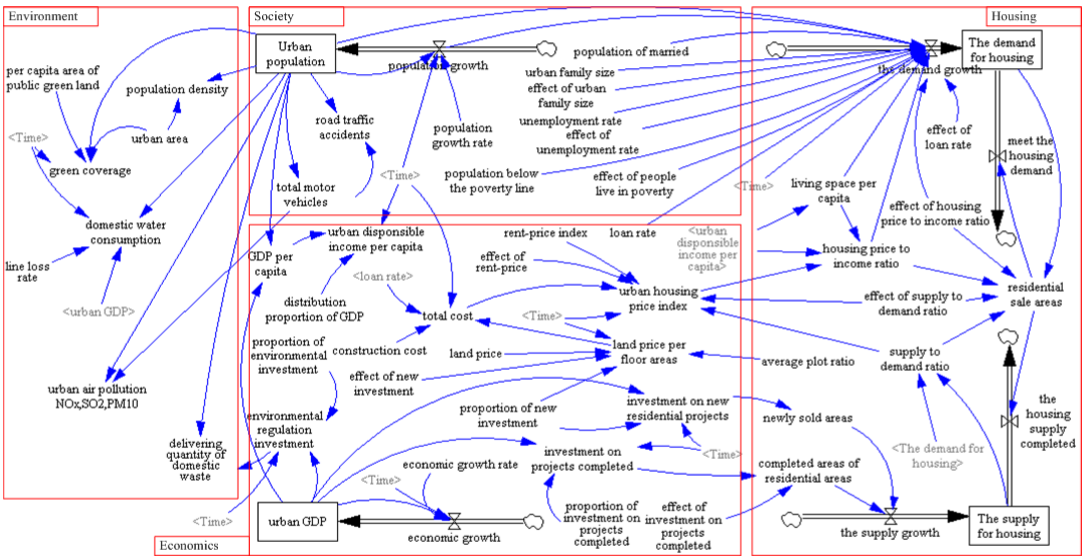

Figure 2: Stock-flow diagrams of 4 sectors.

Based on the structure of the model and the calculation formulas identified, the simulation corresponds to the historic data quite closely (Figure 3, Figure 4). Figure 3 shows that the values of Housing supply for the initial part of the model are slightly inaccurate (142.94 million m^2 in 2002 had a less of 5.33% than the historic value 151 million m^2) but appear to converge towards the same final value in 2009 and they are basically in keeping with the developing trend of the total housing supply in the state of Baden-Wurttemberg. Figure 4 is a graph and also the comparative results of housing supply and housing demand in Stuttgart Region calculated in the model; and the variation of the supply-to-demand ratio remains stable between 0.99 and 1.1.

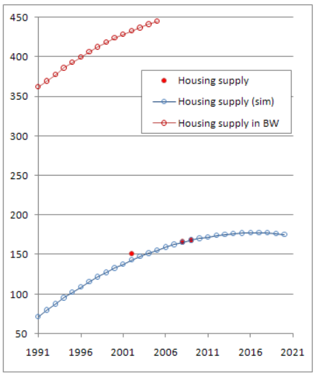

Fig 3: Simulation results of Housing Supply.

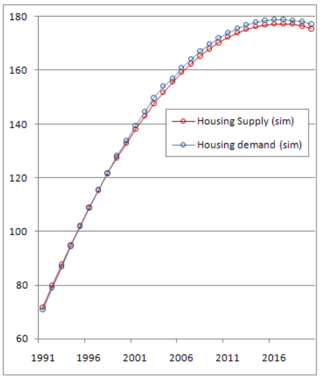

Fig 4: Simulation results of Housing supply and demand.

Validation of SD model

As an important step in system dynamics methodology, the model is verified using the historic data of 2001, 2002, 2006, 2007 and 2008. The examined variables include 3 indicators: I12 "land price", I14 "Rent-price index" and I21 "Completed area of residential projects".

The method of verification is to make a comparison of the simulation results and historic data, and calculate the relative error and mean square deviation of the variables.

$$e_i = |\hat{y}_{it} - y_{it}| / y_{it} \quad (4)$$

$$MSE_i = \sqrt{\sum_1^n e^2_{it} / n} \quad (5)$$

Here, yit represents the historic data of the indicator "i" in the year of "t", ўit represents the simulation result of the indicator "i" in the year of "t". "g" is the number of the selected indicators in this model verification. ei is the relative error of the indicator "i" and MSEi is the mean square error of the indicator "i".

Generally, we take the simulation results as an equitable and reasonable answer, when MSEi <10%. According to function (4), (5), MSEi of the 3 indicators can be calculated: 0.079, 0.018, and 0.082< 0.1 (Table 2), so this model meets the accuracy requirements theoretically.

Table 2: The comparison table of historic data and simulation result

year	2001	2002	2006	2007	2008	MSE

I12	Historic data	16.905	17.498	18.217	19.859	16.353	0.079
	Simulation data	16.309	16.815	18.397	18.946	19.505	
	Relative error- e	0.0365	0.0406	0.01	0.0482	0.1616	
I14	Historic data	1.318	1.348	1.424	1.445	1.47	0.018
	Simulation data	1.329	1.351	1.45	1.439	1.523	
	Relative error- e	0.00827	0.00222	0.018	0.0029	0.035	
I21	Historic data	1.561	1.494	1.484	1.313	1.103	0.082
	Simulation data	1.566	1.5	1.3	1.178	1.116	
	Relative error- e	0.00319	0.004	0.14154	0.1146	0.0116	

4.3, GIS and 3D visualization

GIS technology was used to manage the digital database and to provide a connection to visualization and SD simulation models discussed above. The GIS operations were performed with ArcEditor 9.3.1 the product of the Environmental Systems Research Institute (ESRI, Redlands, CA) and CityEngine. In this part, Plieningen is selected to be the sample district in Stuttgart where 2395 buildings were located in 2009 including 1125 residential buildings and houses. Fig 5 shows the polygon shapefile representing all buildings in Plieningen in 2009 displayed in ArcMap 9.3.1. And then the polygon shapefile was converted to point shapefile using “ArcToolBox –>Data Management Tools –>Features –>Feature to Point” in ArcMap. During this process, the attributes of the input features of the buildings are maintained in the output points feature class.

Fig 5 : the polygon and point shapefile displayed in ArcMap 9.

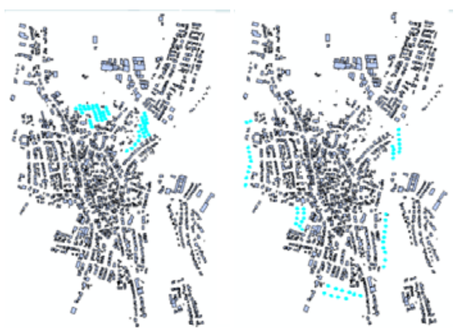

Fig 6: the polygon shapefiles of compact and outward development predicted in 2020

Two assumptions:

1, Table 3 shows the estimated results of housing supply predicted by SD model for next 10 years in the entire Stuttgart Region. The total residential supply will increase by around 4.46% from 168 million m^2 in 2009 to 175.502 million m^2 in 2020. As a small district in entire Stuttgart Region, Plieningen has a residential stock of 335.132 thousand m^2 in 2009 which can be expected to rise to 350.097 thousand m^2 in 2020 by assuming a same average growth rate as Stuttgart Region.
2, Plieningen district has 1125 residential buildings with the total floor areas of 335.132 thousand m^2 in 2009. The average floor areas per one building is 297.89 m^2 (=335132/1125). In all 1125 buildings, a standard building with the average floor areas was found. Meanwhile its location areas are 74.82 m^2 and the building volume is 933.92 m^3. According to assumption 1, the total residential supply in 2020 will exceed the number in 2009 by 14965 m^2. Then the number of new residential buildings required to be added until 2020 is obtained using 14965/297.89=50 assuming all new buildings will be built in the same form of the chosen standard one.

Two urban development patterns

Combining housing supply and mobility practices in cities with high or low densities constitutes two main branch : *compact development and outward development* in architecture and urban planning. The Compact City is an urban planning and urban design concept, characterized relatively high residential density with mixed land uses. While outward development, also known as Urban sprawl, is a multifaceted concept, which includes the spreading outwards of a city and its suburbs to its outskirts to low-density and auto-dependent development on rural land, high segregation of uses (e.g. stores and residential), and various design features that encourage car dependency. Bill Randolph (2006) indicated that Successful compact city policies will require a viable and acceptable strata governance framework to minimize conflicts between neighbors and between owners, as well as maximize long term standards in higher density stock. Thinh. et al. 2002 discussed two dimensions of the compact city: physical and functional and created a ArcInfo- database of land use patterns and to model the physical compactness of the German Regional Cities. Arriba-Bel. et. al 2010 identified the most sprawled areas in Europe characterizing them in terms of population size and used the self-organizing map (SOM) algorithm as a visualization tool to better understand urban sprawl in Europe. Jat. et. al. 2007 investigated the usefulness of the spatial techniques, remote sensing and GIS for urban sprawl detection and handling of spatial and temporal variability of the same. Sudhira. et. al. 2004 analyzed and understand the urban sprawl pattern and dynamics to predict the future sprawls and address effective resource utilization for infrastructure allocation.

In this study, 50 points (in green color shown in Fig 6) having the same attribute values with the standard building were positioned in the point shapefile in two ways: gathering around the district center representing compact development or dispersing along the district boundary representing outward development.

Table 3: the estimated results of the total housing supply in Plieningen.

	Stuttgart Region		Plieningen
	Housing supply (million m2)	Supply variation	Housing supply (thousand m2)
2009	168		335.132
2010	170.292	+1.36%	
2011	172.262	+1.16%	
2012	173.91	+0.96%	
2013	175.236	+0.76%	
2014	176.24	+0.57%	
2015	176.922	+0.39%	
2016	177.282	+0.2%	
2017	177.32	+0.022%	
2018	177.036	+0.023%	
2019	176.43	+0.039%	
2020	175.502	+0.04%	350.097

3D visualization provides a more comprehensive approach to observe the prediction of urban development. Cityengine is a software product which is able to give users in architecture, urban planning, GIS and general 3D content production a design and modeling solution for the efficient creation of 3D cities and buildings. And Cityengine also supports 2D-to-3D-conversion of GIS data. The shapefiles (Plieningen in 2009, Pliningen_Compact development in 2020 and Pliningen_Outward development in 2020) containing the shape data and attributes for each shape were imported into Cityengine using the shapefile importer and shown in Fig 7.

A shape in Cityengine consists of a name, parameters, attributes containing the numeric and spatial description, geometry, scope and pivot. The CGA (Computer Generated Architecture) shape grammar of the CityEngine is a unique programming language specified to generate architectural 3D content based on the shapes which uses a different syntax but provides the same functionality with the widely used GML shape grammar. The idea of grammar-based modeling is to define rules that iteratively refine a design by creating more and more detail (Cityengine Help) and the shapes are replaced by a number of new shapes according to the rules. The rule's script in this paper mainly has 3 parts: extrude the footprint shapes to their specified height, create the roofs and texture the facades which illustrate the implementation of the CGA grammar-based model.

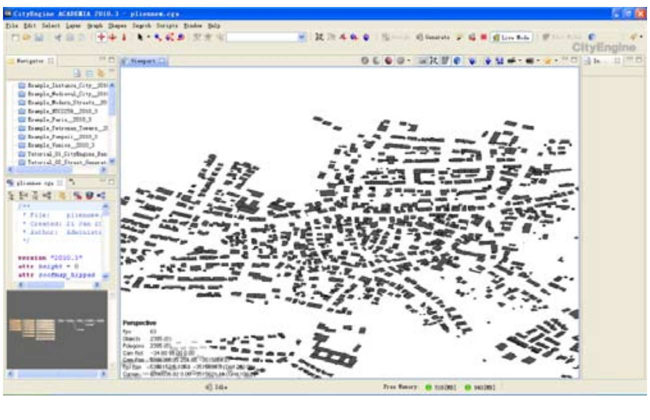

Fig 7: Building shapes shown in CityEngine.

In figure 8 we show two group 3D simulation phenomena on a small scale. On the left we show the 50 new buildings are located centrally in Plieningen. On the right it's a scatter distribution of the 50 buildings in Plieningen.

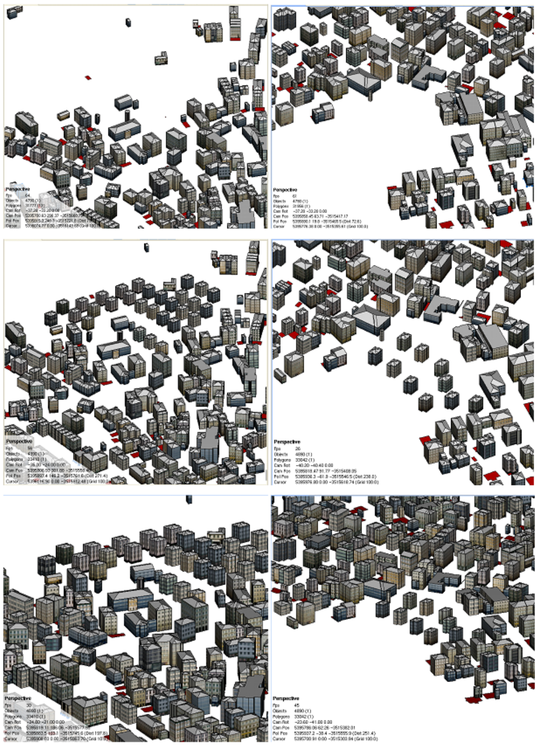

Fig 8: 3D visualization generated in CityEngine for Plieningen in 2020.

5, Conclusion

In this paper, an integrated application of system dynamics model and GIS technology is developed to assist evaluation of the future trend of the residential development in Plieningen district of Stuttgart Region, Germany. The model examines interactions of sustainability indicators in four sectors ("Housing", "Economics", "Society" and "Environment") within a time frame of 30 years, and then the result of this model is discussed with two possible development patterns – compact development and outward development in Plieningen. It can be also concluded that the integration of System Dynamics theory and GIS is a useful strategy to study the development of urban residential areas in terms of sustainability. A validation is undertaken to verify SD model, by comparing with historic data and mean square error. In this study, we can find the development process of our residential areas, and put a further concern on the development of the urban residential development from another point of view.

However, there are still a number of opportunities for expanding the study and for validating the results obtained herein. Firstly, only core-indicators were considered in this work. It would be of scientific interest to add other indicators resulting from policies and strategies. Secondly, further research would be required to collect more historic data and optimize the structure of system dynamics model. Thirdly, in this paper we only considered the a very small district of Stuttgart as the study object and also didn't input terrain data and street data in 3D GIS analysis.

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