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BIM and advanced methods for generic building energy modeling and simulation.

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ABSTRACT

A building or a group of buildings may be considered as a set of thermal zones which exchange energy with the environment through the envelopes and systems: walls, thermal bridges, glazing, HVAC. A thermal model of a building (or group of buildings) may thus be represented by a graph where the vertices stand the capacitive nodes (thermal zones and wall meshes) and the edges carry the heat flows. Therefore, it is possible to convert a BIM representation of a building such as a gbXML file into a graph holding the physical laws of the heat flows and heat balances involved.

The aim of this paper is to introduce a novel methodology to generate building energy models (BEM) from BIM digital mock-ups. This new approach consists in creating a graph model using the Python NetworkX library from the available geometric and physical data extracted in the BIM representation. The graph model is used to generate a set of linear invariant systems for numerical simulation assuming linear or linearizable heat fluxes (such as radiative exchanges). In this contribution, the approach is applied to a test case building and validated by comparison with a reference model generated with an already tested tool chain.

Keywords: building energy modeling, BIM, gbXML, graph representation.

NOMENCLATURE

Abbreviations	
BIM	Building Information Modeling
gbXML	green building XML
BEM	Building Energy Model
BSP	BuildSysPro

1. INTRODUCTION

A building may be seen as a data generator or even big data generator. The building data are stored in data structures or data models such as BIM digital mockups. BIM based mockups are increasingly used today as standard files to facilitate the data exchange between building stakeholders and tools. They make it possible to describe the 3D geometry and the nature of the buildings (construction, thermophysical properties, etc.).

The built environment sector is responsible for up to 35% of the global energy use and energy-related emissions [1]. Reducing the energy consumption of buildings, thereby reducing greenhouse gases emissions, requires methods to facilitate modeling. The building sector is also an industrial sector that is currently lagging in the process of digitization [2].

In this context, the proposed generic modeling method based on BIM and graph representation is presented as a solution to automate and facilitate the modeling of buildings.

Building energy modeling based on BIM is a new way of creating models dedicated to building energy simulation. It makes it possible to transform a BIM model and the useful information it can provide, into a BEM using specific tool chains. The MyBEM toolchain [3], formerly called Merrubi in reference to the MERRUBI project [4] (funded by the French national research agency) is able to generate in a generic way, a BEM expressed in the Modelica language [5] from a BIM model. The BEM relies on the BuildSysPro library [6] which was validated both experimentally [7] and numerically [8]. Simulation results can be generated using a Modelica compiler (such as Dymola [9]). This

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can be created, where the vertices correspond to the capacitive nodes of meshes and ambient thermal zones, and the edges characterize the heat exchange between two neighboring nodes (between current meshes or between a surface mesh and its neighboring zone).

Such graph makes it straightforward to build a linear invariant system of order *n* (where *n* is the number of capacitive nodes) implementing the building model. In the equations below, *T* is the temperature vector of the capacitive nodes of the system, *A′* is a *n*-order square state matrix, *B′* is a control matrix, *C′* is a *n*-order square diagonal capacitance matrix and *U* is the solicitations vector.

$$C'\frac{dT}{dt} = A'.T + B'.U \quad \textbf{or} \quad \frac{dT}{dt} = A.T + B.U$$

Finally, the numerical resolution is carried out using Python scripts or the Dymola solver(Fig. 3).

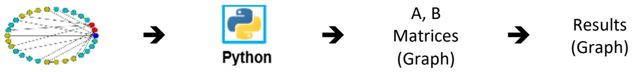

Fig. 3. Process of generating state matrices and results from a graph model using python

Temperatures can be assigned to the vertices and thermal connections to the edges (See paper [12]).

3.3 Reference BEM based BSP and Comparison

To compare and verify the methods used to generate building energy models, a reference BSP model will be developed using the Python platform PyRosette of the MyBEM toolchain. The platform also runs simulation and post-processing to produce the results (Fig. 4).

Fig 4. Process of generating results from a BSP model using MyBEM tool chain

4. RESULTS AND DISCUSSION

This part presents the application of the proposed method to a study case, and the results.

4.1 Application of the Graph Method

4.1.1 Case study

3D model of a campus of five basic buildings drawn using the SketchUp tool was used (Fig. 5).

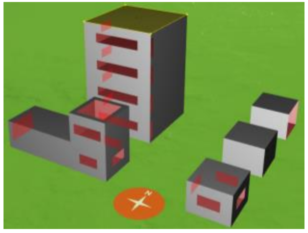

Fig. 5. Use case of five buildings visualized with HelioBIM tool

As described in Section *2.3*, this 3D Model is converted into a gbXML thermal model using the HelioBIM tool. It contains the physical data: boundary conditions, and the occupancy scenarios needed for the building thermal modeling (cf. Tab. 1).

Buildings	Spaces	Boundary conditions (low-floor)	Use scenarios					
			Heating	Cooling	Activity Level	Internal gains		
					Air Changes	Lighting	Occupation	Equipment
1	1	Crawl space	■	x	x	x	x	x
	2		■	x	x	x	x	x
	3		■	x	x	x	x	X
	4	■	■	x	x	x	x	x
2	5	soil	x	■	■	■	■	■
3	6	Heated	x	■	x	x	x	x
	7	■	x	x	x	x	x	X
	8	■	x	x	x	x	x	X
	9	■	x	x	x	x	x	x
4	10	adiabatic	x	x	x	■	x	x
5	11		x	x	x	x	■	■

Tab.1. Boundary conditions and use scenarios from gbXML

Then, the temperature of different nodes is automatically calculated, and finally a graph model with these calculation results is generated based on the considerations listed in section 3.

4.1.2 Simulations

The study case was simulated for one year with an hourly time step, during which the temperature and thermal needs of the 11 spaces were observed. Three simulations were performed (see Tab. 2).

Simulation	Temperature	Ventilation	Solar fluxes	Thermal Regulation
1	Free evolution	Fixed	No	No
2	Free evolution	gbXML schedule	Yes	No
3	gbXML schedule	gbXML schedule	Yes	Yes

Tab.2. Simulation characteristics

4.2 Graph method and results

4.2.1 Graph model generation

The method of integrating the complete process of generating the results from the 3D model has been successfully applied to the case study. The developed program allows to obtain graph models with a selected level of details (see Appendix).

From the graph model, the simulation results are generated and compared to the BSP Model.

4.2.2 Simulation results

Figures 6 , 7 and 8 show the results for simulations 1, 2 and 3 respectively, with statistical values in ℃. Figure 9 shows the final energy needs results in kilowatt-hours.

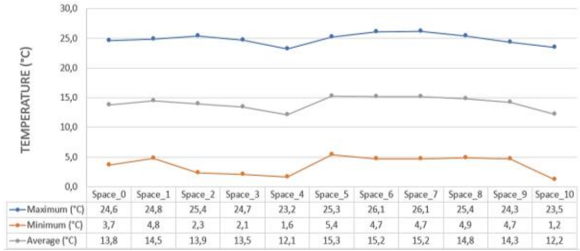

Fig. 6. The maximum, average and minimum temperatures of the 11 thermal zones for simulation 1.

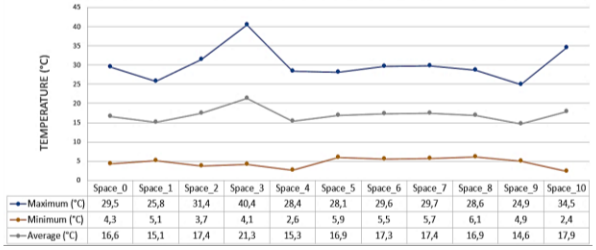

Fig. 7. The maximum, average and minimum temperatures of the 11 thermal zones for simulation 2.

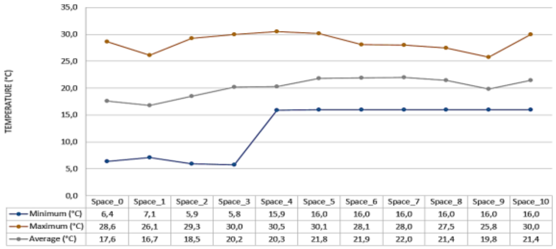

Fig. 8. The maximum, average and minimum temperatures of the 11 thermal zones for simulation 3.

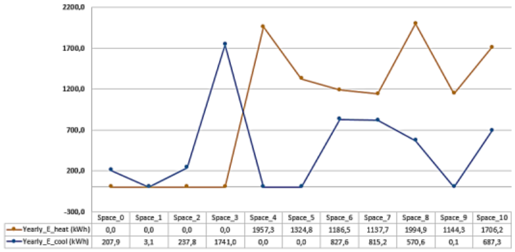

Fig. 9. Yearly final heating and cooling energy needs (in kWh) of the 11 thermal zones for simulation 3.

4.3 Comparison

4.3.1 Gaps in simulation results

Fig. 10 shows the difference between the two models: graph and BuildSysPro.

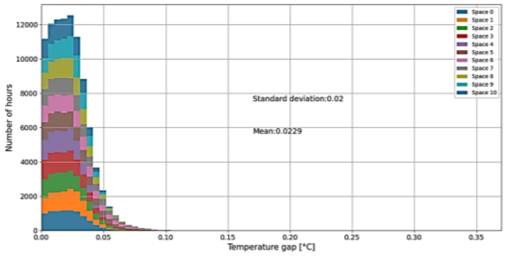

Fig. 10. Yearly distribution of the deviation frequency (°C) to compare the results of the two BEM models for simulation 1.

We obtained an average deviation of 2.29x10-2 °C and a standard deviation of 2x10-2 in °C. These results validate the implementation of internal gains and fixed ventilation. Adding the solar radiation scenario and variable ventilation defined as simulation 2 was successfully implemented, with an average deviation of 4.45x10^{-2} °C and a standard deviation of 4.79x10^{-2}, as shown in Fig 11.

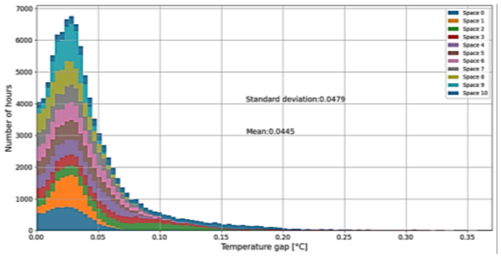

Fig. 11. Yearly distribution of the deviation frequency (°C) compare the results of the two BEM models for simulation 2

Adding the thermal regulation defined as simulation 3 was successfully implemented, with an average deviation of 0.29°C and a standard deviation of 0.12, as shown in Fig 12.

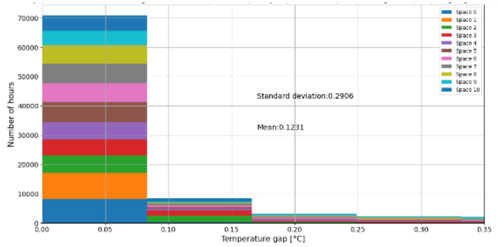

Fig. 12. Yearly distribution of the deviation frequency (°C) compare the results of the two BEM models for simulation 3

The difference in energy needs was also verified with a maximum relative gap of 2%, i.e. a maximum absolute gap of 38 kWh, as shown in Fig 13.

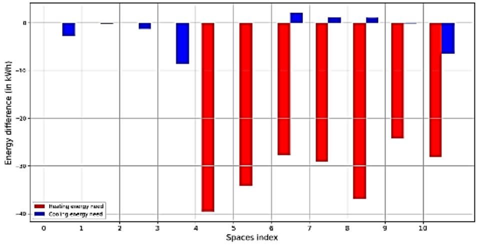

Fig. 13. Gap per space between the final heating and cooling energy needs from the two BEM models for simulation 3

4.4 Discussion

The comparison of the simulation results validates the method based on the BIM model and the graph method for the test case and the simulations.

The main objective of this paper was to verify the feasibility of converting a 3D model into a graph model for a complex use case. It appears that the method used for this purpose can automatically achieve this goal.

The advantages of such an assigned graph are:

- *Connectivity:* Direct access to the information of an element of the building model as well as its connections with the other elements.
- *Assignment:* In the case of thermal elements direct access to the corresponding computed value.
- *Level of detail (LoD) :* Depending on the level of detail required, thermal zones/buildings can be marked and then mixed with more or less detailed thermal models as needed, without the need to modify the corresponding state system.

Indeed, this approach makes it possible to offer great ease of access to the information stored in the models, thanks to graphs geometric properties (connexity). In the case of building energy, this makes it easier to identify and extract information (building structure, thermophysical properties, air conditioning scenarios) at several scales (surface, space, building, group of buildings, etc.) and then, to generate the useful data structures for thermal calculations.

In addition, the ability of developing this tool as a function accessible from a Python program makes automatic modeling possible. This automation has the advantage of greatly simplifying the work of a modeler.

5. CONCLUSIONS

In this paper, the use of graph method applied to building physics was presented as a solution to one of the problems of building energy modeling, which is to facilitate access to data from a BIM mockup in the form of ready-to-simulate structures.

Currently, the developed script is limited to a specific format of the gbXML thermal mockup generated by the HelioBIM tool and it does not integrate HVAC system elements. Other functionalities can be added to this method to achieve other desired goals.

Finally, this methodology can be considered as a step of a new general concept, which consists in better exploiting a graph and applying it to other studies, an analysis of critical nodes and the reciprocal influence of thermal zones on each other. The application of this method to more complex studies using an optimization option will be the subject of a future article.

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APPENDIX

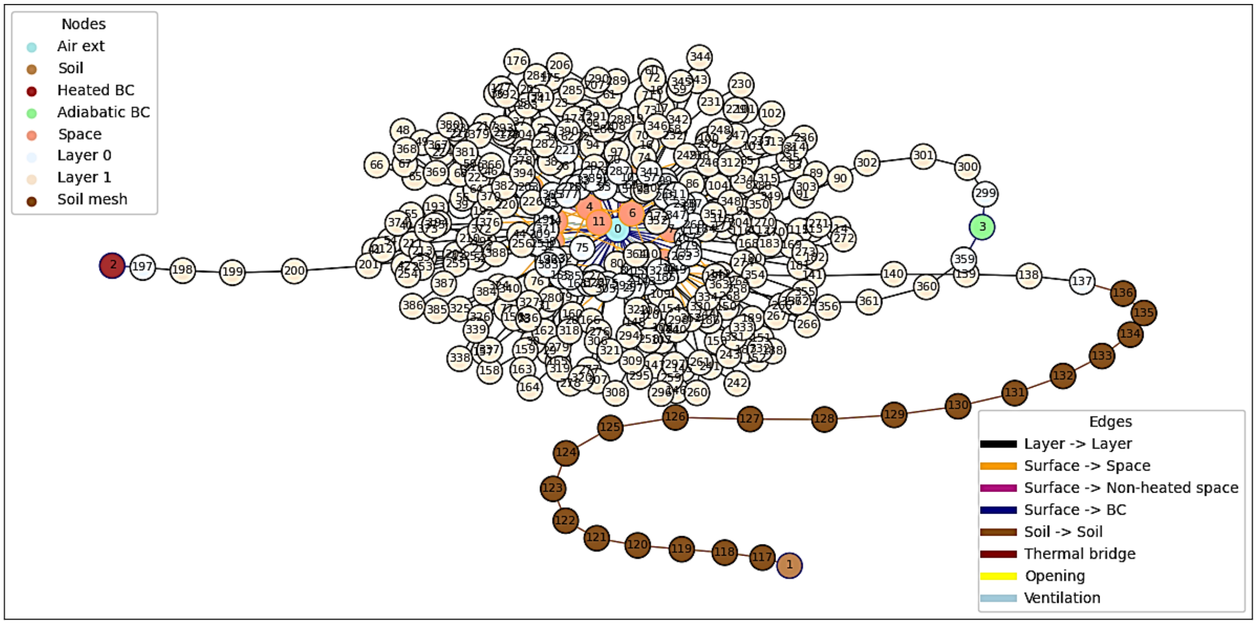

Fig. 1. Graph model of a set of 5 buildings with various boundary conditions (*level 3: mesh scale*)

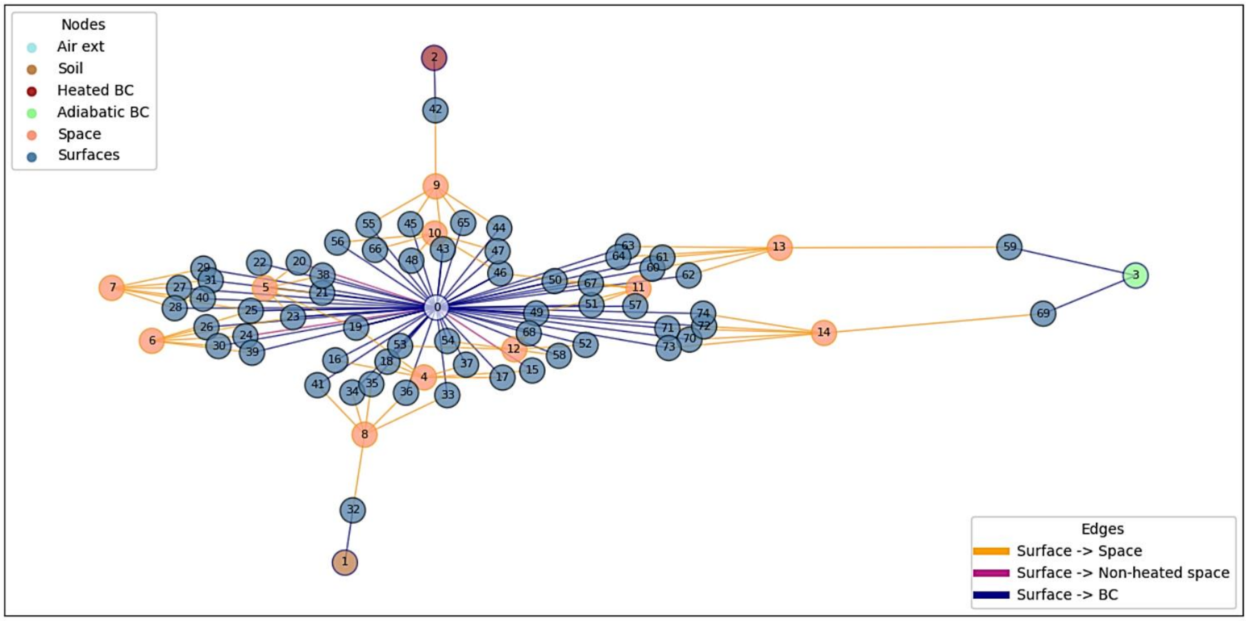

Fig. 2. Graph model of a set of 5 buildings with various boundary conditions (*level 2: wall scale*)