BIM-based energy and acoustic analysis through CVE tools

Mija Sušnik [a], Lavinia Chiara Tagliabue [b,*], Maria Cairoli [c]

[a] *Politecnico di Milano, Piazza Leonardo da Vinci, 32, 20133 Milano, Italy*
[b] *Computer Science Department, University of Turin, Corso Svizzera 185, 10149, Turin, Italy*
[c] *Department of Energy, Politecnico di Milano, Piazza Leonardo da Vinci, 32, 20133 Milano, Italy*

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ABSTRACT

Building information modelling (BIM) is trying to overcome the issue of interoperability by promoting the collaboration between different professions, which enables Building Performance Assessments (BPA) to take place earlier in the design process. Nevertheless, the interoperability is rarely perfect and information is lost during translation from BIM authoring tool to simulation software or the interoperability is limited to the translation of the geometry. The discrepancies in data translations from BIM authoring tool to specific Calculation Virtual Environments (CVE) for energy and acoustic evaluation are considered. For the energy performance evaluation two software tools are tested in the present research paper, namely the Design Builder and IES VE , using IFC and gbXML as data exchange formats. Furthermore, a solution is proposed for overcoming the interoperability issue about acoustic evaluation by adapting programming language in Dynamo Graphical Interface for calculation of acoustic parameters, namely the Reverberation time and Schroeder's frequency, which allow room quality evaluation to take place earlier in the design process as they are crucial for educational and other facility usage buildings.

1. Introduction

One of the main recent goals in building projects is to improve the interoperability and data management (Gray et al., 2017; Ahmed et al., 2010; Kim et al., 2012). Building information modelling (BIM) approach is trying to overcome the issue (García-Valldecabres et al., 2016; Riaz et al., 2017) by promoting collaboration through various export options (Gerrish et al., 2017; Ismail et al., 2018; Bazjanac, 2008) between different professions involved (Dimitriou et al., 2016; Ham and Golparvar-Fard, 2015), using a single model. This also enables building performance assessments (BPA) (Gerrish et al., 2017; Habibi, 2017) to take place earlier in the design process including also holistic evaluations and sustainability check (Motawa and Carter, 2013; Rogage et al., 2019). Detailed architectural models for coordination with other disciplines are usually not designed for direct use in complete volumetric modelling. They first need to be converted into an analytical model in order to perform different types of assessments in Calculation Virtual Environments (CVE) (Prada-Hernández et al., 2015a). Several steps are needed before an architectural model can dialogue with virtual environments (Adamus, 2013) for assessing building's performance (Gray et al., 2017; Ciribini et al., 2016). The focus of the paper is the investigation of the interoperability paths from BIM to CVE for energy (Sanguinetti et al., 2009; Utkucu and Sözer, 2020) and acoustic evaluations (Mastino et al., 2018). A comparison and exploration of different software programs and corresponding flow diagrams is exposed in the paper. The objective of the research is to present the modelling methodologies (Wu and Zhang, 2019; Osello et al., 2011) in BIM in order to make them useful and interoperable for performing different energy and acoustics analyses. The procedure mapping is particularly useful to define and standardize the steps to follow for reliable results, as in most cases modelling issues and data translation in the calculation environment affect the analyses accuracy. The possibility to define the procedure represents a significant benefit in the uninterrupted information chain for consistent analysis and thus trustworthy economic payback of technological solutions and energy saving measures.

1.1. Literature review

An extensive literature review was conducted in order to explore the current state of the art on the specific topic and identify research gaps. A recent bibliometric analysis from 2019 (Jin et al., 2019) showed that the main approach to interoperability is carried out through IFC (Industry foundation Classes) and gbXML (Green Building XML schema) file format. The most frequently

* Corresponding author.
E-mail addresses: mija@demobv.nl (M. Sušnik), laviniachiara.tagliabue@unito.it (L.C. Tagliabue), maria.cairoli@polimi.it (M. Cairoli).
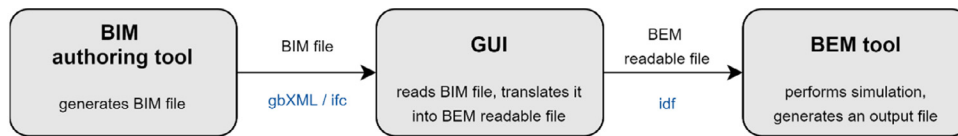
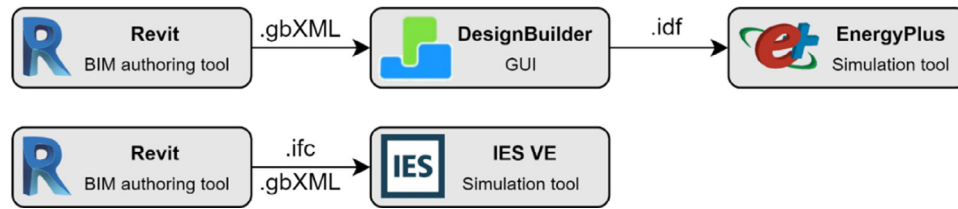**Fig. 1.** BIM to BEM interoperability process.

Fig. 2. First part of the research.

mentioned issue and the most researched topic was the "interoperability" between BIM and BPA tools, with majority of researches focusing on the interoperability between BIM and Building Energy Modelling (BEM) (Prada-Hernández et al., 2015b; Elnabawi, 2020; Garcia and Zhu, 2015). An earlier literature review from 2017 (Jung et al., 2018) explored interoperability for acoustical performance analysis as well (Jung et al., 2018). BIM can be used to deliver information about room geometry and material characteristics; however, the sound source and the audience is usually a domain of acoustic software. The study emphasizes that currently available software cannot perform acoustic analysis using BIM enriched with acoustical data. Another research (Kamel and Memari, 2019) pointed out that the most widely used BIM software is Revit, while BPA was performed with a variety of tested tools.

From BIM to BEM

Some of the software and the issues with the workflows from BIM to BEM, based on the literature review are resumed in the following Table 1 and Fig. 1.

Every simulation engine uses its proprietary format and data from BIM are not always efficiently translated into BEM (Jeong et al., 2014). The usual workflow from BIM to simulation engine is as seen in Fig. 1 (Kamel and Memari, 2019; Gao et al., 2019).

From BIM to Acoustic analysis

The connection between BIM and acoustic simulation is presented in only a few studies in the literature and studies on improvement of indoor acoustic performance are limited (Tan et al., 2017).

Some of the software and the issues with the workflows from BIM to Acoustic tool, based on the literature review, are the following: *Odeon, Ramsete, SoundPlan, VNoise, SEAM 3D, COMSOL Multiphysics, Ecotect, CATT* and *EASE.* The latter two are the leading ones. The geometry can be imported, however the absorption coefficients need to be manually entered by the user (Tan et al., 2017; Kirkegaard and Kamari, 2017; Wu and Clayton, 2013). One of the solutions was a prototype software, which uses Revit API, DirectX toolkit and C# programming language, which allows collection of surfaces and absorption coefficients for calculation of reverberation time and sound intensity level (Wu and Clayton, 2013). There is a plug-in *Pachyderm* for *Rhinoceros* for acoustic simulation that connects with Graphisoft, but Revit on the other hand does not include any tool for acoustic simulations, except an add-in for Dynamo which can perform ray detection (Kirkegaard and Kamari, 2017). A research paper (Aguilar-Aguilera et al., 2019) presented the possibility of using visual programming environment for the calculation of reverberation time and airborne sound insulation between adjacent rooms.

Previous researches (Calquin et al., 2014; Abdelhameed, 2018) have demonstrated the necessity for the integration of BIM in the performance analysis, pointing to the need for further research focussing on acoustical analysis where the lack of interoperability is especially significant. The takeout of the literature review is that interoperability between BIM and acoustic simulation software usually relates only to the translation of the geometry. Given its importance, the topic definitely needs further research and existing tools that are used for and acoustic analysis based on BIM should follow the development of BIM tools, which have been on the rise for several decades.

Although energy performance and acoustics are both very important aspects in building performance engineering, one is notably neglected compared to the other. Since the idea of BIM is to work as a central database that could be used for all kinds of analyses, it was decided to investigate the interoperability issue for both performance aspects and therefore demonstrate that variety of analyses can be performed using single BIM model.

This paper will investigate the issue of interoperability from two different angles, using two different methods. It will show what are the benefits and drawbacks of each and therefore serve as a guide for the user to manage the issue of interoperability when performing BIM based analyses.

2. Method

Based on the literature review, it was decided to validate the data transfer from BIM to BEM by comparing two different approaches using two file formats (part 1 - Section 2.2), followed by exploring how BIM can be used to conduct acoustic analysis (part 2 - Section 2.3).

The workflows of part 1 are presented in Fig. 2. Revit was used as a BIM authoring tool exporting gbXML and IFC. A gbXML file was imported to DesignBuilder, which as a GUI (Graphical User Interface) prepared an IDF input file for EnergyPlus simulation tool. An IFC file was imported to IES VE to perform the simulation.

The second part of the research again used Revit as a BIM authoring tool and Dynamo as a Graphical Programming Interface, as shown in Fig. 3. Values necessary to calculate acoustic parameters were extracted from BIM model using VPL (Visual Programming Language).

2.1. Case study

Revit model that was used for the analysis is a universal simple single-floor school building, that consists of an Entrance area, a Hallway, five Classrooms of different sizes and a Restroom area. Classroom areas are 39 m^2, 53 m^2 and 59 m^2, Hallway is 140 m^2,

Table 1
Interoperability issues for software.

| n.	Software	Issues	References
1	*Excel*	A semi-stationary regime uses quantities that can be extracted through schedules from Revit	De Angelis et al. (2015)
2	*Green Building Studio (GBS)*	In the case of errors at the export, software assigns default values in order to perform the simulation	De Angelis et al. (2015), Ciribini et al. (2016) and Ciribini et al. (2015)
3	*SketchUp plug-in BESTenergy (EnergyPlus)*	Offers a control over input information, however the material properties and geometrical descriptions needed modification	De Angelis et al. (2015), Butera et al. (2013) and Aste et al. (2020)
4	*EnergyPlus through GBS or OpenStudio*	Good geometrical interoperability, but the model includes the default values that come as a consequence of exporting through GBS	Ciribini et al. (2016) and Gao et al. (2019)
5	*DesignBuilder*	Geometry exported well but default values were used for schedules or needed to be manually modified	Ciribini et al. (2016) and Ciribini et al. (2015)
6	*IES VE*	Allows bi-directional information flow	Tagliabue et al. (2018)
7	*C# and Modelica*	Model does not need to be manually recreated in a simulation tool, which is overcoming the issue of file formats	Jeong et al. (2014)
8	*Revit's plug-in RevitPythonShell and Design Performance Viewer*	Enables access to API for extracting data from the BIM	Miller et al. (2014)
9	*Space Boundary Tool*	Translates geometry from IFC file and exports an IDF file	SBT (2020) and Ivanova et al. (2015)
10	*Grasshooper, Honeybee*	Modelling in Rhinoceros was found hard and time consuming	Ciribini et al. (2016) and Ciribini et al. (2015)
11	*Ecodesigner STAR*	Issues were observed in connection with linear thermal bridges and annual heat demand	Lovšin (2016)
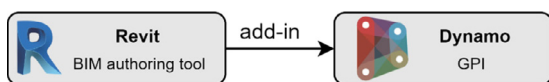
Fig. 3. Second part of the research.

Entrance and both Restrooms are 12 m^2. Total area of the building is 380 m^2. In Fig. 4 the roof is not shown and Table 2 lists all the materials and thermal characteristics of building envelope. All windows have solar heat gain coefficient (SHGC) of 0.56, meaning that 56% of solar radiation is admitted through the window.

2.2. Preparation for part 1: translation from architectural to analytical energy model

Different types of building analyses require different input data for a simulation tool, so different formats were developed by the AEC industry (Ramaji et al., 2020). Industry Foundation Classes (IFC) schema, developed by BuildingSmart (BuildingSmart, 2020), is widely accepted with the main purpose of being universal and allowing data sharing between different stakeholders (Gao et al., 2019). Green Building XML (gbXML) was developed by Autodesk Green Building Studio (gbXML, 2020) mainly to simplify the translation from BIM model to energy simulation software, and it is therefore recognized by many BEM tools. The following CVE tools have been tested:

- Design Builder (DB) is a modelling environment which enables the import of a gbXML file format. It can prepare a simulation input file and thus works as a GUI for Energy Plus, which is a simulation engine for thermal analysis, integrated within DesignBuilder software (DesignBuilder, 2020).
- Virtual Environment, developed by IES (IES VE), combines several analysis tools and it integrates with BIM through gbXML and IFC file format. Its simulation engine for thermal simulation is ApacheSim (IES VE, 2020).

An architectural model needs to be enriched with data that are needed to perform the analysis, which means it is crucial to perform the translation into analytical model. The proposed process consists of a sequence of steps, shown in Fig. 5.

2.3. Preparation for part 2: room acoustic parameters

Simulation software for acoustic analysis is only able to import the geometry without any other data, so the usual workflow consists of exporting the geometry from a BIM authoring tool and manually applying acoustic data inside the simulation tool. The goal was to enable performing preliminary acoustic analysis inside Revit without the need for export and manual insertion of the acoustic parameters, and present the results visually inside Revit. The aim was to make a user-friendly procedure that is adaptable to changes in Revit. Dynamo was adopted as a visual programming environment to create a script, while Dynamo Player was used as an interface for the user to modify the parameters. The presented workflow is focusing on the calculation
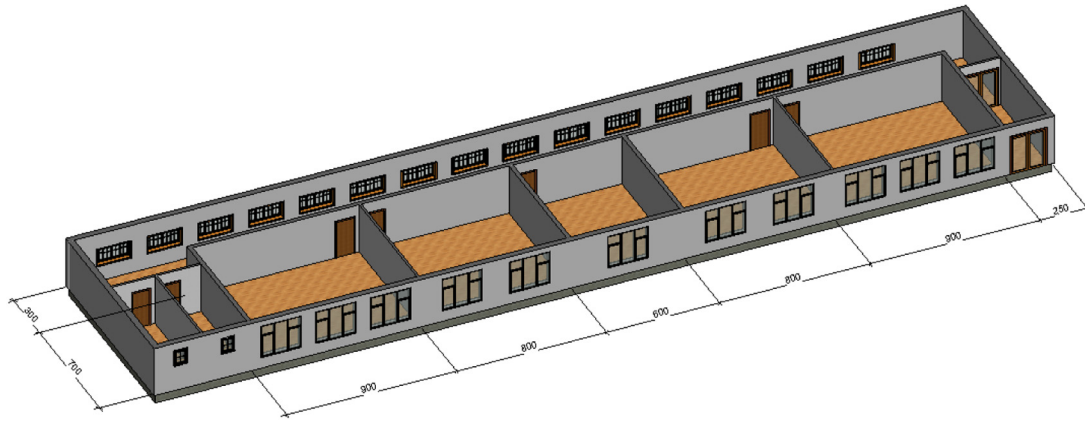
Fig. 4. School building model in Revit.

Table 2
Material properties of building envelope defined in Revit.

| Element	Material	Thermal conductivity	Thickness	Conductance of wall
External wall	Plaster	0.510 W/mK	0.01 m	0.2984 W/m²K
	Rock Wool	0.034 W/mK	0.10 m	
	Brick	0.540 W/mK	0.20 m	
	Plaster	0.510 W/mK	0.01 m	
Roof	Aluminium	230.0 W/mK	0.01 m	0.2178 W/m²K
	Rigid insulation	0.035 W/mK	0.15 m	
	Concrete	1.046 W/mK	0.30 m	
	Plaster	0.510 W/mK	0.01 m	
Floor	Wood flooring	0.180 W/mK	.01 m	0.5224 W/m²K
	Cement Screed	1.046 W/mK	0.05 m	
	Rigid insulation	0.035 W/mK	0.05 m	
	Concrete	1.046 W/mK	0.40 m	
Window	Triple glazing - 1/4 in thick - clear/clear/low-E (e = 0.2) glass			1.5330 W/m²K
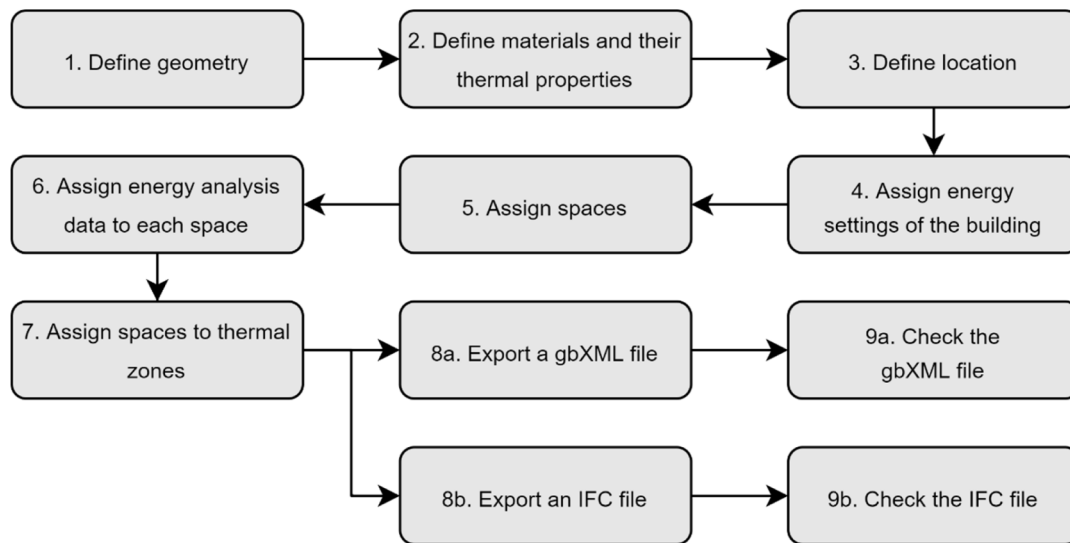
Fig. 5. Step-by-step process.

of Reverberation time and Schroeder's frequency, according with acoustic requirements in indoor spaces and applied to educational buildings as standards, however, following the workflow, other parameters can be calculated as well.

Reverberation time (RT) is defined as a time needed for a sound level to decay for 60 dB after the sound in a room has been switched off. The decay is due to material absorption of a sound at each reflection and air absorption (Barron, 2010).

Sabine's equation for calculating RT, where $A = S \cdot \alpha$ and S is surface, α is average absorption coefficient, is:

$$RT = \frac{0.16 \cdot V}{A} \qquad (1)$$

Slovene regulation (TSG-1-005:2012, 2012) provides an equation for calculating optimal reverberation. The value represents a middle value of RT in octave frequency band between the typical values of 500 Hz and 1000 Hz. For classrooms, the optimal

reverberation time is calculated as:

$$RT_{opt} = 0.32 \cdot log \cdot V - 0.17 \qquad (2)$$

When assessing room acoustics, the whole spectrum of frequencies is analysed in order to identify undesirably high RT that needs to be decreased. In order to do so, the whole frequency spectrum needs to be divided into two parts for an analysis of the sound field. The approximate limit between low and high frequency regions is called Schroeder cut-off frequency (Crocker, 2007). Each frequency spectrum is analysed using a different approach (Kuttruff, 2009). The equation to calculate Schroeder's frequency is:

$$f_{Sch} \cong 2000 \cdot \left(\frac{T_{60}}{V} \right)^{1/2} \qquad (3)$$

These two parameters are fundamental when indoor environmental quality (IEQ) is pursued. In the early design stage, the calculation can support the sizing process and promote the introduction of technological and interior design strategies for correcting the values and improve the performance. It has been demonstrated that in educational facilities students' learning performance and productivity (Huang et al., 2012; Bae et al., 2020) is increased with increased IEQ (Lee et al., 2012; Choi et al., 2014a; Ricciardi and Buratti, 2018; Choi et al., 2014b) and acoustic quality (Mastino et al., 2019). It is therefore of great importance to control those parameters.

3. Results

3.1. Results for part 1: The comparison of different software and file formats

Evaluation criteria for all three import options (gbXML to DB, gbXML to IES VE, IFC to IES VE) were checked for different export settings in Revit, namely the different export category (i.e. Spaces, Rooms) and different export complexity (i.e. Simple, Shading surfaces). All of these settings apply only to gbXML export, since IFC export does not distinguish between them. Nine criteria were evaluated and described for each of the export options.

Building geometry: When exporting a gbXML and IFC file, setting Export Complexity to Simple with Shading Surfaces, shading elements appeared in IES VE and DB even though there were no shadings modelled in Revit. The geometrical comparison of the three models showed that the shading surfaces come from the roof and floor overlapping with grid lines, since both elements are aligned with the external wall, which is modelled as a centreline (see Fig. 6).

Besides Shading surfaces issue, windows in one of the rooms were not imported in IES VE with gbXML file.

Location: IES VE with both Export Category options, both Export Complexity options and both file formats recognized the location. DB, on the other hand, does not import location data at all.

Dimensions (area, volume): Areas and volumes are properly imported into IES VE when all options of gbXML file are tested. With IFC file import in IES VE, the bounding surfaces of spaces are placed on the grid lines, making spaces larger than in Revit. The difference occurs also in volume calculation. In Revit the Space height is the distance between levels, which is the inner height of the room, while in case of IFC file import to IES VE, the height is a sum of inner height of a room and thickness of a roof. Floor areas, computed in DB do not match values from Revit, since software assigns thickness of 10 cm to every wall. The height is a sum of inner height of the room and roof thickness. Areas and

volumes are therefore not comparable to Revit values. Table 3 shows discrepancies in area, height and volume calculations.

Space: All Space Types were properly imported to IES VE with gbXML file format, regardless of Export Complexity, but only when Spaces were used as Export Category. When IFC was imported to IES VE, Zones were imported without any properties. Only one Space Type from Revit was imported and was applied to all spaces. DB uses Activity templates to define space data and regardless of the Export Category or Complexity, Space types from Revit were not imported and software used one of the default templates.

Building construction: in the case of gbXML file import to IES VE and DB, building constructions were properly assigned to building elements, materials, layer thicknesses and their thermal properties were imported (with exception of windows and doors in DB, which need to be manually selected from the Imported folder). The difference to Revit is in the calculation of U-value, where IES VE and DB are more precise and include the resistance of outer and inner surfaces as well. With IFC import to IES VE, almost all constructions were imported, except for the Roof, even though it was exported from Revit. Building constructions were properly assigned to building elements in the model, however, the thermal properties were incorrect.

Occupancy: With gbXML import to IES VE, regardless of export complexity, the number of people, area per person, sensible and latent heat gain and occupancy schedule were correct and properly exported from Revit, but only when Spaces were used as export category. Opening IFC file in IES VE showed that the number of people and occupancy schedules were not correct, while Sensible and Latent heat gain were successfully imported. Due to Activity templates in DB, default values were used and the correct data had to be manually implemented.

Electrical loads: gbXML file in IES VE imported Lightning load and schedules and Power loads and schedule when Spaces were used as export category. In case of IFC import to IES VE, lightning load was imported correctly, but not the lightning schedule. Power loads were not imported at all. Due to Activity templates in DB, default values were used and the correct data had to be entered manually.

Outdoor information: IES VE does not show outdoor information when gbXML or IFC file is imported, although air changes per hour were exported from Revit and due to Activity templates in DB, no outdoor data were imported to DB so default values were used.

HVAC: IES VE imports HVAC data in case of gbXML and IFC, using Spaces, while when using Rooms, this data were not exported, so default values were used and in case of DB, due to Activity template no data were imported, so default values were being used and the correct data had to be entered manually.

Overall comparison summarized

Table 4 summarizes the results of the comparison of the three chosen approaches by looking at nine evaluation criteria, listed in the first column. Green indicates great interoperability without any issues, yellow represents good interoperability with minimum manual work, and red corresponds to no interoperability.

3.2. Results for part 2: Dynamo script for acoustic analysis

There are four Dynamo scripts, corresponding to four task that can be performed through Dynamo Player.

Setting Room parameters script creates room parameters in Revit. In Dynamo Player, user needs to click on a Play sign in order
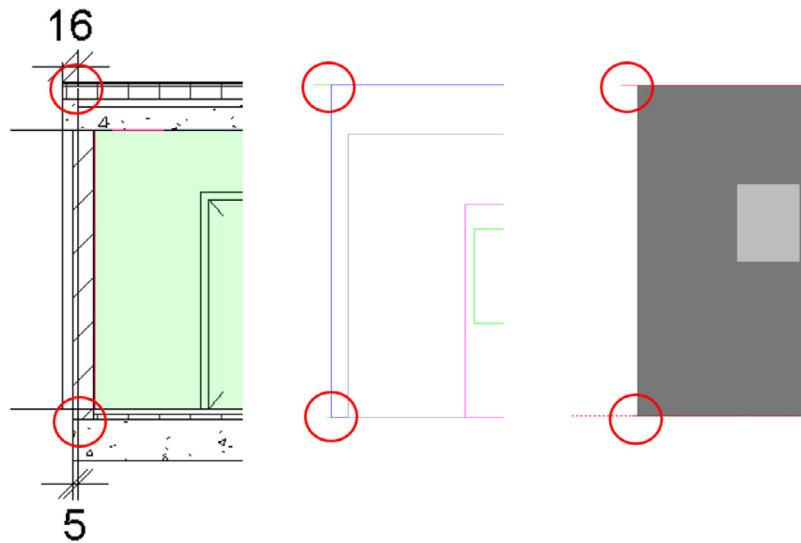
Fig. 6. Comparison between Revit (left), IES VE (middle) and DB (right).

Table 3
Comparison of area, height and volume discrepancies.

	Area (m^2)	Area discrepancy	Height (m)	Height discrepancy	Volume (m^3)	Volume discrepancy
Revit	59.41		2.70		160.41	
IES VE gbXML	59.41	0%	2.70	0%	160.41	0%
IES VE IFC	63.00	6%	3.17	17%	199.71	24%
DB gbXML	60.96	3%	3.17	17%	193.26	20%

Table 4
Comparison of different software and file formats.

Evaluation criteria	IFC import in IES VE	gbXML import in IES VE	gbXML import in DB
Building geometry			
Location			
Dimensions			
Space			
Building construction			
Occupancy			
Electrical load			
Outdoor information			
HVAC			

Fig. 7. Created parameters.

to run the script. Created parameters are stored under Analysis Results and will be filled with values after running the next script (see Fig. 7)

Calculation script is more complex and it was written using packages *GeniusLoci*, *Clockwork*, *Data-Shapes* and *DynamoMEP*. It consists of several parts; the main ones are:

- Selection of a room in Revit and getting desired areas: the user enters the name of the room of which he wishes to

perform the calculation. It was decided to use this approach so that the acoustic parameters were calculated only for rooms that needed acoustic analysis, which is not necessary for e.g. restroom areas, technical rooms etc. Windows and doors areas calculation was extended in such a way that also rooms with no windows or doors were considered. Ceiling and floor area were extracted from Revit, while net wall area was calculated as a multiplication of two extracted values from Revit, the perimeter and the room height, reduced by window and door area. It is therefore of crucial importance that the room Unbounded Height is set correctly.

- Reading values of absorption coefficients from Excel: Excel was used as a database for sound absorption coefficients, which could be extended or modified at any point. In order for user to select the values from Excel database, a multiple input form was introduced with dropdown menus, sliders and text boxes.

- Calculation of final results: once the areas and absorption coefficients of materials were collected, the final results could be calculated. After all the S*a were calculated and room volume was extracted the RT60 was computed. Similarly, the RT optimal and Schroeder's frequency were obtained, followed by the comparison between RT60 and RTopt. The RTopt was valid only for classrooms so the script selected only rooms where Classroom/Lecture/Training was selected as a type, and sets the values to the predefined parameters to only those rooms.
- Setting values to the predefined Room parameters in Revit: the final step of this script was to push the calculated values back to Revit where they were listed under parameters that had been defined with a previous script.

In order to run a script with Dynamo Player, user first needs to enter the room name that needs acoustical evaluation under Edit inputs and select a Play sign (see Fig. 8)

Pop-up window will appear which will require input values of finish materials, door and window materials, data about people, seats, desks and size of a blackboard. User needs to select a value from a dropdown menu, select a number by using a slider and enter the value in a text box. After that, when the run is completed values will appear under Analysis Results(see Fig. 9)

Visualization script consists of three parts:

- The writing of an instruction message that appears in Revit: the instruction message was written as an input for the Python script, which as an output, showed a Task dialogue window in Revit.
- Getting parameter values from Revit: after the initial message was displayed, the script extracted the values from "RT60 equal or less than RTopt" parameter, which was either Yes, No or NA (not applicable).
- Assigning a colour to rooms based on those values: based on the value, three colours were assigned to a room. Green where RT60 was equal or less than RTopt, red when RT60 was larger than RTopt and grey where this parameter was not applicable. If the value was not calculated for room, a default value (light blue) would remain.

When selecting Play sign in Dynamo Player, a message box will appear with instructions and a colour legend. After that, the rooms in the selected view will be coloured according to the colour legend (see Fig. 10)

Clear visualization script can be run if the user wishes to clear the visualization, which is a result of running the Visualization script. It will clear the assigned colours in the view after the user has selected the view as an input in Dynamo Player.

Testing the script: the script was tested in a two-level school. The test was mainly intended to check how the script addresses particular rooms and it showed that there were no issues when a room was defined with a room separation line or when the room stretched over two levels. Perimeter and height of a room adapted accordingly, causing no problems.

4. Discussion

4.1. Discussion for part 1: Interoperability between BIM and BEM

Great difference can be observed when comparing the three tested approaches: Revit to IES VE through IFC or gbXML or Revit to DB through gbXML. Both file formats are capable of communicating with CVE tools and, in terms of importing geometry, both formats performed well. However, the ultimate goal should remain to reach a full interoperability, which entails much more than just building geometry, such as construction materials, schedules and thermal zones setup. Importing a gbXML file into IES VE retrieves almost all of the data from Revit, while the other two approaches have proven less reliable. Nevertheless, in all cases, additional manual and time-consuming implementations are needed. In the ideal workflow, all the data are accurately translated into CVE with no additional editing. It is important to mention that in some cases, the data were properly exported from Revit, yet they were not imported into the tested simulation tool. When the thermal properties calculation is concerned, the difference found in the calculation of U-value in Revit and in the CVEs is due to the specific purpose of the information modelling tool, which is not designed as a software for assessing thermal performance and this function is under development. Overall, it is still important to bear in mind that no software can provide absolute results. Simulations are inherently meant to give an approximation, although having an accurate model increases the possibility to have results that are more reliable and that can be used to promote energy saving measures and payback time calculation of investment. The contribution of the demonstrated discrepancies can therefore serve as a guide for the user when importing the model into a simulation software, in turn enabling a thorough interpretation of the obtained results.

4.2. Discussion for part 2: Interoperability between BIM and acoustic analysis

The acoustic analysis is mandatory in educational facilities and strongly significant for the built environment. Some tools are available for envelope evaluation however, a calculation considering the whole space could be useful to promote a higher quality of the indoor spaces. Revit as a BIM authoring tool can be used to support the analysis aimed at achieving room quality and comfort, which was in this case assessed by acoustic parameters and Dynamo VPL could support the development of scripts with this main key role. The tested script in visual programming environment has been developed inside Revit, with no need for importing the model into another simulation tool to get preliminary acoustic results. This procedure reduces the calculation time and eliminates errors that might occur during the translation of a model from one software to another. Dynamo Player, which is a Dynamo interface, allows the user to run the script without programming knowledge. A high level of design optimization can be achieved by visualizing the results inside the same tool. The ability to write a script in order to perform different analyses represents an extension to the use of a BIM authoring tool. The script can be used for preliminary acoustic analyses by producing values for acoustic parameters and evaluating indoor spaces accordingly. Some of the script's strengths regarding geometry include the assessment of rooms that extend through several levels and the assessment of rooms with no windows and doors. This comes as a consequence of defining a room with a room separation line. It is also possible to automatically recognize whether a room is a classroom and compute its optimal reverberation time, serving as a basis for acoustic evaluation. An additional advantage is that the database of all materials and their sound absorption coefficients can easily be adapted and modified by the user, for example if any custom material has to be included. The overall experience was aimed to be user-friendly. Nevertheless, there is still room for improvement since the script includes several identified limitations. First, user cannot choose different types for windows or doors inside one room. Second, it is assumed that all walls of a room are made of the same material. Third, the script's use is limited to simple shape rooms, therefore a room with an inclined ceiling would not produce accurate results. These limitations of the proposed tool are subject to further research and optimization
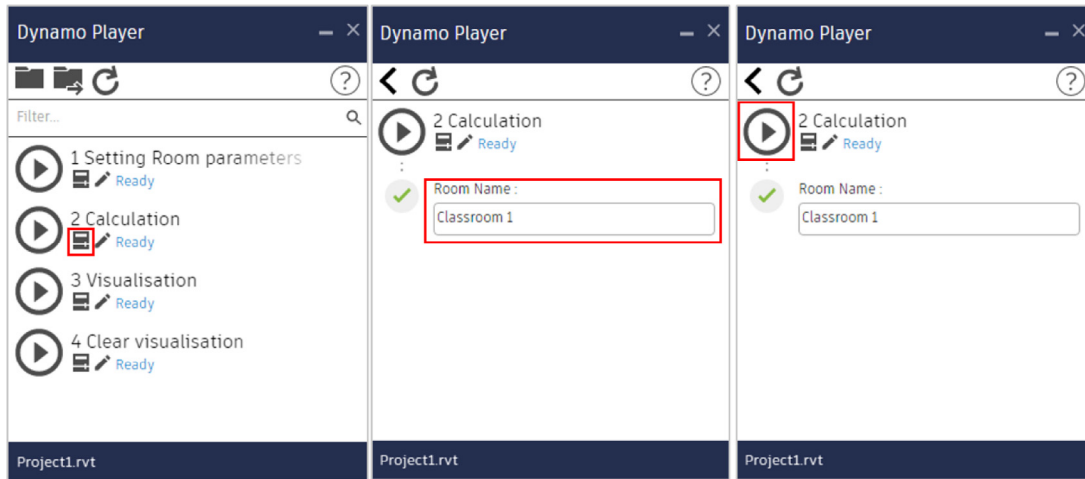
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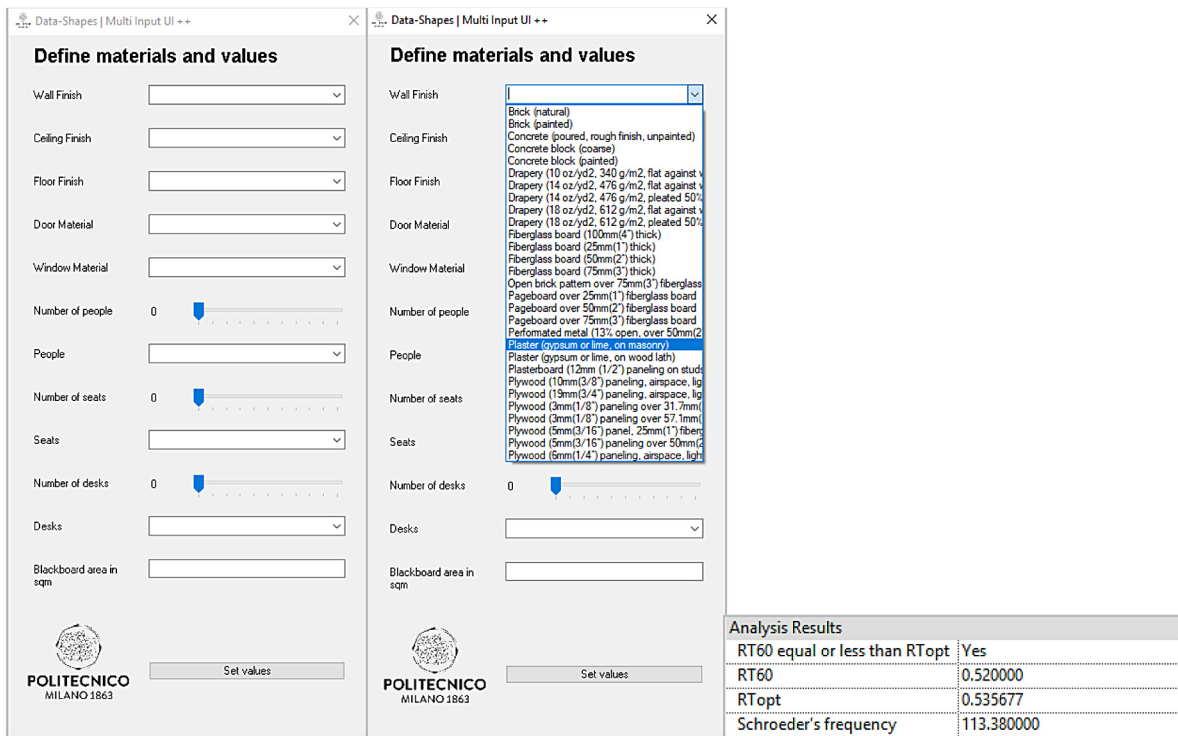**Fig. 8.** Dynamo Player steps for Calculation script.

Fig. 9. Input values in UI dialogue window (left and middle) and values under created parameters (right).
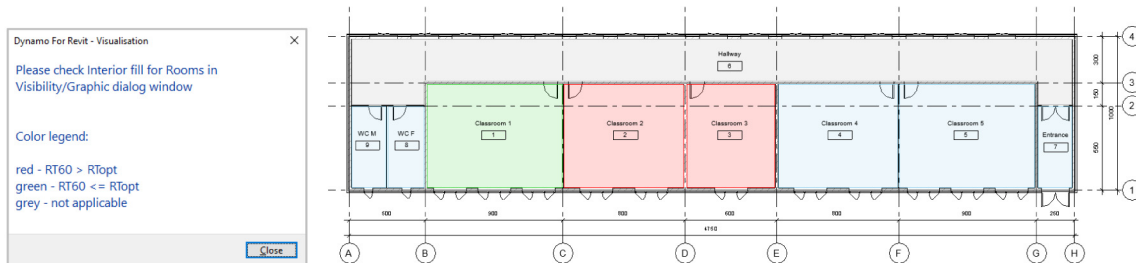

Fig. 10. Text box message (left) and a plan view with applied visualization (right).

through its application however for a number of simple cases that commonly occur in the existing built environment the tool can provide a fast and detailed analysis in the early stage of design for improvement.
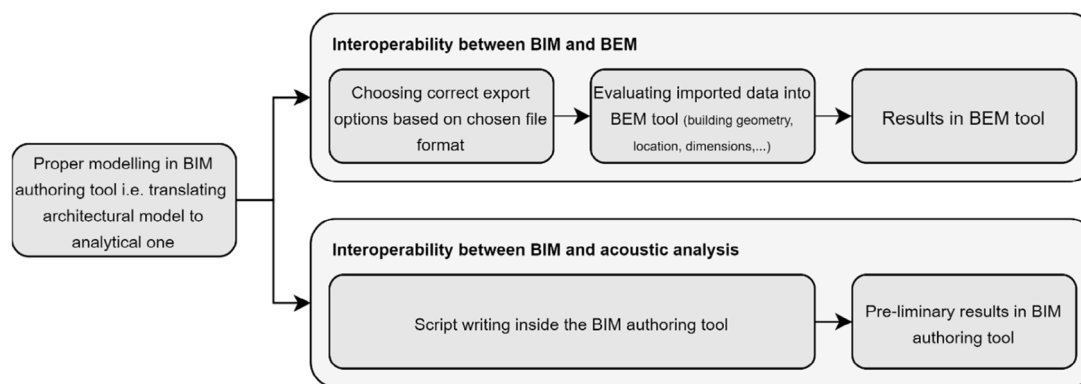
Fig. 11. General approach to two methods.

Generally speaking, it can be said that both presented workflows need to start with a proper modelling in BIM authoring tool, following guidelines, such as the ones, presented in Fig. 5. This translates the architectural model into the analytical one, which can then further be used for the analysis. When exporting into analytical tool, as shown in the case of BIM to BEM analysis in this paper, user should carefully choose the export settings, which differ from software to software and from file format to file format. Before performing the analysis, the imported data should be evaluated, paying attention to items, mentioned in Table 4. Results are then displayed in BEM tool. In the other case, when exporting step is omitted, the script is written in visual programming environment, so no additional data evaluation is needed and pre-liminary results are displayed directly in BIM authoring tool. This general approach is presented in Fig. 11.

5. Conclusion

BIM is a tool that is constantly under development, trying to overcome particular issues. One of these is the interoperability, which remains an obstacle due to constant development of simulation tools. Findings from the literature regarding inefficient translation of data from BIM into BEM tools were confirmed as full interoperability could not have been achieved. Therefore, it is of crucial importance to acknowledge all the discrepancies that come as a result and interpret obtained values accordingly. The presented overview of different import/export approaches can contribute by pointing out strengths and weaknesses of the two mentioned software and export file formats. This can assist user when selecting a software for the analysis, choosing file format for the export, and interpreting the results. Many problems can as well be solved by completely omitting the interoperability part and adopt the use of visual programming languages as suggested in the research paper (Calquin et al., 2014). The BIM authoring tool together with programming languages forms a powerful tool for managing and analysing data from the model. The proposed workflow supports decision making process in achieving comfort and quality of a space, by computing acoustic parameters and therefore contributes to design optimization.

The main takeout of this paper is in presenting two different methods addressing the interoperability issue. One focuses on exporting data from BIM authoring tool into the analysis tool and the other one shows how exporting can be completely avoided. Both options have their benefits and drawbacks which are presented in this paper. Finally, it is up to the user to choose which one fits better based on the desired outcome (comprehensive or pre-liminary results), skills (knowledge in programming language), available software (licence for the analysis tool) etc.

CRediT authorship contribution statement

Mija Sušnik: Data curation, Writing - original draft, Software comparison, Visualization, Investigation. **Lavinia Chiara Tagliabue:** Conceptualization, Methodology, Supervision, Writing - reviewing & editing. **Maria Cairoli:** Supervision, Validation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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