INTRODUCING LARGE SCALE URBAN MODEL TO SYDNEY'S METROPOLITAN PLANNING

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Abstract: By 2036 Sydney's population is expected to reach six million, an increase of 1.7 million since the 2006 census. To achieve a liveable and attractive city, Sydney Metropolitan Strategy 2006 presents detailed plans for Sydney's future and allocates a precise number of additional residents to each local government area using the planning tool named METRIX. As the pattern of human settlement directly impacts on the issues of transport, environment and economy, METRIX, however, is limited and incapable of accounting for the external restrictions to population distribution. There is a further question of the extent to which this strategy will be implemented, since there is no appropriate planning system currently in place. Therefore, a planning model capable of evaluating the suitable locations to accommodate the growing population and providing alternative options for Sydney's future, as well as facilitating the cooperation among different departments, is in urgent need to produce a flexible and responsive metropolitan strategy.

To resolve these practical issues, this paper turns to academic research on the concept of planning support system. By reviewing the presently popular urban models, the author argues that most previous efforts are forced on modelling techniques, and these methods cannot simulate the correct process of urban growth. This also makes the relative research more successful in the laboratory than that in practice. The proposed model in this paper, instead, takes the notion of "Enterprise Resource Planning" to pull the endeavour back to constructing a collaborative population distribution model.

The model first examines the macro level influences in people's choice of living through spatial regression, and then generates suitability score using factor analysis to reflect the micro fitness. Afterwards, the additional population is distributed along the logistic curve with a yearly basis. The whole model is constructed in ModelBuilder of ArcGIS 10 employing the data of 55158 polygons, where the smallest area of residential block is 154 m2.

Keywords: Urban planning, Planning support system, Metropolitan Planning

1. INTRODUCTION

Australia's population is projected to exceed 30 million by 2036, when residents in Sydney will reach 6 million[1]. This massive growth requires sophisticated urban planning to accommodate the growing population and alleviate the tension caused by urbanization. The scientific evidences of climate change in Australia is overwhelming, as the temperature is rising 0.7-0.9 ℃ annually in coastal areas [2], droughts have become longer with effects on rainfall, evaporation and water availability [3], associating with the increasing hot days and warm nights that affect living quality and public health [4]. CSIRO's report also points to the evidence of human influence on the climate change, since human settlement places pressure on environment through the demand for water, energy and land, and through the production of wastes. These human-induced issues pose further challenges to planners when planning Sydney's future, as various ways of population allocation could lead to different environmental consequences.

Being the most populous Australian city, Sydney has a strong need to strengthen its sustainability, and the Sydney metropolitan strategy presents a detailed plan covering a variety of aspects to maintain the city's advantage globally. City of Cities, published in 2005, produces a particular number of target dwellings in each local government area till 2031, using the planning tool METRIX.

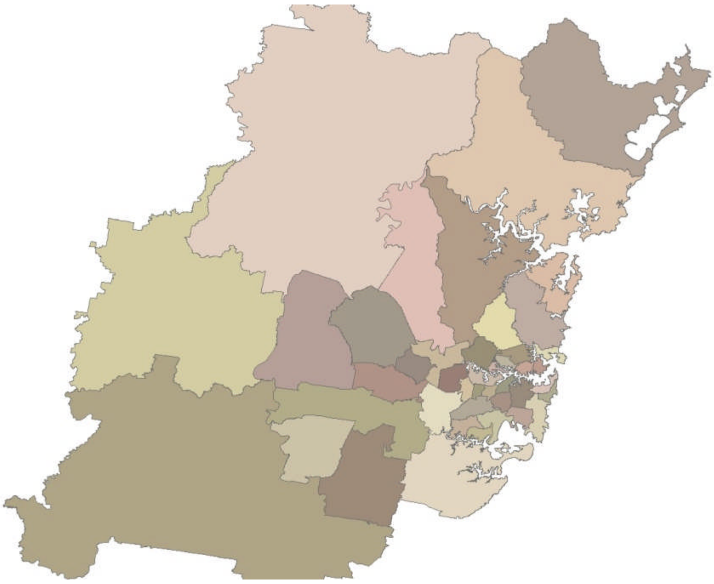


Figure 1: Sydney Metropolitan Areas with 43 LGAs

Table 1: Dwelling Targets for Each LGA in 2031

LGA	Target Dwellings in 2031	LGA	Target Dwellings in 2031	LGA	Target Dwellings in 2031
Ashfield (A)	2000	Fairfield (C)	24000	Manly (A)	2400
Auburn (A)	17000	Gosford (C)	16500	Marrickville (A)	4150
Bankstown (C)	22000	Hawkesbury (C)	5000	Mosman (A)	600
Baulkham Hills (A)	21500	Holroyd (C)	11500	North Sydney (A)	5500
Blacktown (C)	21500	Hornsby (A)	11000	Parramatta (C)	21000
Blue Mountains (C)	7000	Hunter's Hill (A)	1200	Penrith (C)	25000
Botany Bay (C)	6500	Hurstville (C)	4100	Pittwater (A)	4600
Burwood (A)	7700	Kogarah (A)	2550	Randwick (C)	8400
Camden (A)	10274	Ku-ring-gai (A)	10000	Rockdale (C)	7000
Campbelltown (C)	24653	Lane Cove (A)	3900	Ryde (C)	12000
Canada Bay (A)	10000	Leichhardt (A)	2000	Strathfield (A)	8300
Canterbury (C)	7100	Liverpool (C)	13328	Sutherland Shire (A)	10100
Sydney (C)	55000	Waverley (A)	2200	Wollondilly (A)	5230
Warringah (A)	10300	Willoughby (C)	6800	Woollahra (A)	2900
Wyong (A)	39500				

This planning tool, however, is incapable of considering external restrictions on population distribution. As the emphasis of a metropolitan strategy should be placed on managing the change rather than the fixed targets, METRIX and the current planning frameworks are limited in providing alternative options or "back up" plans. To resolve this practical issue, this paper first reviews the Metropolitan strategy 2006 and METRIX, and then turns to research on planning support system. A series of design rules is presented by evaluating the state-of-the-art urban models, while the notion of "Enterprise Resource Planning" is taken as the design principle on which to build a collaborative population model.

II. SYDNEY'S METROPOLITAN STRATEGY

NSW Government published "City of Cities – A plan for Sydney's Future" in 2005 and listed a range of aims in housing, economy, employment, transport and environment [5]. In particular, housing target for future 20 years is subdivided into 43 local government areas (LGA) through the planning tool – METRIX, shown in Fig.1 and Table 1.

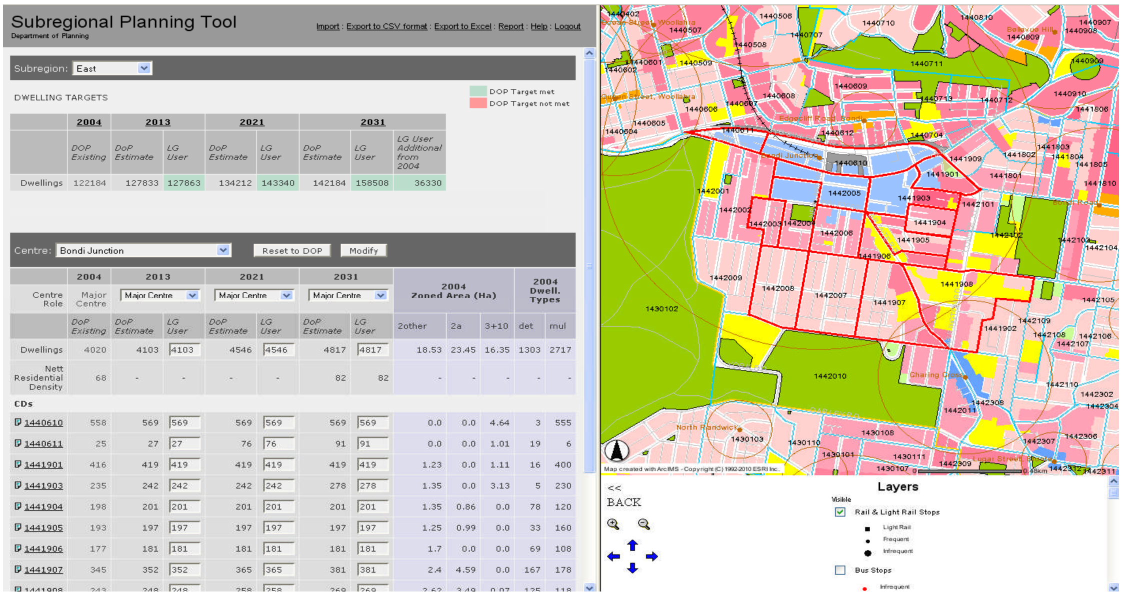


Figure 2: the user interface of METRIX

METRIX was developed in 2005 for councils and the Department of Planning to assess the approximate capacity for housing in existing urban area. This is then used to construct the so-called "subregional plans". METRIX is a web-based calculator that records the dwelling numbers for each collection district. Local councils are required to adjust the distribution of dwellings according to local planning strategies, but based on the initial number generated by planning department (Fig.2). Afterwards, the metropolitan planners only need to ensure the total target is met. The population distribution in this tool, however, is oversimplified and isolated. The scenarios generated only consider the numbers instead of urban form or growth pattern. Some important factors affecting population allocation, such as environment, employment, transport or geographic suitability, are not incorporated, while some "what-if" questions that should be simulated are not answered. For instance, what might happen to the spatial pattern of population if a new employment centre is planned or a new land is released for residential purpose?

Another problem of flexibility also exists as the metropolitan strategy is for managing changes [6] and the objectives in the strategy should not be some fixed target but rather a set of flexible principles that have the ability to influence the evolution of the city [7]. In other words, a flexible and responsive planning system is needed to generate different plans reacting to various scenarios. A further question of the extent to which these goals will be implemented is raised by Bunker[8], since implementation depends on whether appropriate frameworks exist and what kind of methodology, content and process are used in preparing plans[9]. This indicates a significant responsibility of metropolitan planning is to organize different departments to ensure the overall objectives are reasonable and achievable. Thus, a new planning model capable of evaluating the suitable locations for a growing population needs to be built to produce alternative options and to improve the cooperation among various knowledge groups. Therefore this paper turns to academic research on the concept of planning support system to find a solution.

III. PLANNING SUPPORT SYSTEM

A. An Overview of Planning Support System

It has been over twenty years since the term 'planning support system' (PSS) first appeared in the article published by Britton Harris [10]. Brail and Klosterman [11] have described PSS as information technologies that are used specifically by planners to undertake their unique professional responsibilities. In fact, as to support planning activities, numerous PSSs with a variety of functions such as information gathering, data storage, visualization, communication, analysis and modelling [12] have been developed to improve diverse planning tasks of problem definition, data analysis, plan generation and evaluation, decision making, implementation and supervision [13]. As the practical need is a strategic planning tool, the emphasis of this paper is concentrated on land use models that help planners understand the urban growth process [14], examine the potential effects of particular policy [15], and generate different scenarios for planners to make decisions with limited time and technical resources [16].

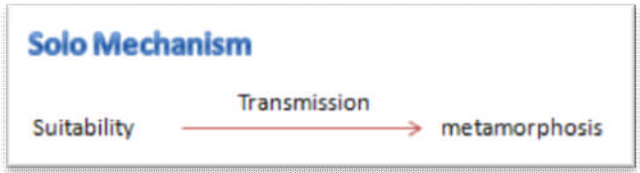


Figure 3: a solo mechanism for land use model

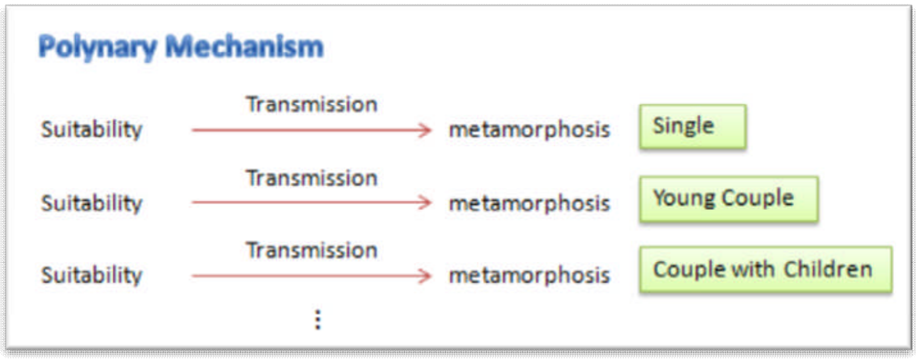


Figure 4: A Polynary mechanism, example of household distribution

Comparing to the emergence of PSS, land use model have been developed for a rather long period. The earliest efforts can be traced a half century back. Two popular methods at that time, known as planned requirements approach [17] and market simulation approach [18], provide fundamental directions for current models. For instance, the planned requirements approach is to match the demand for land and the supply, a good example of which is What-IF™ [19] or Arcgis processing model [20]; UrbanSim [21] on the other hand is designed with the similar thought of market simulation approach, conducting microsimulation to capture more complex urban issues. In the following section, some major issues are argued through reviewing the popular land use models including LEAM [14, 22, 23], SLEUTH[24], UrbanSim [15, 21, 25-27], Clue-s[28-30], What-IF™ [19, 31-33], CommunityViz[34], CUF and CUFII [35-37], and MEROPILUS [38].

B. Modelling Procedure versus Modelling Technique

It is difficult to review the existing PSSs and land use models as the result of the increasing number of applications that have been developed. To either adopt an existing model or build a new one, an understanding of the variety of land models and identifying their differences are critical. The author straightens a procedure (Fig.3) that can be applied in most state-of-art models, which is to determine the suitability for development first and then employ different methods to transmit the suitability to modelling objects, such land parcel or urban area. In other words, in the stage of transmission, the model needs to determine which area will be developed first, based on the suitability scores. At last, the change is triggered according to object's capacity. For instance, a fuzzy state can be utilized to simulate the land change from non-urban to urban.

This solo mechanism can be applied in simulating household, employment or urban land usage. The model of What-IF™ calculates the suitability of residential usage for particular land and allocates the population to the location with highest score; UrbanSim utilizes the multi-logit model to determine the suitability and then transmits it to household allocation based on consumer surplus theory; Cellular Automata also follows this procedure that setting transition rules are to compute the probability of change for a single cell, while the allocation is based on a self-replicated system. In fact, most models simulate more than one element as different households or land uses require different criteria of suitability, which can be described as a polynary mechanism illustrated in Fig.4.

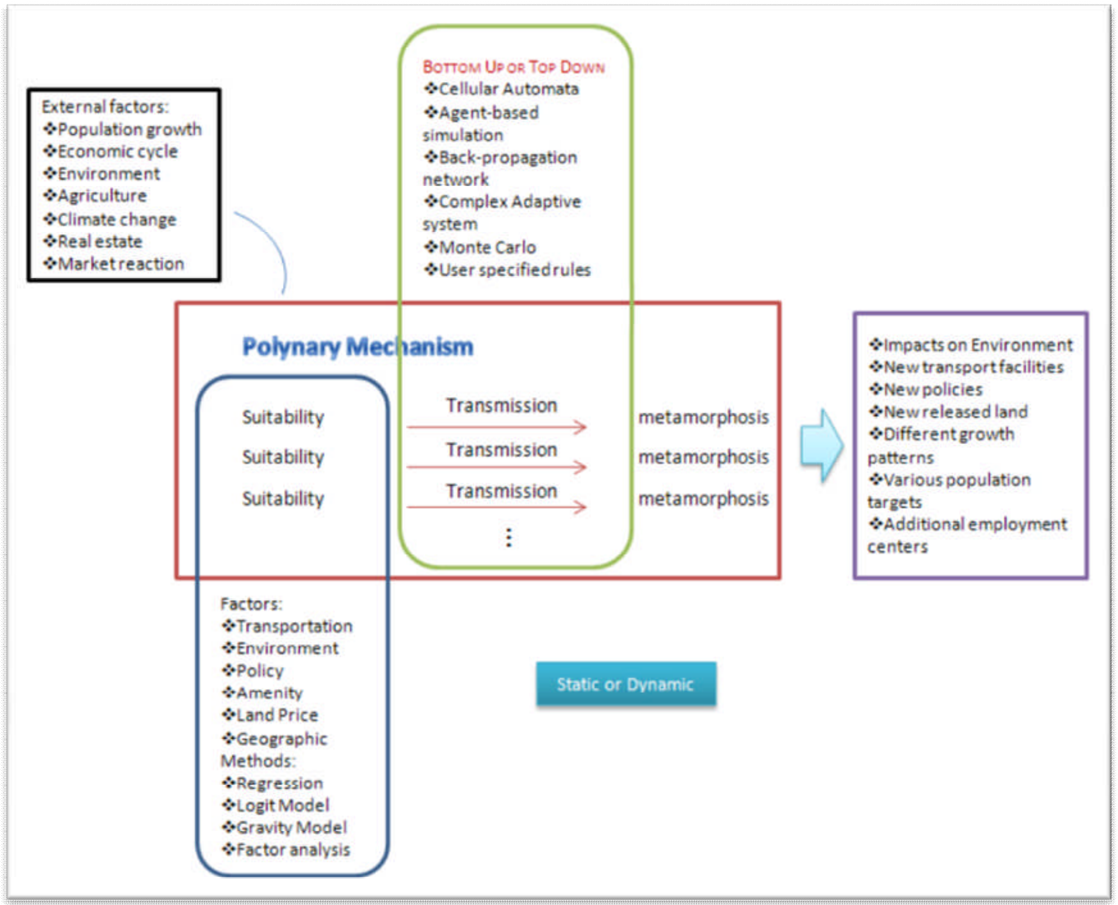


Figure 5: The variety of land use models

Although multiple elements are considered, the procedures involved are similar. CUFII (California Urban Future Model), for example, builds multiple logit regression for various land changes including the transfer from undeveloped area to single household, from commercial land to industrial land and from industrial land to retail. UrbanSim simulates land parcels for different households, business and other infrastructures. The mechanism can be improved further by introducing more completed sub-models to capture the function of market, real estate, land capacity, land biding and so on, through which more complex urban phenomenon can be explains and more what-if questions can be answered.

Fig.5 shows the general ideas of building land use model, which can be run repeatedly if a dynamic model is constructed or run once only if a static model is designed. Different modelling techniques, employed to calculate the suitability of land for development and to allocate the simulated elements, are stimulating the variety of models. Each step in a solo mechanism allows further improvement by various mathematical methods. For instance, logit regression, factor analysis and user specified weights can be employed to calculate the suitability; a bottom up or top down model can be constructed by adopting a cellular automata transmission or rule-based method; the process of metamorphosis has been improved by some advanced approaches as well, such as the fuzzy cellular state [39] and capacity envelop [40]. Besides these traditional techniques, other advanced methods are also applied in modelling like cubic polynomial [41], feed-forward neural network [42], gray modelling [43] and Markov forest [44]. As a matter of fact, currently significant improvement of land model is attributed to using these sophisticated calculate methods. However, plentiful as the modelling techniques are, there is no accurate way able to simulate the urban growth and land change, as Harry Timmermans [45] argued people should wake up from building a complex

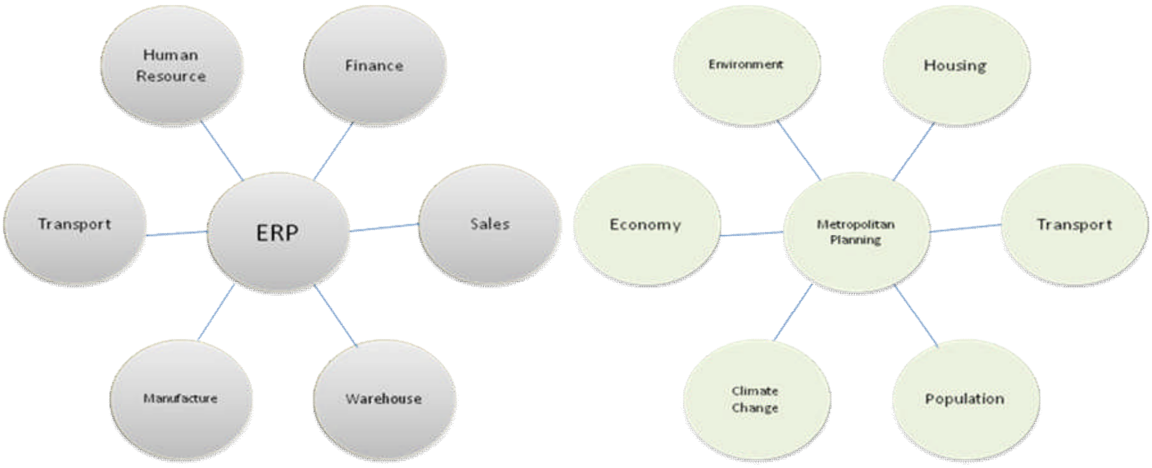


Figure 6: Similarity between ERP and Metropolitan Planning

large scale model. Therefore the proposed model is not spending effort in employing complex and advanced techniques, but rather to use straightforward method that can serve for the purpose and be fitted into the context.

C. Failure Applying Models in Practise

Understanding the limitations of current models is critical when developing a new one. It is unsurprised to notice a number of comparisons and criticisms have been argued, previous to either launching a new model or applying certain model to a region. Such comments, however, are mostly focused on modelling techniques and advocate their superiority comparing to others. Since the experience in the professional practice has been disappointing [33, 46, 47], the analysis in this section emphasizes on the failure of these models being in practice rather than in the laboratory.

First of all, it is not novel to argue that the land use model should be an integral part of the planning process and context; researchers have been advocating this for a long period[48]. It is still hard for some models to explain which phase of practical planning they may be applied to. Most models are academically complicated and trying to include most important aspects of issues that are part of the process of urbanism. However, a complex model leads to a more difficult process of application whereas a specialised model is easier to be accepted by planners. For this reason, the design should focus on the issues important for the target users. For instance, it is obvious that research in housing requires more detailed scale of data than that of transport. In other words, a practical planning model should be user-oriented and stem from realistic issues. Another criticism is the models are far too generic, complex, inflexible and incompatible with the "wicked" nature of most planning tasks [49]. Planning indeed is a transdisciplinary issue and requires knowledge from different professional areas, and most importantly, it does not have precise objectives rather than general goals such as better environment, high accessibility or short time of travelling to work. The ability to model the problems of physical science fall far short of solving a planning issue which are no longer regarded as soluble in the classical scientific sense[13]. In contrast of traditional efforts centred on explaining the urbanisation, a collaborative design aimed to improve the communication of shareholders is taking the lead. A practical planning model should concentrate on providing flexible interfaces and enabling multiple accesses for different knowledge groups to contribute to the final output, instead of seeking a complex mathematical simulation.

IV. POPULATION DISTRIBUTION MODEL

A. Design Philosophy – Enterprise Resource Planning

Enterprise Resource Planning (ERP) means the techniques and concepts for integrated management of businesses as a whole from the viewpoint of the effective use of management resources to improve the efficiency of enterprise management [50]. It is a set of tools and processes that integrates departments and functions across a company into one computer system[51]. ERP is running within a single database and enables different departments to communicate and share the information. In other words, ERP in fact provides a platform with multiple thresholds allowing people to update the associated data, where the overall efficiency is improved synchronously.

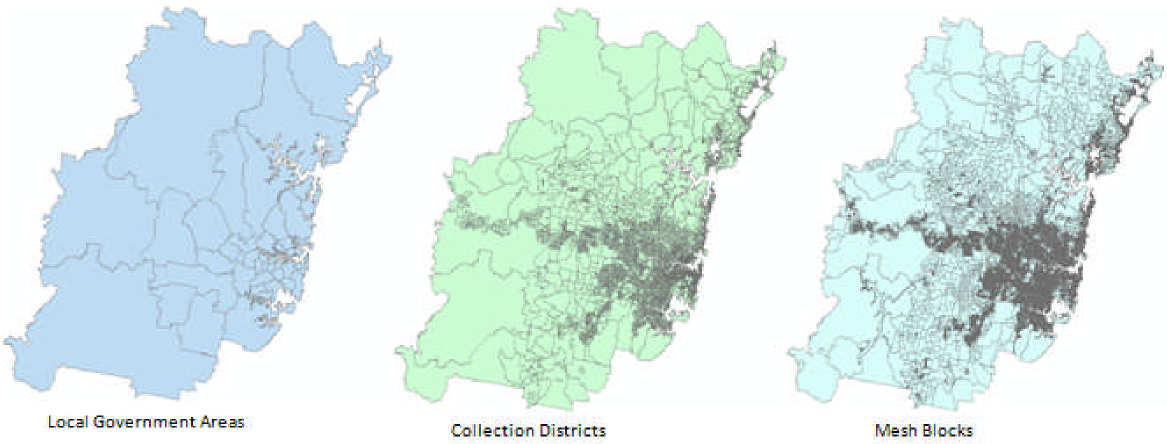


Figure 7: digital boundary data employed in proposed model

This notion can be applied in metropolitan planning, since planners need to mediate among departments and issues, as compared in Fig.6.

A sophisticated ERP system contains a number of modules with advanced mathematical methods to improve its performance. This is also applicable in building a land model. A simple but pivotal platform should be created first with the function of gathering the data and feedbacks, after which more complex tools could be added. This design provides convenience since the mathematical computation is encapsulated as optional tools, while further modifications can be easily made by appending a new sub-model.

B. Modelling Object

The objects simulated by most models are either individuals or land parcels. The objects, however, should have the ability of being easily utilized and integrated by other systems and tools. For instance, the object in ERP is the company's product where the whole system and departments come together to provide the services necessary for selling their product. Population, in other words, is the basic element of any urban analysis because the people place pressure on environment, determine the transport and require living facilities, especially when other data are composed by people no matter of household, employment or residential land. Another reason is considering the practical context and end users' need, where population can be accepted and utilized by other departments and the public. The complication of urbanisation is also of concern as the existing models failed to reflect the nature of urbanism in spite of containing multiple elements, such as employment and infrastructures. In contrast, the purpose of the proposed model is to provide possible plans rather than simulating urban future. Therefore, author grounds on the population distribution and sets other elements as constraints, aiming to display multiple scenarios for metropolitan planners.

C. Data Format

There is no doubt the grid data model is the most popular data format the researchers used to develop their model, owing to its calculation convenience. The grid data model is also the only format accepted by the spatial analysis tools in GIS software and able to finish many operations that the vector data model cannot. However, it is difficult to apply the raster to all users because there is a significant data loss when transferring vector data to grid data as the practical boundary is not regular at all. It means different analyses may generate different results during the conversion. Thus the proposed model employs the mesh blocks from census data, the most original data source, where the smallest polygon is 154 m^2. Fig.7 is the examples of digital boundary map from census data.

D. Model Description

The practical process of building the proposed model is to construct a kernel first, through which further modifications and sub-models can be easily added to form a more complex system. The kernel in this case is to distribute certain number of residents to assigned mesh blocks with flexible interfaces used to link sub-models. Each step indicated in solo mechanism is equipped with a default calculation and several alternative options. The model firstly computes the suitability with two steps that of macro influence and micro fitness.

Macro influence takes into account factors that shape the growth pattern, such as transportation, employment centre, economy or land zoning.

Other factors are also optional being set as variables including the income, the education level, crime rate and age. The default calculation derives from Bid-Rent theory [52, 53] that transportation, employment and household size affect the people's choice of residential location. The data of railway and road are shown in Fig.8, and the size of household is from census 2006, published by Australian Bureau of Statistics.

The employment centre is identified as providing 10000 jobs with at least 25 jobs per hectare [54], so nine centres are recognized according to the report from transport data centre[55], shown in Fig.9.

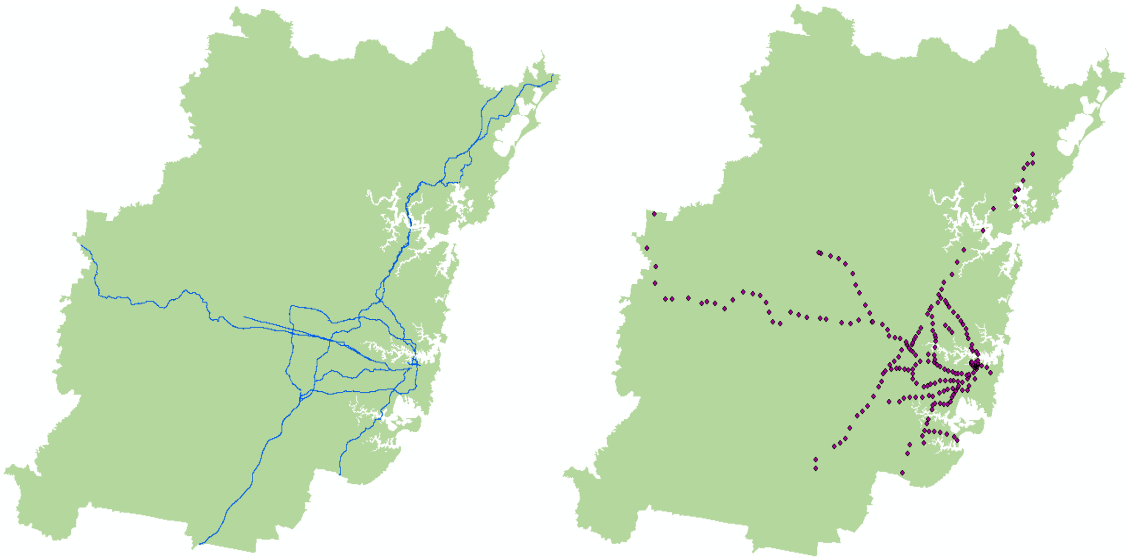
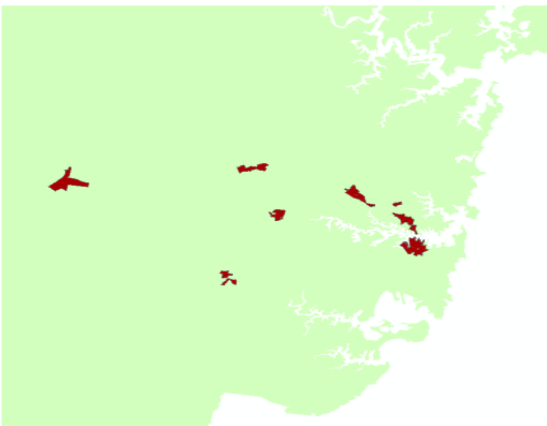


Figure 8: Motorway, primary road and railway station



Centre	Jobs	Density (Jobs/Ha)
CBD	230049	546
North Sydney	35761	369
St Leonards	34447	107
Macquarie Park	31982	69
Chatswood	17901	271
Liverpool	13597	55
Parramatta	34234	131
Penrith	11704	42
Norwest Business Park	10305	44

Figure 9: nine employment centres

The measurement of the influence of urban centres is evolved from the gravity model, stated by Krueckeberg and Silvers [18], that the force of urban centres equals to the average of employment size divided by the distance's square, shown in Eq. (1).

$$F_i = j^{-1} * \sum \frac{P_j}{D_{ij}^2} \quad (1)$$

Where

F_i = the average force to specific mesh block
j = the number of urban centre
D_{ij} = Distance from single block to single centre
P_j = total employment size for centre j

Geoda is employed to generate weights matrix based on 8-point queen rule and test the Moran's I, explained in Fig.10.

DIAGNOSTICS FOR SPATIAL DEPENDENCE
FOR WEIGHT MATRIX : EmpolymentCentre_NEw.gal
(row-standardized weights)

TEST	MI/DF	VALUE	PROB
Moran's I (error)	0.256522	75.0374950	0.0000000
Lagrange Multiplier (lag)	1	5886.8319491	0.0000000
Robust LM (lag)	1	262.9147235	0.0000000
Lagrange Multiplier (error)	1	5624.2385685	0.0000000
Robust LM (error)	1	0.3213429	0.5708017
Lagrange Multiplier (SARMA)	2	5887.1532920	0.0000000

Figure 10: Spatial autocorrelation analysis in Geoda

A significant positive value of Moran's I indicates the strong spatial autocorrelation existing in current population distribution. The spatial lag regression is then run to determine the coefficients in the Eq. (2) [53].

$$y_i = \beta_0 + \beta_1 x_i + \rho w_i y_i + \varepsilon_i \quad (2)$$

where β are the coefficients to estimate and $\rho w_i y_i$ captures the impact of neighbourhood; x_i includes distance to railway, distance to road, household size and average force from urban centres. The result is then encapsulated into ModelBuilder and the coefficient and factors are designed as variables. Fig.11 is the practical design in ModelBuilder.

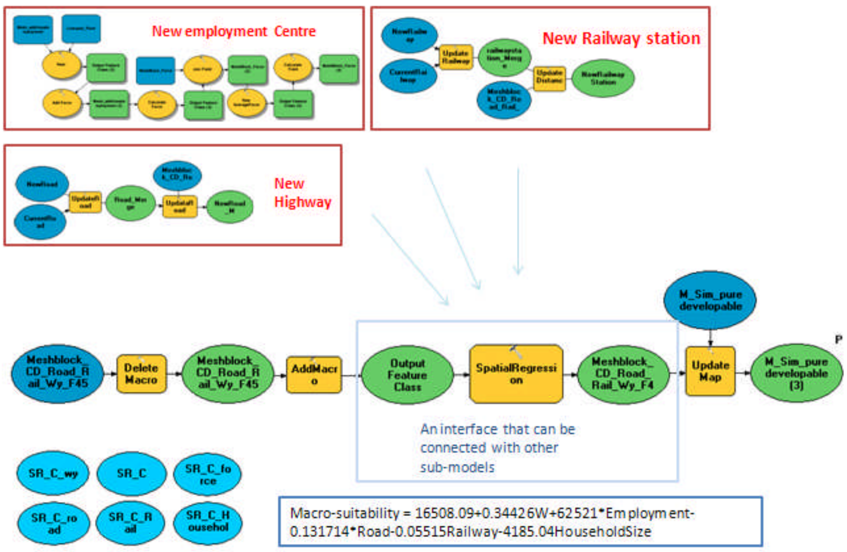


Figure 11: Macro Suitability Module in ModelBuilder

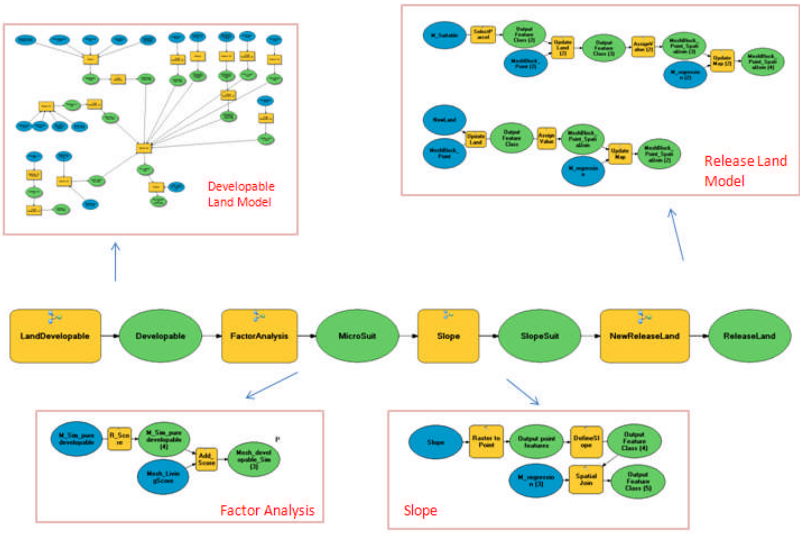


Figure 12: Micro suitability modules in ModelBuilder

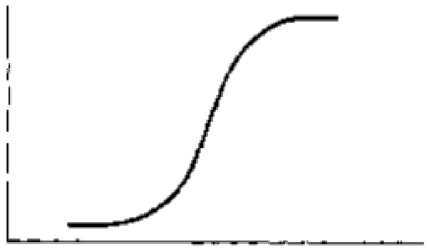


Figure 13: The S-shape of logistic curve

Some typical sub models, like new highways or new employment centres, have also been established. The database will be updated given the users' decision of whether to enable these modules. Thereafter, the order is transferred to the designed interface and the calculation is re-run using the new variables.

The micro suitability is computed flexibly to reflect diverse requirements for the arrangement of the population. The default module considers a range of living related factors, including community facilities, education facilities, recreation areas, hospitals and shopping centres. The factor analysis is employed to reduce the dimension and extract the principle components, through which each mesh block is assigned with a score. Alternatively, a rule-based method can be applied when considering certain type of household. For instance, a couple with children might want to live near to a school but other sorts of households may not want to. The developable land module is to identify the undevelopable areas, such as watercourses, national parks and reserve lands. A slope dataset is also created from the contour data in ModelBuilder. The initialized setting of slope module is that 0-5% is suitable for development and 5%-25% is developable with additional cost[37]. Another module is whether and where to release new land for residential purpose. Users can either determine a specific land area for development or allow the computer to choose automatically according to suitability scores. The detailed process is shown in Fig.12.

The process of allocation is developed under the hypothesis that urban growth follows a logistic curve [54-56] that the growth is slow at first and then increased exponentially, slowing again when saturation begins, known as S-shape curve (Fig.13).

The density data, coving past 20 years of each local government district, are utilized to build the logistic equation, shown in Eq.(3), through which each local area has a unique growth curve since regions like the city of Sydney have already reached its saturation while other areas like Liverpool still have huge capacity.

$$y = \frac{K}{1+ae^{-bt}} \quad (3)$$

where K, a, b are the coefficients and the upper limit is defined as the residential density of city of Sydney. Therefore a speed function is computed in Eq.(4).

$$V_{(t)} = \frac{d_y}{d_t} = \frac{Kabe^{-bt}}{(1+ae^{-bt})^2} \quad (4)$$

The curve is estimated within SPSS and transferred to ModelBuilder with VBA coding. The allocation process is shown in Fig.14.

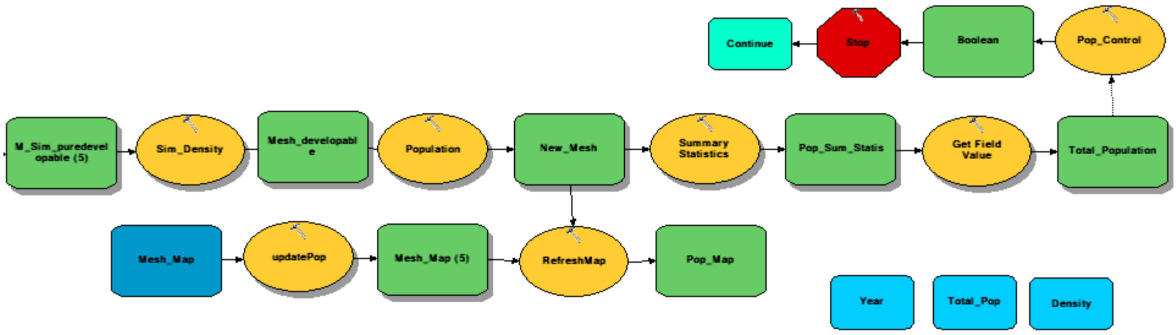


Figure 14: Population distribution module

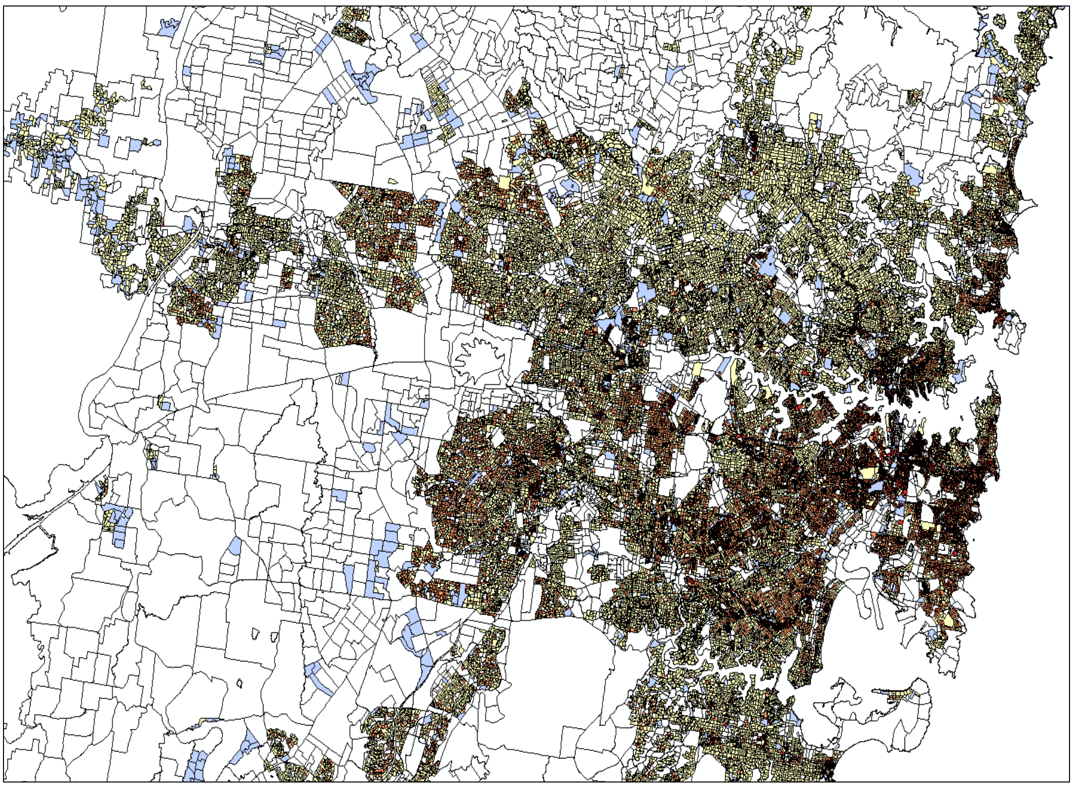


Figure 15: Population density in 2006

The model is encapsulated with an iterator in which the user can specify how many years to simulate. Each step of iteration allocates growing population to certain mesh blocks based on suitability, where the users also need to determine the upper density to decide whether to build a high dense city. The total population is set as a variable that enable the model to simulate certain population amounts rather than years. For instance, users can run the model to accommodate 6 million populations, while the whole model will stop if the number is reached.

A business-as-usual growth is taken as an example to illustrate the model. Population in 2006 is 4 million as shown in Fig.15. In this case, the model uses a default calculation of macro and micro suitability and sets the density level as 8000 people per km^2. The model densifies 5 million population in current residential zones without releasing new land. Fig.16 is the result. Five LGAs located in western region, Liverpool, Fairfield, Penrith, Blacktown and Bankstown, are extracted and zoomed in as shown in Fig.17. The result is also transferrable to ArcScene illustrated by Fig.18.

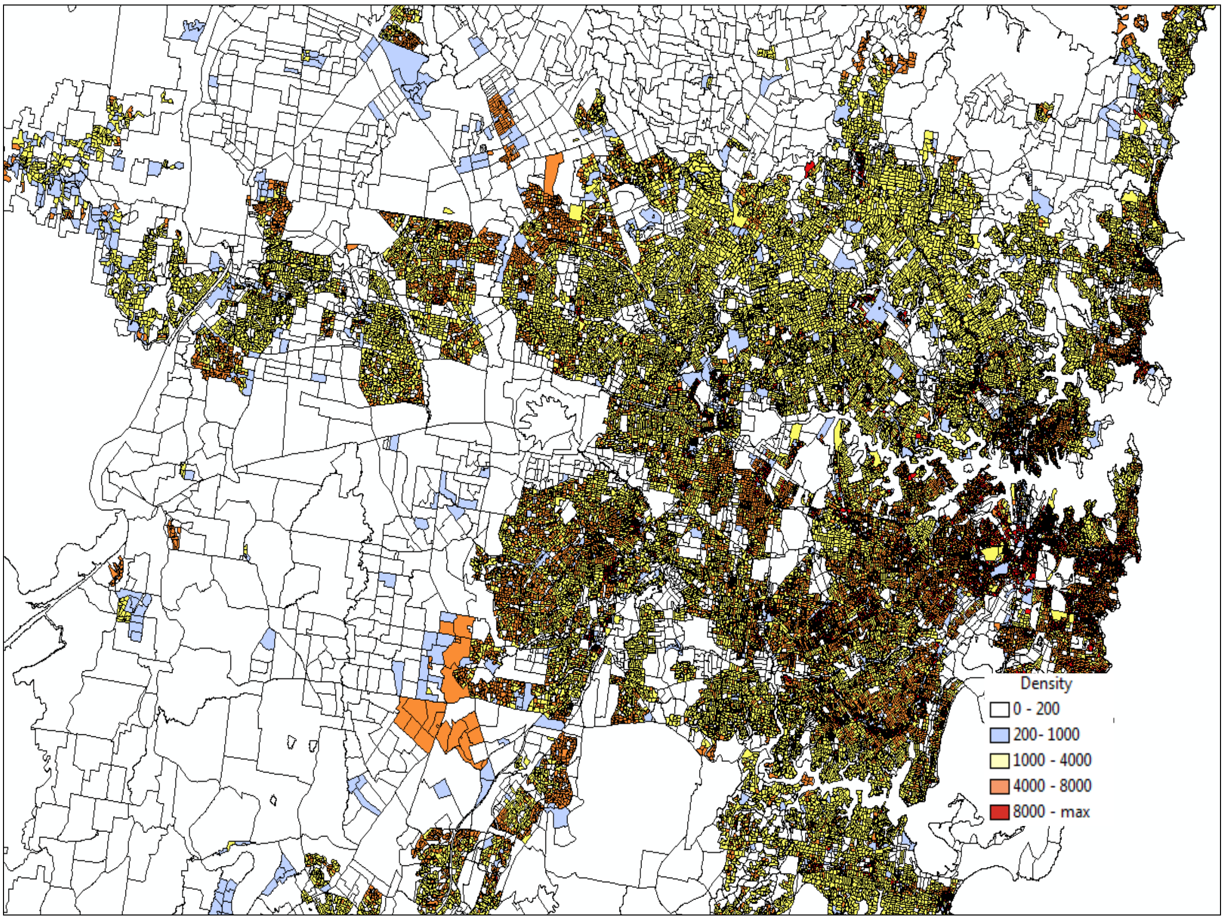


Figure 16: Sydney with 5 million people

Figure 17: A zoomed map of western suburbs

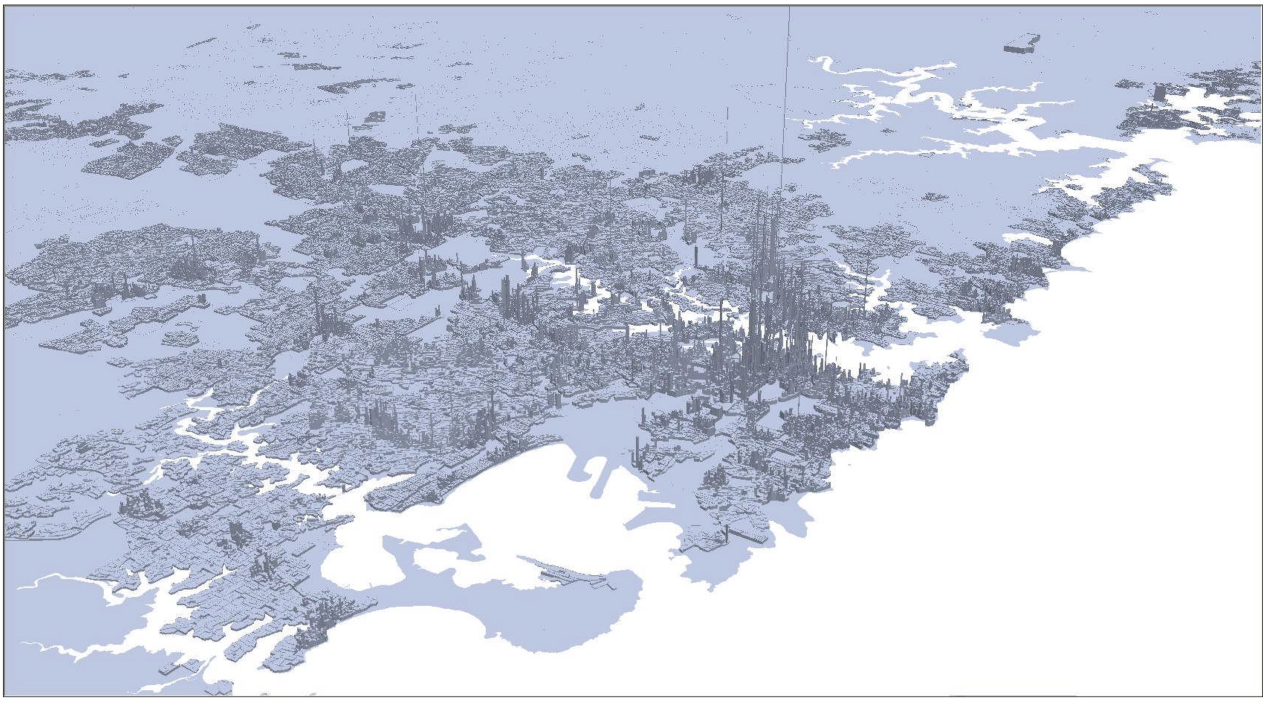


Figure 18: 3D version of the simulation result

V. CONCLUSION

The research of planning support system follows a gradual improvement for a long period while most efforts are to apply more detailed data and advanced computer techniques, especially when the high resolution data is available and GIS related softwares become widespread. A number of models like UrbanSim, Sleuth, Clue-s or what-if, developed for both laboratory and commercial purpose facilitate the spread of PSS and improve the cognition of this concept to urban planners in particular. Comparing to the academic success, the application in the professional world is rather disappointing. Instead, some environmental models in relatively small scale, targeting in particular issues, are more capable of meeting planners' need, such as BEIDGE [57, 58] and PRECINX[59]. To improve the implementation of large PSS, developers should ensure model's adaption to the end users and to the planning tasks.

This paper starts from a series of practical issues existing in metropolitan planning and introduces the concept of ERP to PSS, aiming to apply the academic model in practise and sit them in the planning context. METRIX is not a sophisticated planning tool but an excellent start. It effectively keeps 43 local councils involved in the planning process and allows different knowledge groups to contribute to the master plan. This indicates one of the important functions of urban models is to provide a platform for knowledge to communicate and then generate a more logical output. The notion of building a platform is the spirit of ERP as it organizes company's departments to run as a single entity. The complex calculation modules, instead, are capsulated as a tool that users can choose based on their needs. This migration, from ERP to PSS, could alleviate the tension between laboratory and practise to some degree and inject new energy to urban planning.

As a continuous study, further developments will be constructed to improve this model, including more optional sub-models capturing more realistic urban phenomenon, a more user-friendly interface, and a flexible database that can be easily transferred to other softwares. Thereafter, the designed model will be connected to other environmental models, such as CityGreen, to test the impacts of different scenarios and planning policies.

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