IMAGE BASED 3D CITY MODELING: COMPARATIVE STUDY

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KEY WORDS: Virtual 3D city model, Sketch based 3D model, Procedural grammar based 3D model, Close Range Photogrammetry based 3D model, Computer Vision based 3D model.

ABSTRACT:

3D city model is a digital representation of the Earth's surface and it's related objects such as building, tree, vegetation, and some manmade feature belonging to urban area. The demand of 3D city modeling is increasing rapidly for various engineering and non-engineering applications. Generally four main image based approaches were used for virtual 3D city models generation. In first approach, researchers were used Sketch based modeling, second method is Procedural grammar based modeling, third approach is Close range photogrammetry based modeling and fourth approach is mainly based on Computer Vision techniques. SketchUp, CityEngine, Photomodeler and Agisoft Photoscan are the main softwares to represent these approaches respectively. These softwares have different approaches & methods suitable for image based 3D city modeling. Literature study shows that till date, there is no complete such type of comparative study available to create complete 3D city model by using images.

This paper gives a comparative assessment of these four image based 3D modeling approaches. This comparative study is mainly based on data acquisition methods, data processing techniques and output 3D model products. For this research work, study area is the campus of civil engineering department, Indian Institute of Technology, Roorkee (India). This 3D campus acts as a prototype for city. This study also explains various governing parameters, factors and work experiences. This research work also gives a brief introduction, strengths and weakness of these four image based techniques. Some personal comment is also given as what can do or what can't do from these softwares.

At the last, this study shows; it concluded that, each and every software has some advantages and limitations. Choice of software depends on user requirements of 3D project. For normal visualization project, SketchUp software is a good option. For 3D documentation record, Photomodeler gives good result. For Large city reconstruction; CityEngine is a good product. Agisoft Photoscan software creates much better 3D model with good texture quality and automatic processing. So this image based comparative study is useful for 3D city user community. Thus this study will provide a good roadmap for geomatics user community to create photo-realistic virtual 3D city model by using image based techniques.

1. INTRODUCTION

At present scenario, there are four main image based techniques available to create virtual 3D city model. First, sketch based method, second is procedural based method, third close range photogrammetry based method and fourth technique based on computer vision algorithms.

SketchUp, CityEngine, Photomodeler and Agisoft Photoscan are the main softwares to represent these approaches respectively. Sketch based modeling is simple and not fulfill the engineering requirements. Procedural based modeling is also not easy for normal user. Close range photogrammetry based method is also not suitable for large landscape modeling. Previous available research literature shows that each and every method has some advantages & limitations. Previous study shows that, till date, there is a no perfect comparative study available to study the image based 3D city model. Thus this research paper will fulfill the required gap in 3D modeling community to create 3D city model in efficient way.

The main aim of this research is to give a comparative assessment for these images based 3D modeling softwares. There are so many techniques and commercial software available now days in geospatial market to create photo-realistic 3D models of a city. Image based modeling software gives a good solution for 3D city modeling. Each techniques and softwares have some advantages and limitations too. The main problem is to find out the suitable software and method according to the need of project for 3D modeling. Level of Details (LoD) is also an important key issue for any

3D city modeling project. Same 3D product is not economically feasible for all 3D city modeling project. First, it should analyze, what is the main aim of 3D city model? At what level, it needs the details? How much area of city? What is the composition of city? What is the project cost? After that it should think about that, which software will be more suitable for this work? What methodology should adopt to create 3D city model? At present, there is no such type of study is available anywhere, so in this research paper work, it is trying to give a solution to solve the above problem.

Some previous literature, related with this work summarized as given below:

A good collection of literature can be found on image based 3D city modeling techniques and applications (Singh et al., 2013c), Image based 3D modeling: a review (Remondino, Fabio, and Sabry El-Hakim., 2006).

Zhou and Zhang (2004) explained about a preliminary review on three-dimensional city model. This review was based on the comparison of three 3D data model of GIS, (3D FDS, V3D, GeoToolKit).

Wang (2011), explained about a comparative study of five 3D modeling systems based on the SfM principles. He has taken only four software; Bundler, PMVS2, Project Photofly (Autodesk), and ARC 3D Web Service in their work. The working principle of these software is same ie. computer vision based technique, mainly Structure from Motion (SfM).

The literature study shows that, till date, there is no complete such type of comparative study available for 3D city modeling user community. So this research paper will fulfill gap and useful for image based 3D city modeling community.

The main purpose of this paper is to find out the suitable software for 3D city modeling project. In this research work, SketchUp, CityEngine, Photomodeler and Agisoft Photoscan software, were explained. This comparative study is based on mainly, general overview of software, method of image data acquisition, data processing methods, and result of output 3D model. This study shows that every software has some advantages and limitations.

This research paper will play an important role for 3D city modeling scientist community. At the last, the strengths and weakness of these four images based 3D city modeling software are explored. With the help of this paper, they can easily understand that, which software is more suitable for which project. Choice of software depends on user requirements.

2. STUDY AREA

Study area is civil engineering department, Indian Institute of Technology, Roorkee, (IIT-R), Uttarakhand, India. The civil engineering department surrounded by department of earth science, department of architecture, department of water resources development and management (WRD&M), and this civil engineering department (CED) has the following main sections and buildings: Geomatics section building, Geotechnical section building (having CAD Lab and Research scholar wing), Lecture hall building (having Newton rooms and Rayleigh rooms), Wind engineering section, O.P. Jain auditorium building, Transportation building, Main civil building, and Hydraulics building. (See figure 1.)

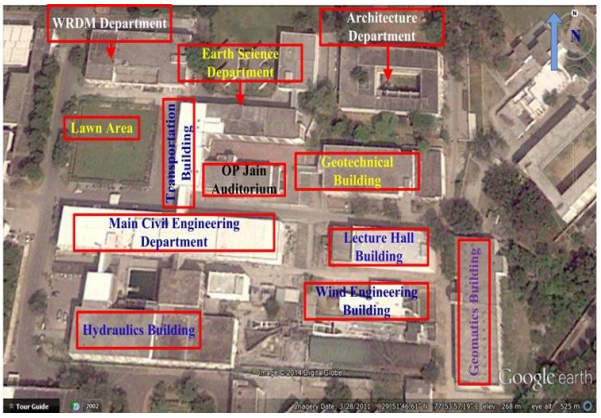

Figure 1: Civil Engineering Department (CED), IIT-Roorkee (Source: Google Earth, January 2014)

3. GENERAL OVERVIEW: COMPARISON OF THE IMAGE BASED 3 CITY MODELING SOFTWARES (Sources: Web-references)

The detail about this section is given in Annexure 1:

4. COMPARATIVE STUDY BASED ON DATA ACQUISITION:

In SketchUp and CityEngine software, photographs should be taken from front shoot of building. Photographs can be taken for each important feature of building façade. So in this type of photography, more detail will obtain. Editing of photograph is essential and can be done by any photo-editing software like Photoshop software and camera calibration is not required.
For Photomodeler software, only convergent photography is useful. Convergent photographs are the photographs in which pairs of photo taken with camera so directed that their optical axes converge. Photomodeler works on basic principles of close range photogrammetry. For any close range photogrammetric project, photos should be taken according to; "3X3 rules", given by Waldhausl and Ogleby, 1994, and further explained by Shashi and Jain, (2007b). These rules are the best suitable for any close range photogrammetric image acquisition with amateur cameras. (Shashi and Jain, 2007b, Singh et al., 2012, Singh et al., 2013d).

Photomodeler generates the 3D positions of points by projecting straight lines from the camera position, through the point on the film or CCD and out into space. When two such rays are used, the intersection of the rays gives the point position. (Photomodeler)

Camera calibration is an essential step for Photomodeler project (Singh et al., 2013d). Camera calibration is the process of determining characteristics of a camera so it can be used as a measurement device. (W. Zhang et al., 2010).

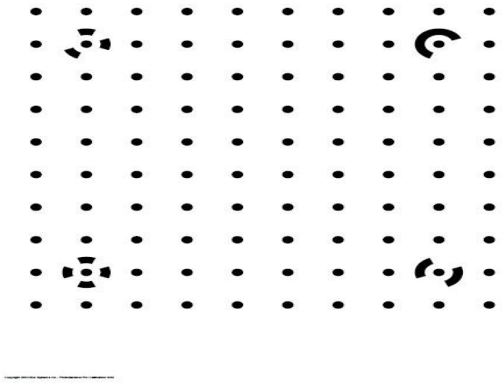

Figure 2. Camera calibration grid for Photomodeler

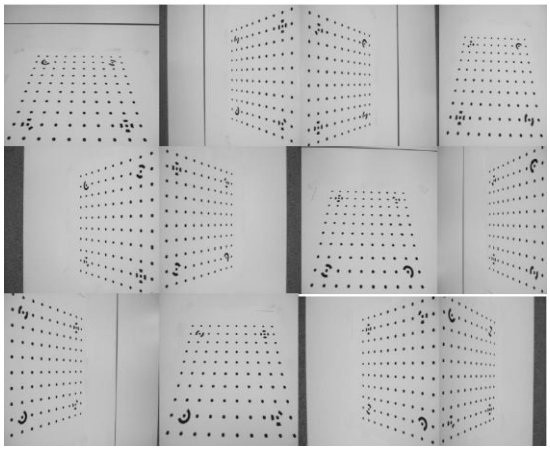

Figure 3. Images of camera calibration grid taken from camera (for Photomodeler project) (Singh et al., 2012)

We should follow the following main points during photography to obtained the best result from Photomodeler software,. [Photomodeler]

1. One should try to get the angles between the shots as close to right angles (90 degrees) as possible.
2. One should try to take at least three photographs but more photographs will be useful because the returning of a person on project site will increase the work load and cost of project.
3. One should try to get all important points on at least three photographs.
4. One should try to get as much overlap between adjacent photographs as possible.
5. One should try to get photographs from both above and below the object, if possible.
6. One should take a special care to ensure good exposure and good focus.
7. One should also take accurate measurement of the distance between two clearly visible points in the scene that will be later useful to scale a close range photogrammetry project.

Figure 4, is showing the example of some photographs, suitable for photomodeler project.

Figure 4. Showing photographs for multi-images project (for Photomodeler software)

Photomodeler gives good result for curves, edge, and cylinders, so special care is needed for photography of these features.

For any close range photography project, initial planning will also play an important role for successful result. First, one should try to decide, how many photographs will take and from where to take them. After that visit on project site and take the photographs. Special care should be taken to ensure better exposure and good focus.

3D model is also possible by using single photograph in Photomodeler software. For single photograph project, the main requirements are:

1. The photographs should be clear and with good focus.
2. For good result, the known objects (shapes, control points, constrained edges & lines) should be very clearly visible and should be spread out over the photograph.
3. For single photograph project, if someone is trying to recover all the camera parameters in an inverse camera procedure, the photograph should be in three point perspective (i.e. have three vanishing points). For this, one should take a picture of building from its corner instead of face-on.

Figure 5. Showing photographs for single-image project (for Photomodeler software)

Camera calibration method is different in Agisoft Photoscan software from Photomodeler software. Free software Agisoft Lens is available for camera calibration. Agisoft Lens is automatic lens calibration software, which uses LCD screen as a calibration target. It supports estimation of the full camera calibration matrix, including non-linear distortion coefficients. Agisoft Lens estimates the following camera calibration parameters:

- f_x, f_y - focal length
- c_x, c_y - principal point coordinates
- K_1, K_2, K_3, P_1, P_2 - radial distortion coefficients, using Brown's distortion model

Figure 6, is showing the camera calibration grid for Agisoft Photoscan. Camera calibration is essential for photomodeler 3D project but it is not necessary for Agisoft Photoscan project. Camera calibration is not useful for SketchUp and CityEngine software.

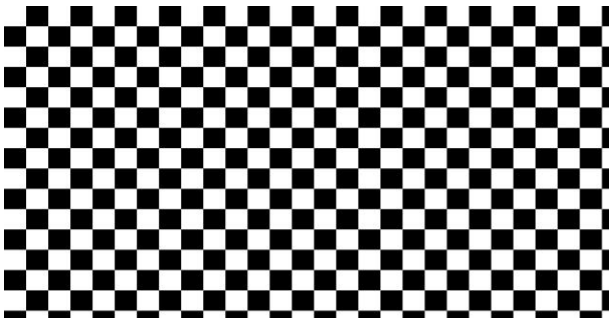

Figure 6. Camera calibration grid (Chess board) in Agisoft Lens

Following are the main points to remember during the capturing the photographs for camera calibration in Agisoft :

1. In case of zoom lens, focal length should be keep constant (or fixed) throughout the session of photography.
2. Glare should be avoided on the photo and move the light sources away if required.
3. Preferably, the whole area of the photos should be covered by calibration pattern and move the camera closer to the LCD screen if required.

One should follow the following main points during photography for Agisoft Photoscan 3D reconstruction project.

1. One should choose high resolution digital camera (More than 5 MP).
2. One should choose wide angle lenses because these lenses are more suitable for reconstructing spatial relations between objects than telephoto ones.
3. One should avoid non-textured and flat object or scenes.
4. One should avoid shiny and transparent objects.
5. One should avoid unwanted foregrounds and moving objects.
6. If objects are shiny then photo should be shoot in cloudy sky condition.
7. Overlap in photographs should be more during photography.
8. Capture most important scene content from multiple viewpoints (3 or more).
9. Agisoft Photoscan is not support manipulated photographs. So one cannot crop or geometrically transform the images.
10. More photos are better than not enough.
11. Before taking the images, spending some time for shot plan might be very useful.
12. Reference coordinate system is also possible for reconstructed 3D model.
13. One should also measure reference distance.

Figure-7, showing the example of some photographs, suitable for Agisoft Photoscan project.

Figure 7. Some photographs suitable for Agisoft Photoscan software

Table 1, is showing the mode of photography and image input format for these softwares.

Table 1. Comparison of mode of photography and image input format

Software	Mode of Photography	Format of input Image
SketchUp	Feature based photography	.jpg, .png, .psd, .tif, .tga, .bmp
CityEngine	Feature based photography	.jpg, or any other image format
Photomodeler	Convergent photography	.jpg, .tif, .bmp, .pcx, .tga, .png, .pct, .psd, .ppm, .mac, .iff, .cal, .pcd, .sgi, .rgb, Jpeg2000 (.jp2/.jpx), .hpd/.wdp
Agisoft Photoscan	Parallel photography	.jpg, .tif, .png, .bmp, .jpeg, Multi-Picture Format (MPO).

5. COMPARATIVE STUDY BASED ON DATA PROCESSING:

Table 2. Comparison of basic working principles (based on data processing)

Software	Processing Method (Basic working principle)
SketchUp	Computer Graphics techniques-(Sketch-based modeling approach)
CityEngine	Procedural programming language
Photomodeler	Close Range Photogrammetry
Agisoft Photoscan	Computer Vision based techniques (SfM and Multi-view reconstruction approach)

SketchUp works mainly on the principles of computer graphics techniques. The main technique is 3D content creation tool or 3D drawing tool or sketch-based modeling. More details of methodology can be seen in Ref Singh et al. 2013b.

CityEngine software mainly works on procedural programming language or also called as Procedural modeling. But it also has the facility to work on image based modeling. Image based modeling approach is easy and simple than procedural programming approach. More detail of methodology based on image based technique in CityEngine software is briefly described by Singh et al. (2014b)

Photomodeler software works on close range photogrammetric principle. It is a good software for 3D model reconstruction by using close range photographs. More detail of close range photogrammetric method and work is described by Shashi and Jain (2007a), Singh et al. (2012), (2013d).

Agisoft Photoscan software works mainly on computer vision based techniques. Structure from Motion (SfM), and multi-view reconstruction techniques are main principles on which Agisoft create 3D model of an object. In this software, both image alignment and 3D model reconstruction are fully automated. With the help of Agisoft Photoscan, 3D scene reconstruction is also possible by using video data. Singh et al., 2014a.

6. COMPARATIVE STUDY BASED ON METHODOLOGY:

Please see Annexure 2.

7. COMPARATIVE STUDY BASED ON OUTPUT 3D MODEL:

Please see Annexure 3.

7.1. Summary of Output model format, Export and Import facility:

(Please see table 3)

Table 3.

Software	Native format of output Model	Import facility	Export facility
SketchUp	SketchUp model (.skp)	.skp, .dwg, .dxt, .3ds, .dem, .ddf, .kmz, .dae	.dae, .kmz, .3ds, .dwg, .dxf, .fbx, .obj, .wrl, .xsi
CityEngine	CityEngine Project	Collada DAE, DXF, File Geodatabase (GDB), KML, Images (Map, Texture, Terrain) OBJ, OSM, SHP(Shape file), Py (Python scripting)	Script (Python) based export, KML, CityEngine Web scene, Collada DAE, , Web front OBJ, FBX, VOB, RIB, GDB,
Photomodeler	(.pmr)	DXF, Wavefront OBJ, 3D Studio 3DS, and Raw Text files.	3ds, Rhino 3DM, DXF, Filmbox FBX, IGES, Google Earth, Maya Script, 3D Studio Max Script, Wavefront OBJ, Raw, and VRML.
Agisoft Photoscan	Photoscan project file (.psz)	**Import mesh:** (.obj, .ply), It can also import t**exture** and c**amera**	**Export Model:** .obj, .3ds, .wrl, .dae, .ply, .dxf, fbx, .u3d, PDF, .kmz. **Export Points:** .las, .obj, .ply, .txt, .u3d, .pdf

8. STRENGTHS AND WEAKNESS:

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Software	Strengths	Weakness
SketchUp	1. This software is simple and easy to use. 2.Less trained person can also make the 3D model by using this software. 3.It is cost effective solution to create 3D city model. 4.Dimensions of buildings can also be added. 5.External city elements can also be added.	1. Its textured quality is not much advanced. 2. The quality of model is not high level. 3. Its accuracy depends on external dimension measurements. 4. The quality of external city elements (like tree, bus) is not good. 5. Roof texture is not accurate.
CityEngine	1. Large area of a city can be generated from a smaller amount of rules. 2. Large area of a city can be created with in less time. 3. User may edit city model manually. 4. The procedural modeling is focus on creating a model from a rule set, rather than editing the model via user input. 5. City Engine gives a cost effective solution to create good Virtual site of an area. 6. The city model can be exported to other software for further various applications. 7.Import of city model from other formats is also possible. 8. Updating of new buildings is easy to add in this model. 9. Real time 3D city modeling is also possible. 10. Layer wise information can be added very easily. 11. Any camera can be used. 12. Open Street Map can be directly open in CityEngine and generate the different layers like road, building, parks etc. 13. Suitable for crowd city area.	1. Skilled person is necessary to create the virtual 3D city model from city Engine. 2. Understanding of procedural programming language is also not that easy. It requires lot of practices and experiences. 3.Dimension of building cannot measure directly. 4. Animation cannot make and play in CityEngine. 5.Photographs should be in rectangular or parallel form for façade modeling. 6. Snaping is useful for adding of two façade but Snaping is not possible in CityEngine. 7. Editing in photographs is necessary for texturing of facade modeling. 8. For each image, one façade is needed, so it increases the load of work in project. 9.For adding the dimension in 3D model, the knowledge of Python programming is necessary.
Photomodeler	1. Any camera can be used. 2. Different kind of camera can also be used in a same project. 3. It gives the best measurement accuracy. 4. Export facility is also useful for further applications.	1. It requires lot of experience in Photogramme try. 2. Finding an appropriate situation of cameras would be the most sensible part. 3. Photography taken for Photomodeler is also need experience. 4. The mathematical model that used in solving photogramme tric parameters is complex. 5. Establishing an excellent situation for exterior view of building could be solved regularly but for the interior side of a building we encountered with some limitations. 6. Camera calibration is also necessary. 7. Roof texture will not come accurate.
Agisoft Photoscan	1. The most beauty of this software is: both image alignment and 3D model reconstruction are fully automated. So it is easy to use. 2. It has good import capability	1. The whole city cannot easy to make. 2. Photography is also not very easy because some tree or vehicle may come in between camera and

	of input images and final model can be exported in various formats for various applications. 3. It supports Python script. 4. It works for convergent photography with high overlapping area. 5. Distance and area can be measured. 6. Coordinate system can be given. 7. Camera calibration is also possible. 8. Sparse point cloud and model geometry can be edit. 9. Project can be merge and split. 10. Masking of the feature is also possible. 11. It has good quality of texture algorithm.	object. 3. It will not work on edited or manipulated photographs. 4. Not suitable for crowd area.

9. WHAT CAN DO & WHAT CANNOT DO?

The detail about this section is given as:

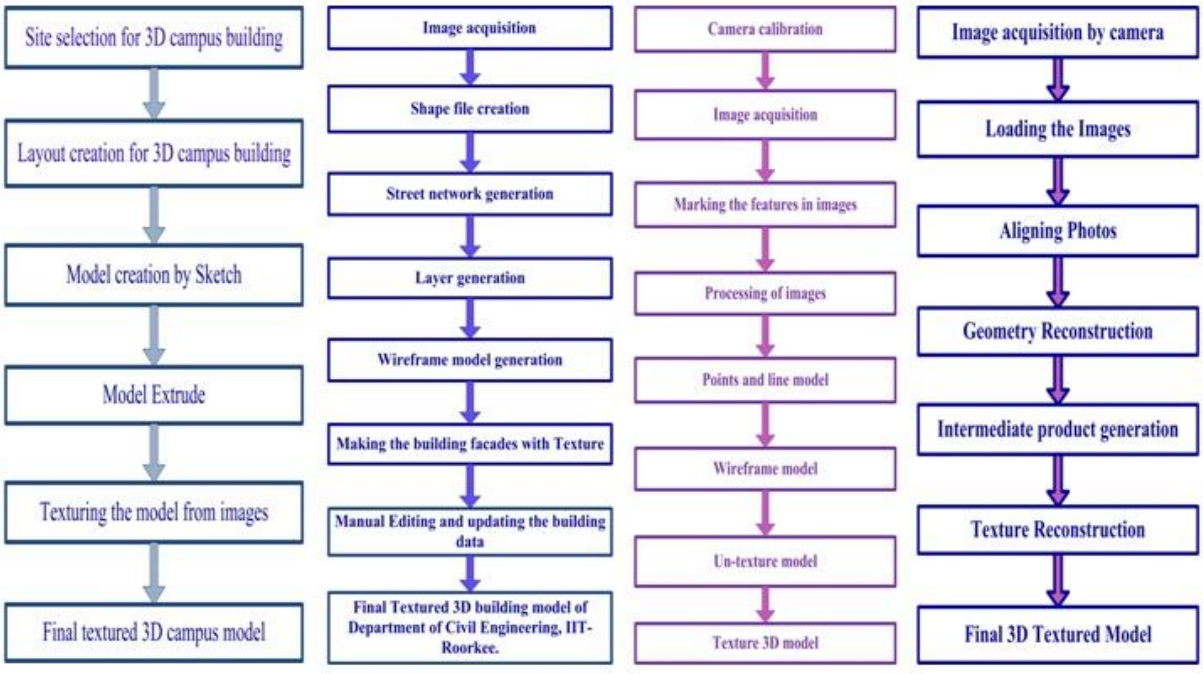
Name of Software	What can do	What cannot do
SketchUP	1. For straight building, it gives good result. 2. It can obtain directly street view from Google street view image. 3. It gives terrain from Google earth. 4. Output 3D model can directly export on Google earth. 5. It is sketch tool based 3D modeling software, so shape of building will come more accurate. 6. Processing is fast due to less complex algorithms.	1. It cannot give the accurate slope of road. 2. Walk-through is not good. 3. Rendering is not good. 4. 3D point cloud model is not possible.
CityEngine	1. It is most suitable for large city area. 2. It can generate various layers such as street layer, building layers and Parks etc.	1. Rendering is not possible 2. Dimension values cannot input directly. 3. 3D point cloud model is not possible
Photomodeler	1. It gives good result for making curve, Edges, and Cylindrical shape of any buildings. 2. Accuracy and measurement is good from images. 3. 3D Point cloud model is also possible.	1. Projection is not accurate 2. Vertex cannot move. 3. Rendering is not good. 4. Walk-through cannot create.
Agisoft Photoscan	1. It gives good projection. 2. It also gives good texture. 3. It can also create 3D point cloud model.	1. It is not suitable for curve, cylindrical buildings. 2. It is not suitable for crowd full area.

ANNEXURE-1.

Software	Latest release date	Developed by	Platforms	Mainly used for	License	Price (June, 2013)
SketchUp Make	May 21,2013	Trimble (Earlier it was Google), (USA)	Mac OS X, Microsoft Windows	Computer Aided Design	Freeware	Free
SketchUp Pro ver. 2013	May 21, 2013	Trimble (USA)	Mac OS Microsoft Windows	Computer Aided Design	Commercial software	$590
CityEngine Ver. 2012	Oct 3, 2012	Now ESRI (formerly Procedural Inc.) , (USA)	Mac OS X, Microsoft Windows, Linux	Procedural Modeling of 3D Cities	Proprietary	$149 - $4950
Photomodeler Ver. 2013	Feb.13, 2013	Eos Systems Inc. (Canada)	Windows	Architectural structure modeling	Proprietary, Commercial software	$1145
Photomodeler Scanner, ver. 2013	Feb.13, 2013	Eos Systems Inc (Canada)	Windows	Architectural structure scanning	Proprietary, Commercial software	$2595
AgiSoft StereoScan	2013	Agisoft (Russia)	Window,	Stereo pair image scanning	Freeware	Free
AgiSoft Photoscan, Pro Edition	2013	Agisoft (Russia)	Window, MacOS, Linux	Image based Scanning model	Educational, and Commercial license	$ 3499

ANNEXURE 1: Comparison of the Image based 3D City modeling software: General overview (Sources: Web-sources- 1,3,5,7)

ANNEXURE 2:



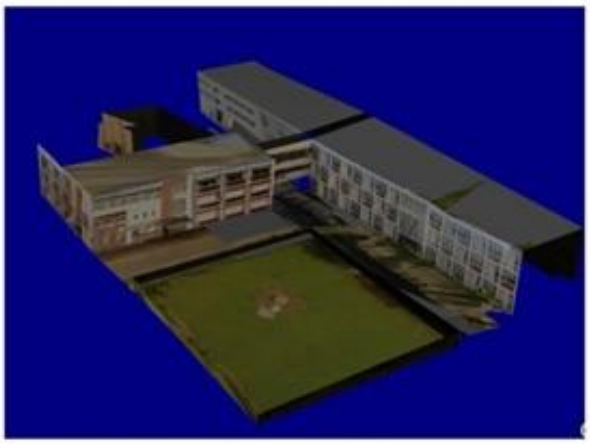
ANNEXURE 2: Comparison of the Image based 3D City modeling software: Based on methodology (**Sources:** Singh et al., 2013a (SketchUp); Singh et al., 2014a (CityEngine); Singh et al., 2013b (Photomodeler), Singh et al., 2014b (Agisoft Photoscan)

ANNEXURE 3:

ANNEXURE 3: Comparison of the Image based 3D City modeling software: Based on output 3D model (**Sources:** Singh et al., 2013a (SketchUp); Singh et al., 2014a (CityEngine); Singh et al., 2013b (Photomodeler), Singh et al., 2014b (Agisoft Photoscan)

Output 3D model from SketchUp software

Output 3D model from CityEngine software



Output 3D model from Photomodeler

Output 3D model from Agisoft Photoscan

10. CONCLUSION:

SkechUp software is an easy and useful tool to create 3D city model. CityEngine works on procedural modeling but also has image based approach to create 3D city model. It gives good realistic virtual scene of a large area in less time. Photomodeler software is works on close range photogrammetric principles and has good measurement accuracy. Agisoft Photoscan works of computer vision based algorithms and gives good 3D model products. So the final conclusion of this work is: these softwares are good and most suitable for image based 3D city modeling. According to user requirement, one can use these softwares. If user wants only a simple 3D city model for visualization purpose, then SkechUp gives a good solution. If user wants only good visualization in less time, then CityEngine gives the best solution. Photomodeler is the best solution for photogrammetric documentation of a city. It gives the best measurement accuracy. Agisoft Photoscan is also gives good 3D model and most of the work done automatic and easy to use. The study area is Civil Engineering Department (CED), Indian Institute of Technology-Roorkee, India.

The main aim of this research paper is, to explore and analyze the potential of various image based 3D city modeling software and to find out a simple and cost effective image based photogrammetric method for 3D modeling user community. This study is based on a small area like campus of any educational institute. 3D model of any educational institute is acts as a prototype of a large city. With the help of this study, anyone can find the suitable method and software to create image based 3D city model. Choice of software depends on user requirements. This study is also useful for various kinds of engineering and non-engineering 3D applications.

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