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COST EFFECTIVE APPROACH FOR SPATIAL MODELING

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ABSTRACT

The paper presents an effort to standardize cost effective to support the development of spatial modeling. It is motivated by the increasing role of both cost effective and spatial modeling to contribute on society development worldwide. Therefore the future of spatial modeling would focus on minimizing cost and required time for model generation, in which cost effective become the only reliable approach to achieve these objectives. Considering that spatial modeling commonly consists of data acquisition, digitations process and model development, hence the characteristic of cost effective to minimize any required resources for system development is required to be presented in each stage. It means the method being utilized in each stage must comply with the objective of cost effective, thus method selection takes a vital role in the development process. The work has presented various strategies consisting of different methods being employed for model development in which each carries its own benefits and flaws. Finally it is important to consider available resources to meet with method selection in order to enable wise implementation of spatial modeling.

Keywords: *Cost Effective, Spatial Modeling, Polygonal Modeling, Procedural Modeling, Resource Consumption*

1. INTRODUCTION

The world has witnessed rapid development of spatial modeling to visualize complex city condition with high realism in the last decade. Even though it was originally intended to deliver only more realistic visualization on city view, however many researchers have been extending its function to enable quantitative spatial analysis to measure environmental condition such as [1] to reconstruct city historical site and [2] to provide data sources for land and property information. Therefore its role to manage environment seems capable of replacing common 2D GIS application in a short time ahead. Many efforts to implement spatial modeling to various cities in the globe however deal with complicated tasks that require complex data set with expensive processes for data acquisition. These factors become the barriers to deploy spatial modeling particularly for the third world where facilities, procedures, data availability and even finances are rarely available.

In fact, managing environmental condition is a vital need but often absence in many third world countries. The need to manage environment using spatial system have come to the scope of even sub-district level in order to deal with a bundle of government official businesses such as tax estimation, prediction of crop production, land administration, population management, and the prevention of contiguous diseases. Thus, it is important to somehow deliver spatial modeling for the third world countries using minimal cost or employing cost effective approach. Therefore the paper aims to figure out any mechanism of cost effective in order to facilitate the implementation and deployment of spatial modeling worldwide.

Started from this point, the organization of the paper is delivered as follows. Section 2 discloses the bottom line of cost effective together with its implementation in spatial modeling field. Various strategies to utilize cost effective are described in this section. It is then continued with Section 3 that delivers practical typical framework to develop spatial modeling. It is worth to note that the framework is suited with the implementation of cost effective in each stage of system development. Section 4 delivers study cases and discussion in order to test and analyze the feasibility of the presented spatial modeling framework that utilizes cost effective approach. Finally Section 5 concludes the work and addresses open issues which become the future work of this field.

2. COST EFFECTIVE APPROACH

There have been many literatures existed today recording the application of cost effective for spatial modeling. Some even claim having

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successful implementation of cost effective to establish spatial modeling [3,4,5], and others however fail to even indentify any benefit delivered by their effort [6]. This phenomenon is due to the definition of cost effective that often misinterpreted by many researchers. It is common to see many researchers judging their effort to develop spatial modeling with minimal cost as a cost effective approach without considering extra cost that would probably be accumulated in multiple times in the deployment stage. Therefore it is important to understand the bottom line of cost effective in order to employ this strategy effectively.

Cost effective originally comes from the field of economic evaluation, in which it measures the effect of intervention from different alternatives that serve the same goal [7]. Main characteristic of this approach is to evaluate the effect of alternative in natural units. In the field of spatial modeling, the effect is to save the utilization of resources during the development and deployment stage which include minimizing cost and simplifying process. Thus a system should be established at low cost i.e. resources consumption shall be minimized such as utilizing simple data and employing uncomplicated development procedure.

In this paper we argue that the application of cost effective aims to achieve greater independency for development and deployment of spatial modeling system. It means the application of cost effective would enable any parties to establish spatial modeling system without worrying on technical requirement and spatial literacy. This approach guarantee that required data can be obtained freely or at low cost, and it is possible to regenerate them at any time using simple procedure. Hence it emphasizes the usage of minimal cost for system development and deployment.

Currently two approaches are usually utilized to implement cost effective. The first is to focus on obtaining free or low cost data, while the second is to simplify the development process. The first aims to minimize the cost for data collection such as [5] that relies on the feedback from Internet users to conduct data sharing. Other approach to utilize stereo vision for video and image recording to generate image [6,8] can also be classified as low cost data acquisition. These approaches however are capable only to regenerate limited scene due to data availability constraint. Meanwhile the latter aims to minimize cost by saving the usage of resources in the processing step. Here the definition of project cost includes the utilization of processing time and the available computing resources such as memory consumption, algorithm complexity, etc. Thus the approaches in this category are established by developing automatic mechanism such as conducted by [3,4] to build automatic building model. However as noted by Michelin *et. al* [4] and Akca *et. al* [9], automatic process cannot guarantee stable and reliable result due to complex natural scene of environmental condition. The complexity of natural scene cannot even be afford although the processes have been supplied with highly detail and accurate information from very high resolution satellite and laser scanning data such [10,11,12]. This condition discloses the flaws of cost effective approach which hinder them from practical usage. However it is worth to notice that the trends of spatial modeling would focus on achieving low cost and time-less generation for spatial system [13], and these two aspects could only be achieved using cost effective. Hence identifying various strategies to implement cost effective would become an endless effort that guarantees the generation of beneficial reward.

3. CONSTRUCTION OF SPATIAL MODEL

Development of spatial modeling requires a set of components that contribute to the completeness of environmental visualization which consists of earth surface model, vegetation model, building model, transportation network model such as railway and road, water resources model such as lake and river network, and so on. Earth surface becomes the first model to exist compared to others since it become the basic platform to locate any terrestrial objects. Therefore all aspects of its existence such as data resolution and the correctness of the presented elevation would significantly influence the visualization of environmental condition. Hence it is important to carefully choose appropriate data set among many available digital elevation models existed today. Generally higher resolution is desired since more detail condition of earth surface can be visualized.

But this common sense is not always compatible with the perspective of cost effective. Other models which reside on the top of earth surface have actually been developed in the last decade, particularly for the case of building model that has been standardized into some level of details (LOD) started from LOD0 for rough building presentation to LOD4 for detail visualization of buildings including their facade and interior. Again the objective of cost effective governs to which detail each model should be presented, since the detail of visualization is not the main concern of the

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approach. Nevertheless the output of the system should not violate the quality of visualization. This condition causes a tradeoff between the efforts to preserve visualization quality against the effort to minimize cost for models generation. Thus some factors need to be considered in order to wisely achieving cost effective. In this case some typical research questions that would arise are how to minimize time consumption to generate 3D visualization, how to minimize algorithm complexities by simplifying their processes, and how to minimize cost to conduct data collection but still maintain desired data quality.

3.1 Data Acquisition

The main intention of cost effective data acquisition is to obtain free or low cost data that has reliable accuracy. Considering that spatial modeling is a type of geospatial applications, it is important to retrieve geospatial data from any available resources such as from the Internet or spatial data bank. There are at least two data types required for spatial modeling development i.e. digital elevation model (DEM) for earth surface modeling and satellite imagery to locate any terrestrial objects existed on earth surface in horizontal orientation.

The first data type i.e. DEM can be obtained for free from many data set available today in the Internet in varied resolution. Some cover only the on land elevation such as SRTM (Shuttle Radar Topographic Mission) and ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer), while others cover both the on land and sea bed such as ETOPO and GTOPO. Although most accurate DEM data set widely admitted by the researchers today is SRTM [14,15,16] which carries approximately 90m and 30m resolution outside and inside US territory respectively, however it would potentially be replaced by ASTER dataset soon due to more detail elevation carried by ASTER i.e. approximately 30m resolution covering the whole area of the globe on land. Moreover, currently it is almost impossible to employ cost effective to develop 3D visualization for seabed due to poor resolution of available data set such as Terrain Base (TBASE) and ETOPO2 which have resolution approximately 10 km and 3.6 km respectively.

Meanwhile other acquisition processes to obtain satellite images can actually be settled in trivial way by utilizing available online facilities from the Internet such as Yahoo Map and Google Earth. The issue that potentially is arisen from this approach is the accuracy of geo coordinate. As it is widely known that satellite images are captured from distances, thus they suffer from the problem of image projection. This problem relates to inconsistent result for recording static distance from the same pair of points which is influenced by the position of the recorder, in this case is a satellite, relatives to the position of the pair of points being recorded. When the satellite moves from a position to other places, it would produce different data from the same scene. Thus a pair of points that have steady distance but reside in different positions relative to the position of the satellite would be acknowledged as different distances. Hence it would be prone to produce inconsistency error when a satellite image is recklessly registered into geo coordinate system. Therefore a set of algorithms is required to normalize this condition.

3.2 Digitations process

This phase aims to convert any information with regard to the existence of terrestrial objects presented in the satellite image to become a set of vector data. It is easier to conduct digitations in 2D although final system being developed would present the result in 3D, since the presentation of terrestrial objects such as buildings, trees, roads etc and their size could clearly be seen from the top. Therefore the task of digitations commonly focuses only to gather information in horizontal orientation. In this case information in vertical orientation would manually be supplied for each object of interest. Actually current technology enables quick data collection in vertical orientation using LIDAR or laser scanning, however this technology is widely known expensive and rarely be found from the third world [17]. Thus it would violate the principle of cost effective, and most probably it would not be feasible for the third world.

Meanwhile many automatic algorithms developed recently are still not reliable to be employed for practical usage due to erroneous information that is often produced by these algorithms. In order to achieve cost effective while fulfilling the standard for practical usage, the process to generate spatial information from data must minimize or even eliminate unnecessary error even though it would increase time consumption or algorithm complexity. Therefore it would be wise to extract spatial information in a conservative way by measuring the object of interest in separate orientation i.e. horizontal and vertical position sequentially.

3.3 Model Development

Developing accurate model for terrestrial objects particularly for vegetation, building, road and river network using simple algorithm with low

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complexity becomes the main intention of cost-effective approach for model visualization. Common sense states that accurate model would most probably be produced by complex algorithm while simple algorithm deliver only inaccurate model. This phenomenon shows the existence of trade off between algorithm complexities against model accuracy. Thus it is important to precisely locating the balance point between both aspects in order to achieve cost-effective wisely. Discovering method for model development which is capable of compromising the above trade off becomes a vital step toward implementing cost-effective for spatial system.

Currently there exist advanced methods to produce 3D modeling such as wireframe or triangulated irregular network. However they would violate cost-effective due to their complexities and resource consumption in developing and computing model shape for each object being visualized. These factors have been preventing them from practical implementation among general users from the third world. Therefore the first step towards conducting 3D model development based on cost effective is to scrutinize the simplicity of each available algorithm and measuring their feasibility for mass usage.

Simple model such as fractal has actually fulfilled the requirement for low complexity. The mechanisms which are based on simple recursive equation as formulated as $z_{k+1} = z_k^2 + a$ with $z_0 = 0$ for Mandelbrot and $z_0 = z$ for Julia set would automatically grow their components in number and size. It is however difficult to control the internal process of fractal in order to model terrestrial object, and most probably the algorithm would deliver unpredictable result. Recognizing the character of each object therefore becomes an important step towards finding mechanism to build the model, and later to achieve model accuracy. This phenomenon shows the importance of matching object appearance against the mechanism for model development. Some methods that have been identified enabling the development of object modeling based on cost effective are as follows:

3.3.1 Polygonal modeling

This method intends to model real world objects based on the formation of polygonal shapes. It assumes that each object is constructed by a set of polygons as formulated as follows. Let $M = \{s_i\}$ denotes the model of a real world object which consists of a set of polygonal shapes $s = \langle v_j, e_k \rangle$, with v is a set of vertices, $e = \langle v_a, v_b \rangle$ is a set of edges connecting pair of vertices, and *i*, *j* and *k* are positive integer value. Here $v = (x_i, y_i) \in \mathbb{R}^2$ for two dimensional space while $v = (x_i, y_i, z_i) \in \mathbb{R}^3$ for three dimensional space.

This model apparently delivers low algorithm complexity while offering full control mechanism over model development. Drawing the model of guided object such as road and river network would easily be settled using this method. It is however difficult to cope with the complexity of real world object. There would be a high degree of tedious manual works to implement polygonal modeling for visualizing other real terrestrial objects such as vegetation and building architecture. Many issues arise from the application of polygonal modeling that merely focuses on automation such as governing direction, size and many other degrees of freedom contained in real world object. An enhancement is therefore necessary to deliver more automatic modeling.

Common approach to cope with this problem is to utilize geometric transformation to manage object direction. It is inserted in the definition of vertices as formulated as $v = (x_i', y_i') \in \mathbb{R}^2$ for two dimensional space and $v = (x_i', y_i', z_i) \in \mathbb{R}^3$ for three dimensional space, while

$$x_i' = x_i \cos\theta - y_i \sin\theta$$

$$y_i' = x_i \sin\theta + y_i \cos\theta$$

with the direction in vertical orientation is untouchable since it is vary only by the changing of view angle. Despite object direction, however there are still many other characteristics of real world objects that have not been touched by polygonal modeling such as the randomness of vegetation appearances and varied building architecture. Thus other approach to support polygonal modeling is needed in order to achieve greater automation.

3.3.2 Procedural modeling

Basic idea behind procedural modeling is to increase automation towards generation of visual model through development of computer program. The aim of this method is to enable the deployment of generic procedure for many typical real-life objects. This condition has motivated the need for data-driven process to impose constraint on model generation which includes generation of basic modeling shapes that commonly absence from this method.

Therefore utilizing procedural modeling to support other conservative modeling technique such as polygonal modeling which generate basic shape

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from scratch for each object of interest, would potentially deliver an added advantage since the approach focuses on the development of automatic procedure to generate final model. It is important then to identify typical processes developed based on this approach which includes fractal and other constraint-based procedure.

Fractal has become a traditional way to deploy procedural modeling, in which its applicability has been proven useful to implement realism on vegetation from a basic simple shape. This technique takes advantage on the randomness of vegetation growth which creates similar appearances of the vegetation from any direction. In this case, self-similar approach has successfully been utilized to model this object such as done by Ragnemalm [18] which shows the possibility to build vegetation model based on statistically self-similar fractals supported by generating random variation. The result is promising although it is still limited to build only tree model.

Other approach originated from fractal such as L-System has also been proven feasible to model vegetation. However it is important to realize massive variation on vegetation appearances, therefore greater randomness to suit with many vegetation species would be desired. Moreover, this method experiences difficulties to model regular man-made objects such as building and transportation network. It is due to the characteristics of man-made objects which carry limited variation on object construction. This condition forces the uniqueness of their appearances from different view angle. Therefore imposing constraint during the modeling process becomes an effective approach towards generating model for man-made objects [19]. The technique offers fully controlled model generation based on their adjacency constraint which is formulated as:

$$M(x+\delta) = E(x'+\delta)$$

in which $x, x' \in \mathbb{R}^3$, $a, b, c, d, e \in x$, and $a', b', c', d', e' \in x'$. This formula states that for every input model E there exists output model M with the same neighboring component in three dimensional spaces. Therefore many variations of regular man-made objects such as building can be described using simple procedure based on basic shape model.

4. CASE STUDY

Study cases have been conducted to enable the disclosure and analysis on the feasibility of each method elaborated in Section 3 to support the development of spatial modeling based on cost effective approach. The first study case focuses on utilizing polygonal modeling to represent a village area that consists of simple terrestrial object, while the second study case is to employ procedural modeling for more complicated object as given in the following sub section.

4.1 Case Study 1 – Polygonal Modeling

A project to implement spatial modeling on a village located at East Java Province at coordinate 112.355 - 112.362 Longitude and 7.8768 - 7.8855 South Latitude has been conducted using polygonal modeling. The attributes of the project is given in Table 1, while satellite photograph of the village is shown in Figure 1. Meanwhile result of implementation is shown in Figure 2. The effort discloses the complexities of polygonal modeling to visualize natural scene. Here polygonal modeling hardly struggles against high realism of natural objects such as vegetation due to primitive mechanism of polygonal modeling that relies on manual arrangement of basic shapes to model any terrestrial object.

Moreover, modeling man-made objects such as building also deliver difficulties because of the appearance of satellite image being visualized as shown in Figure 1 which clearly shows massive variation of building structure. Therefore various model of the building should be developed. It makes the task becomes a tedious manual work to complete. The condition becomes the constraint of polygonal modeling to reach only even LOD 1 which visualizes detail rooftop of the buildings. In term of processing time, polygonal modeling has been proven to consume only small processing time to model a large area of the village which is composed by the model of building, vegetation and road network.

Table 1. Project attributes of Case Study 1

Attributes	Comment
Latitude	7.8768 - 7.8855 South
Longitude	112.355 - 112.362
Village Name	Dusun Plumbang, Desa Pandansari
DEM	SRTM
Satellite Image	Google Earth
Modeling Method	Polygonal Modeling
LOD	1

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Figure 1. Satellite photograph of Case Study 1

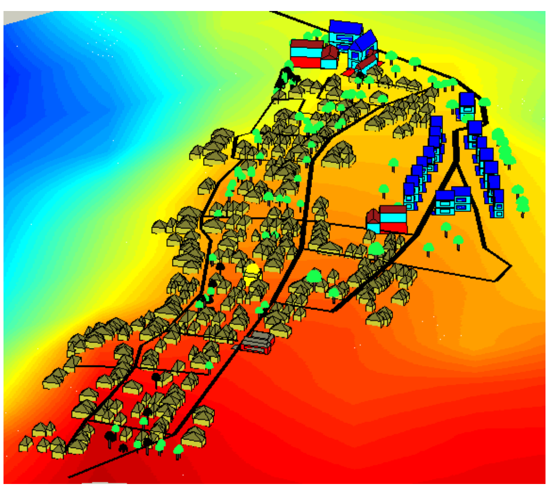
Figure 2. Spatial modeling of Case Study 1

4.2 Case Study 2 – Procedural Modeling

Visualizing higher realism of environmental condition has also been implemented to model multi storey building using procedural modeling. The study is conducted on campus environment located at coordinate 112.606063 - 112.60913 Longitude and 7.953785 - 7.949401 South latitude of East Java Province as seen from project attribute in Table 2. Here satellite photograph of the location of interest is given in Figure 3 while result of implementation is depicted in Figure 4. In this case, spatial system development shows the feasibility of procedural modeling to reach LOD2 i.e. to visualize detail facade of the building.

The results proves the advantage of employing procedural modeling to develop various model from many different buildings based on single building model. Despite its advantage, however this technique requires more step to set up a bundle parameters which need certain literacy of spatial modeling. Besides, it takes a great deal of processing time as shown in Table 3.

Table 2. Project attributes of Case Study 2

Attributes	Comment
Latitude	7.953785 - 7.949401 South
Longitude	112.606063 - 112.60913
Place Name	UIN Maulana Malik Ibrahim Malang
DEM	SRTM
Satellite Image	Google Earth
Modeling Method	Procedural Modeling
LOD	2


Figure 3. Satellite photograph of Case Study 2

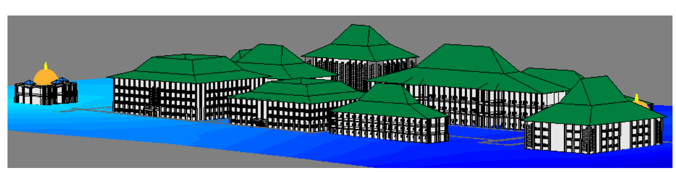
Figure 4. Spatial modeling of Case Study 2

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5. DISCUSSION

Compared to polygonal modeling, procedural approach is clearly capable of producing more complex model of the building with many features. However this method is not possible to operate independently since its basic model is based on the structure of simple object shapes that are generated from a set of polygons. Therefore utilizing procedural modeling is actually operating a hybrid approach that is composed by polygonal and procedural modeling. Here polygonal is employed to generate the seed model of the building that was developed using procedural modeling to produce final visualization of spatial model. In this case procedural modeling approach was used to develop building architecture by growing the seed model and imposing a set of constraints following Merrel and Manocha [19]. Thus hybrid approach which combines polygonal and procedural modeling has been proven useful to implement cost effective in the stage of model development.

Meanwhile previous stages that consist of data collection and digitations process is supplied by free data obtained from the Internet i.e. satellite image from Google Earth and SRTM data set. For the case of satellite image, although it shows clear visualization of earth surface from top view and is also equipped with accurate geo coordinate following SRTM data set, however when the process reach digitations activities other data set to present the object in horizontal orientation which is obtained locally either from building design or using direct measurement is required to collect. The horizontal data set is vital to develop proper visualization of terrestrial objects in term of object's height and features.

It is also important to note that interpolation method is needed to enhance SRTM data set in order to fulfill minimal resolution required by spatial modeling. This necessity depends on the existence of the object of interest relatives to the position of other neighboring objects on earth surface. Here more detail resolution is desired as long as it does not burden the processing time to generate final visualization. Otherwise fair resolution is enough to preserve comfortable visualization particularly when it deals with the computing power of the machine to hold spatial modeling against and the size of data to visualize.

6. CONCLUSION

Developing standard for cost-effective deals with the availability of a set of resources required by all stages of spatial system development which include data collection, digitations process and model development. Each stage is influenced by a set of aspects ranging from the availability of data resources with proper resolution to develop earth surface modeling, defining orientation of digitations process, minimizing complexity of modeling method, etc. All of these aspects aim to save any resources consumed by spatial system development. Since in the practical implementation various strategies could be executed to achieve this objective such as by collecting free available data set from the Internet, simplifying the process executed by modeling algorithm, to minimizing even spatial literacy required by the users by extending automatic process, hence there exist wide area under the scope of cost effective that can be managed to achieve complete spatial system development. Thus it is necessary to standardize cost effective towards the implementation of spatial system. This paper shows the possibility to achieve this standard by disclosing required stages and all aspects that contribute to the development of spatial modeling.

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