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Urban Environment Simulation based on CityGML with EnergyADE and Ladybug

MSC GEOMATICS THESIS PROPOSAL

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1. Introduction

Urban environment simulation is getting more and more important in areas like urban planning, urban or landscape design and urban study. By combining 3D models of urban objects such as buildings, terrain, vegetation and water body with local climate data, practitioners as well as researchers could optimize designing ideas or test theories in the aspects of energy consumption, thermal comfort, day lighting and natural ventilation. Simulation results could not only be used to justify design approach in early stage , but also play an important role in later project operation and management process.

CityGML, as an open standard data model for 3D city developed by Open Geospatial Consortium (OGC), is one ideal input data for above-mentioned simulation. It not only contains geometry information, but also includes texture, semantic attributes and topological relations of city objects. Together with its Energy Application Domain Extension (Energy ADE), which covers even more topics like building physics, material & construction, energy system and occupant behavior [1], it could provide all needed information for urban environment simulation.

There are quite a few simulation programs on the market. This study mainly focusses on Ladybug toolset which consists of Ladybug, Butterfly, Honeybee and Dragonfly. As comparing to other software, it has three major advantages: ease of use, low cost of adoption and high level of customization. All tools are open-source python packages with comprehensive comments, allowing entry-level programmers to follow and understand; They could also be integrated into Rhino with Grasshopper, a visual programming environment normally used in architecture and urban planning which provides instantaneous feedback on design modification; Last but not least, codes or algorithms of each tool could be modified or adjusted by advanced users to fit their needs.

Figure 1 below shows traditional work flow of ladybug tools. Two types of input data are taken: 3D models from Rhino with Grasshopper and weather data from Energy Plus Weather (.EPW) file. 3D models in Rhino only provide basic geometry information and .EPW file, which is simple ascii format contains only necessary climatic information such as location, temperature, wind speed of surroundings in hourly resolution (see Figure 2). Depending on what simulation we are going to run (thermal, airflow or light simulation), there are always some key attributes concerning study objects required during simulation process.

For example, if we use Dragonfly to do an urban heat island simulation, plenty of parameters still need to be filled in or chosen from a list during building typology definition process (Figure 3). These include building type, building age, building height, number of stories, floor area, facade area, glazing ratio, material and so on.

1.1 Scientific relevance

Besides 3D models (geometry information) and .EPW file (local weather data), to use Ladybug tools for urban environment simulation, specific properties are needed. 3D models in Rhino with Grasshopper do not come with these attributes. Entering these data manually is prone to error and may not be feasible when there are too many objects. Also, assigning same values of certain attributes to a group of buildings may over-simplify the situation and lead to inaccurate simulation results.

Some, if not all these information is already there in CityGML with its Energy ADE data schema. However, Ladybug tools, like most of simulation software out there, do not take CityGML as data input option. Even if they did, it is not clear where these parameters are stored as there is no mapping between each other.

To better utilize CityGML data in urban environment simulation, a link between CityGML and simulation software like Ladybug tools is needed. By mapping required parameters needed for urban environment simulation to CityGML with Energy ADE data schema, geometry as well as other important information could be retrieved, stored and fed to simulation engines.

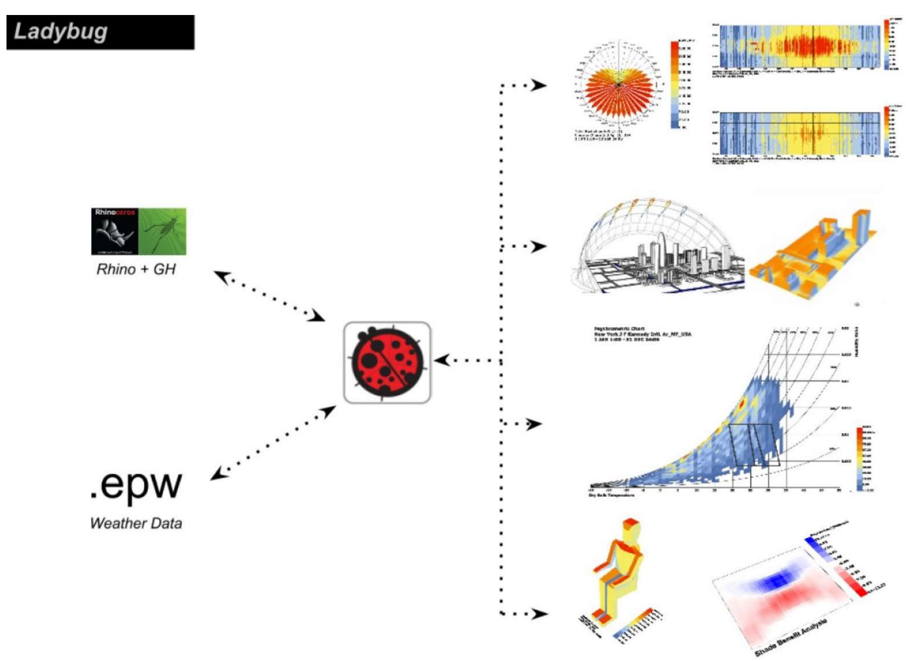

Figure 1: Ladybug workflow and functions. Source: Ladybug Primer.

https://legacy.gitbook.com/book/mostapharoudsari/ladybug-primer/details

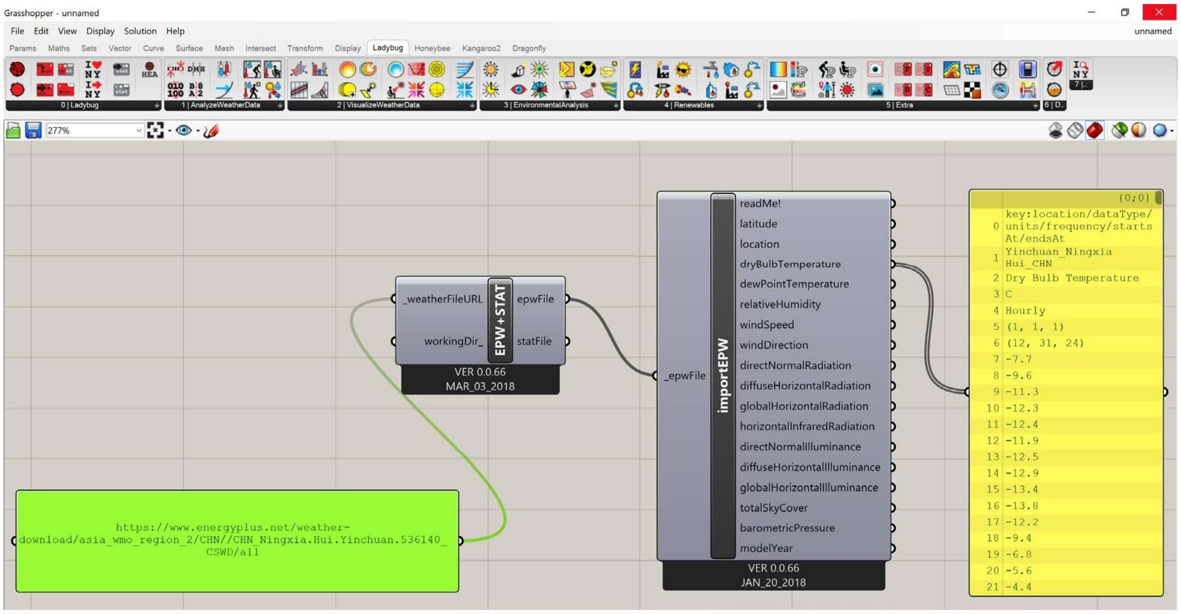

Figure 2: Content of .EPW file. It contains climatic information such as location, temperature, wind speed in hourly resolution.

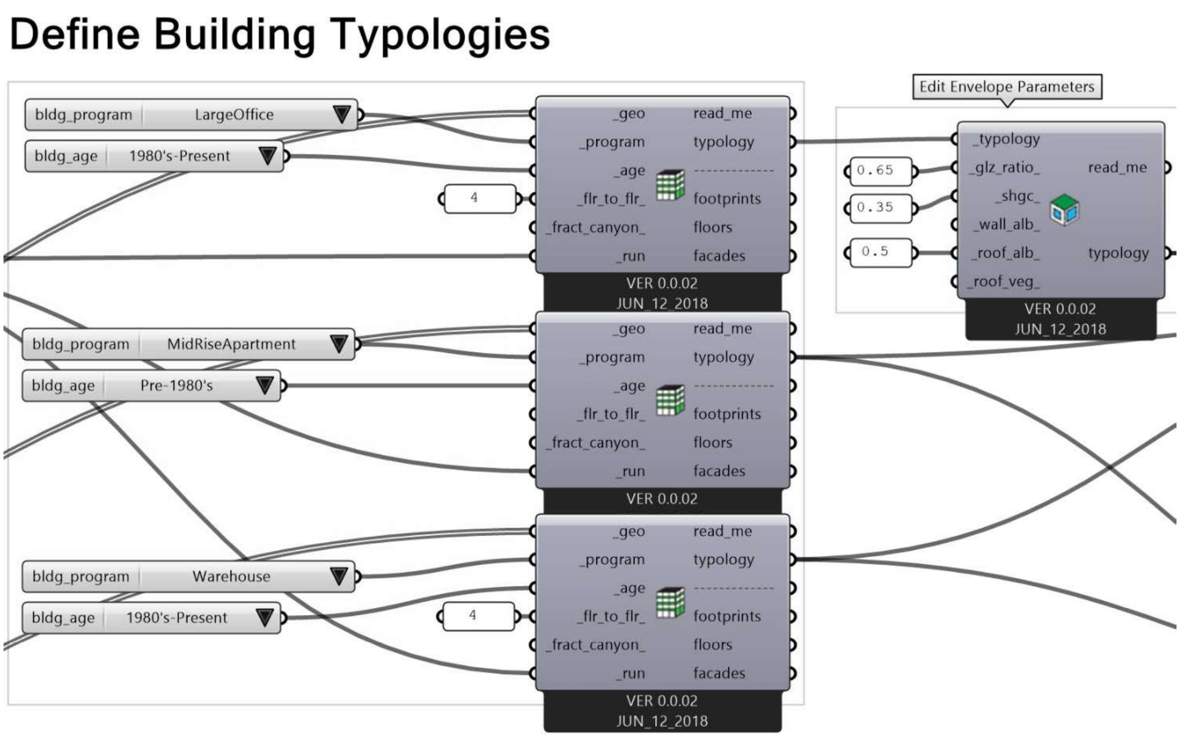

Figure 3: Dragonfly application example. Source:
http://hydrashare.github.io/hydra/viewer?owner=chriswmackey&fork=hydra_2&id=Urban_Weather_Generator_Workflow&slide=0&scale=1.8345001780114019&offset=-493.0855074236929,-151.8754352116178

2. Related Work

2.1 Urban Environment Simulation Data Model and Preparation Approach

Perez, Diane, and Darren Robinson have carried out a research on urban environmental simulation process emphasizing input data [2]. In their opinion, importance of input data is always overlooked. However, for well tested physically-based simulation models, limited degree of detail as well as the use of default data is the main source of uncertainty. If user expect correspondence between simulation results and real-world scenario, input data becomes as important as simulation tools.

In their opinion, good input data should be “Ontology”, A formal description of a given knowledge domain, including precise definitions of entities in the domain and logical explanations of their relationships [3]. For CityGML, it defines classes and relations for the city objects, including geometry, semantical and spatial information. In this way, it becomes an important example for “ontology” and could be used as a shared basis for data exchange.

They also discuss the traditional data preparation process for urban environment simulation, which could be rather haphazard: It is not possible or time-consuming to collect all useful data. Even if all data from different sources could be collected, it involves in diverse format and incompatibilities between each other (conflicting values, different units or time series).To save time in data preparation, maximize the value of available data and increase the longevity of data model, they propose a more “sustainable and holistic” approach (Figure 4). A spatial and temporal database is introduced to organize data all together.

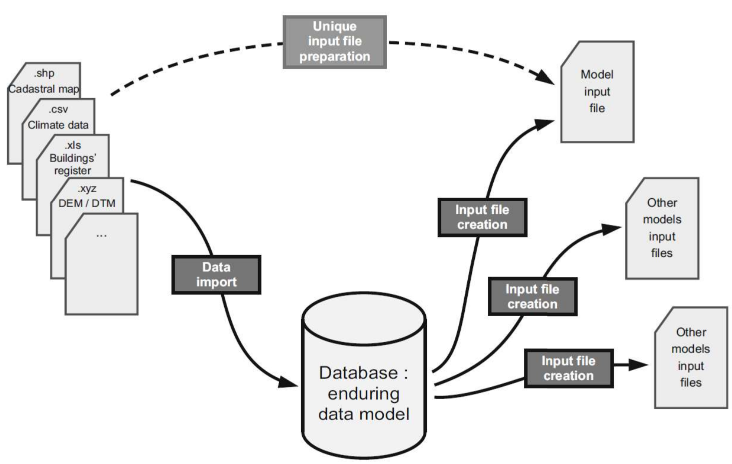

Figure 4: Data preparation process. Organized management of data (continuous line) versus traditional direct input file preparation (dotted line).

2.2 Urban Environment Simulation Methodology

Urban energy simulation methodologies could be categorized as macro-simulation, micro-simulation and hybrid of the two. Macro-simulation approach abstracts a whole system as a set of interrelated stocks, flows and feedback mechanisms of resources between these stocks [4].

For macro-simulation approach, system dynamic modelling [5] is used. Whole city as a system is regarded as aggregation of housing, fossil fuels while the ambient environment as a source of renewable energy. Flows of energy, material and associated feedback mechanisms are simulated. Examples of macro-simulation approach include energy modelling of city of Basel, Switzerland [6] and whole Norway [7]. These simulations are based on aggregated statistical data and provide overview information at a large scale. But they are limited to offer more specific knowledge;

For micro-simulation approach, each individual building is physically presented in its spatial context. During the simulation process, unique scene description for each building needs to be prepared. Thus, a significant amount of data is needed. As there are much more information provided, very detailed simulation programs like EnergyPlus, which is designed for modelling single building could be used.

The middle ground of these two approaches is the methodology which simulate only representative building from various classes of building typology. Later, simulation results could be extrapolated to the whole area. In this way, data volume is reduced dramatically and with proper definition of different building typology classes, simulation results could be valuable for both small and large scale. A good example is Urban Weather Generator developed by Building Technology Program, MIT available at https://github.com/ladybug-tools/uwg.

2.3 Implementing CityGML in Urban Environment Simulation

SimStadt, a modular platform utilizes LOD1 and LOD2 CityGML data for urban scale thermal and energy demand simulation [8]. The platform consists of preprocessing workflow which extracts key parameters (geometry and semantics) from CityGML model. Besides information retrieval, this process could also fix and enrich CityGML models by using CityDoctor [9]. SimStadt team then uses retrieved information to formulate their own input data model (Figure 5) for simulation process. Figure 6 shows the whole workflow of SimStadt platform.

Sameh Zakhary and etc. design a workflow for simulating arbitrary numbers of building simultaneously [10] by using CitySim, a dedicated urban energy micro-simulation software [11]. They also use 3D City DB for import and export of CityGML files. The main contribution of their study is changing original high -

level architecture of CitySim, which is only suited for a standalone simulation engine and could not integrate with other tools to a more open structure. Figure 7 shows the proposed workflow of their study.

Dr. Giorgio Agugiaro and his students have also tried connecting CityGML-based semantic city models to energy simulation engine, namely EnergyPlus. In his research, two approaches are taken separately to estimate heating energy demand of buildings: one is Italian national standard based and the other is by using EnergyPlus with retrived parameters from CityGML data. Both methods compute three different refurbishment scenarios and later approach presents the initial ways of coupling CityGML data with simulation engines. Results of his study suggest that both approaches are complementary, not alternatively [12].

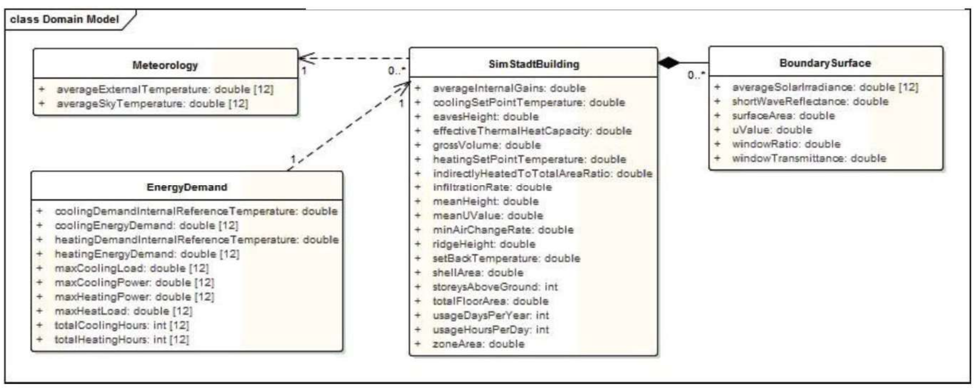

Figure 5: SimStadt input data model for monthly energy balance simulation.

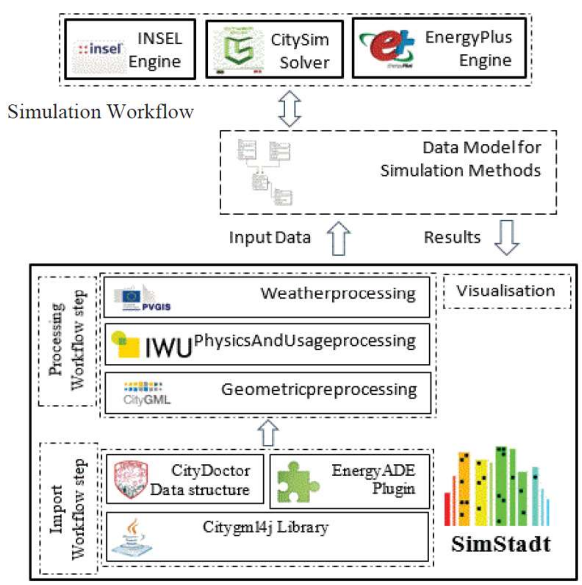

Figure 6: SimStadt workflow.

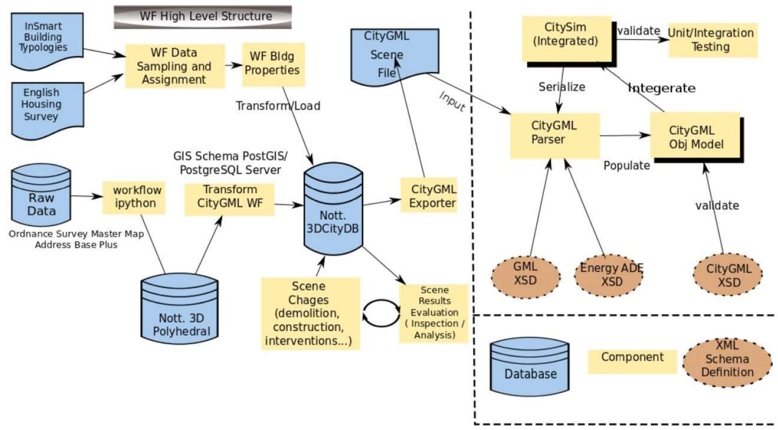

Figure 7: Proposed workflow of urban scene simulation with CitySim.

3. Research Objectives and Scope

3.1 Objectives

The main research question for this master thesis is: How to utilize CityGML with EnergyADE data in urban environment simulation process when using Ladybug toolset?

The goal of this research is to create a mapping between CityGML with EnergyADE with its comprehensive information to data model required when using Ladybug tools. Based on mapping result, a tool would be developed to retrieve, organize mapped information from CityGML data and store it in 3D City Database and later link it to Ladybug simulation engines. To achieve this, following sub-problems would be solved:

1. What key parameters are needed during urban environment simulation process when using Ladybug toolset (Ladybug, Honeybee, Butterfly and Dragonfly)?

2. Where are these key attributes located in CityGML with EnergyADE data schema? More specifically, in which modules and under which classes?

3. How to efficiently retrieve all required information, both geometry and semantic from CityGML dataset? After doing that, how to effectively organize, reformat and store these information in 3D City Database so that it could be later retrieved and fed to Ladybug simulation engines? It would be nice to be able to store simulation results in database too.

3.2 Scope of research

This thesis mainly focuses on finding mapping relation between required key parameters of Ladybug tools and CityGML with EnergyADE data schema. Furthermore, a software would be developed based on mapping relations to retrieve required information from CityGML dataset. These information would be organized, stored in 3D City Database and linked to Ladybug tools. A case study would be carried out to test the software.

This research does not place emphasis on data preparation process for CityGML. We assume data provided is already complete and accurate according to OGC standards. Also, simulation methodologies used in Ladybug tools would not be discussed or benchmarked. This also applies to the simulation results. Only if time allows and there is trust-worthy ground truth data, simulation results may be verified.

4. Methodology and Potential Problems

4.1 Methodology

Figure 8 shows methodology roadmap of this study. It consists of five major parts: Summarize data model for urban environment simulation, map this data model to CityGML with EnergyADE data schema, create interface to retrieve correspondent class values of CityGML, set up 3D city DB to organize and store geometry as well as semantic parameters, test the software platform with a concrete case.

The first step is summarizing data model for urban environment simulation when using Ladybug tools . Ladybug, together with Honeybee, Butterfly and Dragonfly would be tested and possible urban environment simulation, including thermal, ventilation and day lighting would all be examined. During this step, data input of these packages, namely geometry format and key parameters for simulations are summarized as table;

The next step is to compare this comprehensive urban environment simulation data model with CityGML EnergyADE data schema to see if all key parameters could be found in CityGML & EnergyADE and in which modules under which classes are they located. By doing this step, a mapping between Ladybug toolset data model and CityGML with EnergyADE is created. This is the foundation of later software design process;

Most important part of this study is to implement above mentioned mapping relations in building an interface. This interface should have three major functions: Data retrieval (extract geometry as well as correspondent class values of key parameters from CityGML dataset/database), Data formatting and linking (organize retrieved information in a way that could be efficiently stored in 3D city DB and later feed geometry, key attributes together with weather data to Ladybug packages), Results Visualization (visualize stored 3D geometries and simulation results);

For this study, a 3D database would be set up to store original CityGML data, reorganized data for simulation input and simulation results. It might be possible to store weather data retrieved from .EPW file too but if not possible, a stand-alone .EPW file would be used during simulation process. Database should be able to handle query request based on location, time, AOI (Area of Interest) and etc.

Last step is software test. Together with supervisors, a proper dataset would be chosen in order to test/optimize the software developed.

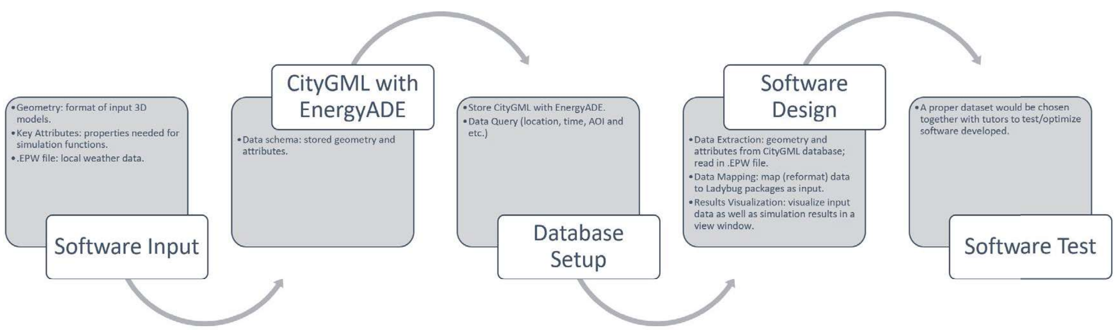

Figure 8: Methodology Roadmap.

4.2 Potential Problems and Alternative Solution

During the first three steps, there is only one potential problem: data schema of CityGML with EnergyADE may not contain all necessary parameters for environment simulation using Ladybug toolset. However, by briefly checking CityGML EnergyADE data schema, I would not worry too much as it includes comprehensive information concerning material and construction, energy system, building physics and even occupant behavior. It should also be noticed that not all input parameters of Ladybug simulation functions are compulsory as simulation could still run with certain parameters missing.

Other potential problems mainly exist in last two steps. For software design part, getting familiar with software development process together with coding and debugging could cost longer time than expected. The original idea is to develop a stand-alone software with its own file management system and viewing window. If this does not go so well, an alternative option could be designing a Rhino Grasshopper plugin which enables reading in CityGML with EnergyADE and extracting geometry and parameters needed by Ladybug plugins. For software test part, one potential problem could be test data. A proper sized CityGML with Energy ADE data of urban area may be hard to find, no need to mention that corresponding weather data (.EPW file which could be downloaded from website http://www.ladybug.tools/epwmap/) is needed too. One solution could be, creating mock-up CityGML Energy ADE data for test purpose.

5. Schedule

5.1 Activities

The following schedule has been created with necessary activities to achieve research objectives:

Start	End	Activity
9th September	5th October	Find graduation topics
6th October	15th November	Familiarize with urban simulation and Ladybug tools
P1 – Progress review Graduation Plan		
16th November	20th December	Literature study
20th December	10th January	Study key parameters required for Ladybug tools
20th December	10th January	Study CityGML with EnergyADE data schema
P2 – Formal assessment Graduation Plan		
15th January	15th Feb	Create mapping between CityGML and Ladybug
15th February	25th April	Set up interface for information retrieval
15th February	25th April	Set up 3D City DB for information storage
P3 – Colloquium midterm		
1st May	15th May	Link interface to 3D City DB
1st May	15th May	Platform testing
1st May	15th May	Thesis writing
P4 – Formal process assessment		
16th May	15th June	Finalize thesis
15th June	23rd June	Prepare presentation
P5 – Public presentation and final assessment.		

5.2 Meetings

Besides above-mentioned activities, regular meetings are schedule with the supervisor Dr. Giorgio Agugiaro. Prof. dr. J.E.Stoter also provides additional feedback and support.

6. Tools and Data

6.1 Tools

Ladybug toolset which consists of Ladybug, Honeybee, Butterfly and Dragonfly are our mainly focused simulation software. They are open source python packages available at https://www.ladybug.tools/. Python will be used for information retrieval from CityGML with EnergyADE and data formatting work. To fast read and handle CityGML data, a series of packages like citygml4j developed by dr. H. Ledoux available at https://github.com/tudelft3d/cityjson/tree/master/software might be used, The interface itself is planned to be built by Qt https://www.qt.io/. 3D City DB, https://www.3dcitydb.org, which is a free geo database to store, represent and manage virtual 3D city models is used to manage retrieved information from CityGML and provide query, visualization and other functions.

6.2 Data

Together with supervisors, data selection is still under discuss. In the worst-case scenario, a mock-up dataset with all necessary classes for urban environment simulation would be created to test the software functions.

References

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