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Unified Data Model of Urban Air Pollution Dispersion and 3D Spatial City Models: Groundwork Assessment towards Sustainable Urban Development for Malaysia

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ABSTRACT

Understanding the behavior of urban air pollution is important en route for sustainable urban development (SUD). Malaysia is on its mission to be a developed country by year 2020 comprehends dealing with air pollution is one of the indicators headed towards it. At present monitoring and managing air pollution in urban areas encompasses sophisticated air quality modeling and data acquisition. However, rapid developments in major cities cause difficulties in acquiring the city geometries. The existing method in acquiring city geometries data via ground or space measurement inspection such as field survey, photogrammetry, laser scanning, remote sensing or using architectural plans appears not to be practical because of its cost and efforts. Moreover, air monitoring stations deployed are intended for regional to global scale model whereby it is not accurate for urban areas with typical resolution of less than 2km. Furthermore in urban areas, the pollutant dispersion movements are trapped between buildings initiating it to move horizontally causing visualization complications which imply the limitations of existing visualization that is based on two-dimensional (2D) framework. Therefore this paper aims is to perform groundwork assessment and discuss on the current scenario in Malaysia in the aspect of current policies towards SUD, air quality monitoring stations, scale model and detail discussion on air pollution dispersion model used called the Operational Street Pollution Model (OSPM). This research proposed the implementation of three-dimensional (3D) spatial city model as a new physical data input for OSPM. The five Level of Details (LOD) of 3D spatial city model shows the scale applicability for the dispersion model implementation. Subsequently 3D spatial city model data commonly available on the web, by having a unified data model shows the advantages in easy data acquisition, 3D visualization of air pollution dispersion and improves visual analysis of air quality monitoring in urban areas.

Keywords: 3D Spatial City Model; Urban Air Dispersion Model; Unified Data Model; Sustainable Urban Development; CityGML; 3D Visualization; 3D GIS

1. Introduction

Since 1950's the world's population increases to triple in 25 years [1]. The world's population is projected up to 7.3 billion in 2015. **Table 1** shows Asia is among the regions that indicate a drastic increase in urban percentage. Asia percentage for average annual rate of change for an urban area is 2.39% and for rural area it decrease -0.2%. In Malaysia, urban population rises from 1,244,000 in 1950 to 20,150,000 in 2010 (**Figure 1**).

Besides population increasing, another factor that comes to pass concomitantly is the urbanization process especially in developing countries. Usually the situation arose when people move from rural areas to urban areas for a better living standard. For instance, in Malaysia the projected annual rate percentage population living in rural areas decreases dramatically from 28% to 12% of the total population at year 2010 and 2050 consecutively (**Figure 1**). Annual rates of change percentage for urbanization retain growing positively and showed the trend will absolutely necessitate urban development.

Urbanization process gives impacts in a range of economic, political, social, cultural, and environmental. Based on current and previous research, it shows that urbanization usually contributes negative impacts on the environment if the developments are not taking into considerations of having a proper development process[3-5].

Table 1. World's urban population from 2011 to 2050 [2].

Country or area	Population (thousand)						Percentage Urban			Average annual rate of change (percentage)	
	Urban			Rural						Urban	Rural
	2011	*2025*	*2050*	*2011*	*2025*	*2050*	*2011*	*2025*	*2050*	*2010-2015*	*2010-2015*
World	3632457	4642582	6252175	3341579	3360397	3053953	52.1	58	67.2	1.97	0.12
Africa	413880	642423	1264629	632043	774635	926970	39.6	45.3	57.7	3.23	1.63
Asia	1895307	2512033	3309694	2312140	2218097	1832526	45	53.1	64.4	2.39	-0.2
Europe	539010	566299	591041	200289	177591	128216	72.9	76.1	82.2	0.4	-0.71
Latin America and the Caribbean	472175	560030	650479	124454	118748	100476	79.1	82.5	86.6	1.42	-0.3
Northern America	285805	330040	395985	61758	58432	50878	82.2	85	88.6	1.13	-0.45
Oceania	26280	31758	40346	10895	12894	14887	70.7	71.1	73	1.49	1.38

Realizing these challenges, major cities tend to minimize the negative effects and build the benefits [6-8]. Therefore people are looking forward to a sustainable urban environment in developing urban spaces that meet the standard for future generations and fulfill current development needs.

Sustainable urban development can be described as development that improves the long-term health of social and ecological cities and towns [9]. It reflects The Rio Declaration on Environment and Development, Agenda 21 by the United Nations, stated:

Principle 1: "Human beings are at the center of concern for sustainable development. They are entitled to a healthy and productive live in harmony with nature".

This situation has caused development tends to organize pollutions by understanding the pollution behavior. Less pollution is one of the major characteristics of sustainable developments [9]. Understanding the pollution behavior is important in the planning stage in order to control and manage pollution. In this paper, focuses are meant for urban air pollution, one of most pronounces urban pollution [10]. In Malaysia, preceding research based on several cases showed that air pollution gives an impact on human health [11]. Since Malaysia is on the move to become a developed country by the year 2020, managing air pollution is one of the indicators headed for that mission. Therefore in this research the discussion is constructed on the unified data model of urban air dispersion models for link-based air pollution source with 3D spatial city models as a useful data input expansion and visualization. Section 2 in this research paper dis-

cussed on the initiatives and limitations in Malaysia regarding to air quality monitoring in urban areas. Meanwhile Section 3 explains the 3D spatial city models technical details, modules and possible implementation for air quality monitoring in urban areas. Moreover thorough discussions were made in Section 4 regarding the integration of urban air pollution dispersion model in 3D spatial city models. Later Section 5 shows the unified data model proposed for implementation and simulation result of air dispersion in 3D spatial city models. The integration was studied thoroughly and a unified data model was presented in this paper.

2. Policies, Monitoring Stations and Scale Model Limitations in Malaysia

In the current 10th Malaysia's Plan, Thrust 4: "To Improve the Standards and Sustainability of Quality of Life" shows that Malaysia be present in positioning its part towards The Rio Declaration on Environment and Development, Agenda 21 by the United Nations. It can be perceived in policies on the subject of land use, climate change and green technology. As an example, for land use - National Physical Plan (NPP) and National Urbanization Policies (NUP); Climate change - National Policies on Climate Change and Road Map for Reduction of GHG Emissions; and Green technology- National Green Technologies Policy.
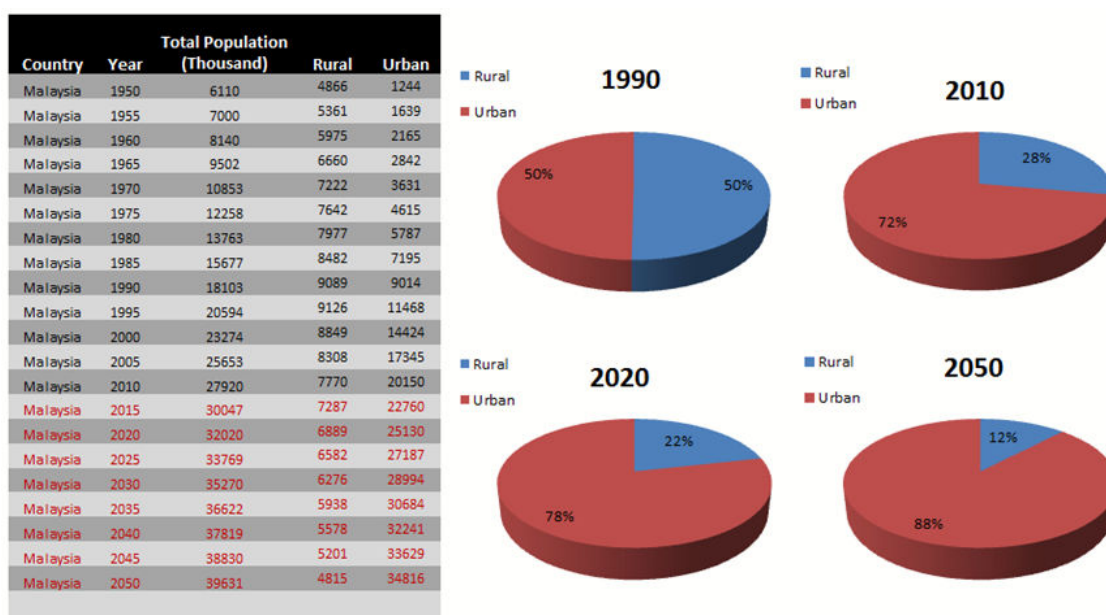
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Country	Year	Total Population (Thousand)	Rural	Urban
Malaysia	1950	6110	4866	1244
Malaysia	1955	7000	5361	1639
Malaysia	1960	8140	5975	2165
Malaysia	1965	9502	6660	2842
Malaysia	1970	10853	7222	3631
Malaysia	1975	12258	7642	4615
Malaysia	1980	13763	7977	5787
Malaysia	1985	15677	8482	7195
Malaysia	1990	18103	9089	9014
Malaysia	1995	20594	9126	11468
Malaysia	2000	23274	8849	14424
Malaysia	2005	25653	8308	17345
Malaysia	2010	27920	7770	20150
Malaysia	2015	30047	7287	22760
Malaysia	2020	32020	6889	25130
Malaysia	2025	33769	6582	27187
Malaysia	2030	35270	6276	28994
Malaysia	2035	36622	5938	30684
Malaysia	2040	37819	5578	32241
Malaysia	2045	38830	5201	33629
Malaysia	2050	39631	4815	34816

Figure 1. Annual percentage of Malaysia's urban population (Source: Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat, World Population Prospects: The 2006 Revision and World Urbanization Prospects: The 2007 Revision, http://esa.un.org/unup, Tuesday, April 24, 2012; 2:19:41 AM).

However, moving towards sustainable development for urban spaces is not an easy task. Despite the fact that policies regarding on the sustainable development are present, but to manage spaces with rapid development, active industrialization and high traffic volumes form a different scenario for the administration. Monitoring air quality in urban areas requires more monitoring stations to be positioned near to cities whereby it is unmanageable and not practical. Due to that limitation, monitoring stations are planned for large scale air quality model [12, 13].

Scale model in air quality modeling can be characterized into several groups. According to Srivastava and Rao [14] the categories are Global, Synoptic, Regional, Meso-scale and Micro-scale model. Different scale model gives difference influence in air quality modeling visualization. **Table 2** shows the different domain scale for each category. Each domain identifies different accuracy of air quality monitoring. Smaller grids will give a more accurate model for specific area compared to larger grids whereby it will calculate the mean for total grids.

Nevertheless, current situations in many countries the available information are range from Global to Regional scale model. It is due to several factors. Vardoulakis,

Table 2. Typical domain for different scale model [14]

Model	Typical Domain Scale	Typical Resolution	Motion Example
Macro Scale	200x200x100m	5m	Molecular diffusion, Molecular viscosity
Meso-Scale (urban)	100x100x5km	2km	Small plumes, Car exhaust, Cumulus clouds
Regional	1000x1000x10km	36km	Gravity waves, Thunderstorm, Tornados, Cloud clusters
Synoptic (continental)	3000x3000x20km	80km	Weathers fronts, Tropical storms, Hurricanes, Antartic ozone hole
Global	65000x65000x20km	4° x 5°	Global wind speed, Rossby (planetary) waves, Global warming

Fisher, Pericleous, and Gonzalez-Flesca [15] discovered that monitoring stations in urban areas are limited to a few sites and often it is located at airports. As for an example, the Malaysian Meteorological Department monitors 22 air pollution monitoring stations throughout the country (**Figure 2**). Meanwhile, Department of Environment Malaysia only has 15 continuous air quality monitoring stations in urban areas and their major focus

is in Klang Valley whereby the capital city of Malaysia, Kuala Lumpur is located (**Figure 3**). These stations are based on regional scale model and did not focus on a specific area that less than 2km grid. Unfortunately, the major source of air pollution in urban cities comes from vehicle emissions [16]. Heavy traffic and slow vehicle movements seem will trap the pollutant emission inside of the urban geometry. The circulation of pollutant between buildings will worsen if there is no natural ventilation or slow background wind speed. However it is crucial to monitor air pollution in urban cities in order to have a better and healthy living standard. But to deploy monitoring stations at street level will affect the cost. This is one of the reasons why it is difficult to have a Micro scale model for air pollution monitoring in urban area [17].

Figure 2. Location of Air Pollution Monitoring Stations by Meteorological Department, Malaysia.


Figure 3. Location of Continuous Air Quality Monitoring Stations by Department of Environment, Malaysia.

Another alternative is to perform air quality modeling in the urban area [18, 19]. Since the agent (pollutants) is a moving object, appropriate modeling approach in a rapid development place need to be deliberate comprehensively. In a practical approach, the urban air quality model requires several data input [15]. The geometry of an area model is important in order to produce a more accurate result. To date, there are complications in data acquisition for rapid development places. New data input like building geometries (e.g. Building's height, width and gaps) need to be collected from ground measure-

ments and re-calculated with other inputs (e.g. street geometries). This data is important in air quality modeling (dispersion model) to produce an accurate output.

In air dispersion models, it consists of two major groups of data: meteorological and physical data (**Figure 4**). Meteorological department monitors information regarding to meteorological circumstances (i.e. Wind speed, pollution concentration, wind direction and etc.). Moreover in several countries these data are available for public use. On the other hand for physical (spatial) data, the exact geometrical state for the modeling is required because different geometries for the street canyon will affect the dispersion movement. Therefore the exact street geometry measurements are necessary in order to calculate the air dispersion model.

Current practice in acquiring those data is via ground or space measurement inspection such as field survey, photogrammetry, laser scanning, remote sensing or using architectural/floor plans [20-22]. But in order to measure the geometrical data for developing areas, there are complications in terms of data acquisition. Development area such as in major cities will involves with rapid changes that causes data updating difficulties for air pollution modeling. Therefore this research proposed a unified data model between air quality models with 3D spatial city modeling. As in **Figure 4**, all spatial information needed in air quality models is available in 3D spatial city modeling. Although 3D spatial city model (i.e. CityGML) is an open-standard data model, nevertheless with a proper amalgamation with air quality modeling, 3D spatial city model can be a new way of data input for visualizing air pollution dispersion model.
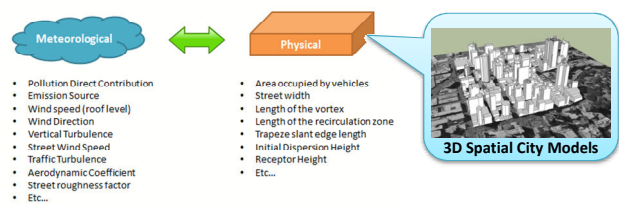
Figure 4. Urban Air Dispersion Modeling and 3D Spatial City Model Conceptual Data Integration.

3. 3D Spatial City Model

Users now interested in the visualization of 3D objects [23-26]. It can be seen from the user demand viewpoint in 3D based applications [27-29]. This is to facilitate the visualization of 3D objects as it is more realistic than the two-dimensional (2D) display. Undoubtedly that a 3D

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Figure 5. 3D Spatial City Models Available on the Web in March 2013.

view of a building model is more realistic compared to 2D floor plan or a cross section of a building plan. At present, in order to promote investors and tourism, most of the major cities have acquired 3D building models (**Figure 5**). They also plan to increase those numbers based on their development growths.

The trends of 3D spatial city model development can be seen from the efforts of many [30, 31]. Some of them are coming from a private business, government, academicians, researchers or group of students. There are various tools on the market which facilitate these parties to develop those 3D models. Some of them develop this model as a hobby while others develop it as a planning for the future. However, these models are mainly used for visualization. Most of the visualization is just to perceive the development that took place in a city or just to get an insight at interesting architectural shapes of buildings with simple information inquiries.
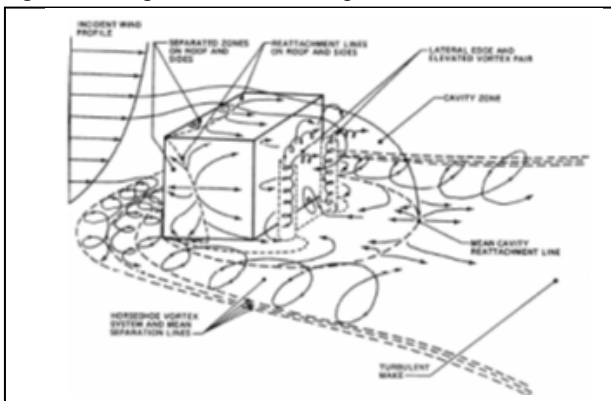

Figure 6. Wind flow around a building [34].

Based on this trend, 3D data will be an important resource in the near future. **Figure 6** and **Figure 7** shows that there is a need in requiring more comprehensive way of describing urban air pollution behavior. Based on these scenarios, researchers try to view urban air pollution in 3D visualization [32, 33].

3D visualization gives a better understanding of air pollution dispersion models. In **Figure 8**, a warning line for NO_2 pollution level is drawn on a 3D building model. Until recently, Metral, Falquet, and Karatzas [34] discovered the integration of air quality models with 3D spatial city model can create an interoperable way for air quality models in 3D. The existing CityGML structure consists of useful information for the ontology of the urban planning process (OUPP).
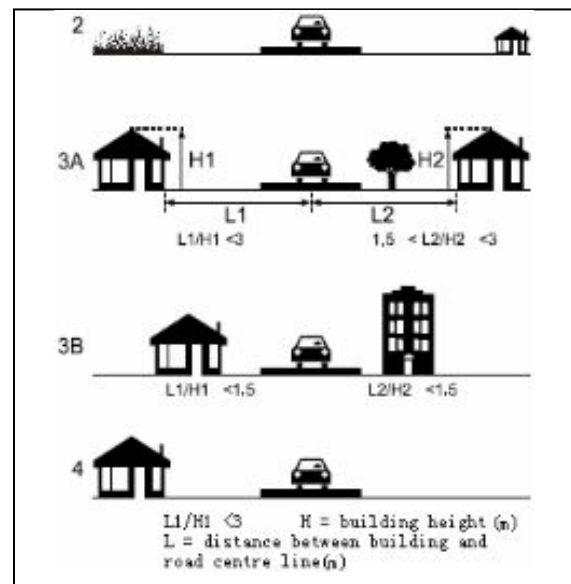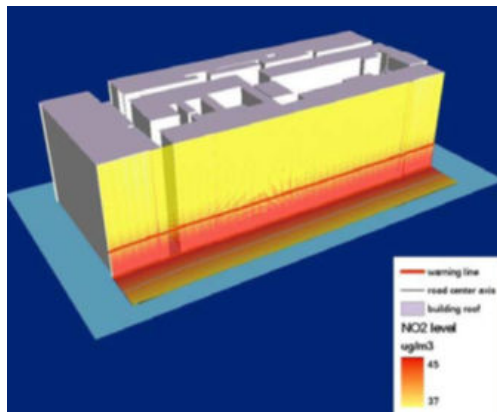

Figure 7. Road type categories [32].

The relevancy of using the 3D spatial city model (CityGML) for air quality monitoring is its scale. As discussed in Section 2, air quality modeling in urban areas requires a scale model that less than 2km resolution. But to acquire data for micro-scale urban areas is challenging. Detailed geometries for buildings and street objects are necessary before executing the calculations. However in CityGML they have different scales for implementations called the Levels of Detail (LOD). Each

Table 3. LOD 0-4 of CityGML with its accuracy requirements [36].

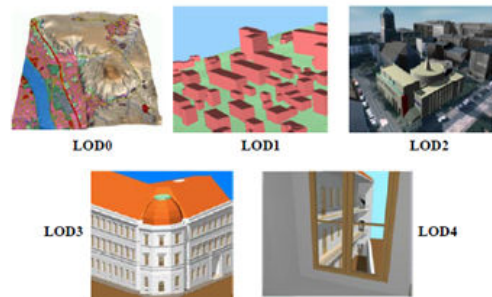|	LOD0	LOD1	LOD2	LOD3	LOD4
Model scale description	regional, landscape	city, region	city districts, projects	architectural models (out-side), landmark	architectural models (interior)
Class of accuracy	lowest	low	middle	high	very high
Absolute 3D point accuracy (position / height)	lower than LOD1	5/5m	2/2m	0.5/0.5m	0.2/0.2m
Generalisation	maximal generalisation (classification of land use)	object blocks as generalised features; > 6*6m/3m	objects as generalised features; > 4*4m/2m	object as real features; > 2*2m/1m	constructive elements and openings are represented
Building installations	-	-	-	representative exterior effects	real object form
Roof form/structure	no	flat	roof type and orientation	real object form	real object form
Roof overhanging parts	-	-	n.a.	n.a.	Yes
CityFurniture	-	important objects	prototypes	real object form	real object form
SolitaryVegetationObject	-	important objects	prototypes, higher 6m	prototypes, higher 2m	prototypes, real object form
PlantCover	-	>50*50m	>5*5m	< LOD2	<LOD2

five LODs are based on precisely in what way specific model required in different applications (**Figure 9**). Based on these LODs, LOD1 and LOD2 appear related to the scale model by less than 2km resolution in urban air pollution dispersion model. LOD1 is the well-known blocks model comprising prismatic buildings with flat roofs. Meanwhile, a building in LOD2 has differentiated roof structures and thematically differentiated surfaces. The generalizations of spatial objects for each LOD are described in **Table 3**.

input for urban air pollution dispersion modeling (**Table 4**). Meanwhile other modules such as the TexturedSurface module will enhance the 3D visualization for perceiving the dispersion process and create a more realistic urban environment for visual analysis.
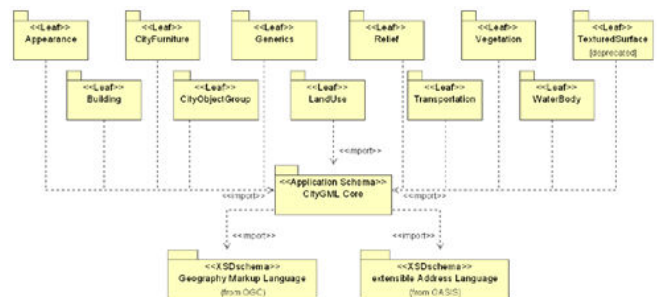
Figure 9. The five levels of detail (LOD) defined by CityGML [35].

Figure 8. Pollution warning line [32].

CityGML consists of modules for different city objects (**Figure 10**). Among those modules are Building module, CityFurniture module and Transportation module whereby those modules is important as a physical data

Figure 10. UML package diagram illustrating the separate modules of CityGML and their schema dependencies [36].

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Table 4. Overview of CityGML's core and thematic extension modules.

Module	Building	CityFurniture	Transportation
XML Namespace Identifier	http://www.opengis.net/citygml/building/1.0	http://www.opengis.net/citygml/cityfurniture/1.0	http://www.opengis.net/citygml/transportation/1.0
XML Schema File	building.xsd	cityFurniture.xsd	Transportation.xsd
Recommended Namespace Prefix	bldg	frn	tran
Module Description	Representation of thematic and spatial aspects of buildings, building parts, building installations, and interior building structures in four levels of detail (LOD 1 – 4).	Represent city furniture objects in cities. City furniture objects are immovable objects like lanterns, traffic signs, advertising columns, benches, or bus stops that can be found in traffic areas, residential areas, on squares, or in built-up areas.	Represent the transportation features within a city, for example roads, tracks, railways, or squares. Transportation features may be represented as a linear network or by geometrically describing their 3D surfaces.

From the discussion, it shows that by having a 3D spatial city model like CityGML, there are potentials in incorporating it with air quality monitoring. With the available sources, format, standard, and modules in CityGML, it will provide a reliable platform for air quality monitoring in the 3D spatial city model. In the next section, the discussion is based on the details of air pollution dispersion model in urban areas. Moreover, in detail explanation about the specific model for air quality monitoring in urban areas called Operational Street Pollution Model (OSPM) which is practical for urban geometries.

## 4. Air Pollution Dispersion Models (APDM) in 3D Spatial City Model

In urban area, major pollution source is contributed by vehicle (land transportation) emission. According to the compendium of environment statistics Malaysia 2012 by Department of Environment Malaysia, motor vehicle sources emit 69.4 percent of pollutants to the atmosphere, followed by stationary sources emit 27.3 percent and other sources emit 3.3 percent in the year 2011. This fact is supported by other researchers [11, 37] in identifying the major source of air pollution in major cities. This moving emission source will create a line of emission along the roadway. Therefore this emission source can be categorized as a link-based emission source.

A link-based of CO emission from land transportation will disperse along the roadway between buildings inside the street geometry. By using parameters required, dispersion models can calculate and map the dispersion movements inside the street geometry. Among dispersion models such as the Statistical Models, Eulerian Models, Street Canyon Models (SCM), Box Models and Gaussian Models, SCM can be seen as the fit model to be implemented in the 3D spatial city model [34]. Parameters in

SCM deliberated most of the major dispersion factors such as street geometries, building geometries, vehicle speed, pollutant emission and background contribution. Therefore a practical Street Canyon Models called Operational Street Pollution Model (OSPM) will be discussed in the next section as one of the suitable models to implement in the 3D spatial city model.

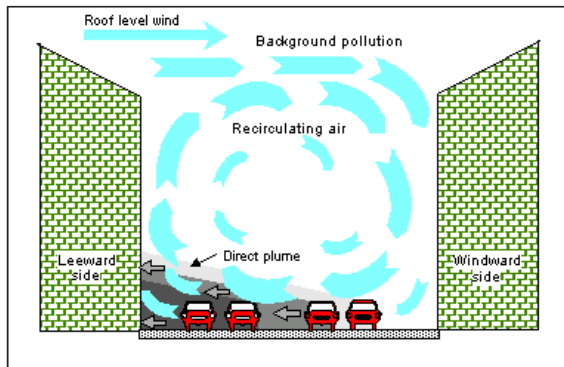### 4.1. The Operational Street Pollution Model (OSPM)

The Operational Street Pollution Model (OSPM) is a consequent of STREET model. The General concept of OSPM: vehicle emission or exhaust gases are calculated using the plume model (for direct contribution), box model (for recirculating pollutant) and background pollutant information. **Figure 11** shows the structure model for OSPM. An assumption in OSPM is that both the traffic and emissions are equally distributed across the street canyon. Next, the cross wind circulation is omitted. Only the wind direction at the street level is assumed to be mirror reflected with the roof level wind. Moreover, the extension of the recirculation zone will identify the length of the integration path.
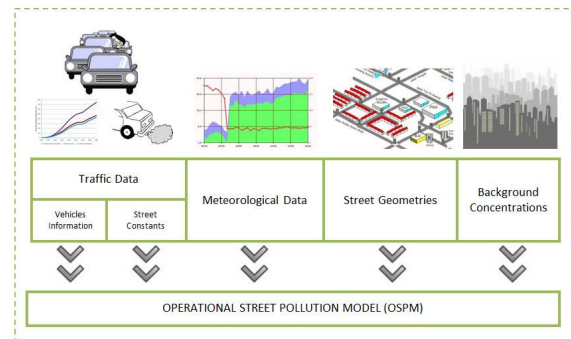
Figure 11. Operational Street Pollution Model Structure.

Considering the detail OSPM concept as shown in **Figure 12**, the main parameters are roof level wind, background pollution, recirculating air, direct plume, leeward and windward information. The length of the vortex, calculated along the wind direction, is twice the upwind building height. For roof-level wind speeds below 2 m/s, the length of the vortex decreases linearly with the wind speed. The buildings along the street may have different heights, affecting the length of the vortex and the modeled concentrations. The upwind receptor (lee-side) receives contributions from the traffic emissions within the area occupied by the vortex (the recirculation zone), the recirculated pollution and a portion of the emissions from outside of the vortex area. The downwind receptor (wind-side) receives contributions from the recirculated pollution and the traffic emissions from outside of the recirculation zone only. As the wind speed approaches zero or is parallel with the street, concentrations on the both sides of the street became equal. The vertical dispersion is modeled assuming a linear growth of the plume with the distance from the source.

Figure 12. Operational Street Pollution Model illustration concept (http://www.dmu.dk/en/air/models/ospm/).

4.2. OSPM in Urban 3D Spatial City Model Application

Pollution concentration in OSPM is contributed by three major aspects. It is the Direct Contribution (C_d), Recirculation Components (C_r) and Background Concentration (C_b). Pollutant Concentration (C_p) can be calculated by adding $C_d + C_r + C_b$.

C_d is caused by vehicle / land transportation emission through wind direction to receptor. Concentration from each vehicle that moves will form a line of emission along the street. The concentration can be calculated using Equation (1).

$$C_d = \sqrt{\frac{2}{\pi}} \cdot \frac{Q}{W \cdot \sigma_w} \cdot \ln\left[\frac{h_o + (\sigma_W / U_b) W}{h_o}\right] \quad (1)$$

Where, C_d = Concentration contribution from the

source; Q = Emission source; W = Street width; σ_w = Vertical turbulence speed; h_o = Initial dispersion height; U_b = Street level wind speed

Where σ_w and σ_{wo} can be calculated using Equation (2) and Equation (3).

$$\sigma_W = \sqrt{(0.1\,U_b)^2 + (\sigma_{wo})^2} \quad (2)$$

$$\sigma_{wo} = b\sqrt{\frac{V_c \cdot N_c \cdot S_c^2 + V_h \cdot N_h \cdot S_h^2}{W}} \quad (3)$$

Where, σ_{wo} = Traffic turbulence speed; V_c = Vehicle speed (passenger car), V_h = Vehicle speed (heavy vehicles); N_c = Number of passenger car, N_h = Number of heavy vehicles; S_c = Horizontal area occupied (passenger car), S_h = Horizontal area occupied (heavy vehicles); b = Aerodynamic coefficient drags (0.3)

Another important calculation in OSPM is street level wind speed (u_b) that can be calculated using Equation (4).

$$u_b = u_t \frac{\ln(h_o / z_o)}{\ln(H / z_o)} (1 - 0.2 \cdot p \cdot \sin(\Phi)) \quad (4)$$

Where, u_t = Wind speed (roof); h_o = Vehicle initial dispersion; H = Average building height (leeward and windward); p = Leeward Height / H; z_o = Roughness length

For Recirculation Components (C_r) it requires street geometry information for calculation. **Figure 13** illustrates the calculation for C_r.
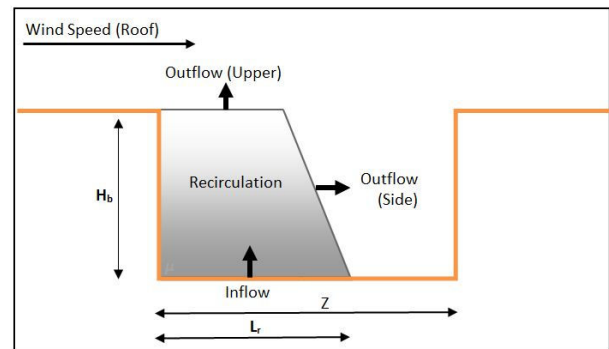
Figure 13. Recirculation Components.

Where Inflow = Outflow (Upper) + Outflow (Side), Outflow (Upper) = $C_r * \sigma_{wt} * 0.5L$ and Outflow (Side) = $C_r * u_d * L_s$.

5. Unified Data Model of Urban Air Dispersion Models in 3D Spatial City Models

Urban air pollution dispersion models involves with meteorological and physical data. According to Vardou-

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lakis, Fisher, Pericleous, and Gonzalez-Flesca [15] five major parameters involved in most dispersion models are presented in **Table 5**.

Table 5. Major data inputs of air dispersion models.

| *PARAMETERS*	*CATEGORIES*	*2D*	*3D*
Meteorological Information	Wind Flow		/
	Wind Vector		/
	Windward		/
	Leeward		/
	Synoptic wind flows		/
	Local wind flow		/
Receptor			/
Traffic Volumes		/	
Emission Factors	Point-based	/	/
	Link-based	/	/
	Area-based	/	/
	Volume-based		/
Physical (Spatial)	Canyon Geometry		/
	• Short canyons		
	• Medium canyons		
	• Long canyons		
	Building Geometry		/
	Aspect Ratio (H)		/
	Ventilation		/
	Building gap		/

Based on **Table 5**, those models require more information in three dimensional (3D) forms whereby the spatial information is retrievable from a 3D spatial city model. This could provide precise and effective urban air quality models for future planning. On the other hand, although it is retrievable from a 3D spatial city model but it is not a straightforward task. The framework of the 3D spatial city model is intended for general application purposes (e.g. 3D data transfer, web-enabled) and is still in a construction phase for specific application implementation. Based on previous work, air pollution data visualization in 3D is complex [33].

Therefore this research proposed an integrated data model between air pollution dispersion model with a 3D spatial city model in an effort to bridge the gap concerning both fields. The 3D spatial city model encompasses geometrical information which is useful in air pollution dispersion model. Furthermore 3D spatial city model offers 3D visualization which will improve insight in understanding the dispersion process based on parameters included. Hence, its implementation will give a better perception of the air pollution in reality. This is ad-

vantageous for decision makers and town planners in order to understand urban ecology in major cities towards sustainable urban development. Many researchers are in the direction towards 3D visualization in air pollution models [32, 38, 39] regarding to the advantages of better visual analysis.

Figure 14 shows a Unified Modeling Language (UML) for the data model. UML is a standardized general-purpose modeling language in the field of object-oriented software engineering. It shows the attributes of CityGML in conjunction with OSPM parameters for the amalgamation.

One of the advantages of implementing OSPM in the 3D spatial city model is the 3D visualization. For instance, recirculation zone (as discussed in the previous section) is one of the important criteria in OSPM. The calculation involved (section 4.1) gives a numerical output for the recirculation zone length. Unfortunately, numerical value is hard to perceive for visual analysis. Moreover, the different roof wind speed will give different values and can affect the canyon geometry. **Figure 15** shows the integration of calculating the recirculation zone in 3D spatial city model visualization with 3 different values for roof wind speed. By taking the roof wind speed data, the affected area in the recirculation zone can be calculated, viewed in 3D and analyzed for future references.
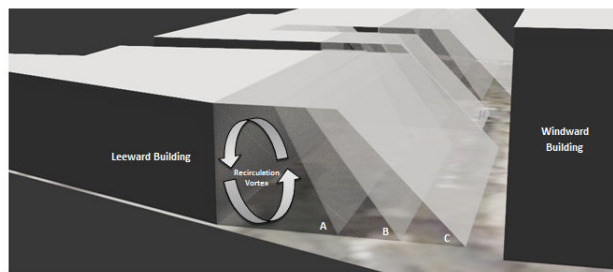
Figure 15. Recirculation zone in the 3D spatial city model with different roof wind speed: (A) 1.0 mph, (B) 1.5 mph and (C) 2.0 mph.

6. Summary

Air quality monitoring in urban areas is a crucial factor in order for Malaysia to achieve sustainable development growth. This research has been motivated by other researchers that studied the relationship, possibilities and advantages of using a 3D spatial city model for air quality monitoring [33, 34, 38, 39]. This paper explains the advantages of using a 3D spatial city model in the urban air quality model (dispersion model) in the aspect of model scaling, data acquiring, 3D visualization and visual analysis. Acquiring information about pollutant dispersion in urban areas requires a scale model of less than
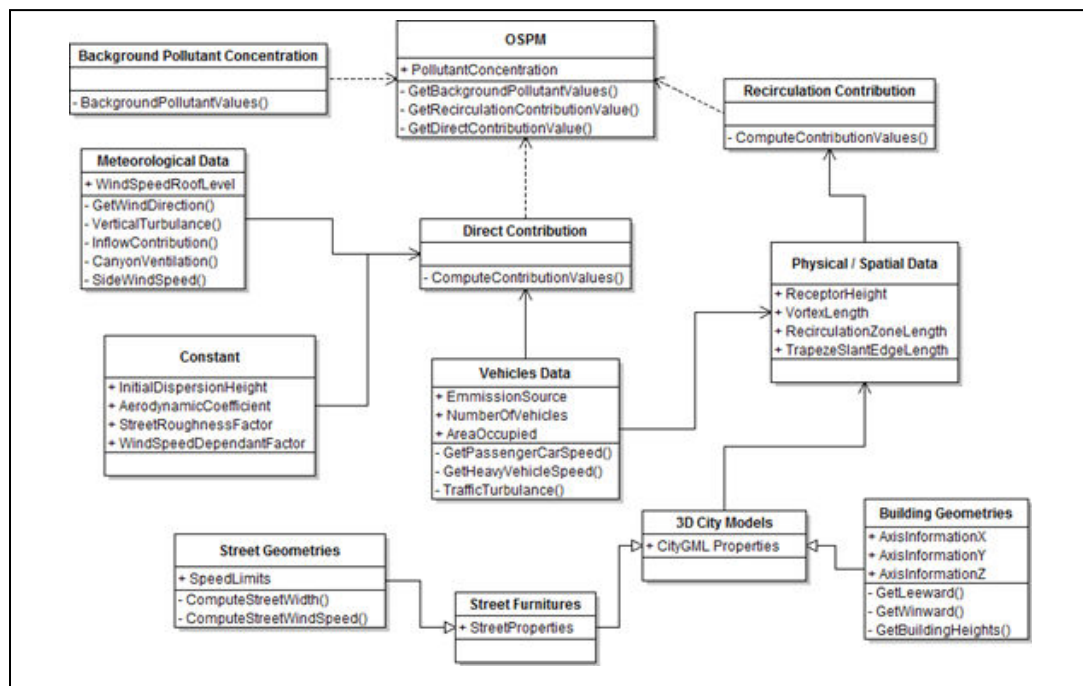
Figure 14. The Unified Modelling Language (UML) for air dispersion model with 3D spatial city model integration.

2km resolution. As discussed in section 2, to set up monitoring stations for each city is not practical. Therefore for meso-scale or micro-scale model, performing urban air pollution dispersion model is relevant to the 3D spatial city model as a new way of data input. Data acquiring for air pollution dispersion model is at ease by having a unified data model for integrating urban air pollution model with a 3D spatial city model proposed in this research. Visualization in 3D will improve the visual analysis for understanding the behavior of air pollutant dispersion. The future idea is to implement the developed unified data model in the aspects of geometrical and topological data structure. By having a 3D topological data structure, information regarding different layers of air pollution concentrations can be straightforwardly identified and analyzed.

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