Testing the BIM-Ladybug Tools Interoperability: A Daylighting Simulation Workflow

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Abstract

While a considerable number of studies on Building Information Modelling (BIM) have been conducted in recent years, this area of research has long been considered important in the building sector, with particular concerns about Energy Design. In this regard, the work proposes an automated early design workflow to evaluate the building daylighting performance during the first design stages. Thanks to the potential use of interchange files and visual coding tools, such as Grasshopper, it is possible to implement the parametric design concepts, thus automating complex tasks. Specifically, in the analysed workflow, environmental algorithms and simulations are integrated to achieve reliable results with the minimum error percentage in data loss. The main finding concerns the BIM applications to perform daylighting design by the use of Ladybug tools from the Autodesk Revit export.

1. Introduction

Thanks to the new technologies in design, simulation and construction phase, it is possible to achieve energy-efficient solutions (De Santoli et al., 2017; Mancini et al, 2017). Nowadays, wide development studies are underway for BIM application in energy and daylighting performance. In this framework, the BIM-BEM (Building Energy Modelling) interoperability has been widely investigated (Kamel and Memari, 2019, Spiridigliozzi et al., 2019a, 2019b). BIM allows to have a central database, where data is not fragmented, thereby avoiding the traditional analysis limitations (Yujie et al., 2017). As reported in the literature (Dong et al., 2007; Ivanova et al., 2015; Kamel and Memari, 2019), numerical simulation and BIM integration are based on manual steps and exporting errors, providing fragmentation of data. The exchange file provides material properties, thermal zone data, limited data for the HVAC system and the site's information (Ivanova et al., 2015; Kamel and Memari, 2019). This research analyses and summarizes which objects are successfully transferred by the gbXML export and which suffer a transmission loss on the base of three export types. Following this preliminary study, the successfully exported data are implemented for the annual daylight simulations. Some researchers have suggested using middleware tools to improve the file export gap from BIM to BEM (Gigliarelli et al., 2017). Based on this, Salakij et al. 2016 developed an energy simulation tool using Matlab, which was able to read gbXML files. Ladan (2018) provides an overview of four programs specializing in energy and daylighting simulations by the gbXML file transmission. In this framework, the presented research aim is to define a methodology that allows information transfer from an architectural software (Autodesk Revit) to Ladybug tools, an environmental/energy open source, by the gbXML data format. In particular, this study focuses on the use of Honeybee, supplied by Ladybug tools, which support users to obtain environmental design by providing daylight simulations using RADIANCE engines. This open-source tool connects to Grasshopper/Rhino visual scripting, making it possible to graphically display the imported geometries. Finally, a calculation of different annual daylighting metrics is performed. The purpose of this paper is to explain the workflow, detailing the different model export set, and

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reporting the data exchange limitations for daylighting simulation. Energy and environmental simulation results will be pursued in future work.

2. Methodology

The role of daylight is a well-known field and has become an essential resource for energy-saving and people's health (Halonen et al., 2010; Jenkins and Newborough, 2007). Accordingly, it is useful to support a properly designed daylighting environment, allowing users to obtain reliable results from the gbXML exchange file.In this study, both analysed tools were designed as parametric software, Revit Autodesk for the model configuration, and Grasshopper/Honeybee for the lighting simulation. To test and validate this methodology, a simplified model was utilized in accordance with the BESTEST CASE ASHRAE 140 reference. Specifically, four base cases (900-930) with high mass were considered. The methodology description in Fig. 1 is reported in the following sections.

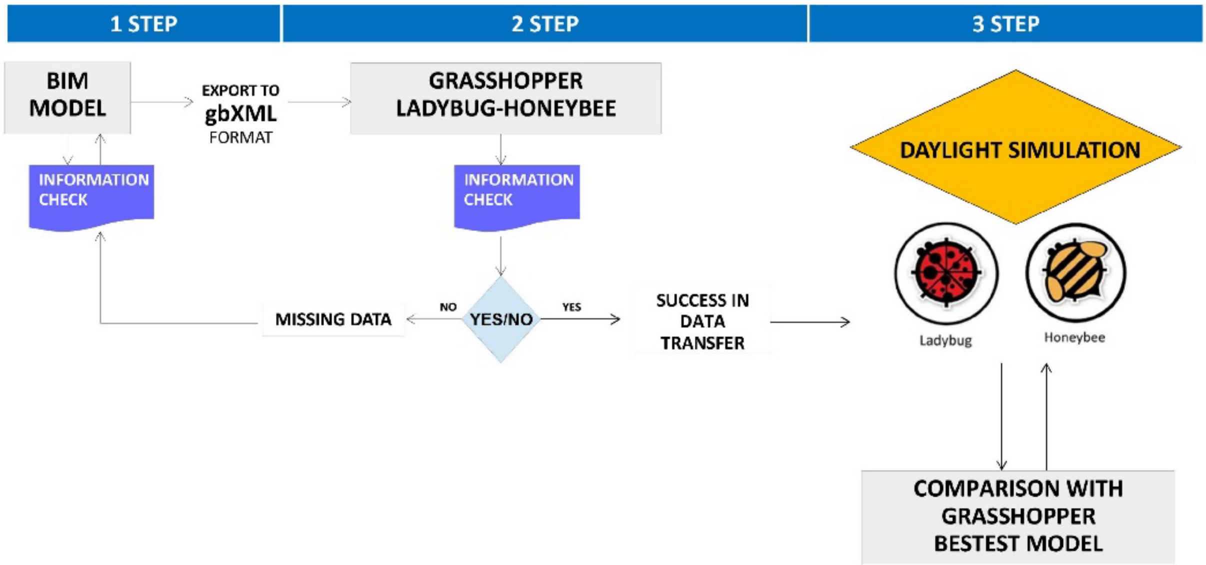

Fig.1 – Workflow applied to BESTEST

2.1 Workflow Description

1. The first step was to create the testing model (BESTEST) in the BIM software Revit, including all its geometric, spatial and thermal characteristics. This part played a fundamental role in the subsequent passages since an incorrect modelling criterion inevitably turns into an incorrect information transfer. Once the 3D model was complete, the analytical surfaces and the thermal zones of the energy model were identified. To correctly export a gbXML file, the first step is choosing between the energy setting or room/space volume; then set the building type, the project phase and the analytic construction. The Structural Function of the main elements (Internal or External) was correctly set for all vertical and horizontal objects. Honeybee needs that information to run the daylighting simulation. Finally, the construction type is the last information to check before exporting the 3D model into Honeybee. Only for windows, is it not automated and requires users to create it manually. Once the model was correctly set, three-model export possibilities were investigated: the room export, the space export and the energy model export. The three export processes were analysed and were then compared to identify the correct methodology.
2. In the second step, the model was correctly exported and imported into the computational design environment. A new component added to Honeybee tool makes it possible to import gbXML files. During this step, all the information from the gbXML file is checked and if some is lost, the procedure is repeated from the

first step. Thanks to the verified data-transfer, it was possible to obtain reliable and fast preliminary results, which were completely in line with the conceptual design stage.

3. The third step consisted of running the daylight simulation in the Honeybee tool. Annual daylighting simulations (DA and sDA) were carried out for each case. Finally, the daylight results of BESTEST imported were compared with the one modelled directly with Rhinoceros/Grasshopper.

2.2 Export Set Types Description

In this section, an explanation of all tested exportation types is reported. The first one is the Room export set type, which implies the room's creation inside Revit. It is the easier gbXML export because few parameters are considered, such as: the export complexity (Simple/Complex), the detailed Elements (yes/no), the project phase (Existing/New Construction) and the building envelope (Use Function Parameter). In this case, the thermal zone properties were not considered. Subsequently, the space export set type implies a creation of spaces in the model. The Revit space includes all the thermal information such as the thermal zone properties, thermal load, systems, occupancy and lighting. In this case, further parameters were considered in addition to the previous ones, such as the building service (HVAC), the schematic types (if necessary) and the building infiltration class. Finally, the Energy Model export is the most complete gbXML export which consists of a separate energy model generation. In this case, the building type, the operating schedule, the HVAC Systems and the outdoor air information were also set. Only this export type needs the energy model creation inside Revit. Subsequently, the three export types were compared once imported into Honeybee. The criteria were mainly dictated by the potential error of the daylight simulation. The information was verified by identifying the data transmission loss inside the Honeybee tool.

2.3 Annual Daylight Simulation Setting

Two annual daylight simulations were carried out for each BESTEST, in order to test the imported files: the Daylight Autonomy (DA) and the Spatial Daylight Autonomy (sDA), using the time-varying illuminances derived from the Rome Ciampino climate file, during the typical 'working year' (i.e. between the hours 09:00–17:00). According to the definition of the Association Suisse des Electricians and the work of Reinhart et al. 2006, the DA at a point in a building is defined as the percentage of occupied hours per year, when the minimum illuminance level can be guaranteed by daylight factor alone. The sDA, instead, measures the percentage of floor area that receives an established illuminance target for at least 50% of the annual occupied hours. For this study, the authors set an illuminance level of 300 lx (useful for normal activities). A grid of 165 points was used as the workplane, with a height of 0.8 m. The distance between consecutive points was 0.5 m, in all directions, in order to provide accurate results.

2.4 Case Study Description

The buildings chosen for testing the interoperability issues are the BESTEST Case 900-930 of ANSI/ASHRAE Standard 140-2004, as shown in Fig. 2. For the simulation analysis, the four case studies are located in Rome. The models have a single thermal zone without internal partition 8 m x 6 m, and two south-facing windows 2 m x 3 m for the cases 900-910, and east/west facing for the cases 920-930. Case study 910 differs from 900 because of the presence of a 1-meter horizontal overhang on the south wall at the roof level, while case 930 includes shade overhangs and shade fins around the east and west windows. The thermal and physical characteristics of the BESTEST construction elements are summarized in Tables 1 and 2. Once in the Honeybee tool, the EPW Rome Ciampino climate file was considered with a latitude of 41°48.0384′ N and a longitude of 12°36.0948′ E.

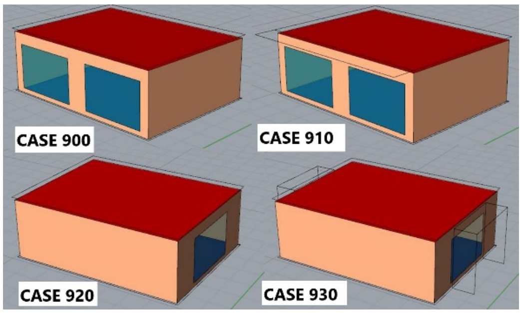

Fig. 2 – BESTEST Case 900-910-920-930

Table 1 – Construction elements properties

Wall Construction U=0.512 (W/m²-K)	Concrete Block 0.1 m Foam Insulation 0.0615 m Wood Siding 0.009 m
Floor Construction U=0.039 (W/m²-K)	Concrete Slab 0.08 m Insulation 1.007 m
Roof Construction U= 0.318 (W/m²-K)	Plasterboard 0.010 m Fiberglass Quilt 0.1118 m Roof Deck 0.019 m

Table 2 – Windows Construction properties (double glazing)

Double glazing U=0.94 (W/m²-K)	Glass thickness 0.003 m Air gap thickness 0.013 m

3. Results

3.1 Export Results

In this section, the three export results are discussed. Table 3 shows a summary report which lists the export types on the left, and the investigated characteristics on the top. The first one, the room export, worked properly, and no errors were found after the transmission process. Geometry and material properties were correctly imported, while space name, thermal load, and space thermal properties were ignored due to the examined set. No were errors were also found for the Space export after the transmission process: the geometry and material properties, the thermal load, and the space thermal properties were correctly imported. Finally, the last Energy model export type showed one error during the transmission process reported as: "2 surfaces have missing constructions, default construction will be used". In this case, no error justification was found, but it was possible to investigate the missing data integration once in the honeybee tool. Following the two missing surfaces replacement, this export type also worked correctly. Moreover, space and room exported work by integrating the window elements into the building envelope, as shown in Fig. 3(a), while the energy model export created a single closed envelope with windows attached over the wall surfaces, as can be seen in Fig. 3(b). However, this difference is only graphical since both these representations give the same simulation results. In our case, to run the daylighting simulation, the room export was considered. The choice was based on the data requirement for the daylight simulation. In this case, the building's thermal and infiltration data derived from the other two export types were not necessary.

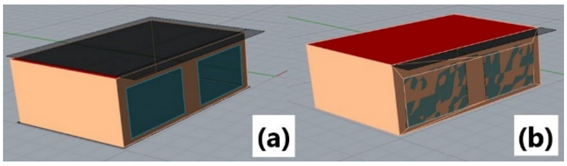

Fig. 3 – Space and room exports (a), Energy model export (b)

Table 3 – Report of the export type comparison

Export type	Case	Orientation	Site Location	Weather Data	Wall Geometry	Window Geometry	Floor Geometry	Roof Geometry	Shading	Shading Properties	Thermal properties	Material Name	Construction Type	Spaces Name	Spaces thermal properties	Thermal Loads
ROOM	*900*	✔	✔	X	✔	✔	✔	✔	-	-	✔	✔	✔	-	-	-
	910	✔	✔	X	✔	✔	✔	✔	X	X	✔	✔	✔	-	-	-
	920	✔	✔	X	✔	✔	✔	✔	-	-	✔	✔	✔	-	-	-
	930	✔	✔	X	✔	✔	✔	✔	X	X	✔	✔	✔	-	-	-
SPACE	*900*	✔	✔	X	✔	✔	✔	✔	-	-	✔	✔	✔	✔	✔	✔
	910	✔	✔	X	✔	✔	✔	✔	X	X	✔	✔	✔	✔	✔	✔
	920	✔	✔	X	✔	✔	✔	✔	-	-	✔	✔	✔	✔	✔	✔
	930	✔	✔	X	✔	✔	✔	✔	X	X	✔	✔	✔	✔	✔	✔
ENERGY	*900*	✔	✔	X	✔	✔	✔	✔	-	-	✔	✔	X	✔	✔	✔
	910	✔	✔	X	✔	✔	✔	✔	X	X	✔	✔	X	✔	✔	✔
	920	✔	✔	X	✔	✔	✔	✔	-	-	✔	✔	X	✔	✔	✔
	930	✔	✔	X	✔	✔	✔	✔	X	X	✔	✔	X	✔	✔	✔

Legend: ✔ Correct import - Not provided X Import error

3.2 Annual Daylighting Results

3.2.1 BESTEST 900: imported and modelled

The Annual Daylighting Autonomy (DA) and Spatial Daylighting Autonomy (sDA) were calculated for the BESTEST 900 (modelled and imported) with a threshold of 300 lx. Fig. 4 shows the Daylighting Autonomy results for each point inside the room.

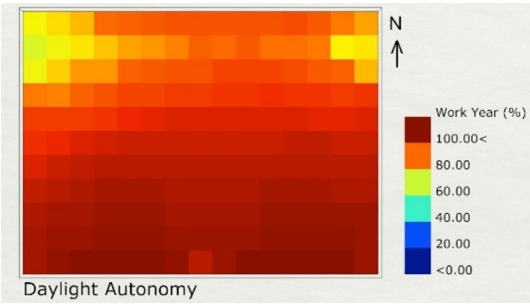

Fig. 4 – Case 900 imported: DA (300 lx) results

Reading from the false colour maps, DA is achieved more than 85% of the working year in the vicinity of the South facade. The lower results instead are located further away from the glazing facade. The large number of results were processed and summarized by the use of statistical indicators (Table 4).

Table 4 – Case 900: DA (300 lx) results

Statistical Indicators	Value (%)
Median	93
Maximum	100
Minimum	62
First Quartile	83
Third Quartile	97

It can be noted that the Median value is 93%, therefore some points registered high DA values, particularly those located near the window (at a distance of 1 m). The sDA simulation provided a value of 100%, highlighting the fact that the 300 lx level is guaranteed for at least 50% of the annual occupied hours. Moreover, case 900 was created by the 3D tool Rhinoceros to obtain reliable results which are useful for the validation of the model imported. Table 5 reports the DA results for case 900 modelled and as can be seen, the Minimum value decreased from 62% to 49%.

Table 5 – Case 900 modelled: DA (300 lx) results

Statistical Indicators	Value (%)
Median	92
Maximum	100
Minimum	49
First Quartile	82
Third Quartile	97

There are therefore some points (3 points) that registered lower values in respect to the case imported, as highlighted by the Median result. However, the global trend of the modelled results is comparable with the case 900 imported. The sDA simulation gives a value of 99.39%, which is compatible with the 900 sDA result.

3.2.2 BESTEST 910: imported and modelled

Daylighting results (e.g. DA and sDA) for case 910 achieved equal value compared to case 900 (see Table 4). Therefore, the comparison with the model created inside Rhinoceros assumed an essential role. Table 6 below summarizes DA results for the BESTEST 910 modelled and some differences can be seen with respect to the imported case. In general, the results are somewhat different compared to Table 4: in this case the values decrease, as can be expected due to the presence of the overhang (Table 6).

Table 6 – Case 910 modelled: DA (300 lx) results

Statistical Indicators	Value (%)
Median	91
Maximum	99
Minimum	42
First Quartile	81
Third Quartile	96

Consequently, BESTEST 910 imported seems to unrecognize the shading geometry, providing daylighting results equal to the case without the overhang. In addition, the sDA simulation obtained a value of 97.58%, lower than the imported gbXML case.

3.2.3 BESTEST 920: imported and modelled

Fig. 5 shows the DA distribution for the BESTEST 920 with 300 lx.

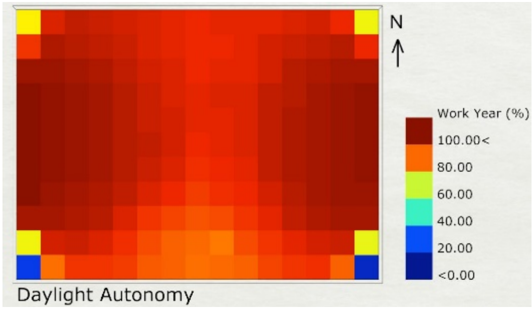

Fig. 5 – Case 920 imported: DA (300 lx) results

Reading from Fig. 5, high DA values are distributed near the glazing facades; conversely, the lower results are located at the corners of the room. The final results are also reported in the table below.

Table 7 – Case 920 imported: DA (300 lx) simulation results

Statistical Indicators	Value (%)
Median	92
Maximum	100
Minimum	7
First Quartile	89
Third Quartile	97

As shown in Table 7, the Minimum value is 7%, and was found in the vicinity of the room corners. Some points achieved the maximum values of 100% and the Median was 92%. In terms of the sDA, the measured value is 98.79%. Results related to the case modelled are reported in Table 8, which shows a few differences compared to Table 7.

Table 8 – Case 920 modelled: DA (300 lx) results

Statistical Indicators	Value (%)
Median	91
Maximum	100
Minimum	6
First Quartile	88
Third Quartile	96

As the BESTEST 900, the 920 is well recognized in its entirety by the simulation tool, providing reliable results. The Median value is lower due to the decrease in the Minimum value from 7% to 6%.

However, those differences are negligible. The value of sDA is 97.68%.

3.2.4 BESTEST 930: imported and modelled

Finally, Table 9 report DA results for the BESTEST 930 with the illuminance levels of 300 lx. The results of this case are not reported as figures due to the small difference between the values that cannot be highlighted through the qualitative images.

Table 9 – Case 930 imported: DA (300 lx) results

Statistical Indicators	Value (%)
Median	92
Maximum	100
Minimum	12
First Quartile	89
Third Quartile	97

The Minimum value is 12%, the Maximum is 100% and the Median is 92%. Moreover, the sDA simulation achieved a value of 98.79%. Table 10 also shows the DA results of this case modelled with the 3D tool.

Table 10 – Case 930 modelled: DA (300 lx) results

Statistical Indicators	Value (%)
Median	88
Maximum	99
Minimum	0
First Quartile	82
Third Quartile	94

The results from the statistical indicators were lower compared to the results from case 930 imported, particularly the Median and the Minimum. The DA trend is generally reduced due to the overhangs above the windows. Moreover, the sDA value of 92.73% underlines those differences with the case imported. In summary, these comparisons were useful for the results validation, highlighting that the shading element is not correctly imported through the gbXML file.

4. Conclusion

The role of BIM is widely recognized in terms of central data for management and exchanges files with other users in the building sectors. Moreover, the interoperability between BIM and the energy model is still underway, due to the different technical languages and information types. In this framework, the research proposes a methodology workflow that can help designers to evaluate the daylighting comfort during the first design stage, thanks to the BIM and Building Energy Modelling (BEM) interoperability. As far as the results are concerned, in general, the three export types work correctly inside the energy tools, due to the proper setting explained in the methodology section. The Room and Space export file has no errors during the importing process. The Energy Model imported is not influenced by the aforementioned warning error related to a specific surface, since it is only a different type of 3D geometrical mass. Some information has to be set inside the Honeybee tool, such as the EPW climate file and the window properties. It is then possible to run the annual daylighting simulations (DA and sDA). Moreover, the authors validated the daylighting results by comparing them to the BESTETEST modelled directly into the 3D software. Due to this comparison, cases 900 and 920 are correctly imported and analysed inside the daylight tool.

On the other hand, BESTEST 910 and 930, the shading cases, did not provide reliable results and Honeybee is not able to recognize the imported overhang geometry. Consequently, the exchange information of the shading element requires further analysis in order to overcome this issue.

In conclusion, the authors note that this is the first step in the application of BIM and BEM interoperability for the daylight analysis. Future developments will investigate more complex case studies to test and verify this methodology by implementing other comfort and energy analysis.

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