Report on the UML diagram and XML Schema Definition (XSD) for the newly proposed FWE ADE

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Short Description:
This document explains the Unified Modelling Language (UML) diagram for the newly proposed Food Water Energy – Application Domain Extension (FWE ADE) of CityGeographicalMarkupLanguage (CityGML v2.0)
Keywords:
Data Model, CityGML ADE, XSD, FWE Nexus

History			
Version	Author(s)	Comment	Date
1.0	Rushikesh Padsala (Rushi)	First internal draft	21.07.19
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	Volker Coors	Approved as a final document	01.06.2020
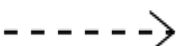
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Abbreviated Terms

FWE	Food Water Energy
OGC	Open Geospatial Consortium
CityGML	City Geography Markup Language
ADE	Application Domain Extensions
UML	Unified Modeling Language
XML	Extensible Markup Language
XSD	XML Schema Definition
GIS	Geographical Information System
DLM	Digital Landscape Model

UML Relations Notation

——→	Association (e.g. An aeroplane is associated with passengers)
——▷	Inheritance (e.g. A child inherits DNA from his/her parents)
- - - - -▷	Realisation (e.g. Printer drivers needs to be installed for the printer to work)
- - - - -→	Dependency (e.g. A car is dependent on its engine)
◇——	Aggregation (e.g. A crowd is an aggregation of people)
◆——	Composition (e.g. A residential building is composed of apartments)

Multiplicity

0	No instances (rare)
0..1	No instances, or one instance
1	Exactly one instance
1..1	Exactly one instance
0..*	Zero or more instances
*	Zero or more instances
1..*	One or more instances
	If the multiplicity is not available, by default multiplicity 1 is assumed

Sustainable Urbanisation Global Initiative (SUGI)
FOOD-WATER-ENERGY NEXUS

BELMONT FORUM

URBAN EUROPE

European Commission

Introduction

Cities are undergoing rapid expansion throughout the globe. As a result, they face common challenges to provide food, water and energy (FWE) supplies under healthy and economically productive conditions. Decision-makers, such as governments, investors and city developers must understand, quantify and visualise multiple interdependent impacts. IN-SOURCE aims to develop an integrated urban data and modelling framework to help cities analyse and characterise FWE systems and its nexus to tackle such an issue.

Given the heterogeneity of temporal and territorial entities, such as population, their FWE demands, and LandUse changes connected to different spatial levels from individual building level to cities or district level, adopting a common shared and open urban data model is crucial. OGC CityGML is used as the only available free standardised urban data model that allows spatial modelling of semantically different georeferenced objects such as buildings, LandUse and other physical elements of the real world. With its built-in mechanism to extend its core data model with domain-specific objects and attributes (a.k.a Application domain Extension – ADE), a new Food Water Energy ADE (FWE ADE) is proposed in this document.

The FWE ADE is a cohesive data model which allows decision-makers to analyse and visualise the study region relating to FWE and its nexus for any urban areas using geospatial information. Further, this data model can support new simulation interfaces for predicting futuristic FWE nexus scenarios connected to population and LandUse change. For quantitative analysis and visualisation across all the spatial levels of any study area, FWE ADE is attached to buildings, scaling it up to LandUse, further extending it up to neighbourhoods, areas or zones and at the end to the regional level of boroughs, cities and districts.

The structure of this document is as follow: (i) A brief introduction on CityGML, and CityGML ADE is explained under the chapter "Scope". (ii) Based on "Scope", the newly proposed FWE ADE and its connection to individual spatial levels are explained under "Concept". (iii) Based on "Concept", for each FWE ADE's spatial level, a UML data model diagram along with its complete list of all the included FWE and its nexus related properties, a possible data source column against each property to find the datasets, related codelist, details about its XSD schema and some web 3D visualisation examples are explained under "FWE ADE". (iv) Lastly, few general notes about the current version of FWE ADE are mentioned under "Remarks".

Scope

Quantitative analysis of FWE and its nexus is essential information to study infrastructural demand and supply chain for any urban area in sustainable urban development. This information can then further be extended to calculate the Green House Gas emissions while dealing with climate change mitigation and adaptation when required. To store, structure and visualise such data and indicators, a data model is of extreme importance. Since such a data model is space and time-bounded, introducing a geospatial component to it is inevitable but of non-existent in the present time. With, the OGC approved XML based open data model of CityGML[1], and its mechanism of further extending its data model with an ADE, developing FWE ADE is made plausible. Already available in the core data model of CityGML are the modules of buildings, LandUse, vegetation, roads, street furniture, bridges, tunnels and water bodies. These modules describe how these individual city elements can be modelled along with its georeferenced geometry and semantics in 4 different levels of details (LoD) from 0 to 4 with appearance textures (optional).
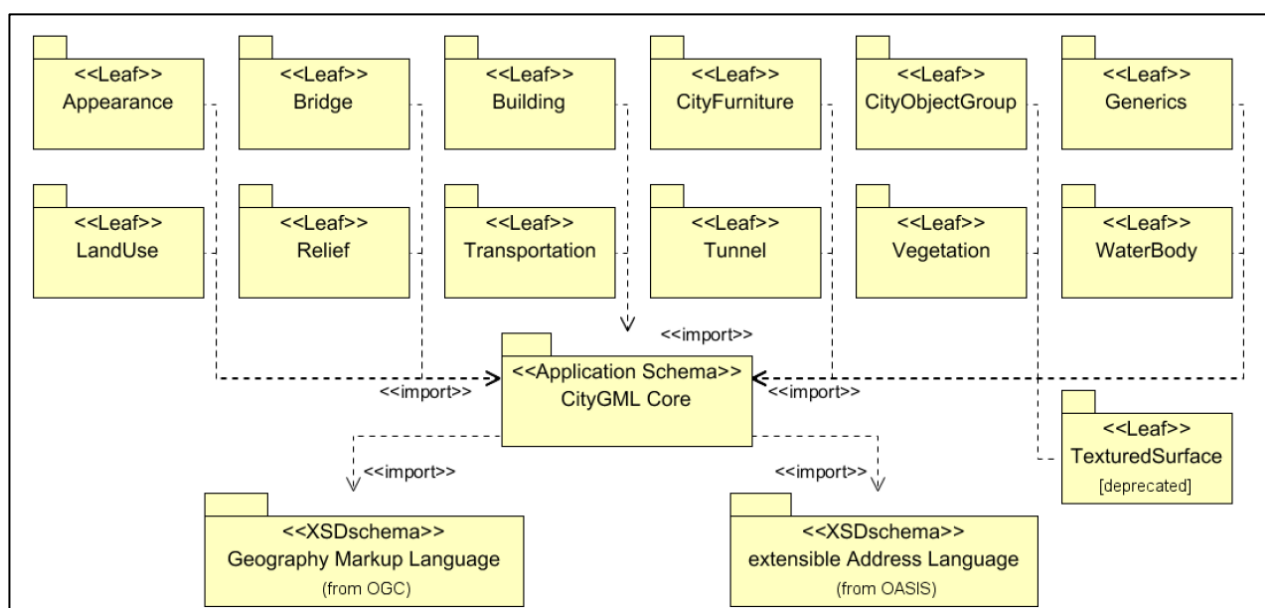
Figure 1: An UML package diagram showing the existing thematical modules of CityGML

To extend the existing CityGML modules with new properties/attributes or to introduce an entirely new thematic module to the core of CityGML, ADEs are used. It essential to note that the CityGML ADEs only stretches the data model of CityGML to fit a particular application needs. It is no way related to data interoperability or data format conversion between CityGML to any other data model/format and vice versa.

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[1] https://www.ogc.org/standards/citygml

In a simple term, CityGML ADE sits on top of CityGML to enrich its core data model to accommodate application-specific new objects and their properties.

As of 2018, 44 different CityGML ADEs were already developed supporting various applications (Biljecki et al., 2018). Out of these 44 ADEs, one ADE which comes close to the current topic of FWE is the Energy ADE[2] (Nouvel et al., 2015). Energy ADE is specifically designed to store building energy-related data and indicators. Different urban energy simulators such as CitySim (Robinson et al., 2009), EnergyPlus (Geiger et al., 2019), SimStadt[3] (Nouvel et al., 2015) makes use of Energy ADE to assess building stock energy demand and simulate its refurbishment scenarios. But, since Energy ADE intends only to support building stock energy simulations, no FWE nexus properties are available. As a result, instead of extending Energy ADE further, altogether, a new FWE ADE is proposed in this document. However, within FWE ADE, specific properties that are linked to building energy demand - potential (explained in further chapters) uses the results of SimStadt's building energy demand - potential workflows.

In the current FWE ADE version, data structure follows a top-down approach with population and landuse driving the data model. This means that all the subsequent FWE and its nexus properties (explained in further chapters), will change based on population and landuse. Indicators and metrics connected to climate change, transportation, GHG emissions, urban heat islands, wind flow - CFD simulations, wind power potential and their effect on FWE and its nexus are excluded at the moment. Still, based on use cases, they may be introduced in the future version of FWE ADE. ADEs can always be restructured and extended based on needs.

FWE ADE Concept

The primary objective of FWE ADE is to extend the existing CityGML data model, store FWE and its nexus related properties for developing a digital twin of the study area. By doing so, not only can the status quo be mapped, analysed and visualised, but future analytical scenarios can also be built, simulated and visualised. For stakeholders, such an integrated data model and visualisation tools can further support them to sketch sustainable urban development policies which is a need of the time.

Keeping in mind the challenges of data availability and its granularity, FWE ADE introduces four thematic modules: "FWEBuilding", "FWELandUse", "FWEArea" and "FWESystem".

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[2] http://www.citygmlwiki.org/index.php/CityGML_Energy_ADE
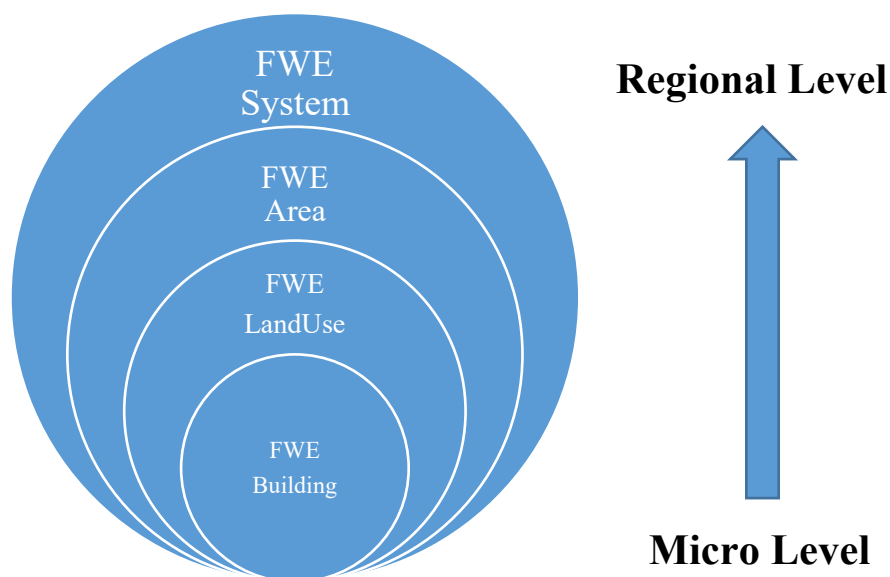[3] http://www.simstadt.eu/de/index.jsp

Figure 2: FWE ADE Thematic Module at different spatial level

FWEBuilding and FWELandUse extend the existing CityGML data model for building and LandUse by introducing new FWE and its nexus related properties and feature classes. FWEArea and FWESystem are the two new thematic modules that are newly introduced to store FWE and its nexus related data at the spatial level of political boundaries such as neighbourhoods/areas/zones scaling it up to the system boundary of the entire study area respectively. The two new thematic modules are introduced in the CityGML Core.

Newly defined FWEArea object is defined as a city object having multisurface geometry covering the entire study area. It can be that neighbourhood boundaries, zonal boundaries, municipality boundaries, or political boundaries that are typically static do not change with time. Based on the underlying FWEBuilding and FWELandUse, FWE and its nexus related properties and temporal changes of population and LandUse change are summarised and introduced at this spatial level. Additionally, properties that naturally belong only at FWEArea level or datasets of certain FWE and its nexus properties available at FWEArea level are introduced here. Like FWEArea, FWESystem is also defined as a city object having multisurface covering the entire study area. Extending FWEArea up by a spatial level, FWESystem covers entire system boundary of the study area which can be borough, city or even an entire district. These boundaries are also static and typically do not change with time. Since FWE ADE is an integrated data model of different spatial levels, for any given time and use case, data related to population properties, FWE and its nexus can easily be scaled up or down from a taken spatial level using data inter or extrapolation.
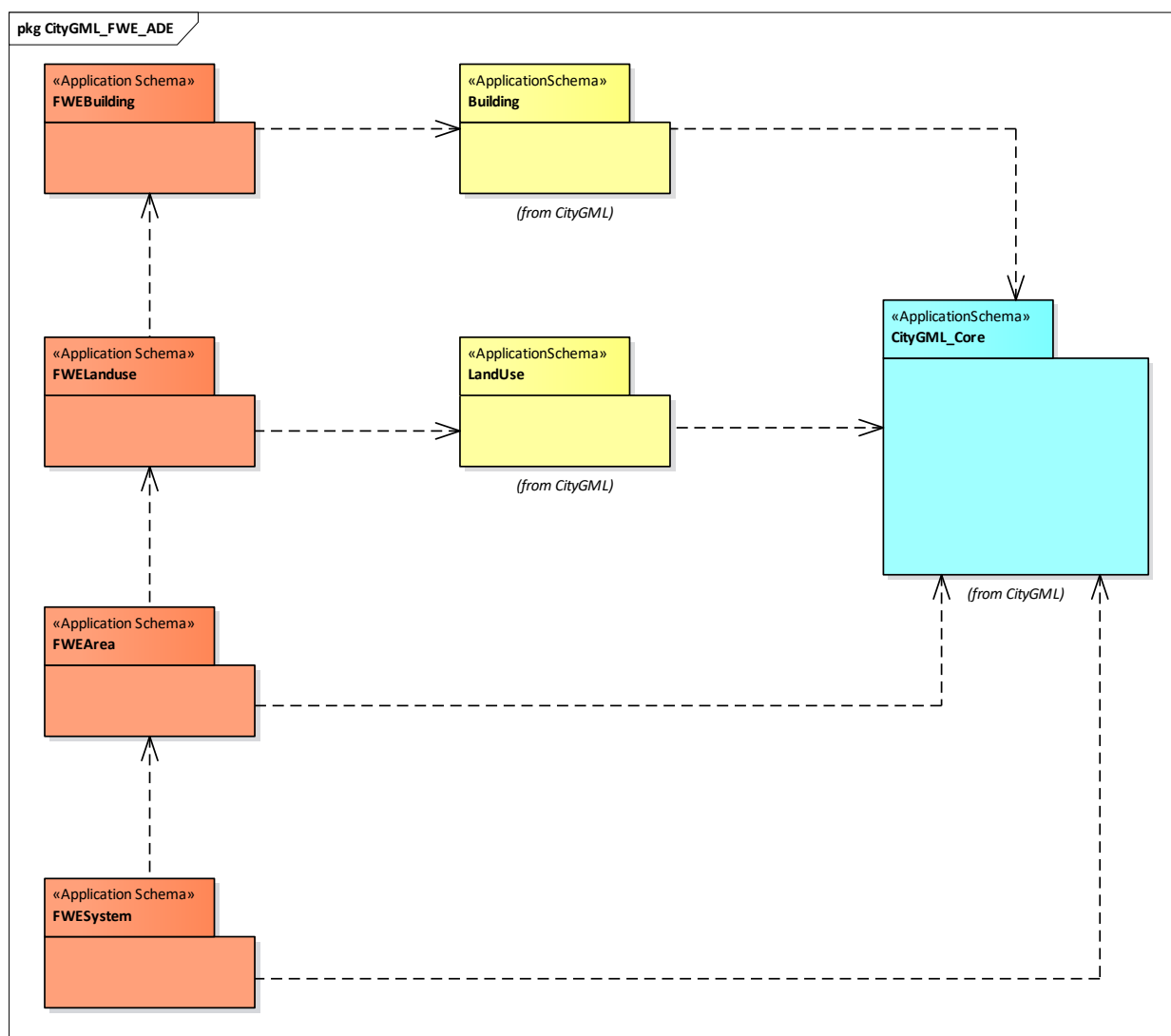
Figure 3: A UML package diagram showing dependencies for FWE ADE

(FWE ADE modules (orange) dependent on CityGML modules (yellow) and CityGML core (blue))

The FWE ADE deems to act as a data interchange format for workflows in the FWE domain. An example of one such data interchange process describing SimStadt's biomass potential workflow with the FWE ADE is explained in the appendix at the end of this document.

Within IN-SOURCE, FWE ADE will be applied to the case study regions of Gowanus (Neighborhood in NYC) / Brooklyn (Borough in NYC), Vienna (City in Austria) and Landkreis Ludwigsburg (District in Germany). A few case study regions related geospatial that will be used along with FWE ADE can be found from:

Gowanus:

CityGML Building/Existing - https://www.dropbox.com/home/IN-SOURCE-Gowanus%20Project/Gowanus_Site_Info/2019/CityGML

CityGML Building/BAU2050 - https://www.dropbox.com/home/IN-SOURCE-Gowanus%20Project/Gowanus_Site_Info/2050_BAU/CityGML

CityGML Building/BP2050 - https://www.dropbox.com/home/IN-SOURCE-Gowanus%20Project/Gowanus_Site_Info/2050_BP/CityGML

LandUse Shapefile/ Existing – DoITT/ZoLa (URL will be available soon)

Admin Boundaries Shapefile - DoITT/ZoLa (URL will be available soon)

System Boundary Shapefile - https://www.dropbox.com/home/IN-SOURCE-Gowanus%20Project/Gowanus_Site_Info/2019?preview=Gowanus_Border_EPSG32118.zip

Brooklyn:

CityGML Building/Existing - https://www.lrg.tum.de/gis/projekte/new-york-city-3d/

LandUse Shapefile/Existing – DoITT/ZoLa (URL will be available soon)

Admin Boundaries Shapefile – DoITT/ZoLa (URL will be available soon)

System Boundary Shapefile – DoITT/ZoLa (URL will be available soon)

Vienna:

CityGML Building/Existing - https://www.wien.gv.at/ma41datenviewer/public/start.aspx

LandUse Shapefile/Existing - https://www.data.gv.at/katalog/dataset/stadt-wien_realnutzungskartierungab200708wien/resource/e644d5b3-7d03-4c7e-b4f2-8204e80b4bc1

Admin Boundaries Shapefile - https://www.data.gv.at/katalog/dataset/stadt-wien_bezirksgrenzenwien

System Boundary Shapefile - https://www.data.gv.at/katalog/dataset/stadt-wien_bezirksgrenzenwien

Landkreis Ludwigsburg:

CityGML Building/Existing - https://www.lgl-bw.de/unsere-themen/Produkte/Geodaten/3D-Gebaeudemodelle/

LandUse Shapefile/Existing - https://www.lgl-bw.de/unsere-themen/Produkte/Geodaten/Digitale-Landschaftsmodelle/

Admin Boundaries Shapefile - https://www.lgl-bw.de/unsere-themen/Produkte/Geodaten/Verwaltungsgrenzen/

System Boundary Shapefile - https://www.lgl-bw.de/unsere-themen/Produkte/Geodaten/Verwaltungsgrenzen/

FWE ADE

A. FWEBuilding – An extension to CityGML Building

The FWEBuilding module of FWE ADE extends the CityGML thematic module of Building with FWE and its nexus related properties. A data model to store semantic georeferenced 3D building geometries and its properties are already available in the data encoding standards for CityGML. From the existing data model, a particular focus is drawn to the properties: "class", "function" and "usage" of feature "_AbstractBuilding" which represents an abstract class of CityGML Building. These properties categorise individual buildings based on building typologies. For the properties: class and function, case study region specific codelist are developed, for the property: usage, a common codelist is adopted for all the case study regions. Codelist of property: usage is based on food-related activities of an individual building (production, consumption and/or distribution) and is derived from the property: function.

Based on these pre-existing properties, the CityGML Building data model is extended further to store FWE and its nexus related domain-specific properties for buildings. A UML diagram for FWEBuilding showing the extended properties of CityGML Building is shown below in figure 4.

As per figure 4, the existing CityGML feature of _AbstractBuilding is extended with additional properties stereotyped as "ADEElement". Stereotype ADEElement is used to distinguish the newly introduced additional properties against the existing properties of _AbstractBuilding. This feature type is further composed with a new feature type "BuildingSurvey" defined as a property: "consistsofFWEsurvey" of the ADEElement _AbstractBuilding. BuildingSurvey is used as a cover term to store all the FWE and its nexus related properties in the CityGML Building. Since a building can be surveyed at different year intervals or not surveyed at all, a multiplicity of zero to many [0...*] is defined between _AbstractBuilding and BuildingSurvey. For each year interval, BuildingSurvey is composed of multiple "FoodSurvey" feature type based on its property of "foodCategory", a "WaterSurvey" feature type and an "EnergySurvey" feature type, each defined as properties of "foodSurvey", "waterSurvey" and "energySurvey" respectively in BuildingSurvey. FoodSurvey, WaterSurvey and EnergySurvey, along with other properties of BuildingSurvey, inherits the property of population and surveyYear from BuildingSurvey. For any individual CityGML building, property:surveyYear enables FWE ADE to store FWE and its nexus related properties for building in different year intervals, including population change.

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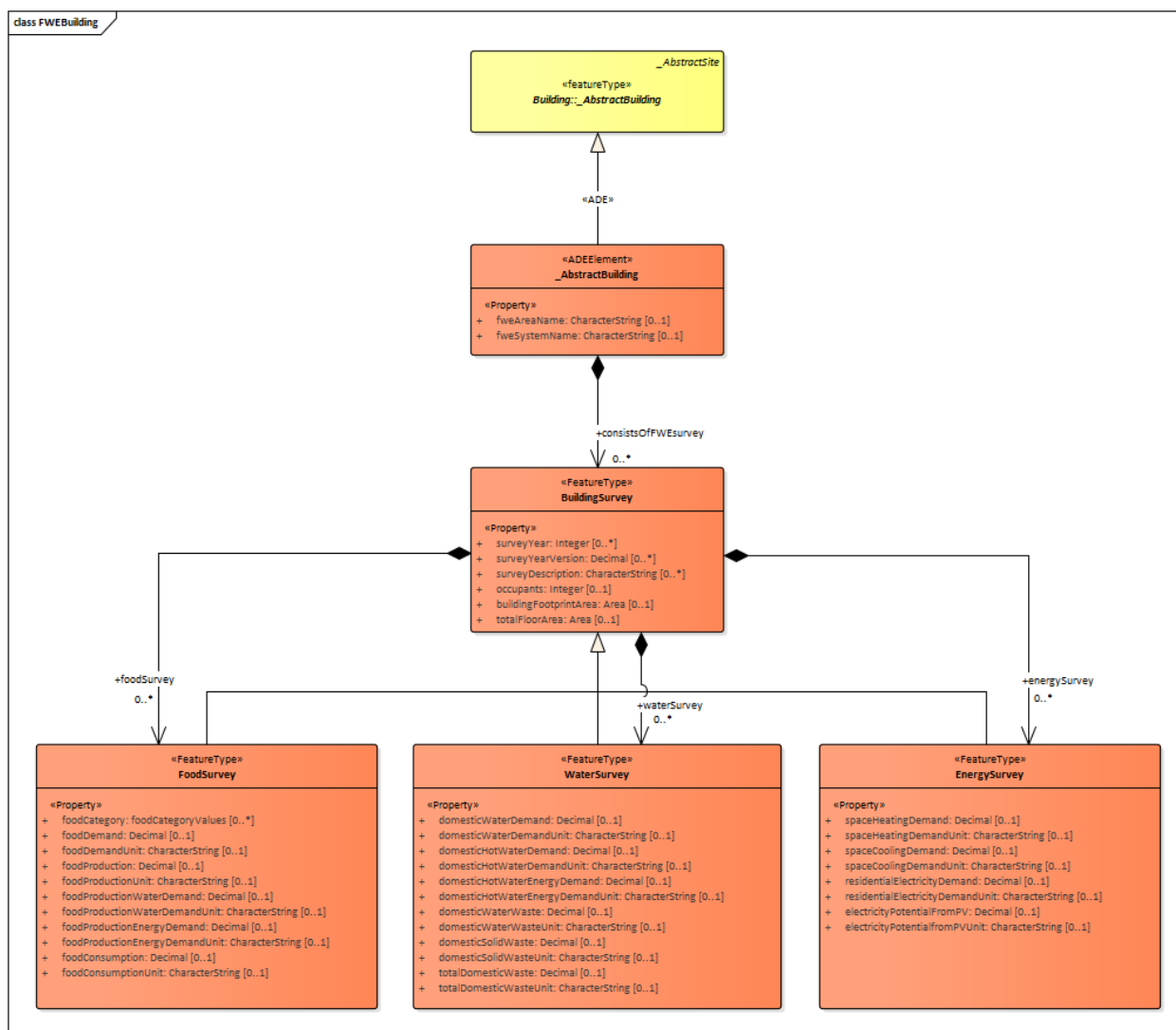
Figure 4: A UML class diagram for FWEBuilding module of FWE ADE

(yellow box is an existing module of CityGML core, orange boxes are designed as part of the FWE ADE)

A complete list of "FWEBuilding" properties along with its description and code list is available as below:

ADEElement: _AbstractBuilding

Property	Description	Data Type	Multiplicity	Possible Data Source
fweAreaName	the name of the belonging FWEArea	string	0..1	user-defined based on overlying FWEArea
fweSystemName	the name of the belonging FWESystem	string	0..1	user-defined based on overlying FWESystem

FeatureType: BuildingSurvey

Property	Description	Data Type	Multiplicity	Possible Data Source
surveyYear	survey year	integer	0..*	user-defined
surveyYearVersion	for survey scenarios belonging to the same survey year (e.g. 2020 existing scenario, 2020 business as usual scenario, 2020 best practice scenario)	double	0..*	user-defined
surveyDescription	user description for survey	string	0..*	user defined
occupants	building population	integer	0..1	census/SimStadt
buildingFootprintArea	building footprint area	double	0..1	SimStadt
totalFloorArea	the total floor area of a building	double	0..1	SimStadt

FeatureType: FoodSurvey

Property	Description	Data Type	Multiplicity	Possible Data Source
foodCategory	list of food categories	codelist	0..*	GIS/literature survey
foodDemand	food demand according to foodCategory in a building	double	0..1	literature survey/estimation based on building population
foodDemandUnit	measuring unit for foodDemand	string	0..1	literature survey
foodProduction	food production according to foodCategory in a building	double	0..1	literature survey/estimation based on building population
foodProductionUnit	measuring unit for foodProduction	string	0..1	literature survey
foodProductionWaterDemand	water demand to grow/process foodCategory in a building	double	0..1	literature survey/estimation based on building population
foodProductionWaterDemandUnit	measuring unit for foodProductionWaterDemand	string	0..1	literature survey
foodProductionEnergyDemand	energy demand to grow/process foodCategory in a building	double	0..1	literature survey/estimation based on building population
foodProductionEnergyDemandUnit	measuring unit for foodProductionEnergyDemand	string	0..1	literature survey

foodConsumption	food consumption according to foodCategory in a building	double	0..1	literature survey/estimation based on building population
foodConsumptionUnit	measuring unit for foodConsumption	string	0..1	literature survey

FeatureType: WaterSurvey

Property	Description	Data Type	Multiplicity	Possible Data Source
domestic Water Demand	the amount of water required for domestic use (includes all building functions) in a building	double	0..1	literature survey/estimation based on building population
domestic Water DemandUnit	measuring unit for domesticWaterDemand	string	0..1	literature survey
domesticHot Water Demand	the amount of hot water required for domestic use (includes all building functions) in a building	double	0..1	literature survey/estimation based on building population
domesticHot Water Demand Unit	measuring unit for domesticHotWater Demand	string	0..1	literature survey
domesticHot WaterEnergy Demand	the energy required for producing hot water for domestic use (includes all building functions)	double	0..1	SimStadt
domesticHot WaterEnergy Demand Unit	measuring unit for domesticHotWaterEnergy Demand	string	0..1	SimStadt
domestic WasteWater	the amount of domestic waste water produced (includes all building functions)	double	0..1	literature survey/estimation based on building population
domesticWaste WaterUnit	measuring unit for domesticWasteWater	string	0..1	literature survey
domestic Solid Waste	the amount of domestic solid waste produced (includes all building functions)	double	0..1	literature survey/estimation based on building population
domestic Solid WasteUnit	measuring unit for domesticSolidWaste	string	0..1	literature survey
totalDomestic Waste	the amount of total domestic waste produced (includes all building functions)	double	0..1	domesticWasteWater+domestic SolidWaste - GIS
totalDomestic WasteUnit	measuring unit for totalDomesticWaste	string	0..1	literature survey

FeatureType: EnergySurvey

Property	Description	DataType	Multiplicity	Possible Data Source
spaceHeatingDemand	the total space heating demand of a building (includes all building functions)	double	0..1	SimStadt
spaceHeatingDemandUnit	measuring unit for spaceHeatingDemand	string	0..1	SimStadt
spaceCoolingDemand	the total space cooling demand of a building (includes all building functions)	double	0..1	SimStadt
spaceCoolingDemandUnit	measuring unit for spaceCoolingDemand	string	0..1	SimStadt
residentialElectricity Demand	electricity demand if residential building	double	0..1	SimStadt
residentialElectricity Demand Unit	measuring unit for residentialElectricity Demand	string	0..1	SimStadt
electricityPotentialFromPV	the total electricity potential from PV panels installed in a building (includes all building functions)	double	0..1	SimStadt
electricityPotentialFromPV Unit	measuring unit for electricityPotentialFromPV	string	0..1	SimStadt

CodeList: Class (CityGML Building: _AbstractBuilding) for Ludwigsburg

ID	Description
31001	Gebaeude
51001	Turm
51002	Bauwerk oder Anlage für Industrie und Gewerbe
51003	Vorratsbehälter, Speicherbauwerk
51006	Bauwerk oder Anlage für Sport, Freizeit und Erholung
51007	Historisches Bauwerk oder historische Einrichtung
51009	Sonstiges Bauwerk oder sonstige Einrichtung

CodeList: Function (CityGML Building: _AbstractBuilding) for Ludwigsburg

http://www.citygmlwiki.org/images/7/7f/BuildingFunctionTypeAdV-trans.xml (ALKIS)

CodeList: Class (CityGML Building: _AbstractBuilding) for Vienna

http://www.sig3d.org/codelists/citygml/2.0/building/2.0/_AbstractBuilding_function.xml

CodeList: Function (CityGML Building: _AbstractBuilding) for Vienna

http://www.sig3d.org/codelists/citygml/2.0/building/2.0/_AbstractBuilding_function.xml

CodeList: Class (CityGML Building: _AbstractBuilding) for New York City

https://www1.nyc.gov/assets/planning/download/pdf/data-maps/open-data/pluto_datadictionary.pdf?r=20v2 (PLUTO Data Dictionary – Pg. C1-C4)

CodeList: Function (CityGML Building: _AbstractBuilding) for New York City

https://www1.nyc.gov/assets/planning/download/pdf/data-maps/open-data/pluto_datadictionary.pdf?r=20v2 (PLUTO Data Dictionary – Pg. C1-C4)

CodeList: Usage (CityGML Building: _AbstractBuilding) - Common

ID	Description
1000	Food production building
1010	Food distribution building
1020	Food consumer building
1030	Food production+distribution building
1040	Food distribution+consumer building
1050	Food production+consumer building
1060	Food production+distribution+consumer building

CodeList: foodCategory (FWEBuilding: FoodSurvey) - Common

ID	Description
1000	Cereals
1010	Vegetables, Pulses and Roots
1020	Fruits and Nuts
1030	Vegetable Oil and Oilseeds
1040	Sugar and other sweeteners
1050	Stimulants (coffee, tea, spices, chocolate)
1060	Meats
1070	Dairy
1080	Poultry and Eggs
1090	Fish and other aquatic products

Location details of FWEBuilding XML schema file are as below:

UML Diagram	https://transfer.hft-stuttgart.de/pages/fwe-ade/FWEBuilding/v2.1/UML/
XSD location	https://transfer.hft-stuttgart.de/pages/fwe-ade/FWEBuilding/v2.1/XSD/FWEBuilding.xsd
Recommended namespace prefix	FWEB

Some web 3D visualisation example of FWEBuilding module using OGC 3D tiles[4] standard and CesiumJS[5] are shown below:

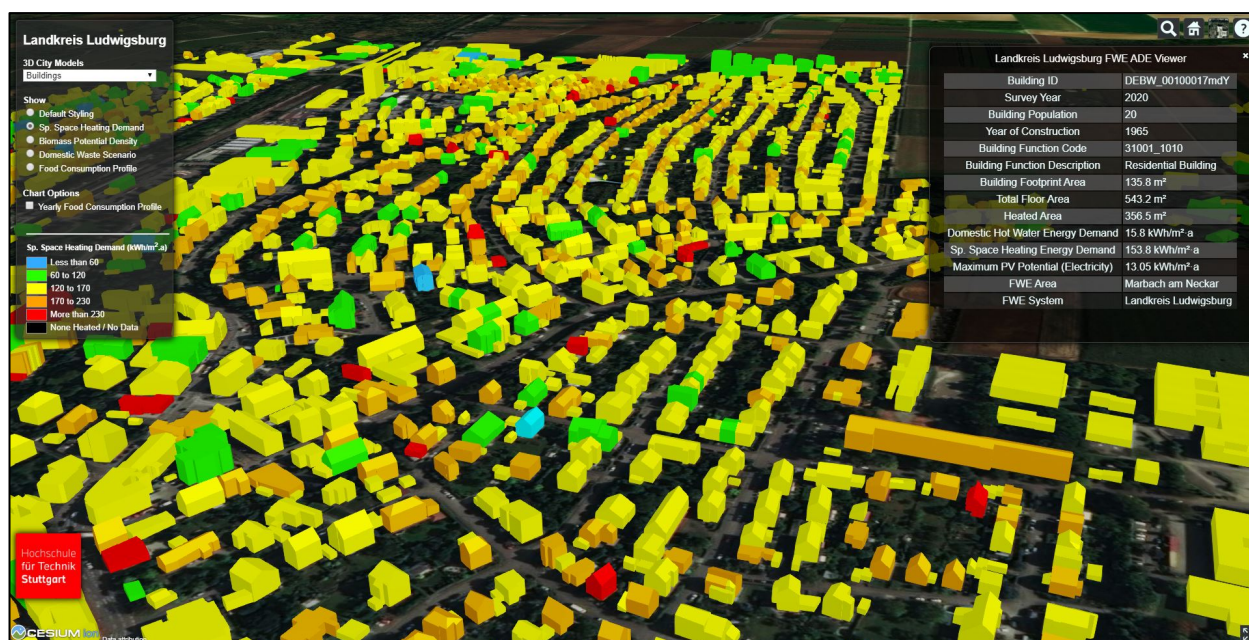Figure 5: The CityGML Building model of Marbach (Landkreis Ludwigsburg)

Figure 6: Visualisation of Marbach's space heating demand using its CityGML Building model

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[4] https://www.ogc.org/standards/3DTiles
[5] https://cesium.com/cesiumjs/

B. FWELandUse – An extension to CityGML LandUse

The FWELandUse module of FWE ADE extends the CityGML thematic module of LandUse with FWE and its nexus related properties. A data model to store semantic georeferenced landuse geometries and its properties are already available in the data encoding standards for CityGML. From the existing data model, a particular focus is drawn to the properties: "class", "function" and "usage" of feature "LandUse". These properties categorise individual landuse polygons based on landuse typologies. For the property: class, a common codelist across all the case study region is adopted. For the property: function and use, case study region specific codelist are developed.

Based on these pre-existing properties, the CityGML LandUse data model is extended further to store FWE and its nexus related domain-specific properties for landuse. A UML diagram for FWELandUse showing the extended properties of CityGML LandUse is shown below in figure 5.

As per figure 7, the existing CityGML feature of LandUse is extended with additional properties stereotyped as "ADEElement". Stereotype ADEElement is used to distinguish the newly introduced additional properties against the existing properties of LandUse. This feature type is further composed with a new feature type "LandUseSurvey" defined as a property: "consistsofFWEsurvey" of the ADEElement LandUse. LandUseSurvey is used as a cover term to store all the FWE and its nexus related properties in the CityGML LandUse. Since landuse can be surveyed at different year intervals or not at all, a multiplicity of zero to many [0...*] is defined between LandUse and LandUseSurvey. For each year interval, LandUseSurvey is composed of multiple "FoodSurvey" feature type based on its property of "foodCategory", a "WaterSurvey" feature type and an "EnergySurvey" feature type, each defined as properties of "foodSurvey", "waterSurvey" and "energySurvey" respectively in LandUseSurvey. FoodSurvey, WaterSurvey and EnergySurvey, along with other properties of LandUseSurvey, inherits the property of population and surveyYear from LandUseSurvey. For any individual CityGML LandUse polygon, property:surveyYear enables FWE ADE to store FWE and its nexus related properties for landuse in different year intervals, including population change.
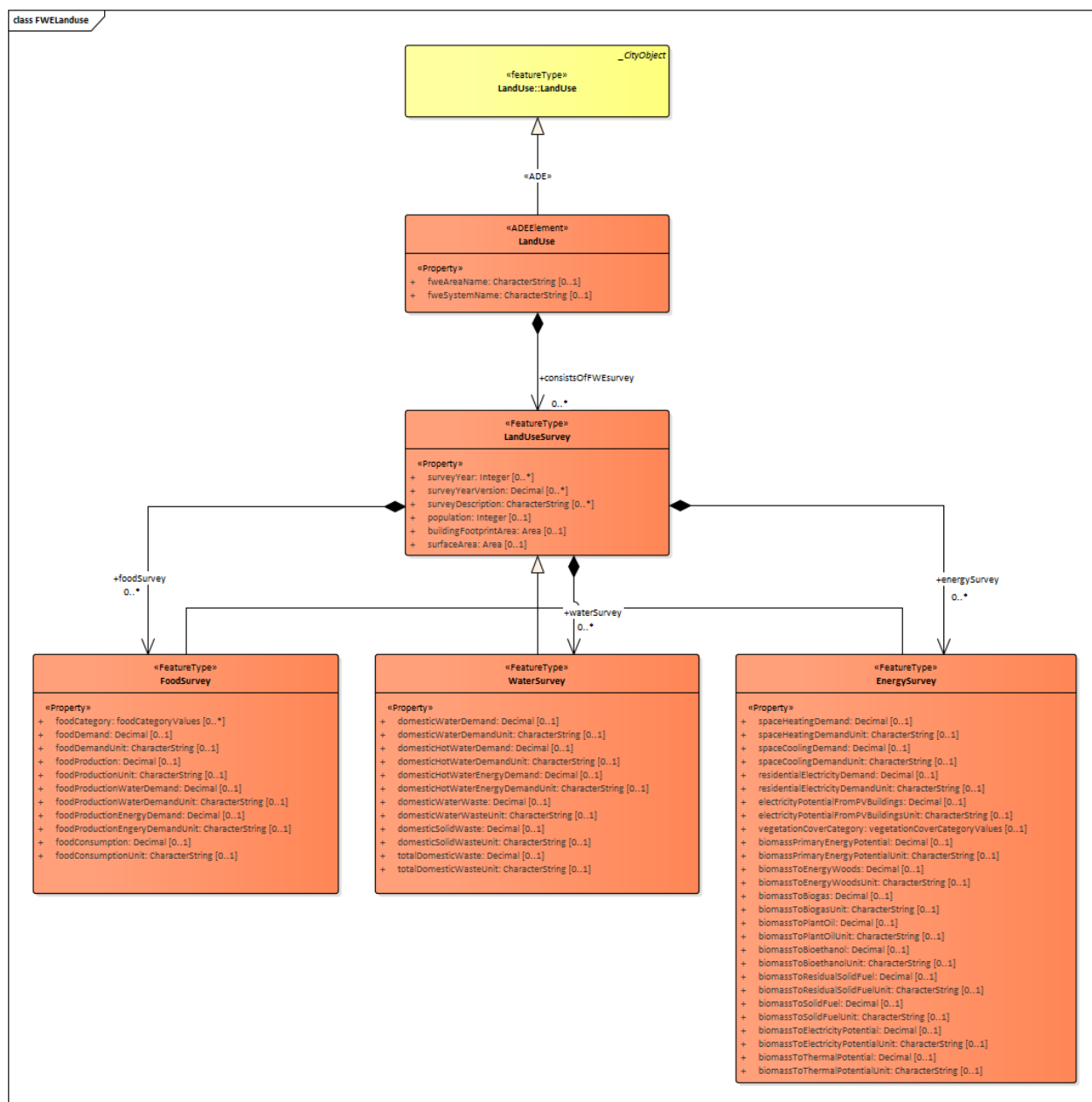
Figure 7: A UML class diagram for FWELandUse module of FWE ADE

(yellow box is an existing module of CityGML core, orange boxes are designed as part of the FWE ADE)

A complete list of "FWELandUse" properties along with its description and code list is available as below:

ADEElement: LandUse

Property	Description	Data Type	Multiplicity	Possible Data Source
fweAreaName	the name of the belonging FWEArea	string	0..1	user-defined based on overlying FWEArea

fweSystemName	the name of the belonging FWESystem	string	0..1	user-defined based on overlying FWESystem

FeatureType: LandUseSurvey

Property	Description	Data Type	Multiplicity	Possible Data Source
surveyYear	survey year	integer	0..*	user-defined
surveyYearVersion	for survey scenarios belonging to the same survey year (e.g. 2020 existing scenario, 2020 business as usual scenario, 2020 best practice scenario)	double	0..*	user-defined
surveyDescription	user description for survey	string	0..*	user defined
population	the total population covered by a landuse polygon based on the overlying FWEBuilding or deriving it from overlying FWEArea	integer	0..1	census/GIS
buildingFootprintArea	the total building footprint area covered by a landuse polygon based on the overlying FWEBuilding	double	0..1	GIS
surfaceArea	landuse polygon area	double	0..1	FME

FeatureType: FoodSurvey

Property	Description	Data Type	Multiplicity	Possible Data Source
foodCategory	list of food categories	codelist	0..*	GIS/literature survey
foodDemand	the total food demand for individual food categories covered by a landuse polygon based on overlying FWEBuilding or deriving it from the overlying FWEArea	double	0..1	literature survey/estimation based on landuse population/GIS

foodDemandUnit	measuring unit for foodDemand	string	0..1	literature survey
foodProduction	the total food production for individual food categories covered by a landuse polygon + total food production from overlying FWEBuilding or deriving it from the overlying FWEArea	double	0..1	literature survey/estimation based on landuse population/GIS
foodProductionUnit	measuring unit for foodProduction	string	0..1	literature survey
foodProductionWater Demand	the total food production water demand of individual food categories covered by a landuse polygon + total food production water demand from overlying FWEBuilding or deriving it from the overlying FWEArea	double	0..1	literature survey/estimation based on landuse population/GIS
foodProductionWater DemandUnit	measuring unit for foodProductionWater Demand	string	0..1	literature survey
foodProductionEnergy Demand	the total food production energy demand of individual food categories covered by a landuse polygon + total food production energy demand from overlying FWEBuilding or deriving it from the overlying FWEArea	double	0..1	literature survey/estimation based on landuse population/GIS
foodProductionEnergy DemandUnit	measuring unit for foodProductionEnergy Demand	string	0..1	literature survey
foodConsumption	the total food consumption per individual food categories of buildings covered by a landuse polygon based on overlying FWEBuilding or deriving it from the overlying FWEArea	double	0..1	literature survey/estimation based on landuse population/GIS
foodConsumptionUnit	measuring unit for foodConsumption	string	0..1	literature survey

FeatureType: WaterSurvey

Property	Description	Data Type	Multiplicity	Possible Data Source
domestic Water Demand	the total domestic water demand of buildings covered by a landuse polygon based on overlying FWEBuilding or deriving it from the overlying FWEArea (includes all building functions)	double	0..1	literature survey/estimation based on landuse population/GIS
domestic Water DemandUnit	measuring unit for domesticWaterDemand	string	0..1	literature survey
domesticHot Water Demand	the total domestic hot water of buildings demand covered by a landuse polygon based on overlying FWEBuilding or deriving it from the overlying FWEArea (includes all building functions)	double	0..1	literature survey/estimation based on landuse population/GIS
domesticHot Water Demand Unit	measuring unit for domesticHotWater Demand	string	0..1	literature survey
domesticHot WaterEnergy Demand	the total domestic hot water energy demand of buildings covered by a landuse polygon based on overlying FWEBuilding or deriving it from the overlying FWEArea (includes all building functions)	double	0..1	GIS
domesticHot WaterEnergy Demand Unit	measuring unit for domesticHotWaterEnergy Demand	string	0..1	GIS
domestic WasteWater	the total domestic waste water demand of buildings covered by a landuse polygon based on overlying FWEBuilding or deriving it from the overlying FWEArea (includes all building functions)	double	0..1	literature survey/estimation based on landuse population/GIS
domesticWaste WaterUnit	measuring unit for domesticWasteWater	string	0..1	literature survey
domestic Solid Waste	the total domestic solid waste of buildings covered by a landuse polygon based on overlying FWEBuilding or deriving it from the overlying FWEArea (includes all building functions)	double	0..1	literature survey/estimation based on landuse population/GIS
domestic Solid WasteUnit	measuring unit for domesticSolidWaste	string	0..1	literature survey

	the total domestic waste of buildings covered by a landuse polygon based on overlying FWEBuilding or deriving it from the overlying FWEArea (includes all building functions)	double	0..1	literature survey/estimation based on landuse population/GIS
totalDomestic Waste				
totalDomestic WasteUnit	measuring unit for totalDomesticWaste	string	0..1	literature survey

FeatureType: EnergySurvey

Property	Description	DataType	Multiplicity	Possible Data Source
spaceHeatingDemand	the total space heating demand of buildings covered by landuse polygon (includes all building functions) based on overlying FWEBuilding	double	0..1	GIS
spaceHeatingDemandUnit	measuring unit for spaceHeatingDemand	string	0..1	GIS
spaceCoolingDemand	the total space cooling demand of buildings covered by landuse polygon (includes all building functions) based on overlying FWEBuilding	double	0..1	GIS
spaceCoolingDemandUnit	measuring unit for spaceCoolingDemand	string	0..1	GIS
residentialElectricity Demand	the total electricity demand of residential buildings covered by landuse polygon based on overlying FWEBuilding	double	0..1	GIS
residentialElectricity Demand Unit	measuring unit for residentialElectricity Demand	string	0..1	GIS
electricityPotentialFromPV Buildings	the total PV (electric) potential from buildings covered by landuse polygon (includes all building functions) based on overlying FWEBuilding	double	0..1	GIS
electricityPotentialFromPV Buildings Unit	measuring unit for electricityPotentialFrom PV Buildings	string	0..1	GIS
vegetationCoverCategory	land cover category for landuse code: 4000	CodeList	0..1	GIS/ Satellite LandCover map
biomassPrimaryEnergy Potential	primary biomass energy potential before converting to a secondary energy carrier	double	0..1	SimStadt

biomassPrimaryEnergy Potential Unit	measuring unit for biomassPrimaryEnergy Potential	string	0..1	SimStadt
biomassToEnergyWoods	the amount of biomass primary energy potential converted to energy woods	double	0..1	SimStadt
biomassToEnergyWoods Unit	measuring unit for biomassToEnergyWoods	string	0..1	SimStadt
biomassToBiogas	the amount of biomass primary energy potential converted to biogas	double	0..1	SimStadt
biomassToBiogasUnit	measuring unit for biomassToBiogas	string	0..1	SimStadt
biomassToPlantOil	the amount of biomass primary energy potential converted to plant oil	double	0..1	SimStadt
biomassToPlantOilUnit	measuring unit for biomassToPlantOil	string	0..1	SimStadt
biomassToBioethanol	the amount of biomass primary energy potential converted to bioethanol	double	0..1	SimStadt
biomassToBioethanolUnit	measuring unit for biomassToBioethanol	string	0..1	SimStadt
biomassToResidualSolid Fuel	the amount of biomass primary energy potential converted to residual solid fuel	double	0..1	SimStadt
biomassToResidualSolid Fuel Unit	measuring unit for biomassToResidualSolidFuel	string	0..1	SimStadt
biomassToSolidFuel	the amount of biomass primary energy potential converted to solid fuel	double	0..1	SimStadt
biomassToSolidFuelUnit	measuring unit for biomassToSolidFuel	string	0..1	SimStadt
biomassToElectricity Potential	the amount of biomass primary energy potential converted to electricity potential	double	0..1	SimStadt
biomassToElectricity Potential Unit	measuring unit for biomassToElectricityPotential	string	0..1	SimStadt
biomassToThermal Potential	the amount of biomass primary energy potential converted to thermal potential	double	0..1	SimStadt
biomassToThermal Potential Unit	measuring unit for biomassToThermalPotential	string	0..1	SimStadt

CodeList: Class (CityGML LandUse: LandUse) - Common

ID	Description
1000	Settlement Area
2000	Open/Vacant Plots
3000	Traffic Area
4000	Vegetation
5000	Water Body

CodeList: Function (CityGML LandUse: LandUse) for Ludwigsburg

https://sg.geodatenzentrum.de/web_public/gdz/dokumentation/deu/ATKIS-OK%20Basis-DLM%206_0.pdf (ALKIS)

CodeList: Usage (CityGML LandUse: LandUse) for Ludwigsburg

https://sg.geodatenzentrum.de/web_public/gdz/dokumentation/deu/ATKIS-OK%20Basis-DLM%206_0.pdf (ALKIS)

CodeList: Function (CityGML LandUse: LandUse) for Vienna

ID	Description
1000_1001	Wohn- u. Mischnutzung (Schwerpunkt Wohnen)
1000_1002	Geschäfts-, Kern- und Mischnutzung (Schwerpunkt betriebliche Tätlgkeit)
1000_1003	Industrie- und Gewerbenutzung
1000_1004	Soziale Infrastruktur
1000_1005	Technische Infrastruktur/Kunstbauten/Sondernutzung
2000_2001	Erholungs- und Freizeltelnrichtugen
3000_3001	Verkehr
4000_4001	Landwirtschaft
4000_4002	Naturraum
5000_5001	Gewässer inkl. Bachbett

CodeList: Usage (CityGML LandUse: LandUse) for Vienna

ID	Description
1000_1001_1	Locker bebautes wohn(misch)geblet
1000_1001_2	Gartenstadt
1000_1001_3	Dichtes wohn(misch)geblet
1000_1001_4	Großvolumlger soltärer wohn(misch)bau
1000_1002_1	Büro- und Verwaltungsvlertel
1000_1002_2	Solitäre Handeisstrukturen
1000_1002_3	Geschäfts-, Kern- und Mischgeblet
1000_1002_4	Mischnutzung wenig dicht / alter Ortskern
1000_1003_1	Industrie, prod. Gewerbe, Großhandel Inkl. Lager
1000_1004_1	Kultur Freizelt, Religion, Messe
1000_1004_2	Gesundhelt und Einsatzorganisationen
1000_1004_3	Bildung
1000_1004_4	Sport und Bad (Indoor)
1000_1005_1	Miltärische Anlagen
1000_1005_2	Klaraniage, Deponie
1000_1005_3	Energieversorgung, Rundfunkanlagen
1000_1005_4	Wasserversorgung
1000_1005_5	Transformationsfläche, Baustelle, Martertalgew
2000_2001_1	Park, Grünaniage
2000_2001_2	Sport und Bad (Outdoor), Camping
2000_2001_3	Friedhof
3000_3001_1	Verkehr
4000_4001_1	Acker

4000_4001_2	Weingarten
4000_4001_3	Gärtnerel, Obstplantagen
4000_4002_1	Wald
4000_4002_2	Wiese
5000_5001_1	Gewässer inkl. Bachbett

CodeList: Function (CityGML LandUse: LandUse) for New York City

https://www1.nyc.gov/assets/planning/download/pdf/data-maps/open-data/pluto_datadictionary.pdf?r=20v2 (PLUTO Data Dictionary – Pg. D1)

CodeList: Usage (CityGML LandUse: LandUse) for New York City

https://www1.nyc.gov/assets/planning/download/pdf/data-maps/open-data/pluto_datadictionary.pdf?r=20v2 (PLUTO Data Dictionary – Pg. D1)

CodeList: foodCategory (FWELandUse: FoodSurvey) - Common

Same as CodeList: foodCategory (FWEBuilding: FoodSurvey) – Pg. 19

CodeList: vegetationCoverCategory (FWELandUse: EnergySurvey) for Ludwigsburg

Based on https://doi.pangaea.de/10.1594/PANGAEA.893195 (Griffiths et al., 2018)

ID	Description
1001	Grassland
1002	Winter Cereals
1003	Maise
1004	Winter Rapeseed
1005	Spring Cereals
1006	Sugar Beet
1007	Potato
1008	Grapevine
1009	Deciduous Mixed Forest
1010	Coniferous Forest

Location details of FWELandUse XML schema file are as below:

UML Diagram	https://transfer.hft-stuttgart.de/pages/fwe-ade/FWELanduse/v2.1/UML/
XSD location	https://transfer.hft-stuttgart.de/pages/fwe-ade/FWELanduse/v2.1/XSD/FWELanduse.xsd
Recommended namespace prefix	FWEL

Some web 3D visualisation example of FWELandUse module using OGC 3D tiles standard and CesiumJS are shown below:

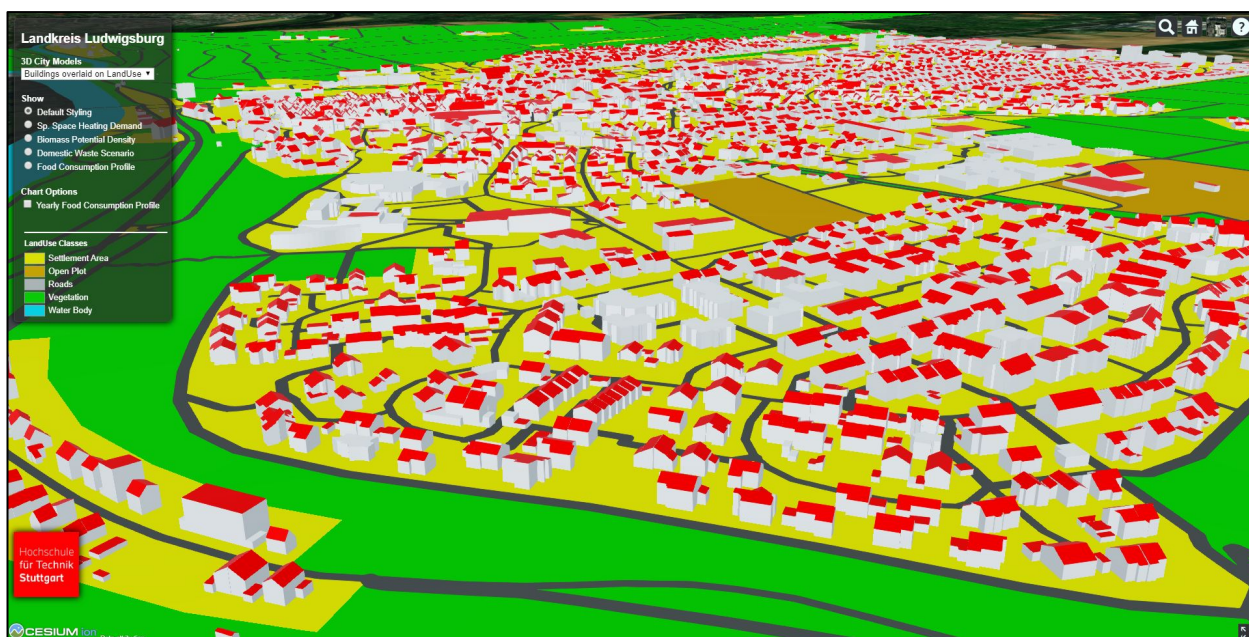Figure 8: The CityGML LandUse model of Marbach

Figure 9: The CityGML Building model of Marbach are overlaid on its CityGML LandUse model

C. FWEArea – An extension to CityGML Core

The FWEArea module of FWE ADE is a new module in the CityGML core.
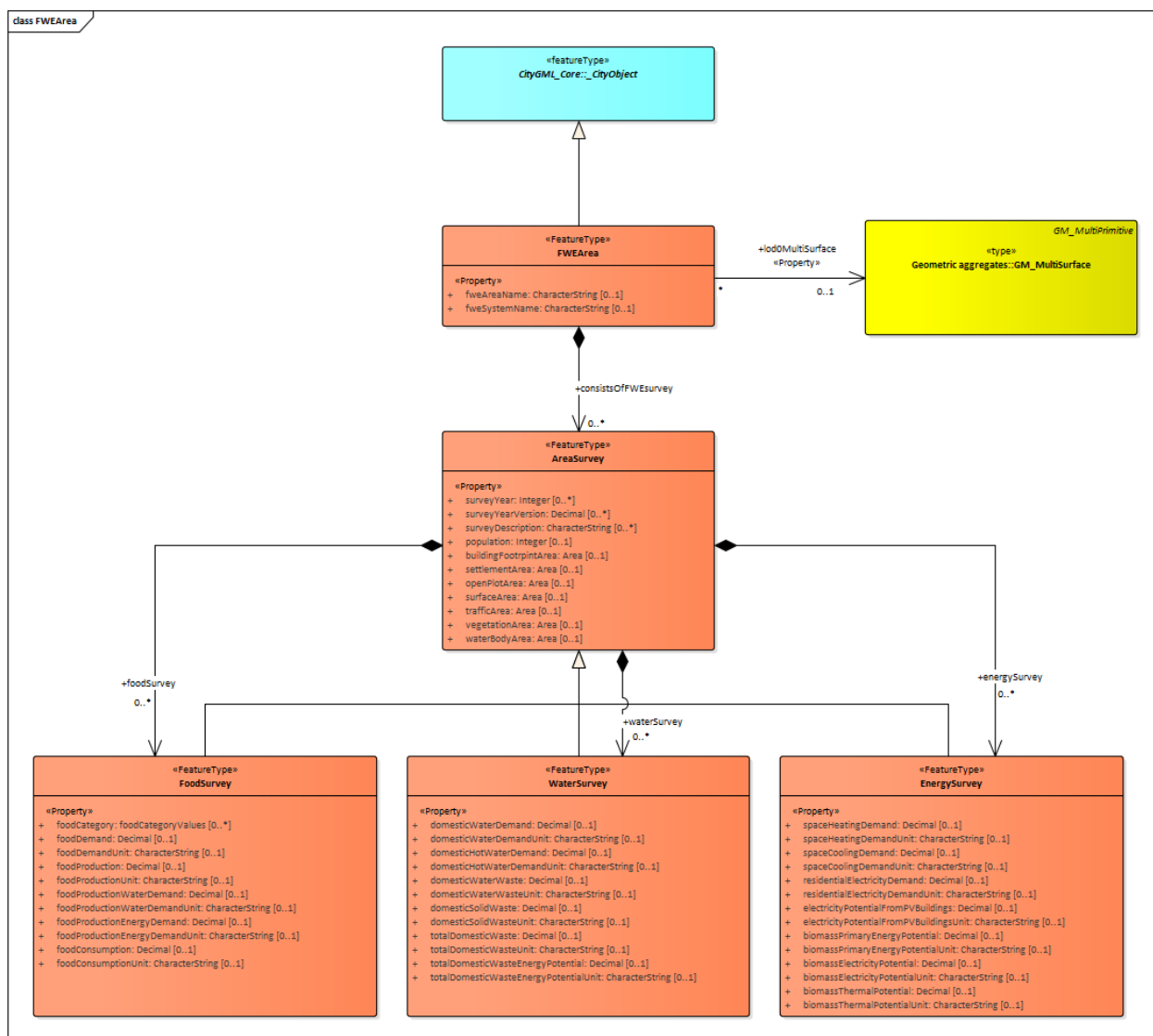
Figure 10: A UML class diagram for FWEArea module of FWE ADE

(blue box shows CityGML core, orange boxes are designed as part of the FWE ADE)

As shown in figure 10, FWEArea feature type (from hereby called as areas) is defined as a city object having multisurface geometry. This geometry represents the political boundaries covering the entire study area, which are usually static and do not change over time. Few examples of FWEArea geometries can be neighbourhood boundaries of Brooklyn, district boundaries of Vienna or town/municipality boundaries of Landkreis Ludwigsburg.

This feature type is then further composed with a new feature type "AreaSurvey" defined as a property: "consistsofFWEsurvey" of feature type FWEArea. AreaSurvey

is used as a cover term to store all the FWE and its nexus related properties in the CityGML FWEArea. Since areas can be surveyed at different year intervals or not at all, a multiplicity of zero to many [o...*] is defined between feature type FWEArea and AreaSurvey. For each year interval, AreaSurvey is composed of multiple "FoodSurvey" feature type based on its property of "foodCategory", a "WaterSurvey" feature type and an "EnergySurvey" feature type, each defined as properties of "foodSurvey", "waterSurvey" and "energySurvey" respectively in AreaSurvey. FoodSurvey, WaterSurvey and EnergySurvey, along with other properties of AreaSurvey, inherits the property of population and surveyYear from AreaSurvey. Property:surveyYear enables FWE ADE to store FWE and its nexus related properties of FWEArea in different year intervals, including population change. This is also of particular importance while analysing temporal landuse change patterns of an area. Along with property:SurveyYear of AreaSurvey, properties:settlementArea, openPlotArea, vegetationArea, waterBodyArea, trafficArea allows to store landuse change data for any given year interval.

A complete list of "FWEArea" properties along with its description and code list is available as below:

FeatureType: FWEArea

Property	Description	Data Type	Multiplicity	Possible Data Source
fweAreaName	the name of the belonging FWEArea	string	0..1	user-defined based on FWEArea
fweSystemName	the name of the belonging FWESystem	string	0..1	user-defined based on overlying FWESystem

FeatureType: AreaSurvey

Property	Description	Data Type	Multiplicity	Possible Data Source
surveyYear	survey year	integer	0..*	user-defined
surveyYearVersion	for survey scenarios belonging to the same survey year (e.g. 2020 existing scenario, 2020 business as usual scenario, 2020 best practice scenario)	double	0..*	user-defined
surveyDescription	user description for survey	string	0..*	user defined
population	the total population covered by FWEArea based on the underlying FWELandUse or deriving it from census	integer	0..1	census/GIS

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buildingFootprintArea	the total building footprint area based on the FWELandUse	double	0..1	GIS
settlementArea	the total settlement area based on the underlying FWELandUse class code: 1000	double	0..1	GIS
openPlotArea	the total open plot area based on the underlying FWELandUse class code: 2000	double	0..1	GIS
surfaceArea	polygon area of taken political boundaries	double	0..1	GIS
trafficArea	the total traffic area (incl. roads, railways) based on the underlying FWELandUse class code: 3000	double	0..1	GIS
vegetationArea	the total vegetation area based on the underlying FWELandUse class code: 4000	double	0..1	GIS
waterBodyArea	the total water body area based on the underlying FWELandUse class code: 5000	double	0..1	GIS

FeatureType: FoodSurvey

Property	Description	Data Type	Multiplicity	Possible Data Source
foodCategory	list of food categories	codelist	0..*	GIS/literature survey
foodDemand	the total food demand for individual food categories of an FWEArea based on underlying FWELandUse or deriving it from the overlying FWESystem	double	0..1	literature survey/estimation based on FWEArea population/GIS
foodDemandUnit	measuring unit for foodDemand	string	0..1	literature survey
foodProduction	the total food production for individual food categories of an FWEArea based on underlying FWELandUse or deriving it from the overlying FWESystem	double	0..1	literature survey/estimation based on FWEArea population/GIS
foodProductionUnit	measuring unit for foodProduction	string	0..1	literature survey
foodProductionWater Demand	the total food production water demand for individual food categories of an FWEArea based on underlying FWELandUse or deriving it from the overlying FWESystem	double	0..1	literature survey/estimation based on FWEArea population/GIS
foodProductionWater DemandUnit	measuring unit for foodProductionWater Demand	string	0..1	literature survey

Property	Description	Data Type	Multiplicity	Possible Data Source
foodProductionEnergyDemand	the total food production energy demand for individual food categories of an FWEArea based on underlying FWELandUse or deriving it from the overlying FWESystem	double	0..1	literature survey/estimation based on FWEArea population/GIS
foodProductionEnergyDemandUnit	measuring unit for foodProductionEnergyDemand	string	0..1	literature survey
foodConsumption	the total food consumption for individual food categories of an FWEArea based on underlying FWELandUse or deriving it from the overlying FWESystem	double	0..1	literature survey/estimation based on FWEArea population/GIS
foodConsumptionUnit	measuring unit for foodConsumption	string	0..1	literature survey

FeatureType: WaterSurvey

Property	Description	Data Type	Multiplicity	Possible Data Source
domestic Water Demand	the total domestic water demand of an FWEArea based on underlying FWELandUse or deriving it from the overlying FWESystem	double	0..1	literature survey/estimation based on FWEArea population /GIS
domestic Water DemandUnit	measuring unit for domesticWaterDemand	string	0..1	literature survey
domesticHot Water Demand	the total domestic hot water demand of an FWEArea based on underlying FWELandUse or deriving it from the overlying FWESystem	double	0..1	literature survey/estimation based on FWEArea population /GIS
domesticHot Water Demand Unit	measuring unit for domesticHotWater Demand	string	0..1	literature survey
domesticHot WaterEnergy Demand	the total domestic hot water energy demand of an FWEArea based on underlying FWELandUse or deriving it from the overlying FWESystem	double	0..1	GIS
domesticHot WaterEnergy Demand Unit	measuring unit for domesticHotWaterEnergy Demand	string	0..1	GIS
domestic WasteWater	the total domestic wastewater of an FWEArea based on underlying FWELandUse or deriving it from the overlying FWESystem	double	0..1	literature survey/estimation based on FWEArea population /GIS
domesticWaste WaterUnit	measuring unit for domesticWasteWater	string	0..1	literature survey

domestic Solid Waste	the total domestic solid waste of an FWEArea based on underlying FWELandUse or deriving it from the overlying FWESystem	double	0..1	literature survey/estimation based on FWEArea population /GIS
domestic Solid WasteUnit	measuring unit for domesticSolidWaste	string	0..1	literature survey
totalDomestic Waste	the total domestic waste of an FWEArea based on underlying FWELandUse or deriving it from the overlying FWESystem	double	0..1	literature survey/estimation based on FWEArea population /GIS
totalDomestic WasteUnit	measuring unit for totalDomesticWaste	string	0..1	literature survey
totalDomestic WasteEnergy Potential	the total energy potential from the total domestic waste of an FWE Area based on overlying FWESystem or deriving it from literature survey	double	0..1	literature survey/estimation based on totalDomesticWaste/ GIS
totalDomestic WasteEnergy PotentialUnit	measuring unit for totalDomestic WasteEnergyPotential	string	0..1	literature survey

FeatureType: EnergySurvey

Property	Description	DataType	Multiplicity	Possible Data Source
spaceHeatingDemand	the total space heating demand of buildings in an FWEArea based on underlying FWELandUse	double	0..1	GIS
spaceHeatingDemandUnit	measuring unit for spaceHeatingDemand	string	0..1	GIS
spaceCoolingDemand	the total space cooling demand of buildings in an FWEArea based on underlying FWELandUse	double	0..1	GIS
spaceCoolingDemandUnit	measuring unit for spaceCoolingDemand	string	0..1	GIS
residentialElectricity Demand	the total electricity demand of residential buildings in an FWEArea based on underlying FWELandUse	double	0..1	GIS
residentialElectricity Demand Unit	measuring unit for residentialElectricity Demand	string	0..1	GIS
electricityPotentialFromPV Buildings	the total PV (electric) potential from buildings in an FWEArea based on underlying FWELandUse	double	0..1	GIS
electricityPotentialFromPV Buildings Unit	measuring unit for electricityPotentialFrom PV Buildings	string	0..1	GIS

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biomassPrimaryEnergy Potential	the primary biomass energy potential of an FWEArea based on underlying FWELandUse	double	0..1	GIS
biomassPrimaryEnergy Potential Unit	measuring unit for biomassPrimaryEnergy Potential	string	0..1	GIS
biomassToElectricity Potential	the electricity energy potential from biomass of an FWEArea based on underlying FWELandUse	double	0..1	GIS
biomassToElectricity Potential Unit	measuring unit for biomassToElectricityPotential	string	0..1	GIS
biomassToThermal Potential	the thermal energy potential from biomass of an FWEArea based on underlying FWELandUse	double	0..1	GIS
biomassToThermal Potential Unit	measuring unit for biomassToThermalPotential	string	0..1	GIS

CodeList: foodCategory (FWEArea: FoodSurvey) - Common

Same as CodeList: foodCategory (FWEBuilding: FoodSurvey) – Pg. 19

Location details of FWEArea XML schema file are as below:

UML Diagram	https://transfer.hft-stuttgart.de/pages/fwe-ade/FWEArea/v2.1/UML/
XSD location	https://transfer.hft-stuttgart.de/pages/fwe-ade/FWEArea/v2.1/XSD/FWEArea.xsd
Recommended namespace prefix	FWEA

A web 3D visualisation example of FWEArea module using OGC 3D tiles standard and CesiumJS is shown below:
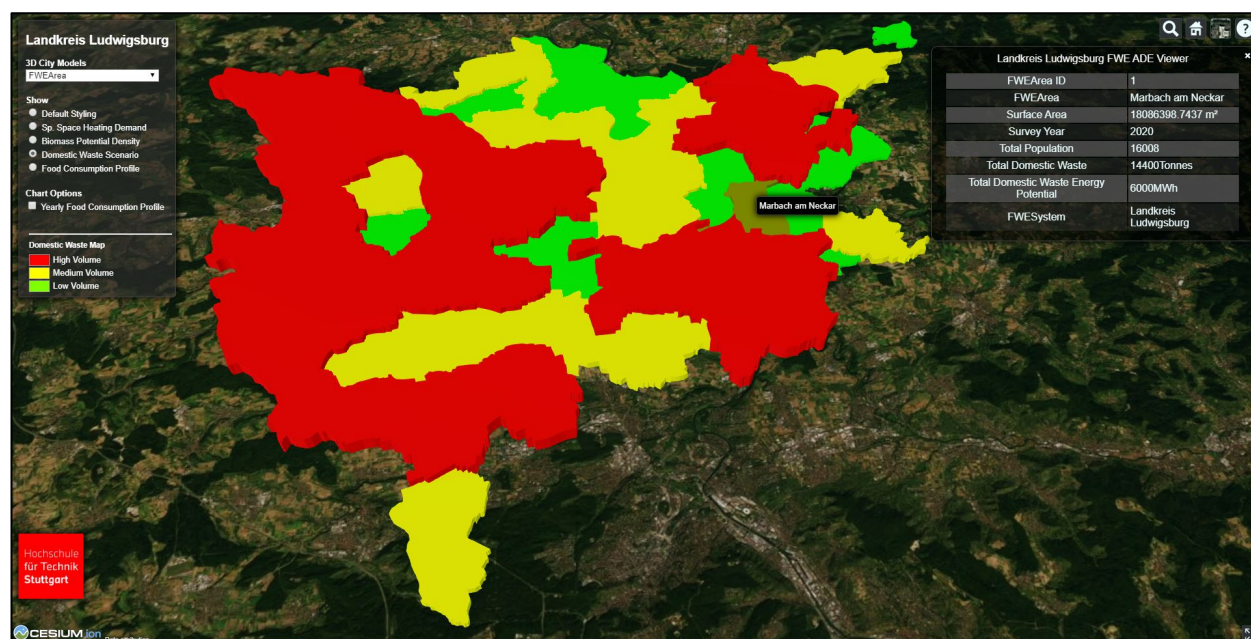

Figure 11: A 3D map of domestic waste production in FWEAreas (municipality boundaries) of Landkreis Ludwigsburg (dummy dataset)

D. FWESystem – An extension to CityGML Core

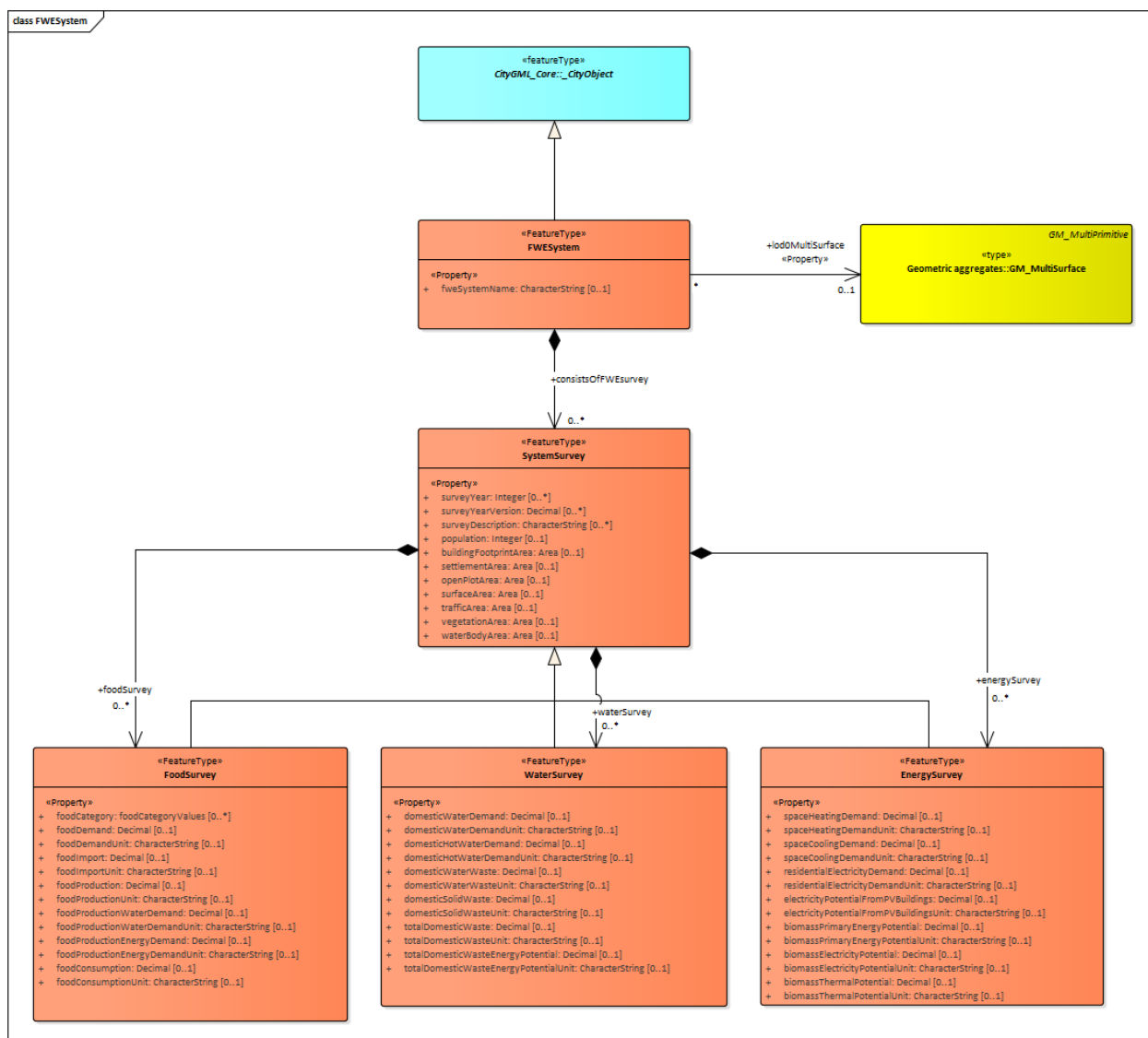The FWESystem module of FWE ADE is a new module in the CityGML core.

Figure 13: A UML class diagram for FWESystem module of FWE ADE

(blue box shows CityGML core, orange boxes are designed as part of the FWE ADE)

As shown in figure 13, FWESystem feature type (from hereby called a system) is defined as a city object having multisurface geometry. This geometry represents a system boundary covering the entire study area, which is usually static and does not change over time. Few examples of FWESystem geometries can be borough boundary of Brooklyn, city boundary of Vienna or district boundary of Landkreis Ludwigsburg.

This feature type is then further composed with a new feature type "SystemSurvey" defined as a property: "consistsofFWEsurvey" of feature type FWESystem. SystemSurvey is used as a cover term to store all the FWE and its nexus related

properties in the CityGML FWESystem. Since systems can be surveyed at different year intervals or not at all, a multiplicity of zero to many [0...*] is defined between feature type FWESystem and SystemSurvey. For each year interval, SystemSurvey is composed of multiple "FoodSurvey" feature type based on its property of "foodCategory", a "WaterSurvey" feature type and an "EnergySurvey" feature type, each defined as properties of "foodSurvey", "waterSurvey" and "energySurvey" respectively in SystemSurvey. FoodSurvey, WaterSurvey and EnergySurvey, along with other properties of SystemSurvey, inherits the property of population and surveyYear from SystemSurvey. Property:surveyYear enables FWE ADE to store FWE and its nexus related properties of FWESystem in different year intervals, including population change. This is also of particular importance while analysing temporal landuse change patterns of a system. Along with property:SurveyYear of SystemSurvey, properties:settlementArea, openPlotArea, vegetationArea, waterBodyArea, trafficArea allows to store landuse change data for any given year interval.

A complete list of "FWESystem" properties along with its description and code list is available as below:

FeatureType: FWESystem

Property	Description	Data Type	Multiplicity	Possible Data Source
fweSystemName	the name of the belonging FWESystem	string	0..1	user-defined based on FWESystem

FeatureType: SystemSurvey

Property	Description	Data Type	Multiplicity	Possible Data Source
surveyYear	survey year	integer	0..*	user-defined
surveyYearVersion	for survey scenarios belonging to the same survey year (e.g. 2020 existing scenario, 2020 business as usual scenario, 2020 best practice scenario)	double	0..*	user-defined
surveyDescription	user description for survey	string	0..*	user defined
population	the total population covered by FWESystem based on the underlying FWEArea or deriving it from census	integer	0..1	census/GIS
buildingFootprintArea	the total building footprint area based on the FWEArea	double	0..1	GIS
settlementArea	the total settlement area based on the underlying FWEArea	double	0..1	GIS

openPlotArea	the total open plot area based on the underlying FWEArea	double	0..1	GIS
surfaceArea	polygon area of taken political boundaries	double	0..1	GIS
trafficArea	the total traffic area (incl. roads, railways) based on the underlying FWEArea	double	0..1	GIS
vegetationArea	the total vegetation area based on the underlying FWEArea	double	0..1	GIS
waterBodyArea	the total water body area based on the underlying FWEArea	double	0..1	GIS

FeatureType: FoodSurvey

Property	Description	Data Type	Multiplicity	Possible Data Source
foodCategory	list of food categories	codelist	0..*	GIS/literature survey
foodDemand	the total food demand for individual food categories of an FWESystem based on underlying FWEArea or deriving it from the literature survey	double	0..1	literature survey/estimation based on FWESystem population/GIS
foodDemandUnit	measuring unit for foodDemand	string	0..1	literature survey
foodImport	the total food import for individual food categories in an FWESystem based on literature survey	double	0..1	literature survey
foodImportUnit	measuring unit for foodImport	string	0..1	literature survey
foodProduction	the total food production for individual food categories of an FWESystem based on underlying FWEArea or deriving it from the literature survey	double	0..1	literature survey/estimation based on FWESystem population/GIS
foodProductionUnit	measuring unit for foodProduction	string	0..1	literature survey
foodProductionWater Demand	the total food production water demand for individual food categories of an FWESystem based on underlying FWEArea or deriving it from the literature survey	double	0..1	literature survey/estimation based on FWESystem population/GIS
foodProductionWater DemandUnit	measuring unit for foodProductionWater Demand	string	0..1	literature survey
foodProductionEnergy Demand	the total food production energy demand of an FWESystem based on underlying FWEArea or deriving it from the literature survey	double	0..1	literature survey/estimation based on FWESystem population/GIS

foodProductionEnergy DemandUnit	measuring unit for foodProductionEnergy Demand	string	0..1	literature survey
foodConsumption	the total food consumption for individual food categories of an FWESystem based on underlying FWEArea or deriving it from the literature survey	double	0..1	literature survey/estimation based on FWESystem population/GIS
foodConsumptionUnit	measuring unit for foodConsumption	string	0..1	literature survey

FeatureType: WaterSurvey

Property	Description	Data Type	Multipl icity	Possible Data Source
domestic Water Demand	the total domestic water demand of an FWESystem based on underlying FWEArea or deriving it from the literature survey	double	0..1	literature survey/estimation based on FWESystem population /GIS
domestic Water DemandUnit	measuring unit for domesticWaterDemand	string	0..1	literature survey
domesticHot Water Demand	the total domestic hot water demand of an FWESystem based on underlying FWEArea or deriving it from the literature survey	double	0..1	literature survey/estimation based on FWESystem population /GIS
domesticHot Water Demand Unit	measuring unit for domesticHotWater Demand	string	0..1	literature survey
domesticHot WaterEnergy Demand	the total domestic hot water energy demand of an FWESystem based on underlying FWEArea	double	0..1	GIS
domesticHot WaterEnergy Demand Unit	measuring unit for domesticHotWaterEnergy Demand	string	0..1	GIS
domestic WasteWater	the total domestic wastewater of an FWESystem based on underlying FWEArea or deriving it from the literature survey	double	0..1	literature survey/estimation based on FWESystem population /GIS
domesticWaste WaterUnit	measuring unit for domesticWasteWater	string	0..1	literature survey
domestic Solid Waste	the total domestic solid waste of an FWESystem based on underlying FWEArea or deriving it from the literature survey	double	0..1	literature survey/estimation based on FWESystem population /GIS
domestic Solid WasteUnit	measuring unit for domesticSolidWaste	string	0..1	literature survey

totalDomestic Waste	the total domestic waste of an FWESystem based on underlying FWEArea or deriving it from the literature survey	double	0..1	literature survey/estimation based on FWESystem population /GIS
totalDomestic WasteUnit	measuring unit for totalDomesticWaste	string	0..1	literature survey
totalDomestic WasteEnergy Potential	the total energy potential from the total domestic waste of an FWESystem or deriving it from the literature survey	double	0..1	literature survey/estimation based on totalDomesticWaste/ GIS
totalDomestic WasteEnergy PotentialUnit	measuring unit for totalDomestic WasteEnergyPotential	string	0..1	literature survey

FeatureType: EnergySurvey

Property	Description	DataType	Multiplicity	Possible Data Source
spaceHeatingDemand	the total space heating demand of buildings in an FWESystem based on underlying FWEArea	double	0..1	GIS
spaceHeatingDemandUnit	measuring unit for spaceHeatingDemand	string	0..1	GIS
spaceCoolingDemand	the total space cooling demand of buildings in an FWESystem based on underlying FWEArea	double	0..1	GIS
spaceCoolingDemandUnit	measuring unit for spaceCoolingDemand	string	0..1	GIS
residentialElectricity Demand	the total electricity demand of residential buildings in an FWESystem based on underlying FWEArea	double	0..1	GIS
residentialElectricity Demand Unit	measuring unit for residentialElectricity Demand	string	0..1	GIS
electricityPotentialFromPV Buildings	the total PV (electric) potential from buildings in an FWESystem based on underlying FWEArea	double	0..1	GIS
electricityPotentialFromPV Buildings Unit	measuring unit for electricityPotentialFrom PV Buildings	string	0..1	GIS
biomassPrimaryEnergy Potential	the primary biomass energy potential of an FWESystem based on underlying FWEArea	double	0..1	GIS
biomassPrimaryEnergy Potential Unit	measuring unit for biomassPrimaryEnergy Potential	string	0..1	GIS

biomassToElectricity Potential	the electricity energy potential from biomass of an FWESystem based on underlying FWEArea	double	0..1	GIS
biomassToElectricity Potential Unit	measuring unit for biomassToElectricityPotential	string	0..1	GIS
biomassToThermal Potential	the thermal energy potential from biomass of an FWESystem based on underlying FWEArea	double	0..1	GIS
biomassToThermal Potential Unit	measuring unit for biomassToThermalPotential	string	0..1	GIS

CodeList: foodCategory (FWESystem: FoodSurvey) - Common

Same as CodeList: foodCategory (FWEBuilding: FoodSurvey) – Pg. 19

Location details of FWESystem XML schema file are as below:

UML Diagram	https://transfer.hft-stuttgart.de/pages/fwe-ade/FWESystem/v2.1/UML/
XSD location	https://transfer.hft-stuttgart.de/pages/fwe-ade/FWESystem/v2.1/XSD/FWESystem.xsd
Recommended namespace prefix	FWES

Some web 3D visualisation example of FWESystem module using OGC 3D tiles standard and CesiumJS are shown below:

Figure 12: The FWESystem model of Landkreis Ludwigsburg

Figure 13: A temporal food consumption profile of Landkreis Ludwigsburg (dummy dataset)

Remarks

- All the CityGML datasets used with the FWE ADE should be according to the OGC conformance requirements for CityGML. Conformance requirements are the set of rules and regulations for modelling any city object in CityGML. These requirements are documented in the encoding standards[6] of CityGML.
- All the properties of the FWE ADE having multiplicity [1] are mandatory.
- All the stationary energy demand - potential calculations will be done using SimStadt at the FWEBuilding level. Then it will be scaled up to the FWELandUse, FWEArea, and at FWESystem level.
- SimStadt calculates space heating and cooling demands of buildings. Energy demand for appliances in buildings or machinery in industries are not calculated
- Electricity demand is only estimated for residential buildings in the current state of SimStadt.
- Minimum requirements to calculate space heating/cooling demand and electricity demand using SimStadt are CityGML buildings in LoD1 and CityGML building property: function and year of construction.
- Additionally, to calculate PV potential (electricity) of buildings using SimStadt, CityGML buildings in LoD2 is minimum.
- Biomass potential calculation will be done using SimStadt at the FWELandUse level, and then it will be scaled up to the FWEArea and FWESystem level. CityGML LandUse dataset having properties: class, function, use, and FWELandUse properties: surfaceArea and vegetationCropCover are mandatory.
- In the current state of the FWE ADE, due to data availability, all the food and water-related parameters will be first integrated at the FWESystem level and then scaled down to the FWEArea level. Scaling further down to the FWEBuilding and FWELandUse level may be done based on use cases/scenarios. 3DcityDB software and PostgresSQL/PostGIS will be investigated and extended to support the FWE ADE.
- Within the FWE ADE, all the food related parameters are based on food category codelist.
- The property of domestic waste includes food consumption waste. Food production waste (agricultural waste) are excluded in the current state of the FWE ADE.
- Based on the use cases/scenarios, it is always possible to extend the ADEs further.

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[6] https://portal.opengeospatial.org/files/?artifact_id=47842

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Appendix

- **SimStadt's biomass workflow interface with the FWE ADE**

As mentioned above in the section "FWE ADE Concept", the FWE ADE will be used as a data interchange format for the simulation workflows in the FWE nexus domain. One such simulation workflow of calculating biomass potential using SimStadt for an urban region using DLM data and FWE ADE is explained here.
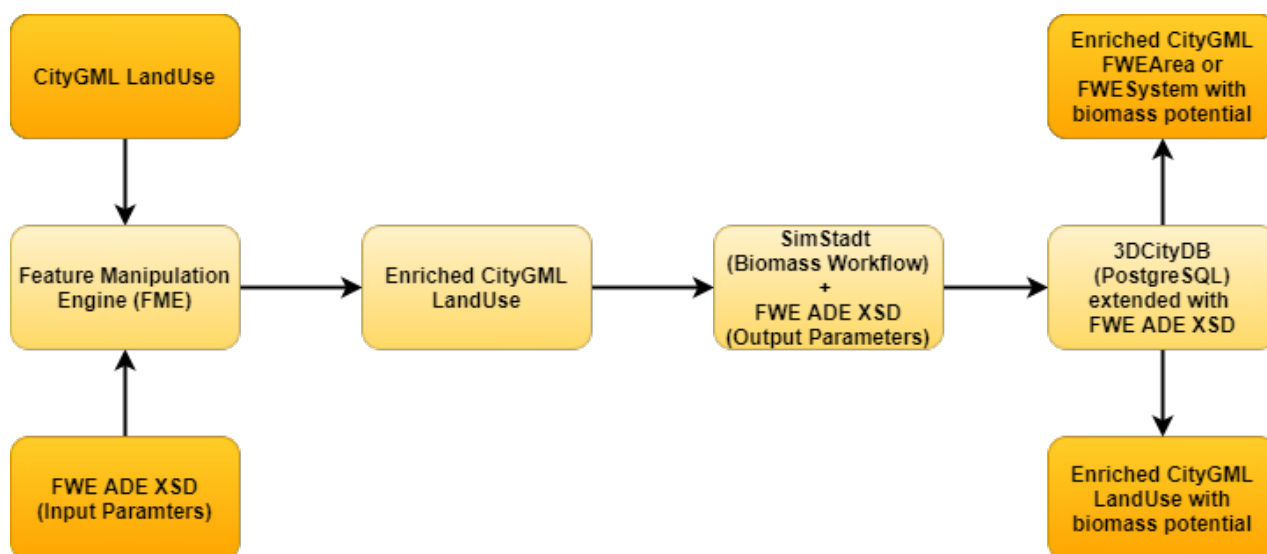

Figure 14: A conceptual sketch of using FWE ADE with SimStadt biomass potential workflow

As shown in the above diagram, as a first step, using FME software, CityGML LandUse dataset will be enriched with the required input parameters of surfaceArea, surfaceAreaUnit and vegetationCoverCategory available in the FWE ADE XSD (as defined in the parameters list under chapter B). surfaceAreas can be calculated using FME while vegetationCoverCateogry is a custom codelist based on land cover satellite images. For the German case study of Landkreis Ludwigsburg, vegetationCoverCategory is derived from the 2016 national scale crop and land cover map of Germany based on imagery acquired by Sentinel-2A and Landsat-8 (Griffiths et al., 2018). These input parameters are mandatory for calculating biomass potential from the CityGML LandUse datasets using SimStadt. The enriched CityGML LandUse is then inputted to the SimStadt's biomass workflow. The output CityGML LandUse file with output parameters from the FWE ADE XSD will be directly added to the 3DCityDB which is already extended to store the FWE ADE parameters. From 3DCityDB, based on the user needs either the enriched CityGML LandUse file with biomass potential can be extracted or the enriched CityGML FWEArea/FWESystem file with biomass potential values can also be extracted.
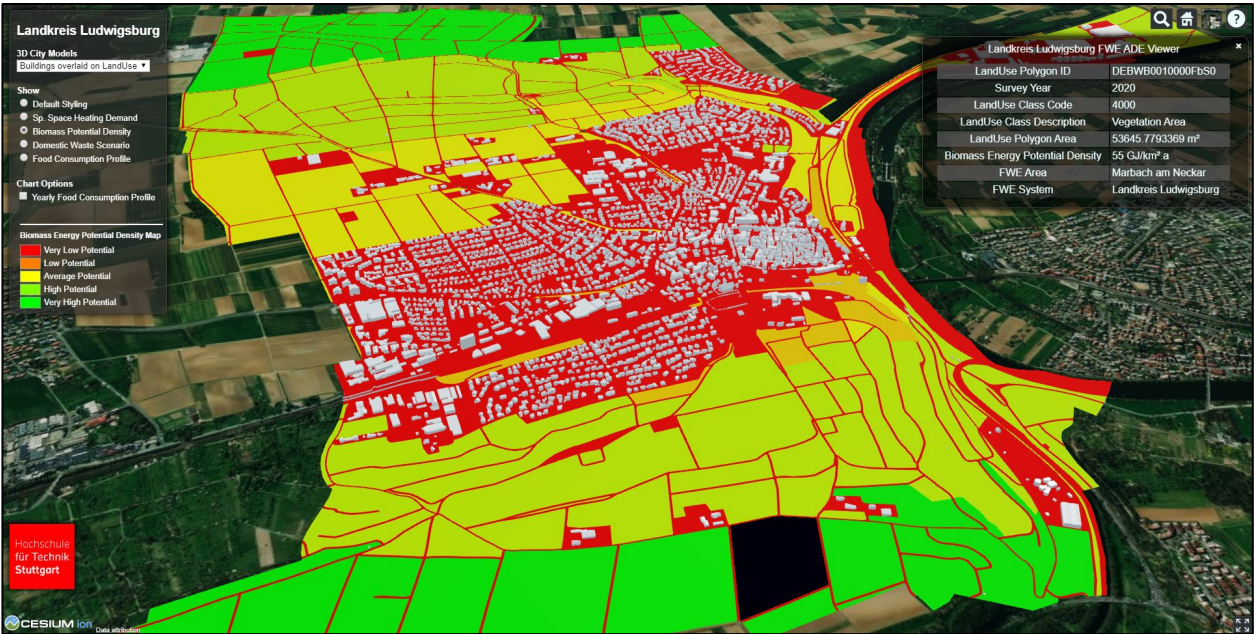
Figure 15: Visualisation of the Marbach's biomass potential using enriched CityGML LandUse

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