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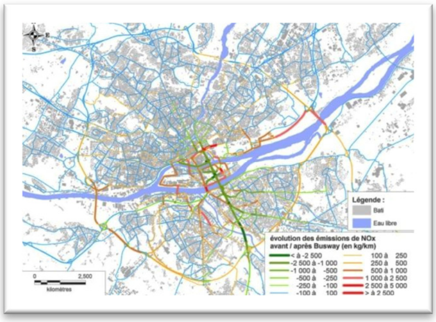

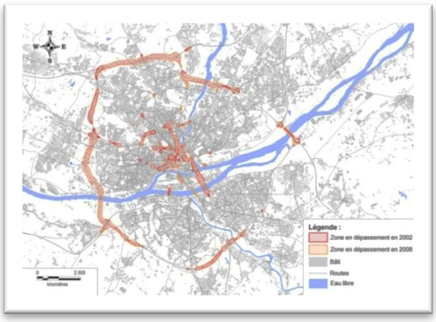

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La modélisation des flux
au service de l'aménagement urbain

Flow modeling for urban development

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PROCEDURAL MODELS TO BETTER COMPUTE SOLAR FLUX AT THE NEIGHBOURHOOD SCALE

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Abstract

The aim of this paper is to define the optimal Level of Detail (LoD) of an urban 3D model for solar energy simulation at the neighbourhood scale. Procedural methods are used to build the geometry. They allow modifying easily the Level of Detail of the windows (first application) and of the roofs (second application). Simulations of direct solar irradiation and Sky View Factors are applied to the model, and the accuracy of the results is compared at different levels. The results show the good behaviour of intermediary LoDs, which should allow the handling of large urban models. Further steps of this research should conduce to establish dynamic LoD procedures, respecting the skyline and allowing an evaluation of the error. This method could be transposed to other fields of the urban physics.

1. Introduction

Buildings energy performance, active solar potential, and access to sunlight and daylight in urban areas are directly influenced by the urban geometry, mainly at the neighbourhood scale. For their assessment using numerical simulations, a well-defined geometrical model of the urban environment is mandatory. Recent improvements in the spatial data acquisition techniques have made available different urban data (2D vectorial data, 2.5D raster data, alphanumerical data, orthophotos, etc.) that can be employed to represent extended urban areas and to perform environmental and urban analysis.

Several environmental analyses have been performed using different urban models. For instance, the analysis of Digital elevation models (DEM) using Image-processing techniques has been employed to derive urban parameters used in Urban morphological analysis [RATTI 2004, CARNEIRO 2010],the assessment of the influence of the urban texture into the building energy consumption [RATTI 2005] and the assessment of solar access [CARNEIRO 2008 a]. DEMs have been analyzed coupling GIS and Image-processing techniques to derive urban parameters, as the Sky View Factor (SVF), in order to study their influence on the Urban Heat Island [LINDBERG 2007, UNGER 2009].

The detection of optimal areas on buildings for installing solar active systems has been performed using different approaches, as the analysis and manipulation of different datasets (DEM, DSM, stereo pictures, etc.,) in a Geographical Information System (GIS) [KASSNER 2008, JOCHEM 2009]. Mardaljevic proposed the Irradiation mapping for Complex Urban Environment (ICUE) approach, which consists in coupling an image-based approach (RADIANCE software) and a GIS-based solar energy planning system (SEP system). The target applications are the assessment of solar potential, the guidance to passive solar design and the quantification of the reduction of solar irradiation into existing buildings caused by a new construction. [MARDALJEVIC 2003].

The results of these studies are very promising and confirm the possibility of using spatial information to perform environmental urban analysis. However, these numerical simulations are performed using models with a predefined level of detail and the user doesn't have the control to adapt it to the needs. As a consequence, the results may not be as accurate as they should be, and the error due to drastic simplifications remains unknown. Indeed, we found that the influence of the results caused by the level of detail of models used in numerical simulations hasn't been studied in the literature.

2. Parametric and Procedural Modeling

Providing robust 3D urban model representations for many purposes are a challenge since various Levels of Detail and different abstractions are required for each particular application. Although all applications may share the same urban structure, in general, requirements are very different for each one [CARNEIRO 2008 b]. Ideally, the same basis of the model should be shared consistently, so information could be exchanged in a coherent way. For example, the result of a solar radiance simulation provided with a rough model could be attached to a highly detailed model for visualization.

Another difficulty dealing with city models is the amount of geometry data to deal with. A highly detail urban model may be huge (of the order of billions of polygons) and manually modeling them is a tedious and complicated task. One promising approach for the efficient low-cost creation of detailed building models is procedural modeling, where rules and parameters are used to generate new content algorithmically [MÜLLER 2006]. In this approach, large-scale city models as well as very detailed building models can be quickly created using procedural techniques, and time-consuming modeling tasks are avoided. The automatic control of model complexity and simplification to improve procedural tools is a current research topic [WATSON 2008].

One advantage of using a procedural approach for urban model generation is that it works parametrically. That is, a single building model could be taken as a sample and reused as among other comparable buildings by changing the corresponding parameters. This advantage could also improve simulation application where different elements should be explored in order to analyze the impact of changing their size or shape.

For the modeling purpose of this paper, we propose the use of a procedural level-of-detail technique in order to obtain a parametric urban model adequate to the level of analysis being used. The main goals of the modeling process can be summarized as:

- Allows to obtain a simple procedural model of an approximated real building where parameters can easily be changed for simulation analysis.

- Allows to obtain automatically different Levels of Details of the model previously defined.

3. Physical model

The physical model must include simple and complementary parameters to perform fast calculations. The results have to allow an analysis of the interaction between geometry and solar paths, in order to achieve conclusions about the Level of Detail. Here, the physical model is reduced to the characterization of solar path, calculation of direct sunlight and Sky View Factor. Direct solar radiation is evaluated from the solar constant, taking into account the absorption of the atmosphere for a clear day, with the isotropic model of Liu and Jordan [LIU 1960].

Sky View Factor can be applied to the assessment of daylight [BECKERS 2009]. It defines the amount of sky visible from a surface, taking into account the angle of inclination to the sky vault. Sky View Factor is a pure geometrical parameter, but it has a physical meaning, deduced from the properties of the radiative exchanges: it represents the proportion of the total power leaving the first element and received by the second one [SILLION 1994]. Indeed, the Sky View Factor has been introduced as a parameter to measure the opening to the sky of the urban fabric, which is associated, among other parameters, to the Urban Heat Island phenomenon [UNGER 2009].

This physical model is applied to the geometry, whose Level of Detail is gradually increased to reach a compromise between accuracy of results, model size and computation time. The sensitivity study has been realized using Heliodon 2 software [BECKERS 2006]. At this stage, we consider these parameters sufficient to determine the Level of Detail of the geometry.

4. Geometric model

At the neighbourhood scale, the geometric model should represent only the envelope of buildings in the area of study and its immediate urban context, so it is important to distinguish the envelope in roofs, walls and windows.

4.1. LoD Procedural Modeling

The main concept of a shape Grammar-based procedural modeling for building, as introduced by Müller et al. [MÜLLER 2006], is based on a rulebase: starting from an initial axiom shape (e.g. a building outline), rules are iteratively applied, replacing shapes with other shapes. A rule has a labeled shape on the left hand side, called predecessor, and one or multiple shapes and commands on the right hand side, called successor.

The whole production process can be seen as a graph where each node represents an operation applied to its incoming geometry stream and the leaf nodes are the geometry assets. This representation results in a Directed Acyclic Graph (DAG), where nodes represent rules and links the stream of geometry [HAEGLER 2010, PATOW 2010]. The main rules that are used in the production process are Subdivision, that performs a subdivision of the current shape into multiple shapes, *Repeat* that performs a repeated subdivision of one shape multiple times, *Component split* that creates new components shapes (faces or edges) from initial volumes, and the *Insert* command that replaces a pre-made asset on a current predecessor.

Figure 1 shows a procedural building model designed using a visual graph-based rule system. By describing a building structure through a ruleset we can obtain a compact representation with geometric details in a simple modeling task process. The main potential of shape grammars lies in the variations they can produce, as each created instance of a building could look different by changing parameters of the rules.

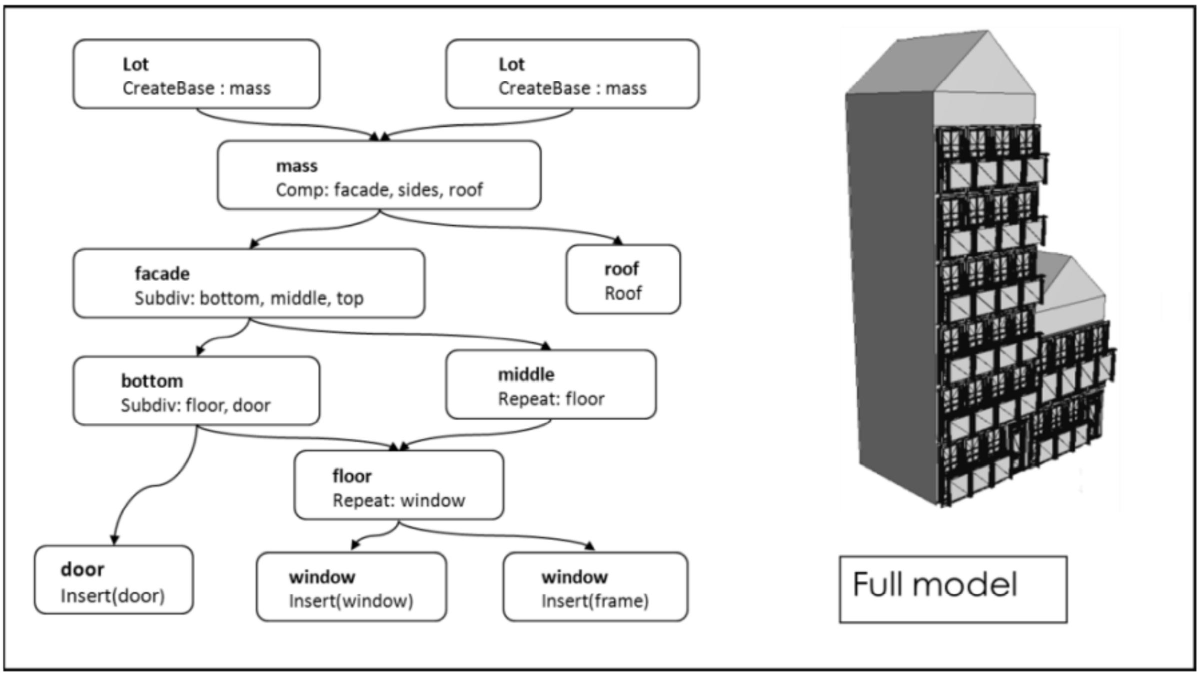

Figure 1: An example of a procedural model of a building. From the envelope mass of the building, facades are selected and described with rules according to the common window and door patterns.

The main goal of our LoD Procedural module is to provide a flexible model generation method that allows the use of Level of Detail to adequate the model to the required analysis needs. Given a set of specific interesting shape elements, we base our approach on a graph transformation process of the original representation, using an extension of the method described in [BESUIEVSKY 2011].

Our module workflow is described in the *Figure 2*. First, a procedural building model is generated at full resolution using semantically enriched rules as in *Figure 1*. Semantic tags represent the architectural structure meaning of the model parts as walls, windows, roofs or balconies. Then, Levels of Detail are described through semantic combinations that are specified using a user-selection interface. The user can use previously defined and stored LoD combinations, as well as build any new specific valid combination. Then, the system automatically processes the model for the specification, transforming the graph and generating the geometric representations. The final model can be exported separately in a 3D geometric format (STL, OBJ or DXF), for being loaded in a simulation analysis package.

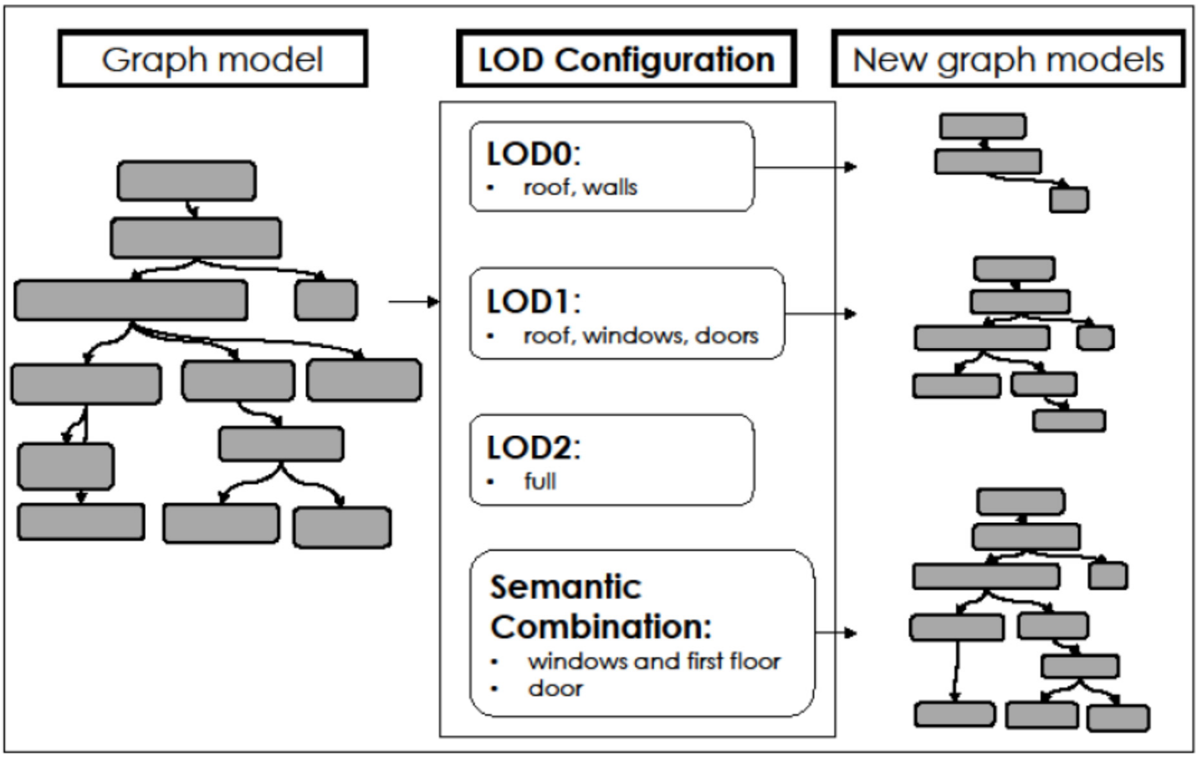

Figure 2: Workflow of the geometric modeling system. From a semantic ruleset model the user configures LoD descriptions using tag labels. An automatic process generates the new graph models representations

4.2 Automatic LoD processing

The base of our system essentially is an automatic transformation of the initial building model. The model is represented by a semantically enriched graph-based interpretation of the original ruleset. The main advantage of this representation is that it allows finding a specific product in the derived geometry, given that all tags produced by any rule can be recovered at any level in the hierarchy. Going forward with this idea, we can build semantic rules relating product names. This is performed by selecting the semantic criteria to apply, called a semantic combination.

We create a new command, called *Filter,* which automatically selects all products in the graph that accomplish a given semantic combination. A valid combination can be described using any expression associating tag labels through boolean operations. For instance, we can locate "*first floor and window*» in the building meaning identifying all windows of the first floor, or we can also specify a predefined LoD level. We let the system find where these criteria are met. Once found, the *Filter* command is instantiated with the required products. In order to locate the semantic label combination, we design an algorithm that traverses the graph processing all required labels and returns the first rule that satisfies the requirements, if any. *Figure 3* shows results of an urban bloc model generated for three Level of Detail specification.

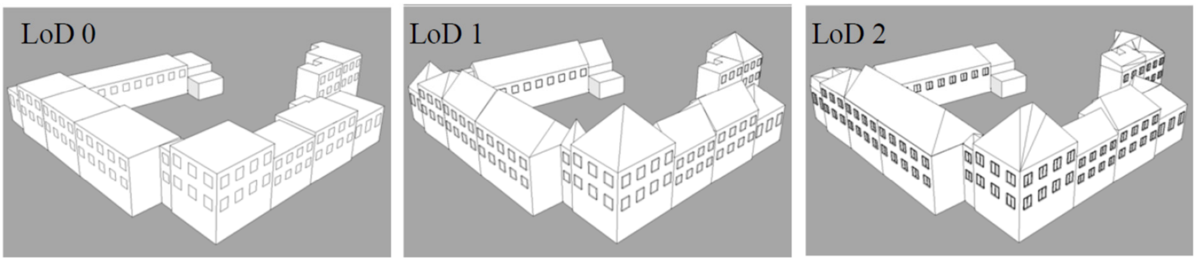

Figure 3. Results for the geometric generation for three different Levels of Details given a specification of windows, roofs and walls at all levels. Our system generates all levels in a single automatic process.

4. Sensitivity study 1: Level of detail of the windows

The definition of the Level of Detail of the windows is could be critical. In previous works [BECKERS 2010], we observed that the direct irradiation and the Sky View Factor depend on several geometrical parameters: orientation, wall thickness, windows aspect ratio and glazing surface. The interactions between them are not predictable; however a realistic representation would provide a huge quantity of polygons. At this stage, we try to assess the Level of Detail of the window, constructing a realistic type and making progressive simplifications.

4.1. Windows LoDs

Four LoDs were proposed. The LoD 0 is a simple plane located at 5 cm from the wall. It just represents the glazing surfaces. The LoD 1 is the same plane but with a wall thickness of 20cm. The LoD 2 includes a simplified frame, in order to represent the actual glazing surface. The LoD 3 includes a realistic representation of the frame and the actual glazing surface. Calculations of SVF and direct radiation were realized.

4.2. Results

4.2.1. SVF

Results of the mean Sky View Factor on the different LoDs confirm that only the wall thickness has an impact on the Level of Detail. The LoD 1, LoD 2 and LoD 3 give the same results. We can conclude that for this kind of window the estimation of mean SVF can be realized in a LoD 1.

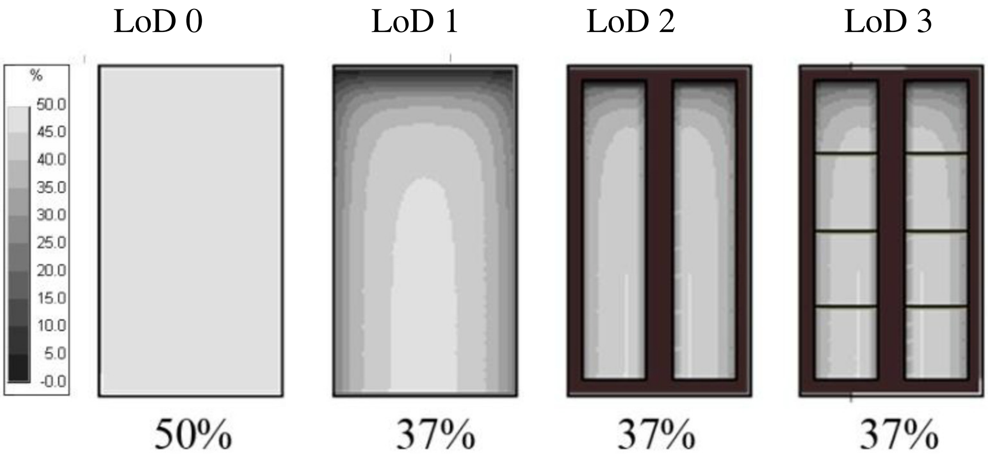

Figure 4. Mean SVF for the different LoDs.

4.2.2. Direct solar irradiation

The estimation of the direct component was computed for each orientation during the solstices and during the whole year. The results in kWh are very different on each orientation, excluding the LoD 2 and LoD 3 where the results are very similar. See *Figure 5* where the lines are overlapped due to the similarity. The results on LoD 0 present the most important variation, due to the lack of the wall thickness.

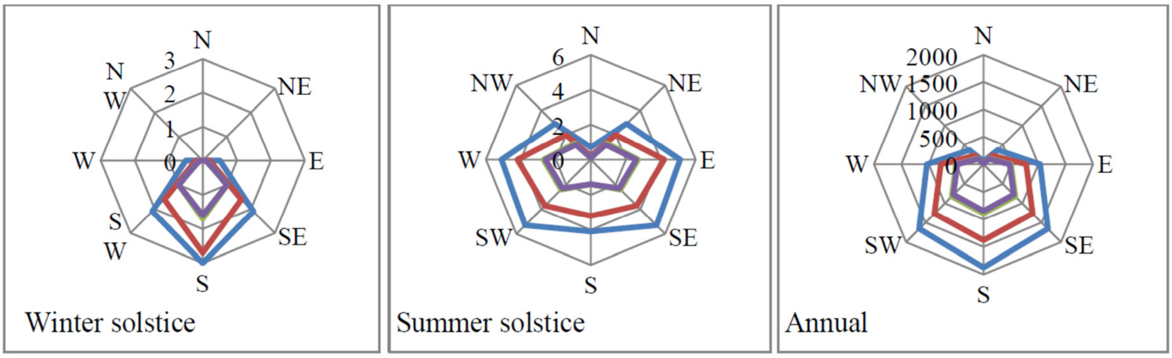

Figure 5. Direct irradiation (kWh) for the different LoDs. LoD 0 in blue, LoD 1 in red, LoD 2 in green and LoD 2 in purple.

An analysis of the results indicates that the difference observed between the Levels of Detail including the wall thickness (LoD 1, 2 and 3) is mainly related to the reduction of the glazing area. Table 1 shows the results of the irradiation (kWh) and the glazing area (m2) expressed in percentages. We can see that these values are related and it could be possible to evaluate the irradiation using LoD 1 and LoD 2 with a post-treatment of the results. This is feasible only if the windows have the same characteristics (aspect ratio, wall thickness and window area).

	LoD 0	LoD 1	LoD 2	LoD 3
Winter solstice	216%	166%	103%	100%
Summer solstice	229%	169%	104%	100%
Annual	222%	163%	106%	100%
Window area	163%	163%	105%	100%

Table 1. Irradiation (kWh) and glazing area (m2) expressed in percentage for the different LoDs.

	LoD 0	LoD 1	LoD 2	LoD 3
Winter solstice	0.57	0.44	0.43	0.43
Summer solstice	2.18	1.61	1.55	1.55
Annual	559	414	411	411

Table 2. Irradiation for the different LoDs (kWh/m2).

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Comparing the results expressed in kWh/m2 allows to illustrate the effect of the wall thickness. LoD 0 gives the most different results, especially in summer where the sun is higher in the sky. However, we can perform the simulations using LoD 1 or LoD 2, which give more similar results. There is no change between LoD 2 and LoD 3. So, we think we can use LoD 2 instead of LoD 3 with good accuracy.

5. Sensitivity study 2: Neighbourhood scale

On previous works, we constructed a 3D urban model of Compiegne city centre manually. We performed several sensitivity studies of its geometry with promising results [RODRIGUEZ 2011]. However, it is evident that a manual simplification of the geometry is not operable, so we decided to continue the geometrical sensitivity study transforming the model into a parametric one. In the next section, we took one block of the model and we changed the LoDs of windows and roofs.

5.1. Results

5.1.1. Level of detail of windows at the neighbourhood scale

We tested the LoD 0, LoD 1 and LoD 2 into the block, as we have seen that LoD 3 is not necessary. Simulation of direct solar irradiation was performed. We found a similar relationship between the irradiation and the glazing area, which proves that it could be possible to do a post-treatment of the results and the need of representing the wall thickness.

	LoD 0	LoD 1	LoD 2
Winter solstice	163%	138%	100%
Summer solstice	178%	135%	100%
Annual	175%	136%	100%
Window area	131%	131%	100%

Table 3. Irradiation (kWh) and glazing area expressed in percentage for the different LoDs.

	LoD 0	LoD 1	LoD 2
Winter solstice	113	96	69.5
Summer solstice	715.7	542.3	401.5
Annual	148118	114926.4	84715.1

Table 4. Irradiation for the different LoDs (kWh).

It is better to use a LoD 1 than a LoD 0, because the results are more accurate and the time of calculus is the same. LoD 2 gives the most accurate results, however the time of calculation is four times longer. If we are interested on kWh/m2 we can use LoD 1.

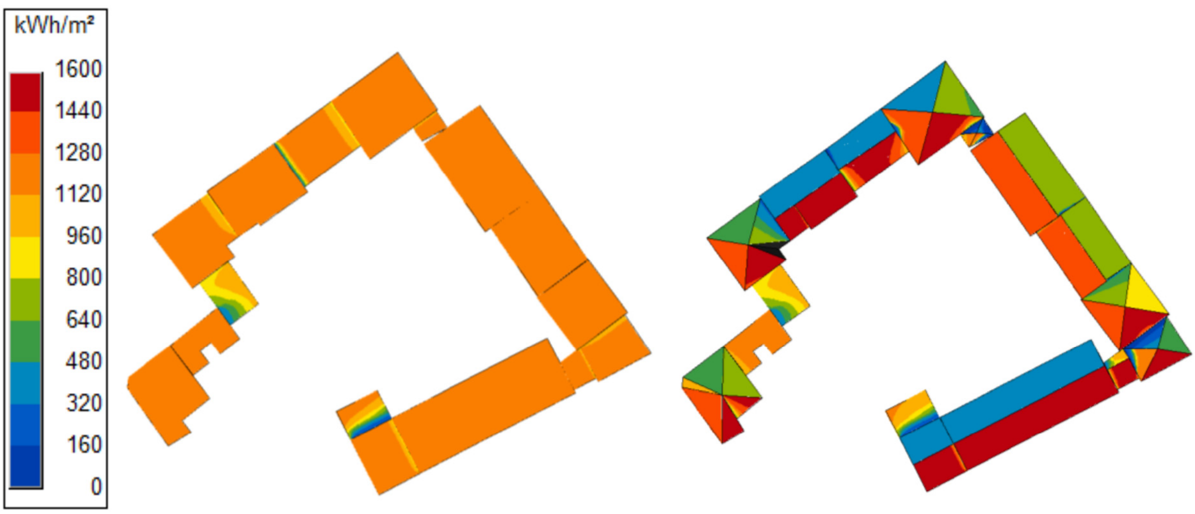
	LoD 0	LoD 1	LoD 2
Winter solstice	0.29	0.25	0.24
Summer solstice	1.85	1.40	1.36
Annual	383	297	287

Table 5. Irradiation for the different LoDs (kWh/m2).

5.1.2. Solar potential of roofs at the neighbourhood scale

At this scale, a correct assessment of the solar potential of roofs requires a detailed representation of the geometry, particularly if the roofs are complex, as the tilted North European ones. Some simulations are performed using models with a LoD 0. However, these models are not adapted at this scale because it does not allow detecting the actual surfaces with a high incident irradiation. One possibility is the use of an intermediate Level of Detail, based on a typology. The results show that it is suitable to use LoD 1 instead of LoD 0. The difference in results is 8%, however LoD 0 does not provide enough graphical information about the localization of the most adapted surfaces for the installation of solar active systems.

ROOFS LoD 0 ROOFS LoD 1



2275657 kWh
1234 kWh/m^2

2471456 kWh
987 kWh/m^2

Figure 6. Solar potential in roofs

6. Conclusions and perspectives

The definition of a specific Level of Detail for solar simulations and urban environment analysis using parametrical models is very useful. Sensitivity studies are fast to elaborate and reflections about the simplification of the geometry are easily made. Next steps of this research should consist in generating bigger models, including the urban context, applying a more complete physical model, and studying the relationship between the different Levels of Details. For example, what is the influence of the urban skyline on the irradiation on windows, and what should be the LoD of the urban context? Procedural methods allow realizing dynamic LoDs (for example, establishing a very high LoD on the studied area and a rough one for the context at each step of the simulation on a mesh). Indeed, such an operation, mandatory for reasonably quick simulations at urban scale, needs a precise methodology that depends on the sensitivity of the simulation to the different LoDs.

Acknowledgements

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