Automatic Modelica BEM generation from IFC BIM

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***Abstract*—The emergence of BIM-assisted building digital twins is facilitating building digitalization efforts across various domains. These digital twins necessitate the creation of building energy models (BEM) derived from BIM data. These models are crucial for conducting building simulations, which in turn evaluate the thermal performance of buildings. To address this need, this study presents a semi-automated workflow for converting BIM data into BEMs. Specifically, the workflow utilizes IFC BIMs generated from point cloud data obtained through building scans. Manual intervention in this workflow is minimal, primarily focusing on detecting and correcting errors in BIM geometry resulting from the semi-automatic conversion of point cloud data to BIM format. The process is applied to an existing office building.**

I. Introduction

In recent times, there has been significant interest in generating building digital twins from the building stock with support from Building Information Modeling (BIM). A building's digital twin can be used as a calibrated simulation tool that can predict the thermal behavior of a building and estimate its thermal comfort and energy needs. It relies on technologically explicit parameters such as the building envelope, systems, usage types, and operational conditions, which can be modified to assess various evolutionary scenarios. Consequently, it can be used as a decision support tool, that leverages simulations to evaluate potential building retrofit strategies aiding in the identification of the most effective energy conservation measures for buildings.

This emerging trend has revealed the need for the generation of calibrated building energy models to support the building's digital twin simulations. Towards this direction, automated processes that convert BIM data into a building energy model (BEM), commonly abbreviated as BIM2BEM, are required. Since 2013 [1], many research efforts have been focused on this transformation process [2]–[4].

Along these lines, this work presents a method for creating building energy models described using the Modelica language. Modelica offers a modeling language that is suitable for this conversion process as it is evidenced by similar research efforts [5]. In the proposed workflow, building geometry is extracted from openBIM IFC4 files- Industry Foundation Classes, and then transformed into a gbXML file– green building XML, an open source standard for interoperability in building energy engineering. This gbXML file serves as the input for constructing the final Modelica model. The proposed workflow is described in the following section, which is succeeded by sections outlining an application example and conclusions.

II. Methodology

A chain of several software tools is used to generate the BEM model of a building's digital twin, as illustrated in the block diagram of Figure 1. The workflow starts from a 3D scan of an existing building. The resulting point cloud is used as input to a BIM editing tool (Autodesk Revit) to generate the BIM of the building. The process can also accept as input IFC BIM files that are designed by hand. After the BIM generation from the point cloud, two subprocesses are required to be executed sequentially: (a) BEM geometry generation process used for the generation of the geometric content of the BEM and (b) MyBEM process used for the final BEM model generation. These sub-processes are indicated in blocks A,B in the diagram of Figure 1 and analyzed in the following subsections.

A. BEM geometry generation

To generate the geometric content of the BEM two software tools are used. These tools are highlighted with blue color blocks in part A of Figure 1. Both tools receive as input the geometric representations of the building's space and opening volumes that are contained in IFC4 BIM files. These files are extracted by Autodesk's Revit BIM authoring tool.

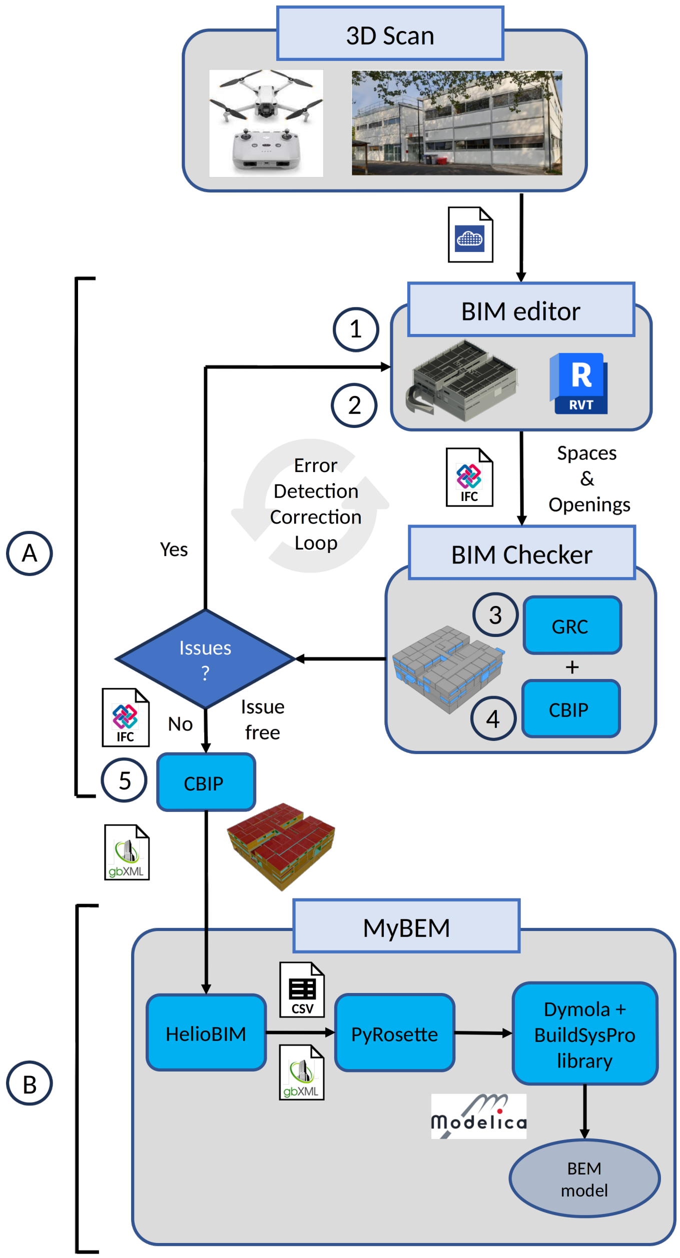

Fig. 1. Proposed workflow from IFC BIM to BEM

The first tool is a BIM checking tool called Geometric Relation Checker (GRC), which checks possible intersections (clashes) among the extracted building space and opening volumes. Two categories of clashes are identified: clashes between space volumes and clashes among opening volumes. Any clash detected between a space and an opening volume is omitted. The detected clashes and the solids involved are displayed to the designer via a GUI [6].

The second tool involved in the BEM geometry generation workflow is the Common Boundary Intersection Projection tool (CBIP). CBIP applies a modified version of the original CBIP algorithm [7], on the extracted building space and opening topology, to generate the second-level space boundary (2LSB) topology [8] of the building and export a gbXML file containing only geometric data from this topology. The simplified CBIP process is applied on the solid geometric representations of the building space and opening volumes, without taking into account the thermal data of the layered bedding of the building constructions, information that is included during the following MyBEM process.

As depicted in Figure 1, the process involves both GRC and CBIP tools in iterative error detection and correction cycles, ultimately resulting in a issue-free IFC4 file. This issue-free IFC4 file serves as input for the CBIP tool, facilitating the export of the final 2LSB topology to a gbXML file. During these cycles, the designer undergoes the following four-step process, as denoted by numbers 1-4 in section A of the process diagram illustrated in Figure 1.

A1. **Space & Opening volume adjustment**. This involves designing space and opening volumes using a BIM editor, ensuring they do not intersect with each other and they are properly attached to surrounding building elements such as walls and slabs.

A2. **IFC file exportation**. Here, an IFC4 file is exported from the BIM editor.

A3. **Clash detection.** The designer checks for potential clashes among space volumes and among opening volumes using the GRC tool.

A4. **2LSB topology generation.** In this final stage, the designer generates an intermediate version of the 2LSB topology using the CBIP tool [7], that is visually inspected using the BIM management platform [6] (BIM-MP).

As it is indicated in the process diagram of Figure 1 two types of issues can be detected using the BIM checker process (steps 3 and 4):

1. **Clash errors**. These refer to intersections among space volumes and among opening volumes, which are identified using the GRC tool in step 3 and visually presented to the user using the BIM management platform (BIM-MP) [6].
2. **2LSB issues:** If the space volumes are designed with a distance greater than the maximum construction thickness tolerance, the 2LSB surfaces related to these space volumes, generated using CBIP in step 4, might be erroneously classified as external. Such issues in the 2LSB topology are identified through visual inspection using BIM-MP's GUI. A snapshot of this platform's GUI is illustrated in Figure 2. The construction thickness tolerance is a user-editable value and for the present work is set at 1 meter.

Once stages 3 and 4 are successfully completed without any detected issues, the resulting IFC4 file is suitable for gbXML file generation. Throughout this iterative process, the designer can carry out an optional space simplification routine, using the BIM editor. Space simplification involves the inclusion of internal constructions, such as walls and columns, in the volumes of the building spaces. By doing

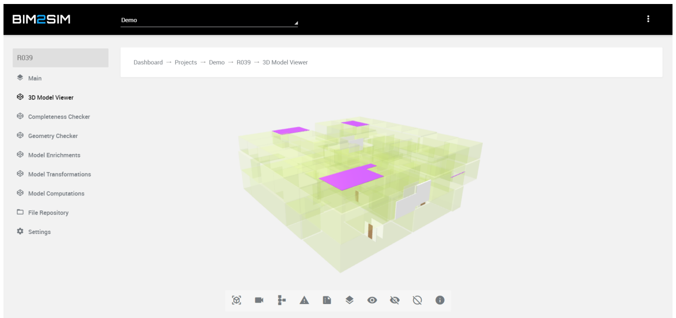

Fig. 2. Snapshot of BIM-MP's GUI environment

so, simpler geometric representations of the volumes of the building spaces are generated, resulting in simplified BEMs with reduced execution times. Finally, during the indicated in Figure 1, stage 5, the final 2LSB topology is generated using the CBIP tool. This topology serves as the basis for creating the gbXML file, which in turn is utilized as input for the MyBEM process detailed in the subsequent subsection.

B. *MyBEM process*

MyBEM is a BIM to BEM platform developed by EDF R&D, able to generate Modelica or linear matrix building energy models from BIM files describing one or several buildings [9]. It represents a chain of tools that allows considering the impact of building location and surrounding urban context on the solar irradiation reaching the building. MyBEM's functionalities include:

- The import of the geometric description of the studied building(s) and the surrounding district
- The assignment of thermal and radiative properties
- The implementation of operation scenarios (heating, cooling, lighting, ventilation, internal gains)
- The calculation of local boundary conditions taking into account the impact of the surrounding
- The generation of the building energy model
- The simulation and assessment of the building energy model and its performances

HelioBIM is the first component of the MyBEM chain. It is a C++ executable that can be used as a local executable or through a user-friendly web app that can be accessed through an account. It is used as a pre-processing tool where developers define materials' characteristics of opaque wall compositions and apply them to indoor / outdoor walls, floors and roofs in addition to the thermal characteristics of openings. Boundary conditions for each surface are also defined (soil, crawlspace, adiabatic, heated or non-heated room) based on the gbXML file generated by the CBIP tool. HelioBIM also carries out solar calculation on the building envelope through extracting the location from a weather data file (TMY2 or EnergyPlus™ EPW) [10], and then running a backward Monte-Carlo ray tracing algorithm, able to take into consideration the district morphology on the solar irradiance from the weather data file.

The enriched gbXML file and the CSVs generated by HelioBIM pass after the preprocessing phase to PyRosette, an EDF Python library for automated generation of BEM in Modelica. The obtained model is a multiphysics and multizone model able to simulate with accuracy the thermal behavior of the building. BuildSysPro, a Modelica library of components using Dymola for building energy modeling, is used as a source of required models to construct the BEM assembly.

The library BuildSysPro is a free open-source Modelica library for building and energy system modeling, developed by EDF R&D [11]. It provides a set of elementary 0D/1D components to describe envelope components, energy systems, and control systems designed for static and dynamic modeling. Its classes are compliant with the Modelica standard library to ensure a good level of interoperability with other Modelica libraries. An energy simulation in BuildSysPro is performed by assembling a building envelope with energy systems and providing the boundary conditions for external (meteorological) and internal (occupancy or heating patterns) conditions. The gbXML schema and the Modelica library BuildSysPro use similar segmentation patterns and properties, so the gbXML to Modelica translation is fairly natural. The BIM to BEM process run by PyRosette contains the following actions:

- Getting the list of building components through parsing the gbXML file
- Instantiating in a Modelica template each building component as a BuildSysPro model instance
- Parametrizing each instance according to the attributes of the corresponding gbXML tag
- Connecting all instances according to their relations through the gbXML ID system.

Due to the size of the models generated by PyRosette which can contain several thermal zones with several tens or thousands of envelope parts, the exported models do not contain a detailed graphical view of all sub-parts of the model rather only the Modelica code is exported.

Finally, the model generated by this process requires calibration before performing the building performance analysis. Onsite measurements (thermal conditions, set point for energy systems, etc.), and the building's power and energy demand could be used to achieve calibration. Several sensitive parameters will be fitted to close the gap between measured and calculated results. Such parameters are many, but material characteristics and air renewal rates are examples of default ones.

III. Application example

The proposed workflow is demonstrated on a 2,500 m² building constructed in the year 1980 and located at EDF Lab Les Renardières (Moret-Loing-et-Orvanne), in the Île-de-France region in north-central France.

The building is the subject of a study in the European project DigiBuild to transform it into a fully equipped and connected site for smart building experiments (energy meters, indoor air quality monitoring, smart HVAC systems, etc. . .). This is achieved through developing an energy model of the building

(BEM model) and personalizing and managing it through the heterogeneous data collected continuously. Therefore, making a digital twin of the real occupied office building.

Figures 3 and 4 show the outcome of the *BEM geometry generation* in the proposed workflow (part- A). figure 2 shows the initial state of the geometry which represents a BIM model generated from a Revit file following a 3D scan of the building. Several errors during the scanning process made the exported file of poor quality and therefore unfit for further building energy modeling. Correcting all errors manually, such as the anomalies in the facades and the broken corner zones (appearing in red), would be unguaranteed and very time-consuming.

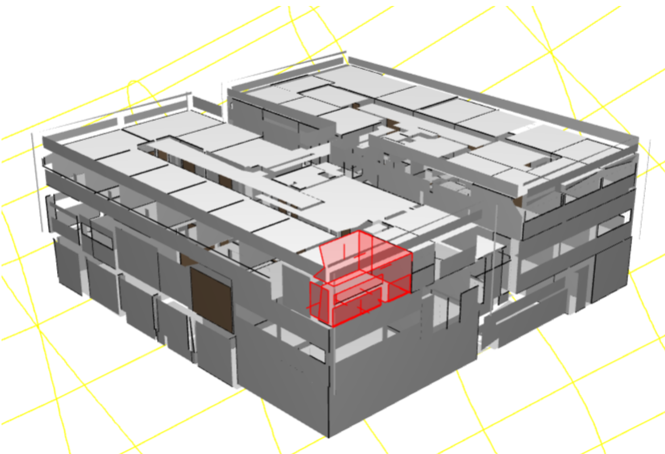

Fig. 3. Initial state of the BIM model

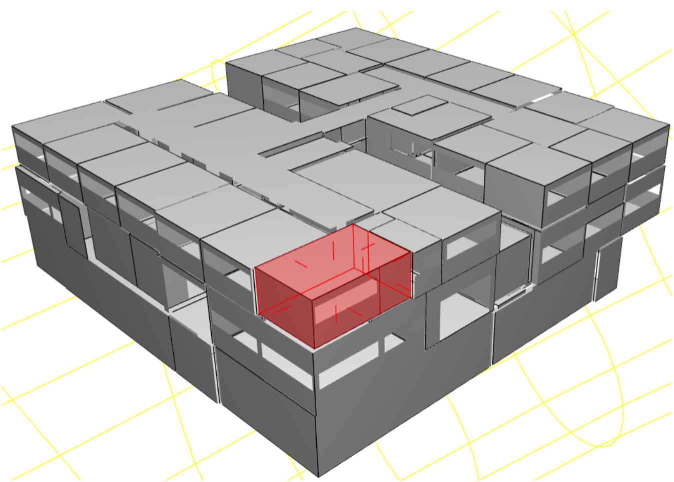

Fig. 4. Corrected BIM model from the BEM geometry generation phase

Figure 4 shows the final exported state of the gbXML geometry, after the iterative phases of BIM checking and editing using GRC,CBIP and Revit tools, and the final transformation using the CBIP tool finish. As is demonstrated with the red color surfaces in these figures, from Figure 3 to 4, all envelope errors have been detected and corrected and space volumes were created correctly containing correct corner zones.

The outcome of the *BEM geometry generation* of the workflow is then passed to the *MyBEM process* which generates a BEM model in modelica using the BuilSysPro library models (Figure 5) after enriching the BIM model with information on construction materials, weather data, and occupancy scenarios in HelioBIM. The BEM model will then be used in energy assessment and building management after being calibrated using onsite measurements.

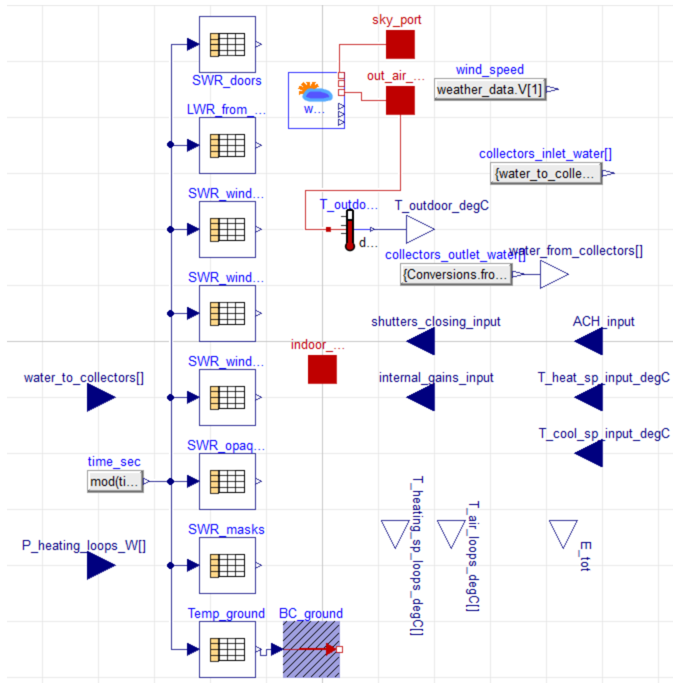

Fig. 5. BEM model from the MyBEM process

IV. Conclusions

To support the automatic generation of digital twins, a two-stage BIM2BEM transformation process is introduced. The process receives as input IFC4 BIM files generated from building scans and produces BEM files that are defined using the Modelica library BuildSysPro.

In the first stage, the geometric errors caused by the semi-automatic point cloud to BIM conversion process are removed using iteratively, the BIM editing capabilities of Autodesk's Revit (error correction) and the BIM checking capabilities of a geometric relation checker (GRC) and a 2LSB generator (CBIP) to produce an intermediate version of the 2LSB topology of the building for visual inspection (error detection). Then from the produced issue-free IFC file, the building space and opening volumes are fed again into the CBIP process, to produce the final second-level space boundary topology of the building, and based on this topology to export the gbXML file of the building.

In the second stage, the obtained gbXML file from the first stage is enriched with information related to the building constructions and solar radiation data produced by HelioBIM to form the final BEM model using Dymola and the BuildSysPro library.

The overall process was successfully applied to the IFC4 data of an existing two-story office building. The results indicate that the process can be generalized to larger and more complex buildings in the future with limited manual design interventions. These manual actions may focus only on removing possible geometry errors from the scan-to-BIM generation process and on possible space simplification operations like space-to-zone grouping, targeting the reduction of the final model complexity.

ACKNOWLEDGMENT

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REFERENCES

[1] J. T. O'Donnell, "Transforming BIM to BEM: Generation of building geometry for the NASA Ames sustainability base BIM," 2013.
[2] I. J. Ramaji, J. I. Messner, and E. Mostavi, "IFC-based BIM-to-BEM model transformation," *Journal of Computing in Civil Engineering*, vol. 34, no. 3, p. 04020005, 2020.
[3] A. Ciccozzi, T. de Rubeis, D. Paoletti, and D. Ambrosini, "BIM to BEM for Building Energy Analysis: A Review of Interoperability Strategies," *Energies*, vol. 16, no. 23, p. 7845, 2023.
[4] M. Hijazi, K. Kensek, and K. Konis, "Bridging the gap: Supporting data transparency from BIM to BEM," *Architectural Research*, p. 149, 2015.
[5] A. Andriamamonjy, D. Saelens, and R. Klein, "An automated IFC-based workflow for building energy performance simulation with Modelica," *Automation in Construction*, vol. 91, pp. 166–181, 2018.
[6] K. Katsigarakis, G. N. Lilis, and D. Rovas, "A cloud IFC-based BIM platform for building energy performance simulation," in *EC3 Conference 2021*, vol. 2, pp. 350–357, ETH, 2021.
[7] G. N. Lilis, G. I. Giannakis, and D. V. Rovas, "Automatic generation of second-level space boundary topology from IFC geometry inputs," *Automation in Construction*, vol. 76, pp. 108–124, 2017.
[8] V. Bazjanac, "Space boundary requirements for modeling of building geometry for energy and other performance simulation," in *CIB W78: 27th International Conference*, 2010.
[9] M. Bouquerel, K. Ruben Deutz, B. Charrier, T. Duforestel, M. Rousset, B. Erich, G. van Riessen, and T. Braun, "Application of MyBEM, a BIM to BEM platform, to a building renovation concept with solar harvesting technologies," in *Proceedings of the Building Simulation Conference, Bruges, Belgium*, pp. 1–3, 2021.
[10] *EnergyPlus™ Version 9.0.1*. US Department of Energy, 2018.
[11] G. Plessis, A. Kaemmerlan, and A. Lindsay, "Buildsyspro: a modelica library for modelling buildings and energy systems," in *Proceedings of the 10th International Modelica Conference*, 2014.