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Conceptualizing, Managing and Developing: A Web Based 3D City Information Model for Urban Energy Demand Simulation

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ABSTRACT

In this paper we describe a concept to manage and develop a web based virtual 3D scene, based on CityGML LoD 2 models, DTM tiles, ortho-photos and energy simulation results of specific heating demand and photovoltaic potential generated from SimStadt simulation platform, by integrating it on ESRI 3D City Information Model (3DCIM) platform. The final output results into a web based 3D visualization of multiple layers of building attributes such as building age, building height, building type, building usage and energy simulation results in terms of specific heating demand and PV potential. Additionally 3D modelling of trees and waterbody were produced based on its location to visually enrich the final virtual 3D scene.

Categories and Subject Descriptors: I.3.1: Three-Dimensional Displays; I.3.5: Modeling Packages; I.3.6: Methodology and Techniques, Languages, Standards; I.3.7: Three-Dimensional Graphics and Realism, Virtual Reality.

1. Introduction

With advances in computer science, algorithms, heavy computation capabilities and web technologies, data visualization techniques has taken a big leap forward. Developments in 3D computer graphics has made 3D an import part in many sector such as computer animations, engineering, architecture, utility mangement and many more. One such sector is of simulation, here urban energy simulation. Unsurprisingly, nowadays 3D being used in Geographical Information System (GIS) effectively, urban energy simulators can take full benefit of these 3D models and its geographical characteristics to calculate accurate building perfomace and energy within an urban context. Input 3D models are most commonly in CityGML, an universally accepted open XML based data model format standard for storing, representing and sharing 3D urban models with all its appropriate information. With such procured CityGML models of a town/city and its calculated urban energy simulated results from a simulating platform, it is equally important of having a proper 3D visualisation with all the object interactivity and information to the users and the decision makers. Recent development [GK15] of 3D visualization on an open source platform like X3DOM, ThreeJs, Cesium has succesfully demonstrated a platform to develop virtual 3D cities and parse it on web using webGL and HTML5. Eventhough with advances on such open source platform, managing a relatively huge 3D dataset of a town/city, automatic mass modelling of 3D city models, enrichment of virtual 3D city with object attributes, interactivitely and performace of relatively heavy database in GB's on web is still an issue and under constant research [GVBPPG*15]. On the other end, proprietory platforms like of ESRI has given the users a platform of 3DCIM where in one can manage, update, develop and even visualize 3D cities on web, enriching it with real terrain characteristics, ortho-photos, vegetation, water body, building textures and all the required building informations including that of simulated energy results.
Following sections describes a concept of how data interoperability from CityGML to ESRI shapefiles was achieved using Feature Manipulation Engine (FME), how a 3DCIM database was managed and generated including simulated urban energy demand results of a study area using ESRI ArcGIS Pro and at the end how a virtual 3D scene was generated with procedural modelling inside ESRI CityEngine and deployed on web using ArcGIS Online for users and decision makers to visualize building informations and urban energy demand results of the study area.

2. 3D City Information Model (3DCIM)

According to [RS14], a 3D city is a huge collection of features, networks, surfaces and there are many approaches to model 3D city for the purpose of processing, analysis

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and visualization. 3D City Information Model is one of those approach developed by ESRI with a goal of providing compact and yet simple in structure, information model which is easy to understand and update it with the new data. 3DCIM is responsible for simplifying creation, maintenance and usage of 3D cities for GIS users. 3DCIM is designed to make the core of the 3D models easy to structure, understand and populate with 3D spatial data, and at the same time to provide seamless exchange with CityGML. 3DCIM is an integration of 3 different but correlated themes: built environment, legal environment and natural environment, residing on basemaps (terrain, satellite images, aerial images, ortho images etc.).

3. SimStadt Simulating Platform

SimStadt is an urban simulating platform being developed at Hochschule für Technik Stuttgart since 2013. The purpose of SimStadt is to produce energy demand analysis of 3D city models. SimStadt produces energy demand results in the form of specific heating demand and photovoltaic potential (PV) by using CityGML LoD 2 models and enriching it by information like building type, building age, building usage, building class, building area, building height, roof type and so on. These enriched CityGML models are then geometrically analysed to find various different information about building geometries corresponding with the thermal characteristics using inbuilt building typology. These data are then combined with weather data to produce all the required energy data outputs like specific heating demand, specific cooling demand, mean U values, PV yield with the best suitable building roof surface of a house for installing PV panels. The results are obtained in a '.csv' file which is then analysed graphically in form of charts and also visualized on a 2D/3D visualization platform.[Sim13].
3D visualization of 67 CityGML LoD 2 models of towns and municiplaities of Landkries Ludwigsburg (District of Ludwisburg) were enriched with SimStadt results of specific heating demand and PV potential and was succesfully demonstrated by [KC15] on an open source platform X3D.

4. Study Area and Data

Study area is a town of Aldingen which comes under the municipality of Remseck am Neckar, Landkries Ludwigsburg, Baden Württemberg, Germany. Building shells CityGML consists of 4,250 buildings at LoD 2, structured as per CityGML ver. 1.0 specifications. As described above, CityGML models includes enrichment of attributes such as LoD, building area, building age, building type, building height, building usage, building class, no. of floors, floor height, roof code and a separate address node which consists information such as building name, street number, street address, municipality name and more.
Terrain profile of Aldingen town were divided into 16 very high resolutions 1m grid spacing '.xyz' files. Correspondingly, there are 16 very high resolution orthophotos tiles of 0.25m resolution, 1 ortho-photo tile corresponding to 1 terrain file, hence 16 ortho-photo tiles in total. Additionally trees and waterbody were manually vectorized from orthophotos in order to develop a natural environment as per the 3DCIM thematic structure and hence to enrich the final 3D scene.

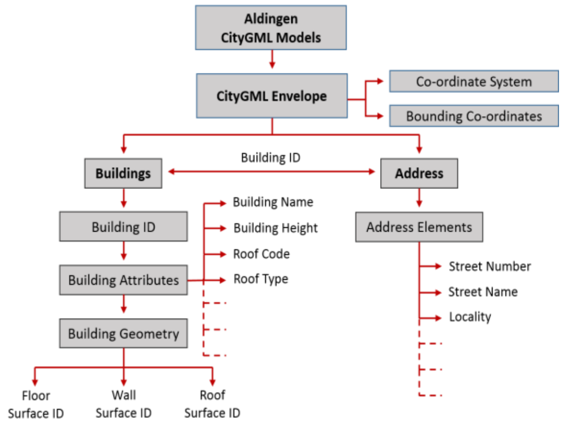


Figure 1: *Aldingen CityGML file schema*

Energy data in form of specific heating demand and PV potential energy of Aldingen town were obtained from SimStadt simulating platform as a '.csv' file. In total, the overall data size was found to be 1.22 GB.

5. Methodology

Methodology is divided into three parts: data processing, data management and then 3D modelling and visualization. Data processing explains how all the 3D spatial database (CityGML LoD 2 model, terrain files with its corresponding orthophotos and natural environment in terms of trees and waterbody) were converted to one common platform of 3DCIM. Data management explains how building information data including energy data from SimStadt simulating platform where managed and bifurcated into different layers. 3D modelling and web visualization explains how procedurally, 3D virtual town of Aldingen got developed and deployed on web for sharing and visualization.

5.1 Data Processing

Since the building models of Aldingen were in CityGML format, it was important that the CityGML file was converted to a multipatch shapefile. Since, these building models had to be enriched with SimStadt energy data, it was very important that Aldingen CityGML file can be converted in such a way that for representing SimStadt specific heating demand data, the conversion output to a multipatch shapefile comes with all the building shells (i.e. roof, wall and floor for LoD 2) merged into one building block and hence a single building ID, while for representing SimStadt PV potential data on appropriate roof surfaces of the buildings of Aldingen town, the conversion output to multipatch shapefile should come with all the buildings shells merged into one building block as explained above except their roof surfaces, which comes out unmerged with its appropriate roof surface ID. With this requirement, it was also equally important that appropriate attributes from the CityGML file were correctly transformed to the attribute table of the converted multipatch shapefile. As a result to obtain such a data interoperability between CityGML and multipatch shapefile, Feature Manipulation Engine (FME) workbenches were created (see fig. 2 & 3).

Feature Manipulation Engine (FME) is a software package created by Safe Software Inc. which is very well known for its ability to losslessly obtain data interoperability between many different platforms.

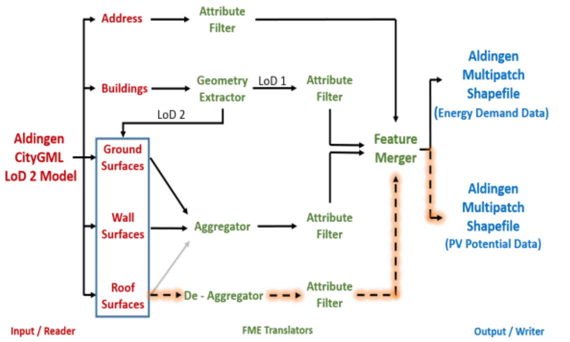


Figure 2: *Flowchart for CityGML to Shapefile using FME*

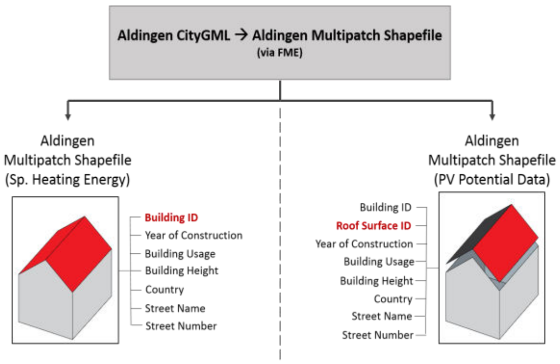


Figure 3: *Obtained CityGML to Shapefile output*

On the other hand, available 16 terrain files in '.xyz' format were first mosaicked and then converted to point shapefile with Z values using 'ASCII 3D to feature class' inside ArcGIS Pro. This obtained feature class was then rasterized to produce a Digital Terrain Model (DTM) using three different surface interpolation techniques: Triangulated Irregular Network (TIN), Inverse Distance Weighting (IDW) and Spline. In order to choose the most appropriate DTM produced from above three different interpolation techniques, DTM so produced where compared on the basis of visual similarities between the produced outputs and google earth terrain model, computational time and overall file size. On the basis of comparison DTM produced by Spline interpolation technique was found to be the best.

Interpolation Technique	Visual similarity with Google Earth	Computation Time	Overall File Size
TIN	Accurate	High	Very High
IDW	High	Medium	High
Spline	Medium	Low	Medium

Correspondingly, as mentioned before, for each terrain file of Aldingen there was its appropriate ortho-photo tile. Hence, 16 ortho-photo tiles where mosaicked into one ortho-photo tile in ArcGIS Pro and then it was draped on the produced DTM to get a realistic view of Aldingen town's ground profile (see fig. 4).

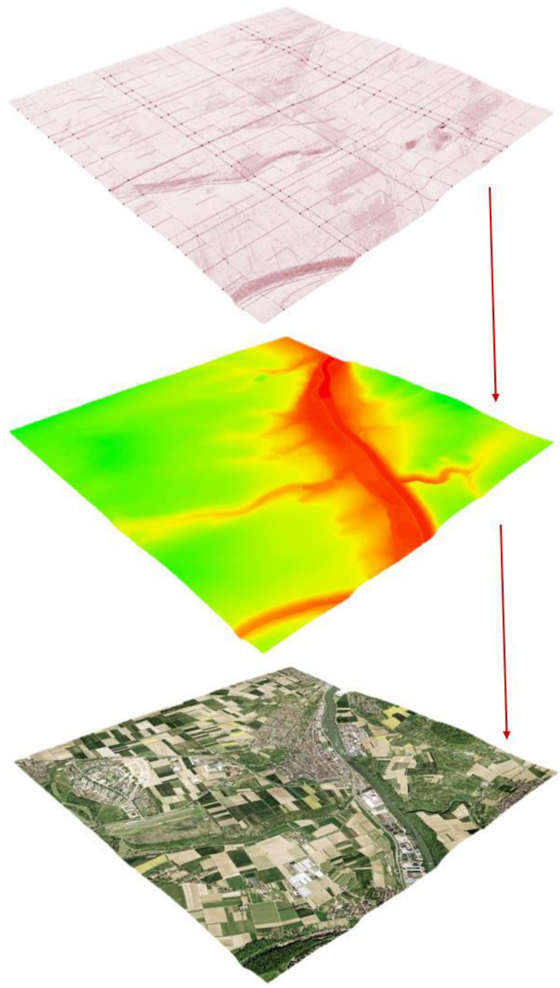


Figure 4: *Realistic Aldingen terrain profile*

With CityGML to shapefile and realistic terrain profile converted to one common ESRI platform, as mentioned above, trees and waterbody were manually vectorized on the basis of ortho-photo and then were given Z information from the DTM.

All these obtained conversions where then merged into one single 3DCIM geo-database as per its thematic structure of Aldingen built environment (multipatch shapefile obtained from CityGML), Aldingen natural environment (trees and waterbody) and Aldingen basemap (ortho-photo draped on DTM).

5.2 Data Management

3DCIM geo-database so prepared was then called up inside ESRI ArcGIS Pro. With ArcGIS Pro's ability of working in 2D and 3D linked side by side, all the attribute information were managed and verfied properly. SimStadts energy data outputs in form of specific heating demand and PV potential were integrated inside the shapefile by joining it with building ID and roof surface ID respectively. Aldingen natural environment in terms of trees and waterbody were given appropriate attributes like tree name, crown height, crown diameter for trees and type of waterbody, waterbody name, locality, for the waterbody feature class. Aldingen basemap were given projection based on the multipatch shapefile.

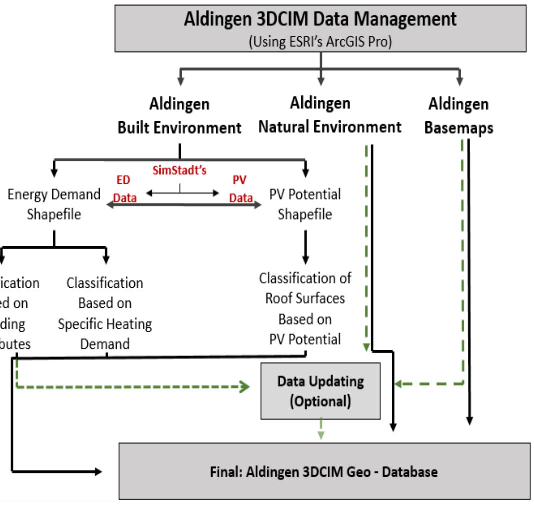


Figure 5: *3DCIM data management in ArcGIS Pro*

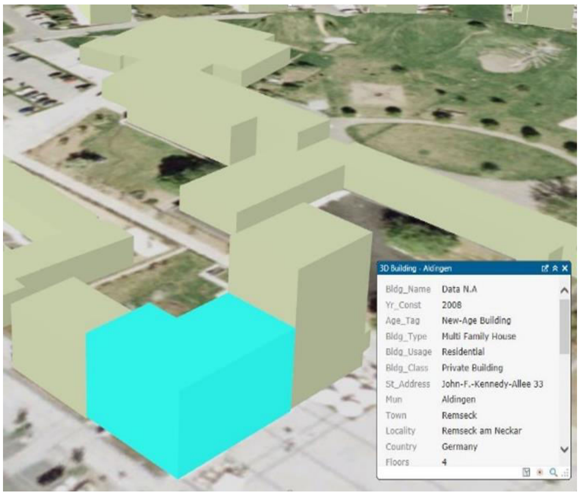


Figure 6: *Data verification in ArcGIS Pro*

Once the SimStadt energy data were properly integrated and all the attribute information were properly verified, building models were classified on the basis of building attributes such as building age, building height (see fig. 7), building type (see fig. 8), building usage; on the basis of specific heating demand (see fig. 9) and on the basis of PV potential (see fig. 10). At this stage, data updating can also be done if any data has to be changed considering future scenario.

At the end, Aldingen 3DCIM database was updated and a final 3DCIM geo-database for Aldingen was hence prepared.

Figure 7: *Classification based on building height*

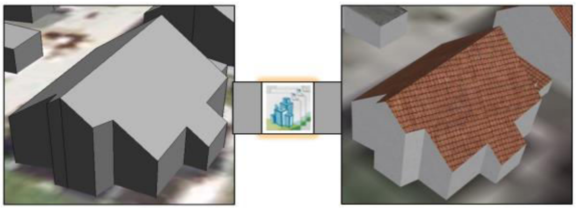
Figure 8: *Classification based on building type*

Figure 9: *Classification based on sp. heating demand*

Figure 10: *Classification based on PV potential*

5.3 3D Modelling and Web Visualization

Prepared final Aldingen 3DCIM database was then imported inside ESRI CityEngine for 3D modelling. CityEngine is a 64 bit procedural 3D modelling software. Procedural modelling or sometimes also called as Computer Generated Architecture (CGA) is a set of rules written by the users to automatically generate models and even huge 3D urban complex environment models. This procedural modelling software and its seamless data import/export capabilities from some very important data exchange formats like ESRI FGDB, COLLADA DAE, Wavefront OBJ, Keyhole KML/KMZ, Autodesk DXF/FBX allows users in urban planning, architecture, building simulations, Building Information Modelling (BIM), 3D animations, to model and generate 3D visualization ranging from a small extent of a single building to a very large mass modelling of a town, city or even a whole district depending on the computer hardware the user is running on.
To produce a 3D virtual town of Aldingen, such set of custom CGA rules were scripted by using certain inbuilt libraries within CityEngine. CGA rules were scripted and applied to input data in order to: enrich building models of Aldingen with roof and wall textures for a realistic view of Aldingen town (see fig. 11); classify buildings according to building age, building height (see fig. 12), building type, building usage, specific heating demand (see fig. 13), PV potential (see fig. 14); generate a realistic 3D model of trees (see fig. 15) and waterbody (see fig. 16) from their respective attributes as per the Aldingen 3DCIM geo-database.



Input CGA Rule Output

Figure 11: *CGA rule for texturing building roof and walls*

Input CGA Rule Output

Figure 12: *CGA rule for building height classification*

Input CGA Rule Output

Figure 13: *CGA rule for Specific heat demand classification.*

Input CGA Rule Output

Figure 14: *CGA rule for PV potential classification*

Input CGA Rule Output

Figure 15: *CGA rule for generating trees*

Input CGA Rule Output

Figure 16: *CGA rule for generating waterbody*

Once all the CGA rules were scripted and applied to its respective data models, the whole 3D modelling scene in CityEngine was exported to a CityEngine web scene from where it can be deployed on web using ESRI ArcGIS online for sharing and web 3D visualization purpose.

6. Results

Once, the produced Aldingen 3D scene was deployed on web using ArcGIS Online, it was embedded inside a personal website for data security purposes. The produced web 3D scene had its overall file size of just 32MB, and it worked with complete object interactivity and interactive fluidity. With ArcGIS online and its built-in CityEngine web viewer built on webGL and HTML5, 3D scene was visualized cross-platformed across any webGL enabled browser without any additional plugin required.

Figure 17: *Web 3D visualization of Aldingen town*

Figure 18: *Web 3D visualization of Specific heating demand for Aldingen town.*

Figure 19: *Web 3D visualization of PV potential on building roofs for Aldingen town.*

In total 7 different building information layers were displayed on web in 3D with full object interactivity. With an inbuilt functionality of CityEngine web viewer, 2 layers were displayed side by side as a comparison mode, with a dynamic illumination and sun-shadow visualization (see fig. 20).

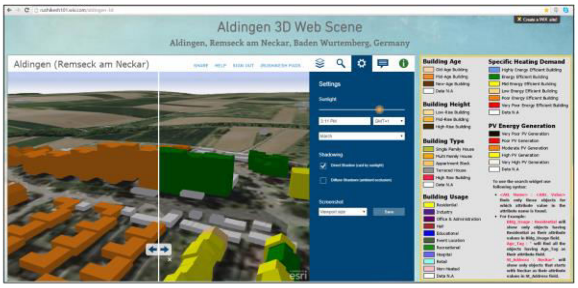


Figure 20: *Comparison mode and real-time dynamic illumination capability of CityEngine web viewer.*

Other additional functionalities like commenting, search by attributes, capturing a screenshot were able to perform with ease.

A step by step workflow of the above described methodology is available on https://www.youtube.com/watch?v=6to-4oIRbFY.

7. Conclusion

Thus an attempt to conceptualize a method to convert, manage, update, and visualize a set of relatively huge 3D spatial database of size 1.22GB on web was made. With the help of ESRI 3DCIM and its simplified structure of managing huge 3D spatial database, such an attempt was made possible. Lossless data interoperability between CityGML and shapefile using FME will help simulating platforms such as SimStadt to generate "existing vs future scenarios" and visualize it on a 3DCIM platform. With software's like ArcGIS Pro and CityEngine, it has now become easier than ever to manage all the spatial data, update it if required and then procedurally, mass model to develop a virtual 3D city from its attribute information and deploy it on web for sharing and visualization.

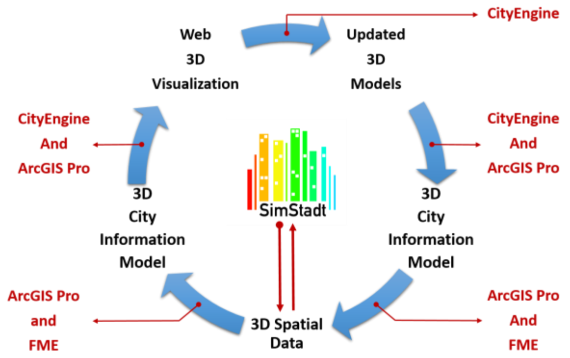


Figure 21: *Concluding conceptual cycle to convert, manage, update and visualize urban 3D spatial database on web.*

8. References

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9. Acknowledgement

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