A NEW EXPEDITIOUS METHOD FOR BUILDINGS 3D MODELS CREATION

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Abstract: *In recent years buildings 3D models have known a great evolution, being used in a wide variety of domains such as industry, cultural heritage, architecture, etc. where high precision is needed and also a high level of detail. For many years, close-range photogrammetry has been dealing with the extraction of high accurate informations from images. But, in order to obtain this precision, we need to use a camera whose intrinsic parameters are determined with high accuracy and we also have to respect some conditions when images are acquired. Therefore, there are some domains and applications, were buildings 3D models can be created with low accuracy, such as GIS applications, but without any lost of detail. So, this paper presents a new method for buildings 3D models creation in an expeditious mode, based on digital images acquired with a digital non-metric camera. The advantage of this method is that the camera doesn't require calibration and we can obtain a very realistic 3D model with a high level of detail and meters accuracy.*

Keywords: *method, expeditious, non-metric images, building, 3D model.*

1. Introduction

Close-range photogrammetry is based on images taken with a digital camera which can be handheld or mounted on a tripod for enhanced stability. Later on, these images are used in order to create 3D models of objects from areas such as: urbanism, architecture, industry, forensics, monuments and archeological sites preservation or even historical monument buildings inventory etc.

Taking into account the evolution of technology in recent years in areas like IT systems and digital cameras, these later being more and more accessible to general public with technical features that are more and more performant, being also included on mobile phones or tablets, as well as taking into account the need to incorporate buildings 3D models into GIS applications, there is the question of finding methods to create efficient the urban area 3D model, with low costs and which will comply with precision requirements of GIS applications.

Nowadays, creating the 3D model of a building, with high details, is a laborious process which requires a lot of time. Developing commercial software, specially designed for architectural photogrammetry, reduces considerably this effort. Likewise, these software are less costly and allow to process the images taken from the top of the space-object with regular non-metric cameras, thus reducing the costs of creating the 3D model.

Due to the interest showed by the international bodies for registering historical monument buildings and for their inventory with the purpose of conserving and restoring the patrimony, the methods of reconstructing and 3D modelling find their application in this domain as well. The digital photogrammetry technologies are using images taken from different angles in order to obtain the 3D model of the object. The object is identified in these images and its geometrical shape is obtained after a series of operations which imply marking on each image the characteristic points, obtaining through a process of bundle block adjustment the tridimensional coordinates of these points, connecting the characteristic points represented in 3D environment and creating the object surfaces [1].

This article presents a new expeditive method for realising the 3D model of a building by using digital images taken with a non-metric camera and in order to proove the efficiency of this method, it was chosen as objective the Rector building of “Gheorghe Asachi” Technical University from Iasi.

2. Material and method

Realizing the 3D model of the Rector building of “Gheorghe Asachi” Technical University from Iasi, by using the new proposed method, it means to create the 3D model based on the digital images acquired with a non-metric digital camera, using “*Autodesk 3ds Max Design*” software [2].

The images have been taken using the digital camera Nikon D7100 equiped with *„all around”* lensn Nikon 18-105 mm F/3,5-5,6G ED VR AF-S. In order to obtain the building 3D model the image processing was conducted by using computer system brand LENOVO Y 580R, Intel Core™ i7-3630QM processor, 2,4 GHz 6MB Cache, HDD 1 TB and 8 GB SSD, 8GB RAM memory, NVIDIA GeForce GTX660M graphic card 2 GB with DirectX 1 and using *„Autodesk 3ds Max Design”* software.

The 3D model of the building was created using the *„Autodesk 3ds Max Design*” software in a local coordinates system and, in order to be integrated into a refference coordinates system, the 3D model was georefferentiated in *„AutoCAD Map 3D*” environment.

3. Results and discussion

3.1 Digital images acquisition

The digital images representing the facades of the Rector building of the “Gheorghe Asachi” Technical University from Iasi, as well as the detail elements, have been captured with the Nikon D 7100 digital camera, in day light conditions as well as in artificial light from the blitz (back entrance to the basement).

The images have been taken by the operator without having mounted the camerra on a tripod, at different distances from the building, the whole process lasting for approximately 2 hours.

It was taken into account that in every image the whole surface of the facade would be wraped and centered in order for the radial and tangential lens deformations to have less influence on the building 3D model [3] (***figures 1 and 2***).

Where the case was that the whole facade would not fit into one image, several images have been taken (***figures 3 and 4***) which were later on processed with *„Adobe Photoshop”* specialized software [4], in order to create a panoramic image of the facade (***figure 5***).

Fig. 1. Digital image representing the lateral facade of the Rectorat building

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Fig. 2. Digital image representing the basement entrance

Fig. 3. Digital image representing the left side of the main facade

Fig. 4. Digital image representing the right side of the main facade

Fig 5. Panoramic image created in „Adobe Photoshop” software representing the main facade of the Rectorat building

3.2 Creating the Rectorat Building 3D model using the “Autodesk 3ds Max Design” software

The 3D model of the Rectorat building was created from different building bodies, using the tools of „*Autodesk 3ds Max Design 2013*” software.

Initially, solid geometrical elementary blocks have been created which were overlaped on images, for an initial dimensioning ***(figure 6).***

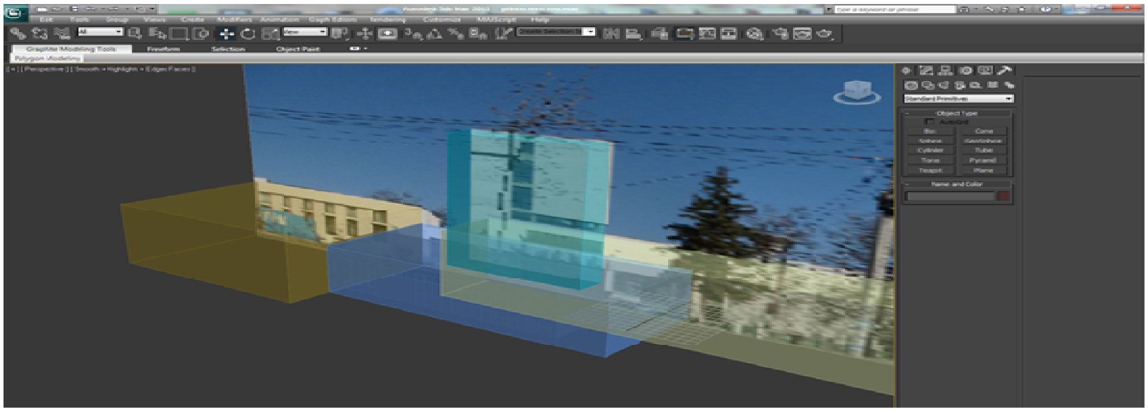

Fig. 6. Creating and dimensioning the solid blocks based on digital images

Later on, after adjusting the transparency of the shaped solid block, characteristic detail lines have been created, the vertexes of the lines being modified properly in order to match the detail elements of the facade in the digital image.

By using *Insert* tool it was created the joinery from the windows and doors (***figure 7***) and by using *Extrude* tool the architectural details have been created (***figure 8***).

By using fragments from digital images representing the facades, the textures of the facades have been created. Later on, textures from the software's library have been added for window's glass and doors and, in the end, the roof and its texture have been created.

In the same way other parts of the building have been shaped and then they were merged in the same project by using the "Group" tool, thus the building 3D model representing the Rector building of the "Gheorghe Asachi" Technical University from Iasi was created.

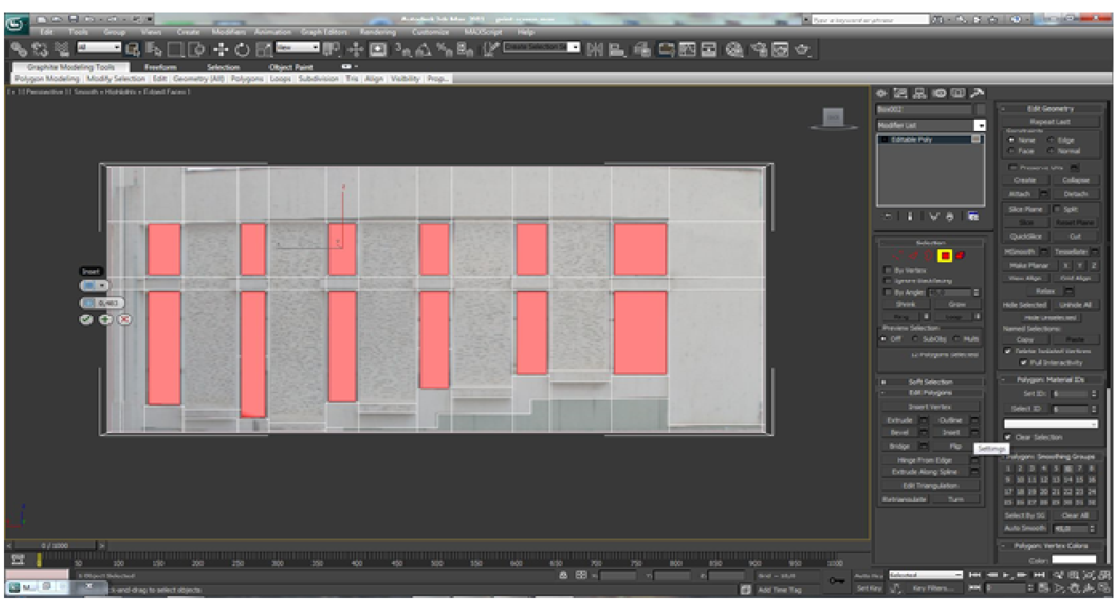

Fig.7. Creating the windows' joinery by using the "Insert" tool

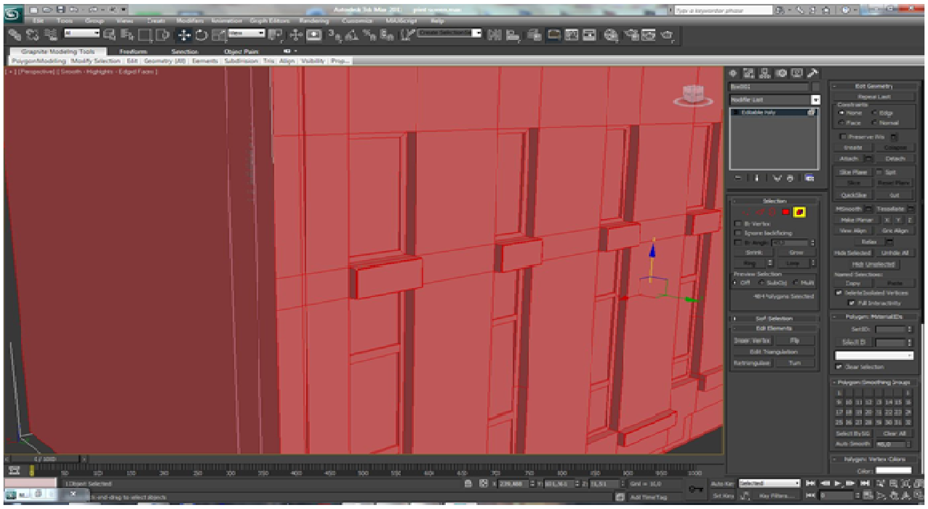

Fig.8 – Creating the architectural details of the building facade by using the “Extrude” tool

By using the complex process of “rendering” (whereby various materials can be attached to the objects, the light sources can be defined, shadowing effects can be generated), the 3D model of the studying building was transformed in a realistic representation, as it can be seen in ***figures 9-11.***

Fig. 9. Realistic view of the Rector building - S-E point of view

Fig. 10. Realistic view of the Rector building - N-V point of view

Fig.11. Realistic view of the Rector building principal facade - detail

Due to the fact that the model was created using the *„3ds Max Design"* software in a local coordinates system, in order to be integrated in a refference coordinates system, the 3D model was scaled and exported, later on being georefferencied in *„AutoCad Mad 3D"* environment [5]. For scaling, one side of the building was measured with a measuring tape.

3.3 Precision evaluation of the Rector building 3D model realisation

The accuracy of the 3D modeling process was evaluated first by pointing out and verifying the differences between the values of two sets of 20 points with known rectangular coordinates (*X, Y, Z*) (Table 1).

These points represent a series of building characteristic points (i.e window edges, door, etc.), as resulted from the TC(R) 405 total station measurements and by interrogation of the 3D model created based on digital images using the "*Autodesk 3ds Max Design*" software, respectively.

Depending on the values of these differences, as presented in Table 2, between the measured coordinates (X_r, Y_r and Z_r) using the total station and the measured coordinates (X_i, Y_i and Z_i), using the "ID" function in "*AutoCAD Map 3D*" environment, the following parameters of transformation precision were determined.

The **Root Mean Square Error** (**RMSE**) is the Euclidian distance between the two coordinate sets for a point calculated with the distance equation [6]:

$$RMSE = \sqrt{(X_r - X_i)^2 + (Y_r - Y_i)^2 + (Z_r - Z_i)^2} \quad (1)$$

where: **(X_r, Y_r, Z_r)** – coordinates of a characteristic point of the building, computed after the total station survey,

(X_i, Y_i, Z_i) – coordinates for a characteristic point of the building, computed after the interrogation of the 3D model created based on digital images using the "*Autodesk 3ds Max Design"* software, by the proposed method.

The resulted error values for the **20 characteristic points** fit in an interval from a minimum value of **0.271 m** to a maximum value of **2.197 m** (Table 2).

Table 1. The coordinates of the building main facade characteristic points measured using both methods

Surface	Point no.	Coordinates computed after total station survey			Computed after building 3D model interrogation		
		X (m)	Y (m)	Z (m)	X (m)	Y (m)	Z (m)
1	1	697195.909	631609.551	42,339	697195,108	631608,954	40,387
	2	697195.155	631611.618	42,34	697194,180	631611,362	40,388
	3	697195.154	631611,617	43,942	697194,177	631611,361	42,261
	4	697195.907	631609,548	43,938	697195,105	631608,953	42,260
2	5	697183.020	631633,048	41,879	697182,118	631632,697	41,433
	6	697182.143	631635,362	41,878	697181,234	631634,983	41,433
	7	697182.141	631635,363	45,092	697181,233	631634,983	44,798
	8	697183.017	631633,047	45,090	697182,117	631632,997	44,799
3	9	697258.309	631614,213	42,164	697258,221	631614,018	41,683
	10	697257.242	631617,017	42,165	697257,043	631616,571	41,683
	11	697257.242	631617,017	46,165	697257,035	631616,568	45,931
	12	697258.307	631614,210	46,163	697258,213	631614,314	45,931
4	13	697231.338	631588,119	48,404	697231,859	631587,440	48,258
	14	697238.999	631590,895	48,403	697239,568	631590,272	48,261
	15	697238.997	631590,896	41,855	697239,571	631590,273	41,253
	16	697231.335	631588,118	41,853	697231,862	631587,441	41,250
5	17	697222.964	631588,601	41,609	697223,192	631588,185	40,526
	18	697228.036	631590,508	41,610	697228,664	631590,488	40,537
	19	697228.035	631590,507	45,931	697228,655	631590,484	45,299
	20	697222.962	631588,598	45,927	697223,183	631588,181	45,288

For the residuals, the following calculations were made to determine the cumulative RMS error, the X RMS error, the Y RMS error and the Z RMS error:

$$R_X = \sqrt{\frac{1}{n}\sum_{i=1}^{n} XR_i^2} = \sqrt{\frac{1}{20}\cdot 8.646} = 0.657(m) \tag{2}$$

$$R_Y = \sqrt{\frac{1}{n}\sum_{i=1}^{n} XR_i^2} = \sqrt{\frac{1}{20}\cdot 3.747} = 0.433(m) \tag{3}$$

$$R_Z = \sqrt{\frac{1}{n}\sum_{i=1}^{n} XR_i^2} = \sqrt{\frac{1}{20}\cdot 18.303} = 0.957(m) \tag{4}$$

$$T = \sqrt{R_x^2 + R_y^2 + R_z^2} = \sqrt{(0.658)^2 + (0.433)^2 + (0.957)^2} = 1.239m \tag{5}$$

$$T = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(xR_x{}^2 + yR_y{}^2 + zR_z{}^2)} = \sqrt{\frac{1}{20}(8.646 + 3.747 + 18.303)} = 1.239m \tag{6}$$

where: $\mathbf{R_x}$ – total X RMS error; **n** – the number of points and **i** – point number;
$\mathbf{R_y}$ – total Y RMS error; $\mathbf{XR_i}$ – the X residual for the point "i";
$\mathbf{R_z}$ – total Y RMS error; $\mathbf{YR_i}$ – the Y residual for the point "i";
T – cumulative RMS error; $\mathbf{ZR_i}$ – the Y residual for the point "i";

The cumulative root mean square error (T) calculated for the 20 characteristic points was evaluated using the value of **1.239 m**, showing that the building 3D model created based on digital non-calibrated images, by the proposed method is not of high precision.

Table 2. The coordinates residual errors

Surface no.	Point no.	Coordinates differences [m]						RMSE	E_i
		$Xr-X_i$	$Yr-Y_i$	$Zr-Z_i$	XR_i^2	YR_i^2	ZR_i^2	R_i	
1	1	0.801	0.597	1.952	0.6416	0.35641	3.81030	2.193	1.770
	2	0.975	0.256	1.952	0.9506	0.06554	3.81030	2.197	1.773
	3	0.977	0.256	1.681	0.9545	0.06554	2.82576	1.961	1.583
	4	0.802	0.595	1.678	0.6432	0.35402	2.81568	1.953	1.576
2	5	0.902	0.351	0.446	0.8136	0.12320	0.19892	1.066	0.860
	6	0.909	0.379	0.445	0.8262	0.14364	0.19803	1.081	0.872
	7	0.908	0.380	0.294	0.8244	0.14440	0.08644	1.027	0.829
	8	0.900	0.050	0.291	0.8100	0.00250	0.08468	0.947	0.765
3	9	0.088	0.195	0.481	0.0077	0.03802	0.23136	0.526	0.425
	10	0.199	0.446	0.482	0.0396	0.19892	0.23232	0.686	0.554
	11	0.207	0.449	0.234	0.0428	0.20160	0.05476	0.547	0.442
	12	0.094	-0.104	0.232	0.0088	0.01082	0.05382	0.271	0.219
4	13	-0.521	0.679	0.146	0.2714	0.46104	0.02132	0.868	0.701
	14	-0.569	0.623	0.142	0.3237	0.38813	0.02016	0.856	0.691
	15	-0.574	0.623	0.602	0.3294	0.38813	0.36240	1.039	0.839
	16	-0.527	0.677	0.603	0.2777	0.45833	0.36361	1.049	0.846
5	17	-0.228	0.416	1.083	0.0519	0.17306	1.17289	1.182	0.954
	18	-0.628	0.020	1.073	0.3943	0.00040	1.15133	1.243	1.004
	19	-0.620	0.023	0.632	0.3844	0.00053	0.39942	0.886	0.715
	20	-0.221	0.417	0.639	0.0488	0.17389	0.40832	0.794	0.641
Total Root Mean Square Error					**0.650**	**0.433**	**0.957**	**1.239**	

A normalized value representing each point RMS error in relation to the cumulative RMS error is given by the relation:

$$E_i = R_i / T \tag{7}$$

where: **E_i** – error contribution of point "i",
R_i – the RMS error for point "i",
T – cumulative RMS error.

In the case study of the 3D modeling process, the standard errors for each analyzed point ranged between a minimum value of **0.219 m** and a maximum value of **1.773 m**.

The surfaces areas were computed in the CAD environment using the "*Area*" or "*List*" functions, each of the surfaces being delimited by a polygonal contour (a polyline).

Between the component surface areas, for the two considered cases, a maximum difference of 37.7% and a minimum of 2.12% was encountered.

In ***Table 3*** there are presented the differences between the surfaces described by the 20 considered points.

Table 3 – Differences between the surfaces calculated based on total station measurements and on the building 3D model created by the proposed method

Surface no.	Main facade surface areas [m²]		Differences	
	Computed after total station survey	Computed after building 3D model interrogation	m²	%
1	3.5227	4.8336	-1.3109	**-37.21%**
2	7.9521	7.7834	0.1687	**2.12%**
3	12.0033	11.3761	0.6272	5.23%
4	53.3735	57.5548	-4.1813	-7.83%
5	2.,4095	28.2716	-4.8621	-20.77%
Total	100.2611	109.820	-9.5584	-9.53%

4. Conclusions

The precision of the 3D modeling, created based on digital images through the proposed method, ensure the necessary precision for objects reconstruction, with application in architecture and historical monument buildings' conservation, where the time for obtaining the 3D model and the degree of detail are very important factors.

The precision of the 3D models created using the proposed method depends on the characteristics of the used photo camera (resolution, lens' characteristics and their degree of deformation) and on the geometry of the network of stationary points for taking the images. Not always one can comply with the conditions regarding the geometry of the network of stationary points for image acquisition because, usually, there are different obstacles surrounding a building (trees, statues, other close buildings etc.).

Nevertheless it is important for the images to be taken under large convergence angles and to have at least 60% double coverage area.

By using the proposed method for building 3D model creation based on digital images taken from a short distance with an uncalibrated camera, one can create and view realistic 3D models under different angles. If the 3D models are exported in other graphic editing software, these can be successfully used in different applications or can even be imported in an urban GIS.

This method offers the possibility to obtain 3D coordinates of some object from 2D digital images in a rapid and low cost manner. These coordinates are used to model the object at better results as regards the realistic representation.

Thus, the proposed expeditious method of building 3D model creation has the following advantages and disadvantages:

Advantages:

– The main advantage is the value for money (the low cost regarding the equipment and the software needed to acquire and process the data versus the quality and the precision of the final 3D model);
– The building 3D model is fotorealistic and has a high level of detail;
– Little time is needed to collect the data by comparison with other established methods mentioned in the specialty literature.

Disadvantages:

- The precision of the building 3D model is low, the maximum positioning errors encountered for the characteristic points is 2.197 m in plane, 1.952 m on the vertical axis and 1.773 m from the spatial point of view respectively;
- Between the surfaces areas, for the two considered cases, a maximum difference of 37.21% and a minimum of 2.12% was encountered.
- For a good functioning *"Autodesk 3ds Max Studio"* requires a highly performance computer system and in order to create images or animations it requires a superior quality for presentations. Thus, we can appreciate that the high amount of time needed to create them is a disadvantage. In this regard, in order to create of movie of 1'40'' in length made out of 3000 frames, the software used the computer system at maximum capacity for 110 hours, which represents approximately 4.5 days.

Taking into account the quality of the final 3D model, the number of possibilities to realize the animation and the design, the existing libraries with an important diversity of textures and objects at the finest detail, *"Autodesk 3ds Max Design 2013"* software is suited for various domains of design and advertising creation. But, when used with software such as "*AutoCAD Civil 3D"* or "*AutoCAD Map 3D"* it can be used also in civilian engineering in order to create some visual realistic representations for projects within this area or even for GIS applications, where the needed precision is not so high.

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