

Interoperability between building information models and software for lighting analysis

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Abstract

Lighting analysis models are being integrated into building information models (BIM) quickly. The BIM of the Politecnico di Torino (Polito) campus used in the Smart Energy Efficient Middleware for Public Spaces (SEEMPubS) project is an integrated representation of each building to merge architectural, structural, electrical and HVAC elements and components. In the Polito campus there are three types of buildings: historical, modern and contemporary. A special approach has been adopted to model and to exchange data between software about historical buildings because they are characterized by paints, stuccos, etc.

The aim of this research was to set a parametric model able to share information without data loss, testing the interoperability between architectural software like Revit Architecture and lighting analysis software like Daysim and Radiance. As the process of exchanging data from Revit to Daysim and Radiance is not direct, Ecotect Analysis was used as an “interoperable bridge” with good results. Three different formats were tested: IFC, gbXML and FBX and for each one problems and possible solutions were analysed. Up to now, Ecotect was used in two different ways: to define material parameters before the export phase and to visualize analytical data obtained from Daysim and Radiance. In our tests some errors have occurred referring to data retention like material properties, but at present the main problems have been solved. Indications about performance of daylighting and energy consumption have been obtained, although a lot of work should still be done. The correct data exchange that we obtained enabled the optimization of the building

simulation process by avoiding the need to remodel the same building in the lighting applications.

1. Introduction

Building information modelling (BIM) has received much attention in recent years due to its possibility of developing a new methodology of design, construction and facility management based on information exchange. This process is achieved through the interoperability of software that is defined as “the need to pass data between applications, and for multiple applications to jointly contribute to the work at hand” (Eastman C. et al., 2008). In this way a single building model can be used to perform all the simulations needed for its design and operation like lighting and thermal analysis, without the necessity to remodel it in any applications. On the other hand, this process is still not easy on account of the shortage of complete technical standards.

“Detailed technical standards are required to unambiguously define the requirements of specific information exchanges as user of the exchange standards will do so with various types of software.”

“At present, data exchanges between two application are typically carried out in four ways: direct; proprietary links between specific BIM tools; proprietary file exchange formats, primarily dealing with geometry; public product data model exchange

formats like IFC, or XML – based exchange format” (Osello A., 2012). However, although the possibilities of exchange may appear numerous, there are cases which still require the use of an “interoperable bridge” to complete the procedure.

The present paper presents a set of criteria for the creation of a suitable parametric model. On the basis of these criteria, it describes the related tests aimed at data exchange between architectural and lighting analysis software carried out during the Smart Energy Efficient Middleware for Public Spaces (SEEMPubS) project. The project in fact is aimed at implementing a Building Management System based on the integration of both building information modelling and advanced ICT based control and monitoring system to increase the energy efficiency of public buildings. Actually, energy efficiency was, in the design phase of the project, mainly assessed through lighting and HVAC dynamic simulations.

The tests on data exchange between architectural and energy software have come to the definition of a procedure that allows interoperability by avoiding the need for external input from users for the exchange of information related to the model.

2. Simulation

All tests were conducted on six couples of rooms, selected for the SEEMPubS project, on the campus of the Polito. In these rooms, the new control and monitoring solutions for lighting, heating/cooling and electrical appliances were deployed to demonstrate the efficacy of the planned BMS. For these rooms lighting and thermal simulations were needed to assess the effectiveness, in terms of comfort and energy savings, of possible different control strategies. The choice of the rooms was conducted according to the following criteria: representativeness with respect to the campus and other public buildings; energy saving potential, estimated according to their architecture, orientation, system and occupancy characteristics. The selected spaces are divided as follows:

- Four offices at the Valentino Castle, premises of the School of Architecture
- Two offices and two classrooms at the Main Campus in Corso Duca degli Abruzzi

- Four offices at Cittadella Politecnica, recently built next to the Main Campus, Politecnico’s research centre

Building information model of each room was realized through Autodesk Revit, merging the architectural model with structural, mechanical, electrical and HVAC models. Methodologically, the model setup followed five phases which were functional to the type of activity for which the model itself is built.

The first phase provided for the definition of standards necessary to enable the collaborative work. The model was organized by dividing the various elements, according to their specific function, thanks to the use of WORKSETS in order to facilitate the sharing of work.

The second phase, related to a preliminary site inspection and starting from achieved documents, concerned modelling quickly the existing structure in an urban scale. This model includes building location, typology, size, volume, construction period and is used to analyze the main aspects of the building’s performance, with a particular emphasis on energy efficient and sustainable design and management.

The third phase enabled the realization of a preliminary model that, at any time, can be enriched with all the specific information such as doors and windows, materials and walls stratigraphy. A survey was carried out in two different and complementary ways:

- Using a total station and a GPS receiver in order to establish precise GPS coordinates of the essential exterior and interior building elements

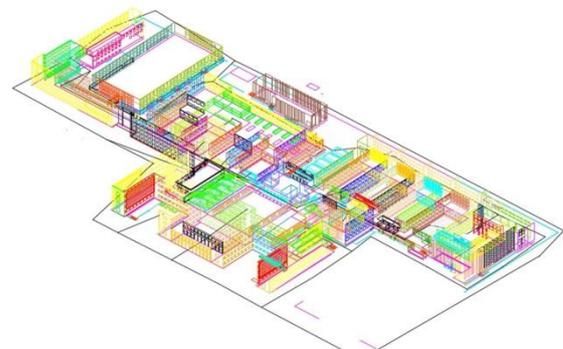


Fig. 1 – Survey of the Main Campus realized through a total station

- Using Electronic Distance Meter (EDM laser) to take quickly the measurements of the rooms

The fourth phase concerned the choice of the software tools that may be used in an interoperable way like Revit Architecture, Revit MEP, 3dStudioMax, Ecotect Analysis, Daysim, Radiance, Sketch Up and AutoCAD.

With the fifth phase began the setting of a method of continuous cross-checking and updating of data, with the intention to create an integrated model which is as correct as possible for each use. This phase was closely related to the previous one and it is continuously evolving. In fact, the exact knowledge of what type of data and from which software they can be successfully exchanged requires interesting considerations on the standards to be used in the integrated model to optimize the BIM process.



Fig. 2 – Example of final model of the Main Campus

Subsequently to the setting of the model, in the SEEMPubS project, thermal and daylighting simulations were required to estimate the rooms' energy performance.

In this paper the tests and procedures adopted to exchange data between architectural model and software for daylighting analysis are described. In the project lighting simulation was necessary to estimate the availability of daylight in the rooms, in order to define the control strategy of electric lighting based on daylight availability and on the rooms' utilization schedules. Furthermore, after the definition of the possible electric lighting control rules, the lighting simulation was used to estimate the consequent energy performance of the lighting systems (Fracastoro G.V. et al., 2012).

To proceed with the lighting analysis it was

necessary to correctly characterize all construction components of the model (walls, floors, false ceiling, windows, window's frame, doors, internal obstruction and furniture etc.). This process occurred utilizing the Revit embedded logical division, thus reaching the Typology detail level (Family type). Therefore, in each family of homogeneous elements different types have been created for each object according to the materials that constitute them. As far as the modeling of the external environment surrounding the study object is concerned, which might influence the daylighting calculation, it has also been modeled with different typologies of building elements. To speed up the analysis process, the spaces were modelled using simplified furniture and external obstruction. Then, to obtain a correct lighting analysis, it was necessary to proceed with the optical characterization of all surfaces that may be involved in terms of interaction with light inside the room.

The characterization of materials' optical properties is an essential phase of 3D model preparation for the subsequent lighting simulation. Therefore, the reflection and/or transmission properties of each material and its mode of reflection (specular, diffused, mixed, etc.) must be defined. In this project the optical properties of the room and furniture surfaces were defined measuring, with a spectrophotometer, the chromatic characteristics and the visible reflectance. Transparent materials were characterized measuring the visible transmittance with a luminance meter. Moreover, by using software that in addition to numerical results also provides a rendering of the lighting environment, it is also necessary to define the materials' chromatic characteristics. The general rule consists therefore in diversifying volumes in relation to material, so that it is possible to associate their light reflection, light transmission and the chosen material's rugosity.

Several applications are available to perform daylighting analysis, characterized by different calculation approaches, accuracy and type of achievable results (Pellegrino A., 2012). Some of them are based on the concept of daylight factor, which assesses a room's daylight availability through the calculation of the ratio between indoor and outdoor illuminance under a reference sky condition (Dialux, Ecotect Analysis, etc.), others

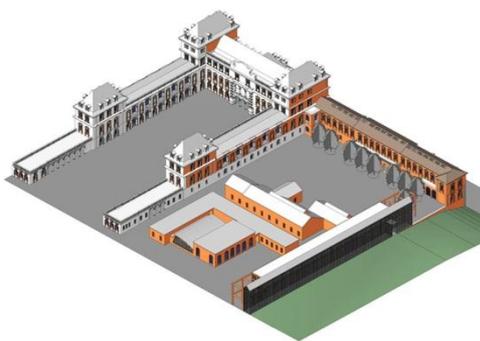


Fig. 3 – Final model of the Valentino castle Campus

calculate the illuminances within a room taking into account more detailed sky luminance distribution, which could vary from clear to intermediate to overcast, depending on the designer's input or on the climate of the considered site (Radiance, Daysim, Lightsolve, etc.). The two groups of software usually differ also for the accuracy of the algorithms used to calculate both direct and reflected components of daylight. Among the second group of applications some can be used to calculate time varying illuminances profile, for instance to assess Dynamic Daylighting Performance Metrics such as Daylight Availability or Useful Daylight Illuminances. This analysis, based on climate data and, usually, on a yearly basis, is the premise for a more detailed calculation of the electric energy consumption of the lighting systems, in particular when automatic control systems are used.

For the SEEMPubS project, daylighting simulations and consequent electric lighting energy calculations were performed using the climate-based dynamic application called Daysim (Reinhardt C.F., 2001). From the operating point of view, to start the simulations it was necessary to import a 3D model of the room under study and its external obstructions. The 3D model, in this case, was realized with the Revit applications, which allow a complete modeling from the architectural and systems point of view, compared to other software such as SketchUp, AutoCAD, Ecotect Analysis. Hence, Ecotect Analysis has been used for the following three purposes:

- Like an "interoperable bridge", because, unlike Revit, one of Ecotect Analysis' functions allows model exportation to lighting application such as Daysim or Radiance, automatically creating the files required for the subsequent lighting

calculation. These contain the geometric characterization and material assignment (.rad extension), viewport definition (.vf extension), coordinates and orientation of points in the calculation grid (.pts extension), climatic file (.wea) and finally the complete Daysim file (.hea)

- In order to define materials' optical properties and the calculation plan to be used in Radiance or Daysim simulation
- In order to graphically process the numerical data obtained with Daysim / Radiance, which are imported in the .dat format (coming from Radiance) and .da (coming from Daysim) and therefore their 3D visualization.

It must be specified that, despite Ecotect being developed as a simulation program aimed at evaluating buildings' performance, with particular attention to energy aspects from the point of view of sustainable design, in this case it was not used directly to perform the lighting analysis because higher accuracy and more detailed results were required. Moreover, this software does not directly allow a dynamic climate-based simulation.

In order to proceed with model exportation from Revit into Ecotect Analysis, and later to Daysim, three different procedures are defined and tested. Different results are analyzed and the most appropriate procedure from the point of view of lighting simulation is chosen.

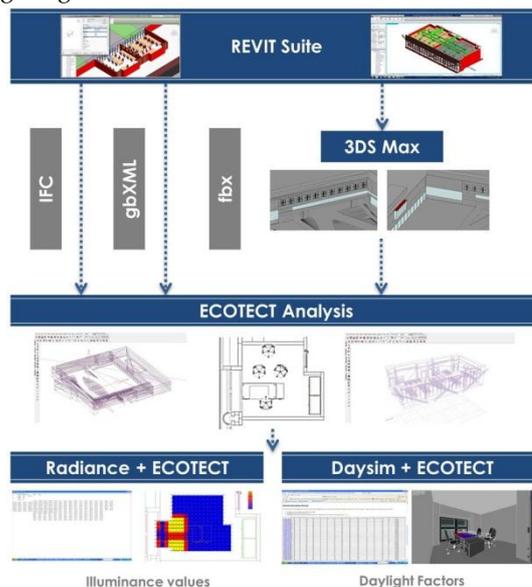


Fig. 4 – Layout of the procedures followed

The first export procedure consisted in following the traditional approach suggested by literature: exporting the file in Industry Foundation Classes (IFC) format. IFC is the main buildingSMART data model standard and it is an open format; therefore it can be used to exchange and share BIM data between applications developed by different software vendors without having to support numerous native formats. IFC is registered by ISO as ISO/PAS 16739 and is in the process of becoming official International Standard ISO/IS 16739. File importation occurs through the MODEL/ANALYSIS DATA modality because is the only one of the two available importation modes to be compatible with .ifc files, and it can directly import the .ifc files in the Ecotect Analysis application. During the procedure, the imported elements are listed in the importation window, including surface and single elements, as well as elements realized in Revit that are being imported in Ecotect Analysis.

The second procedure analyzed consists in exporting the 3D model through the creation of a Green Building schema XML file (gbXML). gbXML is an open scheme which facilitates data exchange of building properties stored in 3D building information models (BIM) to engineering analysis tools. In order to correctly export the data in the gbXML format it is essential to include in Revit model the ROOM entity. This consists in assigning to every closed space (delimited by a floor, walls, and ceiling) a label, precisely ROOM, identifying the room's volume; this operation allows thus to identify in advance the THERMAL ZONE used by Ecotect Analysis to the lighting simulations. If this operation is not performed, the gbXML file is not created. The gbXML standard enables the export of various types of information, in addition to ROOMS. In fact, it is possible to export the building's geographical location, its construction type, shading surfaces and any other architectural element that makes up the building. Trying to import the file in Ecotect Analysis, it is possible to verify that the ROOMS are imported as well as the building elements modeled with Revit.

Both the first two procedures presented problems during the importation phase in Ecotect Analysis. Therefore the third methodology was studied and tested.

The third procedure concerns exporting the model from Revit in the .fbx format. In this case exportation only occurs correctly in an elevation or axonometric view of the model, otherwise the command is not available. This operation has no control setting, because the command is closed and the operator cannot interact. Since Ecotect do not accept .fbx files, a third intermediate application has been introduced. This additional tool is 3dStudioMax. The use of this application has been necessary because it was not possible to export from Revit a file format compatible with Ecotect Analysis maintaining the model unaltered. Through 3dStudioMax, it is possible to export the file in a .3ds format fully compatible with the lighting simulation application used for the SEEMPubS project.

In the 3dStudioMax environment, the .fbx files are not directly imported, but a linkage operation must be performed through the command FILE LINK MANAGER. This instrument also allows the user to select among different link options, the one most appropriate for the creation modality of the Revit files. Among the available options, the importation of the elements composing the model was chosen grouping them based on the element TYPOLOGY. In this way, the parametric model realization logic in Revit was respected completely. In this phase, measurement unit setup operations are very important, in fact the right setting must be verified before linking the Revit file; in particular it is necessary that the 3dStudioMax units are consistent with those in which the parametric model has been realized.

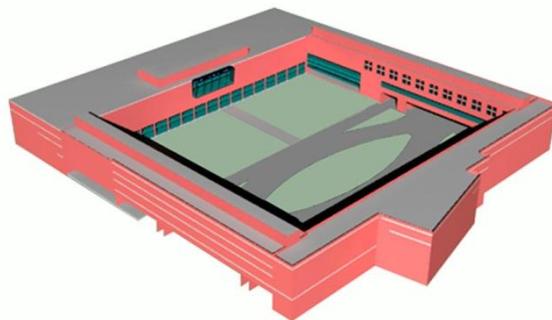


Fig. 5 – Model optimized in 3dStudioMax

Within the 3dStudioMax environment it is possible, as opposed to the previous procedures, to make changes to the model both from the architectural

point of view and on the denomination of the element typologies in order to obtain a better uniformity. Another operation, recommended, though not essential, is to eliminate the camera and the light spot that the 3dStudioMax application automatically imports from .fbx file. This last operation is feasible reloading the .fbx file and unchecking the relative options in the dialog box. Moreover, these two specific objects are not useful for modelling and for subsequent simulation. At this point it is possible to export the file in the .3ds format and subsequently to import in Ecotect Analysis.

The import mode, with respect to the previous procedures, is not MODEL/ANALYSIS DATA but the command denominated 3D CAD GEOMETRY, which allows for the listing of all model elements grouped by TYPOLOGY and to assign them the correct ZONE.

The materials, after importing the model in Ecotect Analysis, were characterized. Particular attention was paid to analysing each surface, consequently, reflection and/or transmission properties were defined. For the SEEMPubS models, field measurements of luminous reflectances and transmittances of the different room and furniture surfaces were carried out and the data used to characterize the materials' optical properties of the models.

Finally, through the specific command the model can be exported to Daysim for the final lighting and energy simulations.

Before starting lighting simulations with Daysim, the models, built in Revit and exported in Ecotect, were validated using the Radiance application.

Radiance is an open-source, highly accurate, ray-tracing software system for UNIX computers and it predicts the light levels and appearance of a space (Larson G.W. et al.,1998). Its algorithms (Monte Carlo backwards raytracing) allow an accurate simulation of the phenomenon of interaction between light and surfaces; furthermore Radiance does not have any limitation on the geometry or the spaces that can be simulated. As for daylight sources, Radiance can take into account different sky luminance distributions, considering both direct and diffuse solar radiation.

From Ecotect, the model was then imported into

Radiance and its validation was carried out by comparing the illuminances calculated with Radiance to the illuminance measured in the corresponding real room with same sun position and sky condition (Mardaljevic J., 1995).

As an example, table 1 presents some first results obtained for a clear and an overcast sky condition. The measurements were done in a single office (DAUIN office) in correspondence of two points on a horizontal plane: one near the window (point 1), one far from the window (point 2). The relative differences between calculated and measured values range from -12% to 29.4%, therefore confirming a good accuracy of the model used for the lighting simulation.

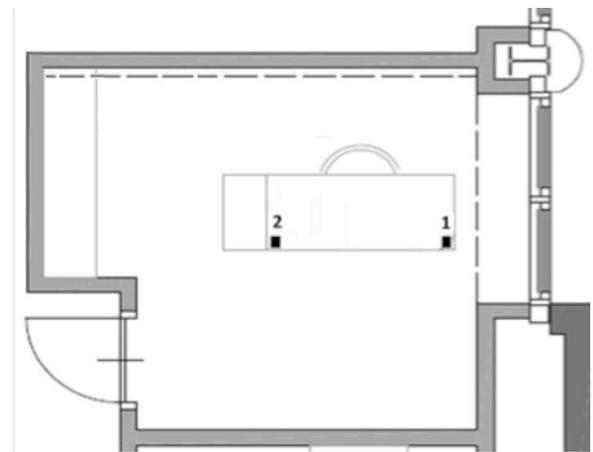


Fig. 6 – Detection point in DAUIN office

Sky condition	Point	Measured Illuminance (lx)	Calculated Illuminance (lx)	Relative difference (%)
Clear Sky	1	26618	31840	19.6
	2	1088	958	-12.0
Overcast sky	1	246	276	11.9
	2	74	96	29.4

Table 1 – Comparison between measured and calculated illuminances.

After validation, the models were used for lighting analysis with Daysim. Daysim in fact, calculates the annual daylight availability in arbitrary buildings based on the Radiance backward ray tracer, using external daylighting conditions derived from standard meteorological local datasets. It includes specific occupant behaviour model algorithms to mimic occupant use of personal controls such as

light switches and venetian blinds and to predict the electric lighting use due to automated lighting controls such as occupancy sensors and photocell controlled dimming systems. In addition to daylighting metrics, among its outputs, the total annual energy demand for lighting [kWh] and the LENI value [kWh/m²year] are included (EN 15193, 2007).

Within the SEEMPubS project, Daysim was used to calculate the rooms' electric lighting energy demand for different proposed control strategies and to estimate the corresponding energy saving with respect to the manual lighting control usually adopted in the Politecnico rooms (Acquaviva A., et al., 2012).

In this paper an example of the achieved results is presented (figure 7; table 2). Results are referred to the DAUIN office, which is a single office, with an internal movable shading device, southwest oriented. Inputs for simulation are:

Occupancy profile: from 9:00 a.m. to 6:00 p.m., with lunch and intermediate breaks

User requirements and behaviour: target illuminance of 500 lx, mix of active and passive user's behaviour and active user behaviour for lighting; active behaviour depending on the user's need to avoid direct sunlight on work plan for blinds

Lighting control systems: different lighting control strategies were simulated to compare their effectiveness with respect to the manual control

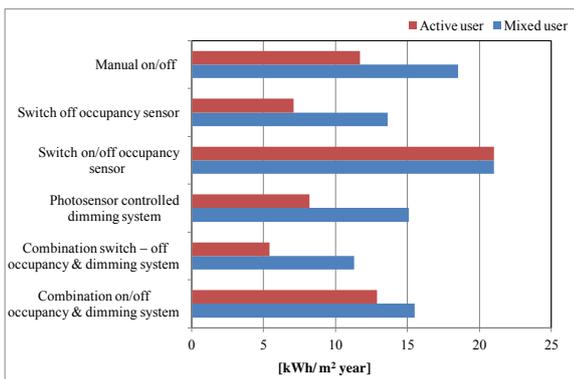


Fig. 7 – Energy demand for different control strategies

Control strategies	Energy savings with respect to manual control (%)
	Mixed user behaviour
Switch off occupancy sensor	-26%
Switch on/off occupancy sensor	+14%
Photosensor controlled dimming system	-18%
Combination switch off occupancy and dimming system	-39%
Combination on/off occupancy and dimming system	-16%

Table 2 – Calculated percentage of energy saving with different control strategies, respect to manual control

3. Discussion And Result Analysis

As outlined in the introduction, interoperability of software is the basic instrument for a successful Building Information Model process. In order to realize a complete parametric model, suitable for data exchange between architectural software and energy analysis software, three different procedures were investigated.

Each procedure has presented difficulties or errors. In the first two cases, data exchange was realized through open formats like IFC and gbXML that have proven not fully adaptable to the cases under study. Among the errors encountered with the first procedure, which used the IFC standard, it is of particular importance the fact that window frames, which are fundamental for lighting analysis, are not imported. Besides, model representation turns out incomplete because it is imported with the constructive elements misaligned with respect to the original model. This suggests that the first procedure is not the best one and for these reasons a second way was analyzed.

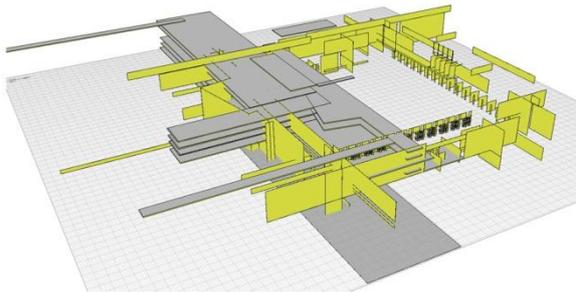


Fig. 8 – Errors encountered during the importation of IFC file in Ecotect Analysis

The second procedure consisted in the use of gbXML exchange format, which required that each space is defined by a ROOM. Even in this case several issues arose when opening the file in Ecotect Analysis.

Through this kind of exportation, the model is correctly regenerated and all elements maintain their reciprocal position, nevertheless the elements' volumetric characteristic is not maintained. Solids lose their connotation because they are transformed into surface, placed side by side but not exactly matching. The same problem occurred for the ROOMS that are represented by their surfaces. For instance, in the case of the window frames, they are broken down in two orthogonal planes composing the structure of the frame itself. A similar problem concerns vertical and horizontal surfaces, like walls, floor, ceiling, etc.

These transformations make lighting simulation unfeasible because, due to the excessive model simplification, there is a risk of destroying the real glass surface obstruction and of identifying daylight penetration points where surfaces do not perfectly match. Consequently, the model becomes unusable for lighting calculations.

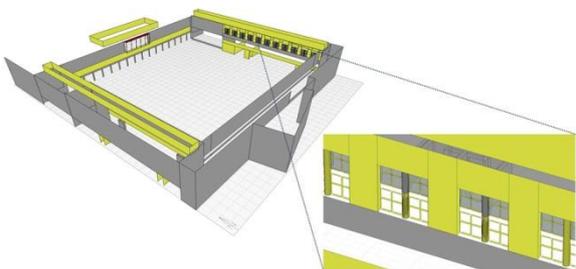


Fig. 9 – Elements exported by gbXML which do not maintain their volumetric characteristic

The third procedure, that concerns the use of an intermediate application (3dStudioMax), appears to be the most appropriate both for what concerns

modeling in the Revit applications and for the analyses in Ecotect Analysis. However, it is necessary to highlight some basic steps for successful data exchange.

Firstly, the elements used for modelling in Revit environment (FAMILY TYPE) must be created in a suitable way in order to facilitate the subsequent operations of ZONE assignment in Ecotect Analysis. Besides, particular attention must be paid to the materials, which will concretely conform to their belonging ZONE. At the same time, the nomenclature of these elements (TYPE) must not exceed twelve characters, in fact, a longer denomination would be cut in the Ecotect Analysis environment with the risk of losing information useful for identification. For example, glass component modeling is very important because with Revit, it was not possible to export the component as 3DFACE. 3DFACE is the best typology of elements to import in Daysim and Radiance for the units characteristics association, like insulated glass or triple glazed, in order to avoid simulation errors due to the calculation complexity in terms of refraction of the light beam hitting the entire glass component. In this way, during the importation phase in Ecotect Analysis glass, being a solid, it is divided in its components' faces. However, materials' characteristic must be associated to one face only and other faces must be deleted. The following simulations could be influenced by the choice of characterizing inner or outer face and some errors can occur in the results (not very significant).

Afterwards, linking and file opening times are slightly longer than the two previous procedures. Obviously, the higher the simplification of the 3D model, the shorter the time is. Longer file opening times were found when the Revit model contained particularly elaborate windows and when the model included several objects. Moreover, particularly complex parametric elements (higher than 64K) are not automatically exported by 3dStudioMax. This implies that a MERGE operation on the model must be performed before the exportation in order to include these elements.

Particular problems arise while modeling a glass curtain wall, in a Revit environment. This family type differs from the importation rules in 3dStudioMax seen above; in fact, assigning two

different names to two different curtain walls is not influential. In the importation into Ecotect Analysis they were recognized as one single element: the problem was solved temporarily by replacing the glass curtain walls with a WALL object to which transparency characteristic was assigned.

Finally, whereas Daysim and Radiance require a reference surface against which lighting simulations perform, it is possible to define this surface directly in Revit through the creation of a specific solid exportable into Ecotect Analysis and employable without problems.

Unlike the two first procedures, also in this case solids are converted into surface, but these are well aligned with each other and are perfectly matched. The same happens for the window frames that guarantee the correct obstruction compared to the incoming daylight.

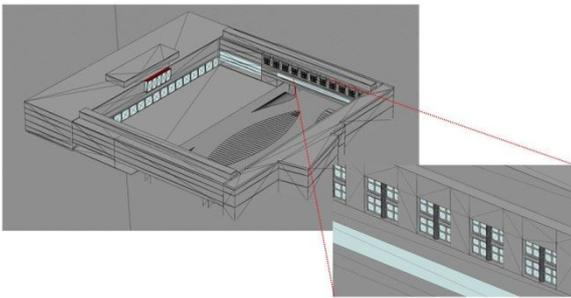


Fig. 10 – Ecotect Analysis view of the correct 3ds file exported through FBX

It could be concluded that this type of exportation allows to import the model in Ecotect Analysis correctly and appropriately with regard to the technical needs for lighting simulation.

The results of the validation phase of the model, carried out with Radiance, showed a difference between measured and simulated illuminances ranging from -12% to +30%, depending on the considered sky conditions (clear or overcast sky) and on the position of the verification point within the room. This discrepancy might be attributed to the interaction of the different aspects which are involved in the simulation process: 1) the correspondence of the sky model generated by Radiance starting from the measured outdoor illuminances (direct and diffuse horizontal illuminances) with the real sky condition; 2) the optical characterization of room with opaque and

transparent surfaces; 3) the accuracy of the instruments which were used for the indoor and outdoor illuminance measures; 4) the accuracy of the geometrical model, with particular attention to the modeling of the glass surfaces.

As for the buildings' energy performance, simulations carried out with Daysim for the SEEMPubS project were very useful in defining the most effective control strategy to reduce energy consumption for lighting, based on both the annual daylighting conditions and the use of the space (type of activity, user behavior, etc.). From the data presented in the paper a combination of manual and automatic control turned out to be the most effective solution (39% of saving with respect to totally manual on/off control). The control strategy provides for turning on lights manually, and for automatic dimming and switching off. The control strategy based on switching on/off light through the occupancy sensor was more expensive than the others, manual control included. This result can be explained by the presence of daylight in the room during the year. When daylight is sufficient for the occupants' needs, users, with not a completely passive behavior, can switch lights off, while occupancy sensors, detecting the users' presence, always keeps them on. Furthermore, occupancy sensors have a stand-by power consumption during the year which increases the overall energy demand for lighting.

4. Conclusion

In the last few years, interoperability has become a crucial topic to develop Building Information Modeling. Our study focused on interoperability between architectural software and lighting analysis software. Three different procedures were studied and tested many times to guarantee correct data exchange that allowed lighting simulations.

Firstly, a Building Information Model was realized for each couple of rooms in order to enable correct energy analysis, then the exportation phase started. In all procedures difficulties or errors related to the definition of the elements' geometry and their mutual spatial arrangement were found; only in the third procedure this did not happen, due to the

introduction of additional software like 3dStudioMax.

Ecotect Analysis has played a key role in our tests, becoming an “interoperable bridge” that allowed us to exchange the information required from Revit to Daysim or Radiance and vice versa. At the end, the goal of interoperability is clear, but many unsolved issues still exist to turn this idea into reality. However, with this study we have tried to overcome the difficulties explained above allowing for a better sharing of information between the different subjects involved in the design process.

This interoperable bridge allowed the lighting simulation to run, both with Radiance and Daysim, thanks to the development of 3D models complete with all the information needed.

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