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The Application of CityGML Food Water Energy ADE to Estimate the Biomass Potential for a Land Use Scenario

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1 ABSTRACT

Cities are undergoing rapid urbanisation throughout the globe. A common challenge amongst them is to provide food, water, and energy (FWE) supplies under sustainable and economically productive conditions. As a result, new tools and techniques must be developed to support domain experts and decision-makersto understand, simulate and visualise the nexus impact on the sustainable supply of the FWE resources. A critical part of such a development process is to eliminate data silos and move towards an integrated FWE based data model, which can then be used to connect domain-specific urban simulation tools to simulate FWE nexus scenarios based on changes in landuse, population, and climatic conditions.This paper demonstrates the CityGML FWE Application Domain Extension (ADE) application as a central data exchange format to connect different urban simulation tools. First, it gives an insight into the ongoing development of the FWE ADE to the standardised open city information data model of CityGML. Secondly, it demonstrates the role of the CityGML FWE ADE in exchanging datasets between a FWE based landuse simulator built with UD_InfraSim and an urban energy simulator SimStadt to estimate the biomass potential for a landuse scenario of Vienna based on its future population and climatic changes.

Keywords: Data Modelling, 3D CIty Modelling, Food Water Energy ADE, CityGML, Food Water Energy Nexus

2 INTRODUCTION

Food, water, and energy (FWE) are critical for human survival. In the 21st century, cities across the globe are pressing for natural resources more than ever before. They are undergoing rapid urbanisation, and together with population growth and climate change, they are continuously challenged to provide FWE resources under healthy, sustainable and economically productive conditions. To help face such a challenge, solutions should not beproposed in their silos, as these three domainsinteract with each other. For example, according to an estimate[1] from the United Nations, by 2050, the world population will increase by 2 billion, entailing the global food production increase by 60%, which will require 40% more water and 50% more energy.[2] Such an increase in food production will demandmore significantland, water, energy, or their combination.A critical challenge here would be finding a balance between the supply and demand of such critical urban infrastructures.Understanding and finding solutions within the individual domain silos of food, water, energy, land management, climate change would no longer be helpful. Thus new tools and techniques that can support domain experts and decision-makers to understand, analyse, and visualise the entire urban infrastructural system as a whole must be developed and prioritised.

The past decade has shown a rapid rise in the use of information and communication technology in sustainable urban development. Computer science and geo-informatics experts from both public and private sectors have developed manyopen and proprietary geospatial tools (e.g. ArcGIS, QGIS, ERDAS Imagine, GRASS GIS, and others), whichprovided new digital methods for city planning and decision making. Conventionally, a two-dimensional method of analysing the built environment has now been upgraded to three dimensions by developing the digital twins of cities. While geospatial tools and techniques allow users to generate and analyse geo-datasets, various urban simulation tools have also been developed to use geo-datasets to simulate different present and future built environment scenarios. With such a hand in hand development between geospatial technology and urban simulators, a commonly adopted and standardised city informationmodel to store and exchange datasets related to different built environment objects (e.g. buildings, roads, vegetation, landuse, water bodies and others) became crucial for data interoperability

[1] https://population.un.org/wpp/
[2] http://www.fao.org/news/story/en/item/275009/icode/

between tools, domain experts and decision-makers.In 2008, the Open Geospatial Consortium (OGC) standardised and released an open city information data model called CityGML.CityGML is a commonly adopted standardised open city information data model, which has been used in more than 100 cities[3] publicly or privately. Moreover,it offers flexibility to extend its original data model with domain-specific objects and attributes. Therefore, it shows promising signs for developing a CityGML based Food Water Energy Application Domain Extension (FWE ADE). The development process of the FWE ADEhas been led by an international group of domain experts from the food, water, energy, urban design and geoinformatics domains as a part of IN-SOURCE (INtegrated analysis and modelling for the management of sustainable urban FEW Res-SOURCEs) project (2018-2021). An integrated urban data model can become a vital software infrastructure for the planning, operation, and maintenance of present and future cities (Eicker et al. 2020). FWE ADE will not onlyallow FWE related data storage and exchange across different bottom-up or top-down urban simulation tools since it provides a data frame from building stocks to the regional level. But, it will also allow the domain experts and decision-makers to visualise the integrated FWE datasets driven by population, land use and climate change.

With this background, first in section 3, CityGML and its extension mechanism in developing the FWE ADE is explained in detail. Later as an example concept in section 4, the role of CityGML FWE ADE to connect the FWE land use simulator based on UD_InfraSim with an urban energy simulator SimStadt to estimate the biomass potential for a landuse scenario in Vienna is documented. Having such a data exchange setup can allow connecting domain specific simulation tools to simulate FWE resources based on changed population, land use and climatic conditions.

3 SHARED DATA MODEL: CITYGML AND FWE ADE

3.1 CityGML and its Extension Mechanisms

CityGML is an XML-based open city information data model standardised by OGC in 2008. The encoding standard documentation[4] for its last release, version 2.0, is available from the OGC website. The CityGML standard document uses Unified Modelling Language (UML) diagram and its XML schema definition (XSD) to describe data models, which explains how to model virtual 3D city models, also called CityObject, such as buildings, vegetations, land use, roads, bridges, tunnels, street furniture and water bodies in terms of their geometry, topology, semantics and appearance in five different Level of Details (LoD). For example, a building in CityGML can be represented as a 2D building footprint in LoD0, an extruded building block model in LoD1, while LoD2 includes additional roof geometries. Moreover, LoD3, in addition to LoD2, includes building openings, e.g. doors and windows, while LoD4, in addition to LoD3, also includes building interiors. Different use cases have shown the usefulness of CityGML globally with the development of various CityGML based tools and workflow pipelines. For example, its use in city planning (Agugiaro et al., 2020), disaster mapping (Kilsedar et al., 2019), urban energy demand (Padsala et al., 2020), urban water demand (Bao et al., 2020) and many such urban modelling and simulation related use cases.

CityGML is a domain independent city information data model. Hence it does not contain domain specific objects and attributes. However, CityGML offers two official ways to extend its original data model 1) generics and 2) a formalised mechanism to develop domain specific extensions called Application Domain Extension (ADE). Generics, which can also be called “CityGML extension during the run time”, is the easiest way to extend the original data model of CityGML. Using generics, users can add an arbitrary number of extra attributes, known as genericAttribute, to any CityObject without preparing a new data model or its application schema. Users can also define a new CityObject known as genericCityObjects, which can have arbitrary geometries with genericAttribute for its every LoD. Both genericAttribute and genericCityObjects are given an XML namespace of “gen” to differentiate themselves from the original XML namespace of CityObjects. XML namespaces are a set of unique element names which prevents conflicts between elements of the same name. For example, Bao et al. (2020a), in their biomass workflow of SimStadt, extended the CityGML CityObject of LandUse by adding land use area, soil type, crop type as some of the many other generic attributes for its later use in estimating biomass and its derived bio-energy for the counties of Ludwigsburg, Dithmarschen and Ilm-Kreis in Germany. Figure 1 shows a typical

[3] https://3d.bk.tudelft.nl/opendata/opencities/
[4] https://www.ogc.org/standards/citygml

workflow of adding genericAttributes or genericCityObjects using Feature Manipulation Engine (FME) [5] to extend CityGML. FME is a commercial extract, transform and load (ETL) tool commonly used for data conversion, integration and manipulation.

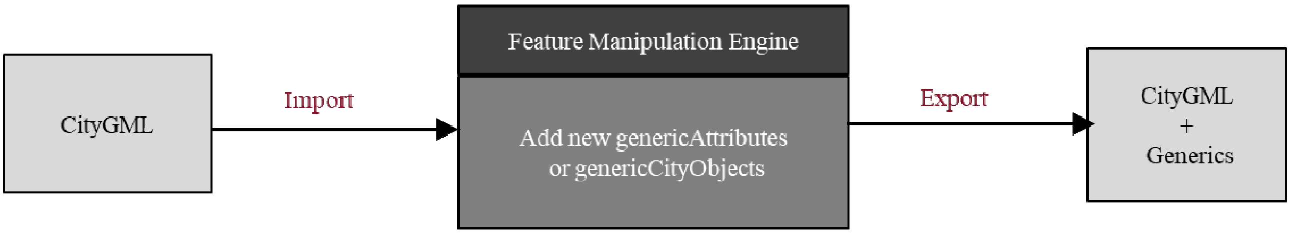

Fig. 1: A typical workflow to extend CityGML with generics using FME

On the other hand, application Domain Extension, or ADE, is a formalised way to extend the CityGML data model for a specific domain. Like generics, ADE is also an extension mechanism to CityGML for introducing domain-specific objects and attributes, which is often the case as specific applications require specific objects, attributes, and relationships that are not available in the original data model of CityGML. However, unlike generics, which 1) does not change the original CityGML XML schema, 2) have the same XML namespace and 3) can be specified at run time, ADEs 1) can change the original CityGML XML schema with domain specific new objects, attributes and relationships, 2) must have ADE specific unique XML namespaces to allow using multiple ADEs and prevent conflicts amongst the same CityGML document and 3)must be specified using UML diagrams or XSD.Such advantages over generics allow domain experts to adopt ADEs as a commonly adopted data model to support specific domains and applications. Though initially, using XSD as the only way to model ADEswas described in the CityGML encoding standard, van den Brink et al. (2012), in their article and later, OGC in their CityGML best practise document (OGC, 2014), described modelling an ADE using UML diagrams. Since then, a commonly adopted process to implement an ADE includes 1) Using software such as Enterprise Architect[6] (EA) to create a UML diagram to represent a data model 2) converting UML diagram to XSD either using EA's inbuilt XSD converter or open source tool such as ShapeChange[7] and 3) validate the ADE injected CityGML document against the original XSD of CityGML using tools such as FME validator, val3dity[8], CityDoctor[9]. Validation will make sure that it satisfies the CityGML's standardised specifications and definitions set by the OGC. Figure 2 explains a typical ADE implementation workflow using FME.

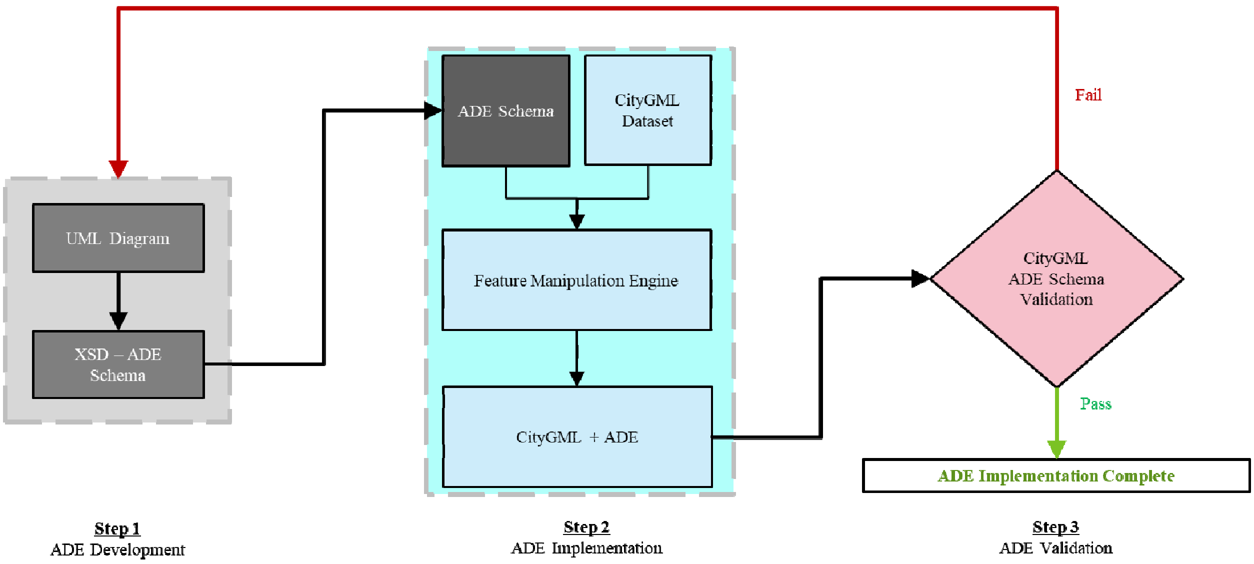

Fig. 2: A typical workflow to extend CityGML with ADE using FME

[5] https://www.safe.com/
[6] https://sparxsystems.com/
[7] https://shapechange.net/
[8] https://github.com/tudelft3d/val3dity
[9] https://projekt.beuth-hochschule.de/citydoctor2/

Because with ADEs, a formalised domain specific objects, attributes, and relationships can be modelled, it is commonly used amongst the domain experts to store and exchange their datasets amongst different tools and simulation workflows.Biljecki et al. (2018) found that until 2018, around 44 ADEs supported a wide range of domains and applications. Some of the regularly used ADEs are Energy ADE (Agugiaro, 2018) and its use in building stock energy demand simulations (Geiger et al., 2019; Rossknecht and Airaksinen, 2020), Utility Network ADE (Becker et al., 2011) and its use in modelling below ground utility networks (Duijin et al., 2018; Fossatti et al., 2020), Noise ADE (Groger et al., 2012) and its use in noise mapping (Czerwinski et al., 2006; Kumar et al. 2017) and Dynamizer ADE (Chaturvedi et al., 2015) to store time dependent variables in CityGML (Chaturvedi et al., 2019;Chatzinikolaou et al., 2020). However, despite different ADEs supporting different individual domains, a single integrated data model supporting multiple domains such as food, water, and energy, that can be used for FWE nexus related simulations is still missing. Hence, as one of the IN-SOURCE project outcomes, a new FWE ADE is under constant development. Its first version extending the CityGML version 2.0 was recently made available using the project's GitLab page.[10]

3.2 The CityGML Food Water EnergyADE

In its current version, the FWE ADE is divided into four modules, each representing a spatial level 1) FWEBuilding, 2) FWELanduse, 3) FWEArea, and 4) FWESystem. FWEBuilding targets building stock level and extends the original CityGML CityObject of Buildings with FWE related parameters. FWELanduse targets land use polygons representing land use (e.g. residential, commercial, vegetation) and extends the original CityGML CityObject of LandUse with FWE related parameters. Finally, FWEArea and FWESystem are introduced as two new CityObjects with multi-surface geometry in the CityGML data model to store FWE related parameters at administrative boundaries. A multi-surface geometry is a two dimensional geometry collection of surfaces representing a feature boundary. Using multi-surface geometries,FWEArea represents zonal or municipality boundaries, FWESystem represents city or regionallevel boundary. Two main reasons behind dividing FWE ADE into these four modules are 1) to cover different spatial level of any study area as shown in figure 3 and 2) to introduce FWE parameters specific to a spatial level that might not be available on other spatial levels.

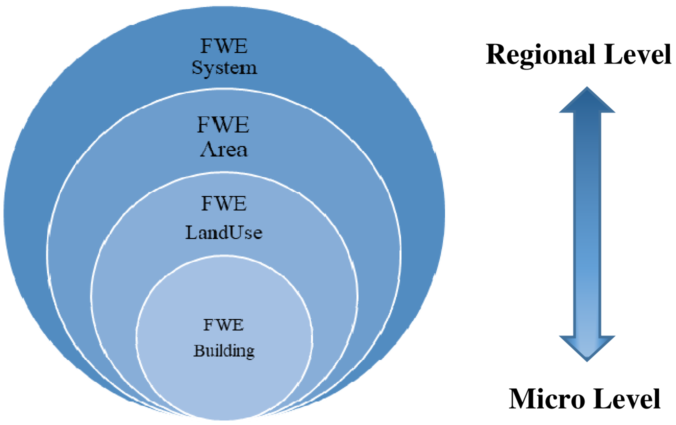

Fig. 3: A conceptual diagram showing the FWE ADE at different spatial levels

The complete documentation of FWE ADE, UML diagrams and its XSD schemas are available through the project's GitLab page as referenced before. In the context of this paper, because the biomass workflow of SimStadt using the CityGML CityObject of LandUse as its input, the FWELanduse module is explained further.

As mentioned before, the FWELanduse module is an extension to the CityGML CityObject of LandUse. CityGML LandUse is defined as a multi-surface geometry describing areas of land dedicated to a specific use. To indicate land use attributes,class, function, and useare already part of the CityGML LandUse data model. While the class attribute is used to classify land use objects, like settlement area, vegetation, water body etc., the attribute function defines the nature of the land use object, e.g. residential, commercial, institutional etc. The attribute use can be used for more detailed classification such as single-family houses, multi-family houses, hospitals, schools, etc. As an extension to the CityGML LandUse data model, FWE

[10] https://transfer.hft-stuttgart.de/gitlab/in-source/fwe-ade

related parameters such as population, survey year, land use area, crop type, soil type, irrigation demand, transpiration loss, biomass primary energy potential are introduced as a part of new FWELanduse objects for CityGML LandUse CityObejct. These new parameters, along with the CityGML LandUse geometry, are required as an input to the SimStadt's biomass workflow.

4 FWE ADE APPLICATION: BIOMASSPOTENTIAL FOR A LAND USE CHANGE SCENARIO

In the following section, as an example concept showcasing the role of FWE ADE in connecting two different urban simulator tools to achieve a data flow amongst them is explained in detail. A high level workflow of the data exchange setup between UD_InfraSim and SimStadt via FWE ADE capsulated inside 3DCityDB is shown in figure 4.

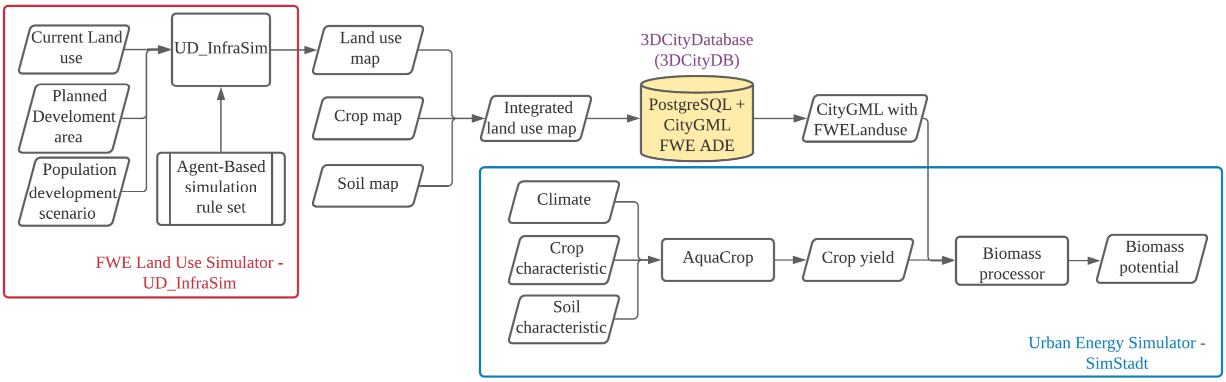

Fig. 4: Workflow Diagram

4.1 UD_InfraSim and its FWE Land Use Simulator

The UD_InfraSim is a simulation platform that enables urban planners to estimate the impact of infrastructure costs, for example, for road and water networks, in relation to changes in land uses (growth patterns) in the urban region[11] (Gebetsroither-Geringer et al., 2015). It is built upon earlier 'urban development simulation tools' (Gebetsroither-Geringer and Loibl, 2007; Gebetsroither, 2009; Gebetsroither and Loibl, 2014). Within the IN-SOURCEproject, the simulation platform was used, adapted and extended to build the FWE Land Use Simulator[12].

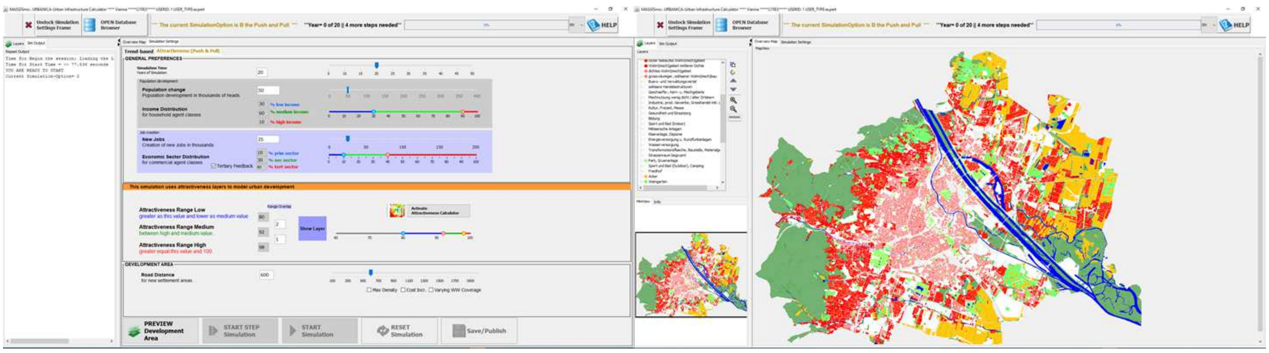

Fig. 6: Screenshot of the FWE Land Use Simulator

Different data sources have been used for the case study in Vienna.For example, open government data regarding the current land use in Vienna and remote sensingdata for crop type classification to derive the spatial crop distribution for different crop types (Vuolo et al., 2018). For the biomass calculation with Aqua Crop, the soil type was needed, which was gained from BFW.[13] Using the FWELand Use Simulator, the current and a scenario for future land use were simulated. For the future land use scenario, an additional population of 150,000 new inhabitants in Vienna was assumed.The scenario also uses information about the future development plan of Vienna to estimate the loss of arable land due to new settlements and the

[11] https://www.ait.ac.at/en/research-topics/digital-resilient-cities/projects/ud-infrasim
[12] https://drc.ait.ac.at/sites/insource/fwe-land-use-simulator/
[13] digital soil map, the 1km raster data set is open source and can be downloaded here https://bodenkarte.at/

corresponding loss of biomass. This assumed population increase is lower than the official prognosis show[14], but as it is assumed that the growth concentrates on the already planned new development areas in Vienna,it is reasonable. The chosen scenario frameconditions depict just one possible city development pathway. However, in the context of this paper, itisnot necessary to derive the most likely development scenario as the goal of the paper is to demonstrate the concept of connecting different domain specific tools using CityGML FWE ADE. As a final output from the UD_InfraSim based FWE land use simulator, an integrated map showing the land use scenario merged with crop type, and soil type dataset is produced in the shapefile data format. Using FME, shapefile is converted to the CityGML LandUse dataset,which is then imported to 3DCityDB.

4.2 3DCityDB and its connection to FWE ADE

3D City Database or 3DCityDB is an open source software to store, manage, analyse and visualise CityGML datasets (Yao et al., 2018). It is built on top of spatial relational database management system Oracle Spatial/Locator or PostgreSQL with PostGIS. For the present work, 3DCityDB with PostgreSQL is used. It consists of SQL scripts that comply with the CityGML standards to generate required database tables, functions, procedures and views that allow users to store, manage and query CityGML datasets in PostgreSQL. For easy operation of 3DCityDB, a free importer Importer/Exporter tool for 3DCityDB is also distributed as a part of the 3DCityDB package. Importer/Export tool is available in both graphical user interface and command line interface version. Apart from allowing users to import, manage, query and export CityGML datasets, the tool also allows users to export their CityGML datasets to other data formats such as KML, COLLADA and glTF, which are some of the commonly used data formats to visualise 3D city models on the web using digital globes. The complete list of its functionalities, along with its source code and documentation, is available on their GitHub[15] page. An important feature of the tool used in the present work is its ADE manager plugin. Using the ADE manager plugin, new database tables related to the FWELanduse module of the FWE ADE and its required operational SQL syntax, also called Data Definition Language (DDL) statements, could be generated automatically. The DDL statements are required to define the data structure and modify the datasets inside PostgreSQL. By default, 3DCityDB does not allow importing and exporting CityGML datasets enriched with ADEs. Hence, two custom FWE ADE based java modules, 1) citygml4j and 2) ADE specific importer-exporter extension for 3DCityDB,are in development. While citygml4j will be used by the Importer/Exporter tool toparse and write ADE specific CityGML datasets, the ADE specific importer-exporter extensionwill be used to read and write datasets to ADE tables in the PostgreSQL/3DCityDB. An example implementation to develop such ADE specific importer/exporters to 3DCityDB is available on its GitHub[16] page. Figure 7 shows a typical workflow for importing, managing and exporting FWE ADE enriched CityGML datasets in 3DCityDB.

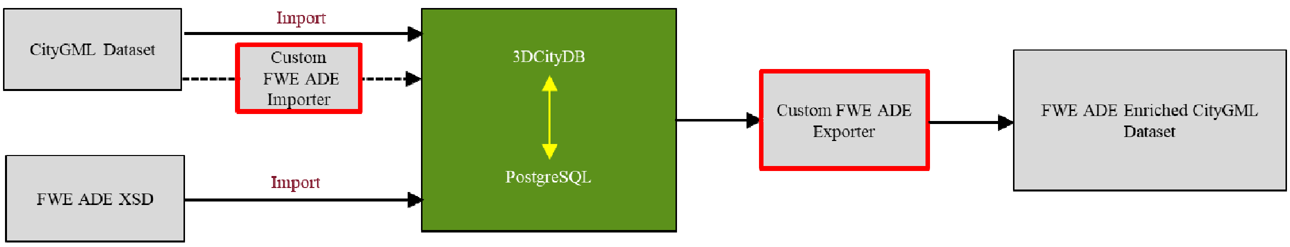

Fig. 7: 3DCityDB's FWE ADE Importer/Exporter workflow

After importing the CityGML LandUse scenario map from UD_InfraSim to 3DCityDB, an internal mapping of the required FWE parameters of land use polygon area, crop type, soil type was made between the imported CityGML LandUse datasets converted from the UD_InfraSim's integrated land use map and the FWELanduse ADE schema using SQL scripts in PostgreSQL. With this, the imported CityGML land use data is made to comply with the FWE ADE's module of FWELanduse and exported as an FWE ADE enriched CityGML LandUse dataset. This dataset is then used as an input to SimStadt's biomass workflow.

[14] https://www.wien.gv.at/statistik/bevoelkerung/tabellen/bev-2048.html
[15] https://github.com/3dcitydb
[16] https://github.com/3dcitydb/extension-test-ade

4.3 SimStadt and its BiomassWorkflow

The assessment of energetic biomass potentials from agriculture is based on an existing biomassworkflow that has been introduced before in section 3.1, validated, and applied at the example of three German counties as case studies. The workflow was reconfigured from accepting inputs using genericAttributes to complying with the FWE ADE schema. The workflow is now compatible with and transferable to other regions, as long as (i) land use information was provided under FWE ADE schemain CityGML format, (ii) information on new land use/crop types is available and is added to an existing SimStadt's XML library and (iii) the new crop/soil types are described and written in standard inputs crop/soil files for the yield simulation software AquaCrop (Raes, 2016). The workflow is part of a versatile regional energy system modelling environment, SimStadt[17], that aims to compare different renewable energy resource potentials and contrasts these with local energetic demands in a given region. SimStadt, which is under constant development at HfT Stuttgart since 2012 (Nouvel et al., 2015), comprises modular workflow management, with each workflow serving a specific purpose. To date, it can assess building-related demands (cooling and heating (Weiler et al., 2019), residential electricity (Kohler et al., 2010), water (Bao et al., 2020b) and renewable energy potentials (rooftop photovoltaics (RomeroRodriguez et al., 2017) and biomass (Bao et al., 2020c) on a single-building or single-field level using 3D city models or digital landscape models in the CityGML format.

For the biomass workflow, a key input is the FWE ADE's FWELanduse enrichedCityGMLLandUse object having multi-surface geometries.Besides geometric and attribute data from theFWE ADE, meteorological data of Vienna's current climate, i.e. the average over the past 10 years, and forecasted climate data in 2040 in TMY3[18] format, was provided by Meteonorm[19].

To calculate the biomass yield based on local climate, soil characteristics, land management pattern, and irrigation pattern for most crops, a validated external crop yield and water simulation tool named AquaCrop, developed by the Food and Agriculture Organization of the United Nations (FAO, 2018) was integrated with SimStadt. The key characteristics of the crop and soil files that were generated as inputs for AquaCrop were collected based on statistical literature values (KTBL, 2018).The specific yields in fresh mass (tFM/ha/yr) of selected key crop types under average climate between 2000 and 2010 were validated with the statistical yield in 2015 and 2016 fromthe Vienna Agriculture Report(Wiener Landwirtschaftsbericht, 2017).The specific yieldresulting frombiomass workflow is based on the dry mass of the above-ground biomass. To compare with the fresh yield from the Vienna Agriculture Report, the harvest rate and water content (KTBL, 2018) were applied to convert the dry mass to fresh mass. The validation result is shown in table 1.

	Specific yield in t_{FM}/ha/yr		Area in ha	
Crop type	Simulation	Statistic	Simulation	Statistic
Maize	7.0	6.8 - 8.4	293	121 - 138
Potato	28.1	43.4 - 26.5	84	66 – 88
Soybean	3.1	1.5 - 2.2	132	54 – 81
Sugar beet	48.9	65.1 - 76.7	254	219 – 230
Sunflower	3.1	2.5 - 2.8	189	11 - 21
Wheat	5.8	4.9 - 4.4	2776	2172 - 2200

Table 1: Areas and specific yields of selected crops from simulation and literature.

Table 1 shows that the area allocation of potato and sugarbeet aligns with the statistical values. However, for sunflower that occupied less than 0.4 % of the agricultural area, the difference of area between simulation and statistic can be up to 17 times, as a part of the polygons were either overlooked or misplaced due to the limitation of the method of satellite image recognition (Vuolo et al., 2018). For the main crop type, i.e., wheat, the deviation is less than 10 %. At the aspect of specific yield, the error of the input map was isolated; only the accuracy of the biomass workflow was shown. According to table 1, the yields of most crops fall within the range from the statistic, except for sugar beet and wheat. The crop map did not differentiate the

[17] https://simstadt.hft-stuttgart.de/de/index.jsp
[18] https://www.nrel.gov/docs/fy08osti/43156.pdf
[19] https://meteonorm.com/

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subtypes of wheat; therefore, winter cereal was applied to represent the family. The statistical yield of winter cereal was 5.5 to 6.3 tFM/ha/yr compared with the simulation result of 5.8 tFM/ha/yr, verifying the yield simulation result. As for sugar beet, the deviation might be brought by the inaccurate crop characters input for AquaCrop. Therefore, the standard sugar beet growing characteristic combined with the typical growing period in Vienna was applied, which might bring the yield difference.

4.4 ApplicationResults

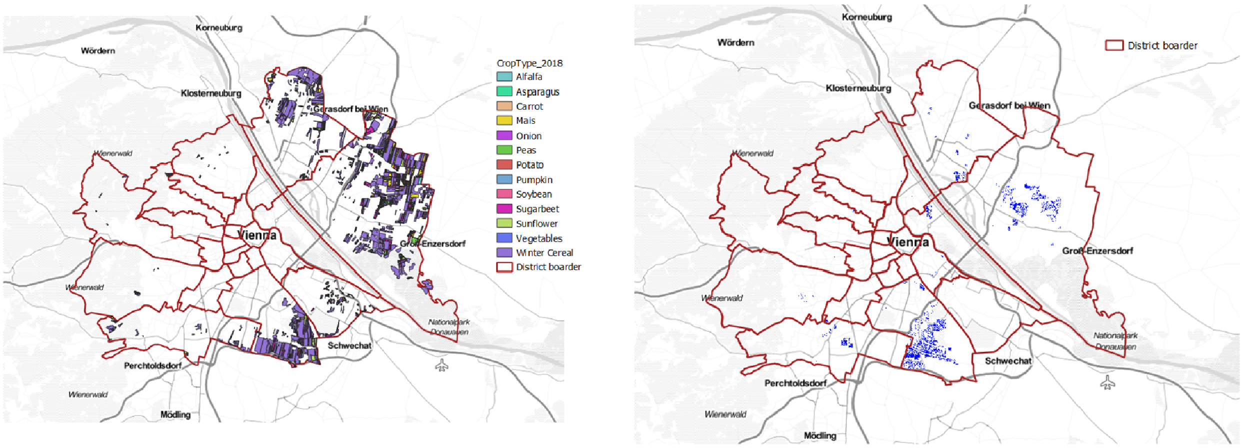

Fig. 8:Crop map 2018 depicted from remote sensing (left image)and a future settlement scenario2038 (right image)

Figure 8 shows the crop distribution map gained from remote sensing on the left side and a population growth scenario within the next 20 years on the right side. The images show that, especially in the south and northeast of Vienna, arable land and thus crop biomass production is affected. In this scenario, the destruction of arable land is not extreme because many of the planned new development areas already are not anymore used for agriculture, and it was assumed that the population density for new settlements is relatively high.

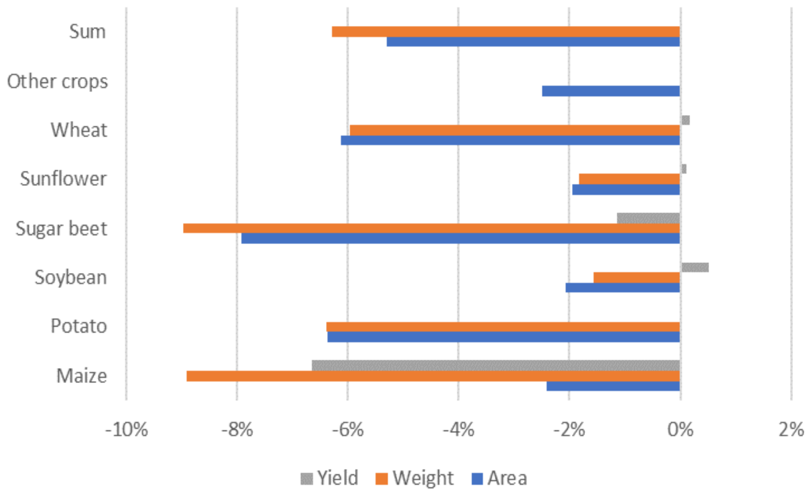

Fig. 9: Percentage change of area, weight, and yield of selected crops in the current scenario and 2038 scenario.

Figure 9shows the development of the agricultural area, the amount of biomass produced, and the specific yield of several crop types. Climate difference, i.e., the annual average temperature dropped from 11.8 °C to 11.6 °C, and precipitation increased from 608 mm/yr to 618 mm/yr, influenced specific yields to various extends depending on the crop types. Maise acted most negatively to the climate change with a yield drop of 6.7 % following by sugar beet with -1.2%. For other crops, i.e., potato, soybean, sunflower, and wheat, the yield increase by 0.5 %. In the term of the total agricultural area according to the scenario setting of the FWE land use simulator, there would be 2.1% to 7.9 % less land for crop growing in 2038 comparing with the current case (2018). The most significant area decreases were estimated for sugarbeet (7.9 %) and wheat (6.1 %). Even though few crops would be more productive, i.e., up to 0.5 %, under the 2040 climate, combined with the more significant drop of the agricultural areas, the total biomass weight was estimated to drop from 1.6 % to 9 % varying from crop types.

5 CONCLUSION

This paper introducesthe concept of data exchange between two simulationtools in two domains using a shared FWEADEextended from thestandardised open city information data model of CityGML.Unlike the genericsextension methodof CityGML, whichcannot have a formal data structure or schema, afull ADE can be formally specified, has a well-defined data structure, and its realisation can be validated against its schema, which is not possible with generic attributes and objects. Translating the use of ADE in a complicated real life application involving several domain specific tools, an ADE can providea well structured data framework to store and exchangedatasetsbetween different tools. Moreover, CityGML being a city information model and ADE being its domain specific extension mechanism was proved to be very helpful in translating integrated urban infrastructural systems such as the FWE nexus domain to an object oriented data model.Such an integrated data model provides data interoperability between different urban simulation tools in the FWE nexus domainsand helps develop simulation workflows that can analyse the entire urban infrastructural system as a whole and not just in their silos.

In terms of spatial and temporal detail levels, FWE ADE defined data at different spatial levels, i.e., building stocks, land field, community, or region, and additionally introduced time as a variable, i.e., the value of an attribute in a specific year. In the context of this paper,due to the fine spatial resolution down to land use polygons, bottom-up simulation tools can directly take geographical inputs or store outputs at the corresponding level achieving a high level of data accuracy and detail. For example, with such information,a trade-off between an open-field PV system and food production can be determined according to the potential simulation results.The top-down analysis method can also find inputs through the FWE ADE, i.e., by aggregating the values of land field polygons in the study region and store output at the regional level. The temporal variable enables the FWE ADE to present the changes in attributes over a certain period, i.e., the yield change in 10 years due to climate change.

Within the application of linking two tools addressing different issues within the FWE nexus, the proposed FWE ADE alsoproved its usefulness.UD_InfraSim simulated the land use change, i.e., the expansion of residential area at the expense of arable lands. A workflow from SimStadt simulated the biomass potential of arable lands. The accuracy of the final results wasdefinedby several factors, including the quality of the crop distribution map, the crop rotation, and the yield simulation tool. The nature of seasonal and annual agriculture rotation makes it difficult to estimate the exact crop distribution. Regardless, the decentralised crop map (with a resolution of 5 m) and soil distribution map (with a resolution of 200 m) served as the input of FWE ADE, later applied in the FWE Land Use Simulator and the bottom-up biomass workflow in SimStadt. The geographical resolution in the presented applicationis 25 meters.As already mentioned above,the elaborated scenario is just one possible scenario of how Vienna can developbased on “forecasted” frame conditions, i.e., government policies, forecasted population growth and climate change.The established connection can be used to easily calculate other development scenarios. It enables urban planners and sustainability experts to compare future landuse scenarios and evaluate its effect on the biomass potential to find scenarios with less reduction in the region’s biomass production. Furthermore, it supports spatial energy planning to estimate the renewable bioenergy production potential in the region to increase the local share of renewable energy supply.

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7 REFERENCES

Agugiaro, G., Benner, J., Cipriano, P. et al.: The Energy Application Domain Extension for CityGML: enhancing interoperability for urban energy simulations. Open geospatial data, softw. stand. 3, 2. https://doi.org/10.1186/s40965-018-0042-y, 2018.

Agugiaro, G., García G., Francisco G., and Cavallo, R.: The City of Tomorrow from… the Data of Today. International Journal of Geo-Information, 9. https://doi.org/10.3390/ijgi9090554, 2020.

Bao, K., Padsala, R., Coors, V., Thrän, D., and Schröter, B.: GIS-Based Assessment of Regional Biomass Potentials at the Example of Two Counties In Germany. https://doi.org/10.5071/28thEUBCE2020-1CV.4.15, 2020.

Bao, K., Padsala, R., Coors, V., Thrän, D., and Schröter, B.: A Method for Assessing Regional Bioenergy Potentials Based on GIS Data and a Dynamic Yield Simulation Model. Energies. 13. https://doi.org/10.3390/en13246488, 2020.

Bao, K., Padsala, R., Thrän, D., Schröter, B.: Urban Water Demand Simulation in Residential and Non-Residential Buildings Based on a CityGML Data Model. ISPRS Int. J. Geo-Inf., 9, 642. https://doi.org/10.3390/ijgi9110642, 2020.

Becker, T., Nagel, C. & Kolbe, T.H.: Integrated 3D Modeling of Multi-utility Networks and Their Interdependencies for Critical Infrastructure Analysis. https://mediatum.ub.tum.de/doc/1145740/1145740.pdf, 2011.

Biljecki, F., Kumar, K., and Nagel, C.: CityGML Application Domain Extension (ADE): overview of developments. Open Geospatial Data, Software and Standards. 3. 13. https://doi.org/10.1186/s40965-018-0055-6, 2018.

Chaturvedi, K. and T. H. Kolbe.: Dynamizers - Modeling and Implementing Dynamic Properties for Semantic 3D City Models. Eurographics Workshop on Urban Data Modelling and Visualisation Workshop. https://dx.doi.org/10.2312/udmv.20151348, 2015.

Chaturvedi, K., Yao, Z., and Kolbe, T.: INTEGRATED MANAGEMENT AND VISUALISATION OF STATIC AND DYNAMIC PROPERTIES OF SEMANTIC 3D CITY MODELS. ISPRS - International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences. XLII-4/W17. 7-14. https://doi.org/10.5194/isprs-archives-XLII-4-W17-7-2019, 2019.

Chatzinikolaou, E., Pispidikis, I., and Dimopoulou, E.: A SEMANTICALLY ENRICHED AND WEB-BASED 3D ENERGY MODEL VISUALISATION AND RETRIEVAL FOR SMART BUILDING IMPLEMENTATION USING CITYGML AND DYNAMIZER ADE, ISPRS Ann. Photogramm. Remote Sens. Spatial Inf. Sci., VI-4/W1-2020, 53–60. https://doi.org/10.5194/isprs-annals-VI-4-W1-2020-53-2020, 2020.

Czerwinski, A., Kolbe, T. H., Plumer, L. and Stocker-Meier, E.: Interoperability and accuracy requirements for EU environmental noise mapping. In: H. Kremers and V. Tikunov (eds), International Conference on GIS and Sustainable Development (InterCarto – InterGIS 12), Berlin, Germany, pp. 182–194. https://api.semanticscholar.org/CorpusID:2222165, 2006.

den Duijn, X., Agugiaro, G., and Zlatanova, S.: MODELLING BELOW- AND ABOVE-GROUND UTILITY NETWORK FEATURES WITH THE CITYGML UTILITY NETWORK ADE: EXPERIENCES FROM ROTTERDAM, ISPRS Ann. Photogramm. Remote Sens. Spatial Inf. Sci., IV-4/W7, 43–50. https://doi.org/10.5194/isprs-annals-IV-4-W7-43-2018, 2018.

Eicker, U., Weiler, V., Schumacher, J., Braun, R.: On thedesign of an urban data and modeling platform and its application to urban district analyses. Energy and Buildings. https://doi.org/10.1016/j.enbuild.2020.109954, 2020.

Fossatti, F., Agugiaro, G., Olde Scholtenhuis, L., Doree, A.: Data modeling for operation and maintenance of utility networks: Implementation and testing. ISPRS Annals of Photogrammetry, Remote Sensing and Spatial Information Sciences, 6 (4/W1), 69-76. https://doi.org/10.5194/isprs-annals-VI-4-W1-2020-69-2020, 2020.

FAO: AquaCrop Reference Manual. http://www.fao.org/publications/card/en/c/BR244E/, 2018.

FAO: AquaCrop Training Handbook. https://www.fao.org/aquacrop/software/aquacropstandardwindowsprogramme/en/, 2018.

Gebetsroither-Geringer, E., and Loibl, W.: Urban Development and Infrastructure Cost Modelling for Managing Urban Growth in Latin American Cities. https://www.corp.at/archive/CORP2015_120.pdf, 2015.

Gebetsroither-Geringer, E., Loibl, W.: GIS-Based Water Resource Management of the Dead Sea Region – Integrating GIS, System Dynamics and Agent Based Modelling. In: Zeil, Peter; Kienberger, Stefan (eds.): Geoinformation for Development: Bridging the Divide through Partnerships. pp. 26-32, Heidelberg: Wichmann, 2007.

Gebetsroither-Geringer, E.: Combining Multi-Agent Systems Modelling and System Dynamics Modelling in Theory and Practice. Alpen-Adria Universität Klagenfurt: Fakultät für Technische Wissenschaften, p. 166, Klagenfurt, 2009.

Gebetsroither-Geringer, E., Loibl, W.: Urban Development Simulator: An interactive decision support tool for urban planners enabling citizen's participation. RealCORP 2014. Proceedings, 749-756, Vienna, 2014.

Groger, G., Kolbe, T. H., Nagel, C. and Hafele, K.-H.: OGC City Geography Markup Language (CityGML) Encoding Standard version 2.0.0. https://portal.ogc.org/files/?artifact_id=47842, 2012.

Geiger, A., Joachim, B., Häfele, K., Hagenmeyer, V.: Building Energy Simulations at Urban Scale Based on Standardized Data Models Using a Transparent Enrichment Process. 3202-3208. https://doi.org/10.26868/25222708.2019.210250, 2019.

Kilsedar, C., Fissore, F., Pirotti, F. and Brovelli, M. EXTRACTION AND VISUALISATION OF 3D BUILDING MODELS IN URBAN AREAS FOR FLOOD SIMULATION. XLII-2/W11. 669-673. https://doi.org/10.5194/isprs-archives-XLII-2-W11-669-2019, 2019.

Kumar, K., Ledoux, H., Commandeur, T. J. F., and Stoter, J. E.: MODELLING URBAN NOISE IN CITYGML ADE: CASE OF THE NETHERLANDS, ISPRS Ann. Photogramm. Remote Sens. Spatial Inf. Sci., IV-4/W5, 73–81. https://doi.org/10.5194/isprs-annals-IV-4-W5-73-2017, 2017.

Köhler, S., Betz, M., Eicker, U.: Stochastic generation of household electricity load profiles in 15-minute resolution on building level for whole city quarters. Energy Challenges for the Next Decade, 16th IAEE European Conference, August 25-28, 2019. International Association for Energy Economics. https://api.semanticscholar.org/CorpusID:211053294, 2019.

KTBL: General figures for agriculture. https://www.ktbl.de/shop/produktkatalog/19523, 2018.

Nouvel, R., BRASSEL, K., BRUSE, M., Duminil, E., Coors, V., Eicker, U and Robinson, D.: SimStadt, a new workflow-driven urban energy simulation platform for CityGML city models. CISBAT 2015, EPFL, Lausanne, September 9-11th. https://doi.org/10.5075/epfl-cisbat2015-889-894, 2015.

OGC.: Modeling an application domain extension of CityGML in UML (OGC Best Practice). OGC, Best Practice OGC 12-066. Open Geospatial Consortium. https://portal.ogc.org/files/?artifact_id=49000, 2014.

Padsala, R., Theresa, F., Peters-Anders, J., Gebetsroither-Geringer, E., Coors, V.: From Urban Design to Energy Simulation – a Data Conversion Process Bridging the Gap Between Two Domains. Real CORP 2020. https://doi.org/10.48494/REALCORP2020.1054, 2020.

Rossknecht, M. and Airaksinen, E.: Concept and Evaluation of Heating Demand Prediction Based on 3D City Models and the CityGML Energy ADE–Case Study Helsinki. ISPRS Int. J. Geo-Inf. 2020, 9, 602. https://doi.org/10.3390/ijgi9100602, 2020.

Romero Rodriguez, L., Duminil, E., Jose Sanchez, R. and Eicker, U.: Assessment of the photovoltaic potential at urban level based on 3D city models: A case study and new methodological approach. Solar Energy. 146. 264-275. https://doi.org/10.1016/j.solener.2017.02.043, 2017.

Weiler, V., Stave, J. and Eicker, U.: Renewable Energy Generation Scenarios Using 3D Urban Modeling Tools–Methodology for Heat Pump and Co-Generation Systems with Case Study Application †. Energies, 12, 403. https://doi.org/10.3390/en12030403, 2019.

Yao, Z., Nagel, C., Kunde, F. et al.: 3DCityDB - a 3D geodatabase solution for the management, analysis, and visualisation of semantic 3D city models based on CityGML. Open geospatial data, softw. stand. 3, 5. https://doi.org/10.1186/s40965-018-0046-7, 2018.