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Developing 3D real estate tax visualization / management system with GIS based procedural modelling approach

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ABSTRACT

Creating detailed 3D building models with independent sections presents some challenging obstacles, including the gathering and managing of massive 2D and 3D datasets. In order to solve the problems that arise during the evaluation and management of real estate taxation, it is necessary to investigate what kind of advantages 3D systems can offer. Most part of the datasets to be used are not available directly (e.g. architectural plan, building models etc.). It is aimed to develop methods for saving time and standardizing by providing automations in the process of making these data available. It is aimed to develop a feasible, cost-effective approach that balances performance and quality in the subject-specific 3D model production process. Rule-based modelling was preferred as a 3D modelling method. With this modelling approach, necessary coding has been made in CGA language for producing 3D models. Thus, 3D models can be produced automatically with independent sections regardless of the number of buildings. The relational database was transferred with City Engine, a procedural 3D modelling program, with CGA codes prepared. Afterwards, 2D geometries of buildings and building independent sections were arranged in GIS program and associated with attribute data including real estate tax parameters and other GIS attributes.

1. Introduction

A 3D city model is by definition a three-dimensional graphic image capable of translating real city objects, like buildings or urban furniture, into a virtual scene (Catita et al., 2014). The use of geoinformation for enabling and facilitating smart city environments covers a wide range of fields including 3D modelling (Işıkdağ, 2020).

Compared with 2D, 3D GIS describes the objective world in a more realistic way, and shows geospatial phenomena to users via 3D modelling technology (Zhang et al., 2014). Incorporating 3D models into the land development industry addresses such challenges by providing data that better describes land and buildings in 3D (Kalantari and Nechifor, 2017). In the transformation from 2D GIS to 3D GIS, a great number of 3D datasets (e.g., city models) become necessary (Atila et al., 2013). 3D GIS would be a good solution for the representation, registration, and management of different legal information associated to cadastral location (Hajji et al., 2021). Işıkdağ et al., 2014 stated that 3D representations can support mass computation of net area and consequently facilitate taxations of properties (Işıkdağ et al., 2014). There will be positive impacts of the 3D cadastre as it is supportive of the land market for a larger number of land objects and so increases in the real estate contribution to GDP are anticipated (Griffith-Charlesand and Sutherland, 2013).

The objective of this paper was to enable GIS, 3D and real estate tax evaluation integration by creating 3D models for buildings with separate floors and independent sections. The term 'independent section' here corresponds to a section, which is separated from other sections by walls or other partitions and has its own title deed or certificate of ownership. In other words, a section, which is individually managed, sold or bought, is considered to be an independent section. This division is complicated and can be changeable, according to the different functions and architectural plans of the building. Large numbers of independent sections may exist on a floor, a floor may be a completely independent section, or the whole building may be one independent

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section. GIS based procedural 3D modelling method is used for creating building models with independent sections including real estate tax evaluation parameters. It is seen that this method is an efficient and cost-effective approach for purpose of study. With this paper, we plan to help solving these scientific problems. Investigating the advantages of 3D systems to detect great and minor errors and ensuring compliance with the principle of transparency that arise during the evaluation and management of real estate taxation. Conducting comprehensive research on 3D model production methods, detail levels of models and other parameters that can be used in real estate tax management. Developing an applicable, cost-effective approach that balances performance and quality in the subject-specific 3D model production process. Since the vast majority of data sets to be used cannot be used directly (e.g. architectural plan, etc.), developing methods for saving time and standardization by providing automation in the process of making these datasets available. Analyzing the cost-benefit analysis, efficiency and evaluating the result effects of 3D systems carried out for these purposes

2. Method

Workflow of whole system is shown at Figure 1. When the methods are considered in detail, hierarchical processing sequences were designed and implemented. Geodatabase was designed in GIS software ArcGIS. Related GIS attribute files about real estate tax determination were linked with main GIS geodatabase after preparation of UML schema shown at figure 2. Next step was applying real estate tax calculations with related parameters. CGA language was used for the purpose of procedural 3D modelling and each independent section of the building models was created. Attribute files related to these independent sections were then connected with the 3D model geometries. The independent sections were linked with the related attribute GIS files which included tabular data within footprints of sections. In the following stage, rule-based parameters and codes were created to extrude independent sections. These codes were created using CGA language, and GIS-based 3D models were generated via City Engine software. Orthoimagery was posed with the 3D land surface containing 3D models of the ground surface. For these operations, data such as orthoimagery and DEM are first prepared / arranged in the GIS program. In order to perform these operations in the City Engine program, orthoimagery and DEM are directly matched in places where there are no buildings. In places where there are buildings, with the "rule" file we prepared for the City Engine program, Orthoimagery parts corresponding to the roof of the buildings are assigned to the roof as "texture". Thus, image matching to the roof could be done automatically over a single orthoimagery without the orthoimagery breaking down. This 3D approach to model creation was applied to 121 buildings and 1814 independent sections related to them. The details of methodology and study is explained briefly in following section with case study.

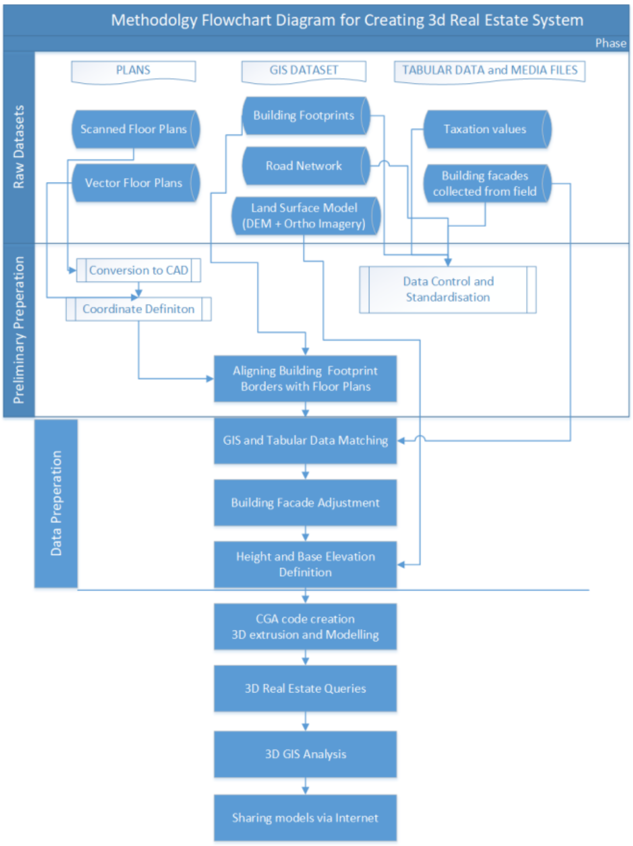

Figure 1. Methodology workflow diagram

2.1. Tax evaluation parameters

In order to generate the real estate tax values on the models produced in the study make the determination and tracking of tax values more accurate, current, transparent and fair we have investigated the real estate tax criteria applied in our country and in the world. During the research and determination of coefficients, we were in constant contact with the local government to think contrary to current practices. There are different and contradictory practices in our country regarding the determination of real estate tax rates. Although the coefficients and scoring differ according to the countries, similar parameters are generally used and these parameters and coefficients can be updated according to the need. These determined parameters and real estate tax value calculation formula is presented below.

α: General fair value on street basis
β: Material of the building (quality of building)
βk: Building material coefficient
θ: Age of the building
θk: Age coefficient
φ: Construction area of building
φk: Area coefficient
ω: Function of independent section (shop, flat, apartment etc.)
ωk: Function coefficient
ψ: Floor number of independent section (height from street)
ψk: Floor number coefficient
λ: Independent section real estate tax

2.2. Case study

2.2.1. Data preparation

This stage of study was the main part of job before 3D model creation. First step was matching and aligning floor plans and building footprints with ArcGIS software. Study area is located at Trabzon / Turkey. At the end of study final 3D models will be in 2 parts such as independent section 3D models and building exterior 3D models with facades. If these raw datasets were not aligned, final models will seem horizontally shifted. GIS data obtained from municipality includes too many essential GIS attributes but some part was relevant for our study and some part was not. Figure 2 shows a screen of raw data processing and gathering necessary data for model creation. Other side there was some non-standard attribute data and we corrected them. We have collected building facades from 4 sides (aspects) of buildings. Facades of buildings were stored in jpeg format and named in folder building_number_aspect, i.e. building_1001_north. These specially named facades will be automatically matched with related building exteriors with the help of CGA code and name of files.

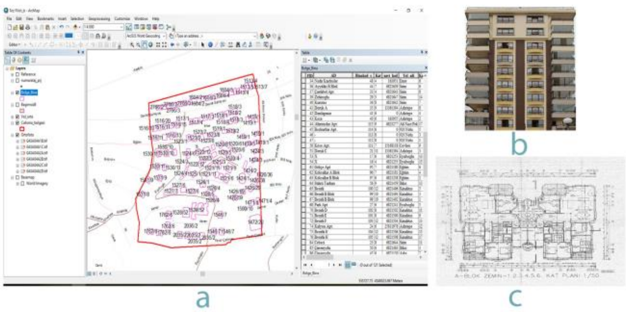

Figure 2. Data preparation stages

2.2.2. Extrusion of building independent sections in City Engine

After these three parameters were matched, the CGA rule was redesigned for the recognition of these height parameters. All the independent sections of the whole building from ground to roof were 3D extruded via City Engine (Figure 3). In Trabzon, 121 different buildings and 1814 related independent sections were modelled in 3D via procedural modelling. In addition to the 3D models of the independent sections, building façade models were created by taking photographs of the building façades in the field. The GIS information for these models was obtained from the local government and was associated with the relevant models in the database. General views of the 3D building models are shown in Figure 3.

3. Results

The procedural modelling method has proven to be suitable for studies conducted at the neighborhood, district or city scale level. First, its integration of GIS data into the system has advantages over other methods. In the case of a 3D model of a single building, software like 3d Max and SketchUp become advantageous because knowledge of professional 3D modelling is not required, and thus, there is no need for preliminary studies in the procedural modelling method. These systems are desirable for small projects; however, if the number of buildings subject to 3D modelling is overly numerous, the correct choice would be procedural modelling. As the number of buildings increases, the procedural modelling method makes a significant difference in the total number of iterations, i.e., the number of 3D models produced over time, the accuracy of the study, the details of the models, the total number of polygons within the model, etc. If the architectural plans used for modelling are in the form of precise CAD data and the buildings are produced in accordance with the plans, the produced 3D models will have high accuracy. On the other hand, if the data used is scanned raster data, like that which is currently stored in most of the local administrative systems, then the accuracy will be slightly reduced.

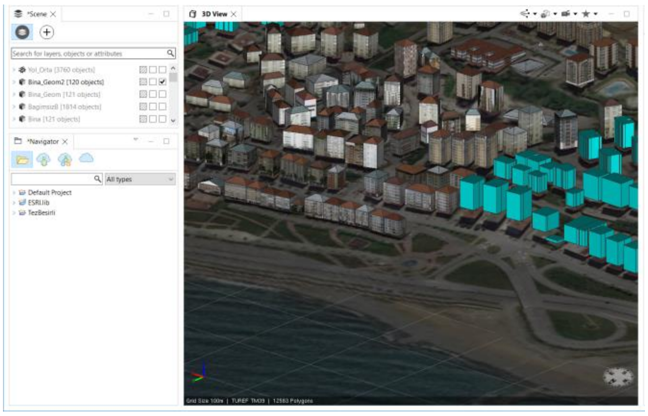

Figure 3. General view of created 3D building models

With the help of GIS based procedural 3D modelling technique, 3D visualizations can be made quickly in the system. In figure 4, 3D visualization of real estate taxes was made according to the square meter unit value. This visualization can definitely be done with normal modelling approaches, but thanks to procedural modelling, this visualization can be done very quickly with attribute data. For this purpose, we have created a colour ramp for real estate tax values and set RGB colour codes as attribute. CGA can directly visualize the colour due to attribute.

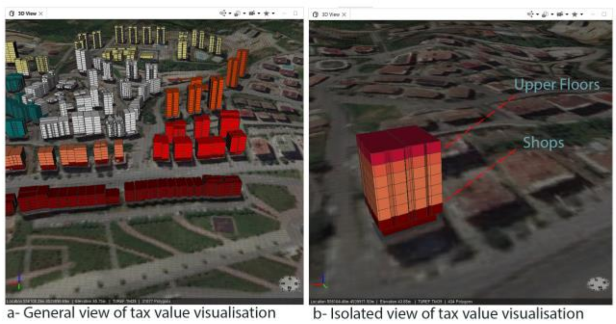

Figure 4. 3D visualization of real estate square meter unit value

Another visual output that may be produced quickly in the system is the 3D visualization of taxpayers who paid and did not pay the property tax in the past years. In order to make this visualization, the visualization shown in figure 10 was made by using the attribute information in the database. For this purpose, we have created a color ramp for real estate tax payer and non-payers by setting RGB color codes as attribute. CGA can directly visualize the color due to attribute. Light green means taxpayer has no loan and dark green means taxpayer has one or two year tax loan. Shades of red means related taxpayers has more than two year accumulated loan.

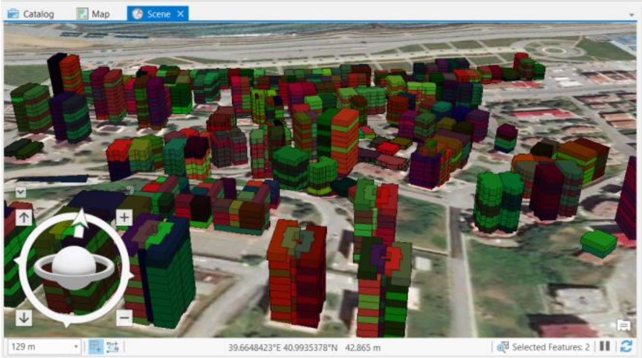

Figure 5. 3D visualization of paying and non-paying taxpayers

4. Conclusion

Results indicated that the procedural modelling is an efficient approach for creating the core features of 3D building components for 3D city models. Using 3D models produced in this study, 3D visualization of property tax values calculated by mass appraisal method could be made practically via GIS attribute information recently prepared by municipality technical works office. All the 3D models and GIS files can also be shared with citizens due to permission of administrator at local authority. System brings transparency and accountability for local government studies. In study, 2" cases were found most useful cases. First is colouring the independent sections and buildings due to update tax values. Second is colouring same objects due to payment status of taxes. With the help of parametric modelling users are able to make these visualizations and queries in a few seconds. Now this system is at evaluation and informing platform however the model may be a decision support system in recent future.

The system brings speed and flexibility to 3D modelling studies. One rule can be used for modelling many buildings, thus making the system fast. In addition, applying any changes to the 3D models for any possible scenario is easy, as the system provides an adaptable environment. This flexibility works in terms of changing 3D models in an automatic system for integration with other formats such as City GML and COLLADA. This study has shown that 3D modelling provides easy understanding and functionality for taxation applications with the help of visualization. Users can easily query tax values in 3D and get access about detailed GIS information related with the independent section.

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