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Integrated Design and Modelling-based Smart School Concept to Renovate the Existing School Building Sector

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Abstract

The schools lacking energy performance promotes deep buildings refurbishments, considering also LCC evaluation to define the cost-optimality criteria in building renovation. Moreover, available funding programs are not frequently appropriate to deal with energy law compliance because of the safety and accessibility issues are currently leading topics to be accomplished before. The governance indicates the school as the favoured centre of local community improvement and activities and the school building is advocated to encourage social interaction, clusters' cooperation and space sharing, as a civic centre. These growing needs ask for new methodologies to approach the renovation of the school buildings considering on the one hand the energy demand and on the other hand the management of the spaces flexibility and of the whole asset during the entire life span. The method described here and applied to a case study is based on BIM to BEM procedures; it aims to demonstrate how to define a building database to store all the data able to endorse the management of maintenance strategies and energy developments, together with cost analysis for energy retrofitting.

1. Introduction

Existing buildings realized before energy laws (i.e. 70% between 1941 and 1990) mainly compose the school buildings Italian scenario and the high inefficiency is transversal in the European schools scenario. The lacking energy performance of schools promote a deep refurbishments of the buildings considering also the need of life cycle cost evaluation to define the cost-optimality criteria in building renovation. Moreover, the available funding programs are not frequently appropriate to deal with energy law compliance because of the safety and accessibility issues are currently leading topics to be accomplished before. New concepts of school renovation based on enhancement of the learning performance and spaces upgrade are encompassed and try to shape the new schools design following the European trend. Current national Guidelines (2013) are changing the paradigm from the mere sizing-based criteria of traditional school's spaces to integration and cooperation core areas, applicable to users' activity and space programming, consistently with the north European countries. The governance indicates the school as the favored center of local community improvement and activities and the school building is advocated to encourage social interaction, clusters' cooperation and space sharing, as a civic center. These growing needs ask for new methodologies to approach the renovation of the school buildings considering on the one hand the energy demand and on the other hand the management of the spaces flexibility and of the whole asset during the entire life span. The method described in the paper and applied to a representative case study is based on BIM to BEM procedures. The aim is to demonstrate how to define a building database to store in all the fundamental information able to endorse the management of maintenance strategies and energy developments, together with cost analysis for energy retrofitting and refurbishment. The methodology is driven by the circular economy principles for built environment to increase energy saving reducing waste and optimizing the building spaces.

One of the most challenging improvement that AEC sector is facing can be identified with nearly-zero energy buildings task by 2020 (2018 for Public buildings) started with the assumption from the EU Member States of the core pillars included in the EPBD recast (Directive 2010/31/EU). At European level also digitalization and computational environment for public construction are promoted to endorse transparency and cost efficient management of the asset. BIM is a complex set of procedures and instruments to manage data from early design stages to the end of life of an asset with different related issues, input data and target to be achieved to (Volk et al., 2014). A critical feature is interoperability between software (BuildingSmart, 2015) such as the capability to be able to import and export data (the complete model and/or some parts) from/to other different software allowing an efficient exchange of the huge amount of information (Bahar et al., 2013) constantly increasing with the number of stakeholders (O'Donnell et al., 2013).

Even a partial interoperability is a good goal to pursue, as not all the stakeholders need the whole set of information about a project, but a specific set (East et al., 2013). The same could be assumed for the energy evaluation (Yu, 2014), which mainly requires data about surfaces, technologies, occupants, loads and ventilation, however data about service life, structural strength, related costs, etc., are redundant (Jeong et al., 2014). BIM encompasses cooperation, enabled by a clear understanding of both roles and responsibilities as defined in the BIM-level 2 (NBS, 2015).

It is also necessary to specify the Level of Detail (LOD) and a Level of Information (LOI) (BimForum, 2013) of a BIM model has: the first represents the detail used in the model, while the second represents the number of information added during the different phases of building process (i.e. design, tender, construction, operation, handover, disposal, etc.). Consequently, coupling Building Information Modeling (BIM) methodology to Building Energy Modeling (BEM) for detailed assessment of energy performance are strongly sponsored and investigation in the field as also refinement of tools' functions are developing. In the last few years, various software have been settled to translate geometrical and technical information into an energy framework trying to support designers in analyzing thermal performance in the first design phase and predicting buildings energy consumption to evaluate implementing interventions after a tuning process to actual thermal behavior. Even though software are getting more and more powerful and user-friendly, results provided by different BEM software diverges and information chain, interoperability and comparability are existing concerns. The goal of the present research is to evaluate the accuracy and reliability of energy results given by some BIM and BEM software and the national calculation protocols stated by the law. The analyses have been carried out on a case study: the primary school building in Nerviano, northern Italy in Province of Milan. Starting from a BIM model (LOD 200 and LOI 350) defined in Autodesk Revit, it has been directly exported to Green Building Studio to calculate the energy performance. The file could be exported into EnergyPlus and the result has been compared to those achieved with a semi-stationary calculation method, according to UNI TR 11300:2014. The dynamic simulations in Energy Plus (Energy Plus, 2013) have been performed by a commercial software and an academic tool developed at Politecnico di Milano. The BIM and BEM model have been used to run a preliminary retrofit cost simulation to identify the affordability of a traditional retrofit intervention: an Exterior Insulation and Finishing System (EIFS).

2. Methodology

The paper focus on the workflow to promote the extraction of information from a BIM model, able to be used as repository for management of the asset, to BEM methodologies, comparing different calculation protocols going from the semi-stationary evaluation method required by the national regulation (D.L. 63/13) to the most advanced software based on dynamic calculation methods.

The energy performance calculation for the case study has been implemented using four methods, consistently with the objectives of the research (Figure 1). The analyzed calculation methods are used at national (a, b) and international (c, d) level and they have different interoperability levels with Autodesk Revit BIM software:

a) *UNI 11300:2014 standard*: it is a widely used and licensed semi-stationary method used at national level based on a *.xls spreadsheet to calculate the energy balance of a multi-zone building: it has a weak integration with BIM however it can be manually implemented with the extract quantities (e.g. envelope surfaces) and thermal properties from Autodesk Revit into *.xls tables (UNI 11300).
b) *EnergyPlus plug-in for SkecthUp*: OpenStudio (NREL) customization developed by Architecture, Built environment and Construction Engineering Department, Politecnico di Milano performing a dynamic simulation with a detailed and internationally qualified energy software manually implemented for the thermal data (EP);
c) *Green Building Studio*: cloud-based energy-analysis software performing a dynamic simulation directly from the BIM model created in Autodesk Revit; some critical issues rise about exportation and automatically data fulfillment which can lead to low level of confidence and control in the results (GBS);
d) *DesignBuilder*: commercial software used widely in the engineering sector using EnergyPlus directly importing *.gbXML files with geometrical information (DB).

The problem of interoperability is not described in deep in this paper however has been analyzed in deep in other research papers (Cirbini et al., 2016; De Angelis et al., 2015).

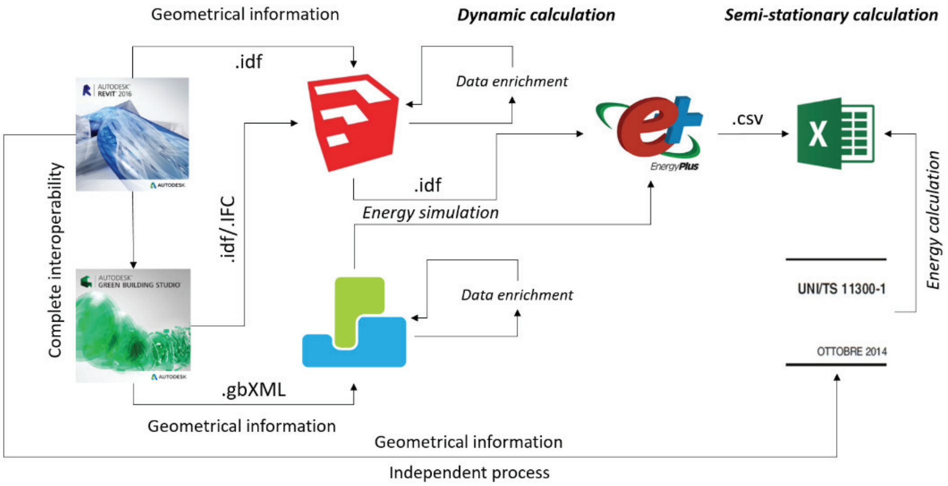

Fig. 1 Methodological process of energy analysis and tools with interchange files.

3. Case study

The case study is a primary school located in northern Italy, in Nerviano, Milan province, built in the ’50s and not refurbished except for the ordinary maintenance operations. The occupants, both students and staff are estimated around 400 people. The floor area is around 3’000 m^2 counting classrooms spaces, toilets, multi-task rooms, offices and canteen. A BIM model has been created on the documental data and information derived by a survey. Each building envelope component identified during the survey has been modelled in terms of thickness and materials (Figure 2). The internal height has been assumed based on external measures and standard height for the national built environment (~3 m). In Table 1 the dimensions of the envelope components with a brief description are listed.

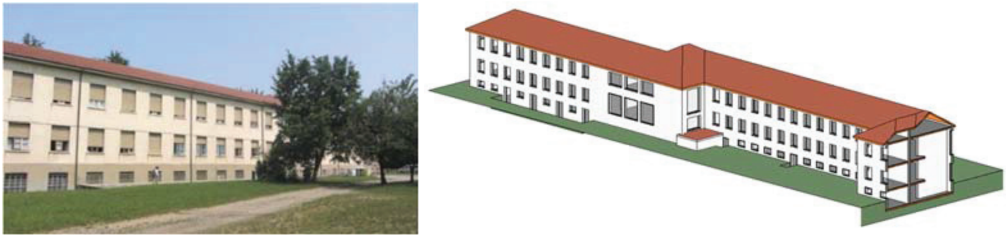

Fig. 2 External view of Nerviano School and BIM model with render view.

Tab. 1 Technological components of the transparent and opaque envelope

Component	*Area [m^2]*	*Description*	*Thickness [cm]*
Roof	1’610	Concrete roof, tile shingles, not isolated	25
External Wall	2’340	Structural masonry wall, not isolated	50
Interiors Wall	625	Not structural air-brick wall, not isolated	20
Interior Floors	3’115	Concrete floor, not isolated	30
Slabs in Grade	1’210	Concrete slab on ground, not isolated	30
Windows	760	Single-glazed wood frame window	5

4. BIM-based Energy Modelling

The BIM model geographically located has been created with a low LOD (200) because of the main core topic of the research. The information needed for the energy assessment have been updated into the model and Green Building Studio simulation run through the creation of thermal spaces. It is worthy to note that a dynamic simulation is performed based on hourly weather data of the specific location. The weather file used in the simulation with Energy Plus engine is the same *.epw file while the data used in the semi-stationary spreadsheet are based on UNI 10349:1994 and GBS used another weather database. For that reason the Degree Days – DD have been used in the results section to normalize the energy results and avoid deviances due to climate description dissimilarities. The most appropriate weather station has been selected considering the quality of the information of two stations nearby the school. The sources has been checked through a comparison with *.epw data for Milano Linate and UNI 10349 for Milano Province, double checking the average daily temperature and solar radiation. Additionally, specific opaque envelope components equipped with thermal properties have been created and assigned. In Table 2 the threshold values by regulation are reported to check the thermal quality of the existing envelope. Windows and other transparent components have been chosen from an internal single glass windows database and modified according to the actual properties (4.83 W/m^{2}K of transmittance and SHGC= 0.86). After the definition of the thermal performance of the envelope, the thermal zoning were identified through the "spaces" which are not only architectural components (such as "rooms") but they are mostly used for the MEP definition (Figure 3). The spaces with the same characteristics have been included in the same thermal zone and internal gains and set-point temperatures have been set. Autodesk Revit encompasses default settings for thermal zones in K-12 schools nevertheless the values coming from ASHRAE standard strongly differ from the ones defined by the Italian standard UNI/TS 11300-1.

Tab. 2 Thermal transmittance (U) and excess percentage compared to law threshold.

Component	*U [W/m^{2}K]*	*Compliance to law threshold*	
Roof	2.30	+86%	✗
External Wall	1.35	+75%	✗
Interiors Wall	1.35	-	✓
Interior Floors	2.17	-	✓
Slabs in Grade	2.10	+84%	✗
Windows	4.83	+54%	✗

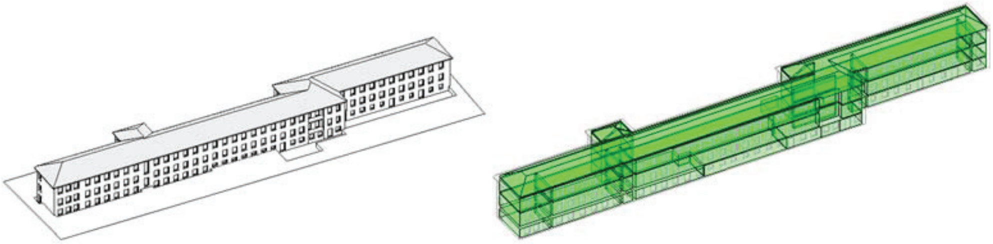

Fig. 3 BIM model (Autodesk Revit) and thermal zone with spaces to export towards GBS.

Therefore, new settings have been arranged for the parameters included in Table 3. Finally, the heating and ventilation system power unit associated to mechanical ventilation has chosen as the most similar system identified in the software database. For the EnergyPlus based software the same setting was adopted to allow the comparability of results. Due to specific capabilities of the calculation methods some assumptions and simplification have been adopted mainly in the geometrical shape definition for the spreadsheet tool (UNI/TS 11300-1) while for the EnergyPlus plug-in and Design Builder (Figure 4), the final results have been refined.

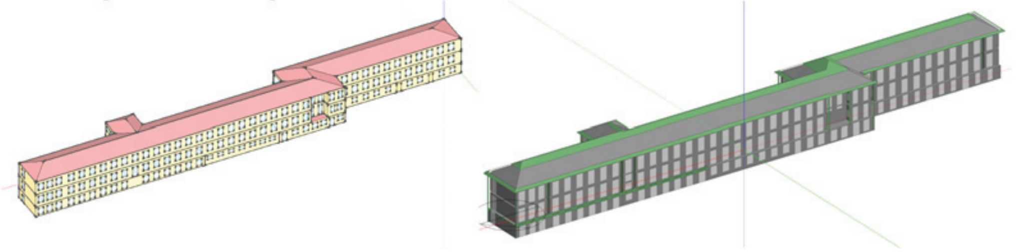

Fig. 4 BEM model in SkecthUp and DesignBuilder forEnergyPlus dynamic simulation.

The comparison is thus based on the energy demand because of the standard solution available in Green Building Studio and the lack of thermal plant definition inside the same software in the academic plug-in for SkecthUp.

Tab. 3 Thermal setting of the zones

Parameter	*Unit*	*Value*
Internal heating set temperature	°C	20
Outside air flow volume	volumes/h	0.47
Internal heat gains people, lighting, electronic devices	W/m^2	4
Occupancy and operating schedule Monday to Friday		
• Students	h	8:30 - 16:30
• employees/staff	h	7:30 - 18:30
Heating and ventilation system		
• central VAV, HW Heat, Chiller	COP	5.96
• Boilers	h	0.845

5. Results

The amount energy needs calculated with the four different methods are resumed in Figure 5. The Green Building Studio (GBS) value is higher of about 12% than the semi-stationary value (UNI 11300) and the EnergyPlus simulation shows a value that is lower of about 50% than the semi-stationary energy need. Design Builder (DB) is aligned to EnergyPlus plug-in (EP) considering the depuration of the thermal plant efficiency with a lower value of about 6%. The GBS value based on hourly data is a 57% higher than the Energy Plus simulation software. The BIM model was used to define retrofit intervention related to pathologies and costs have been deduced. Furthermore the BIM model could be connected to a Facility Management (FM) software. The EnergyPlus result has been used to calculate a cost simulation for a retrofit intervention of Exterior Insulation and Finishing System (EIFS).

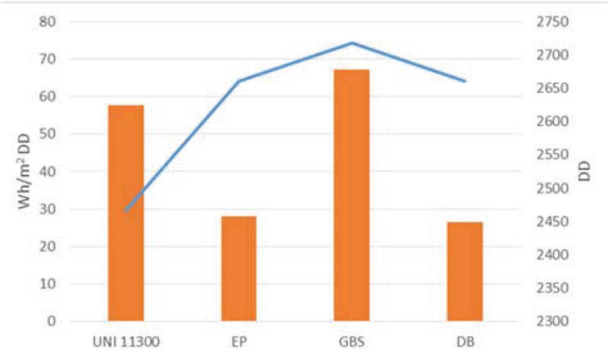

Fig. 5 Energy results comparison: Energy consumption and Loads.

Stated the need to refurbish the facade, one or more energy retrofitting alternatives can be evaluated on the same components:

a) Replacement of windows and doors with a more thermally resistant model;
b) Replacement of the external layer with a EIFS to be applied on existing wall.

The thermal losses decrease has been calculated in -38% calculated on the opaque envelope (Figure 6). So the main results are listed below:

c) Refurbishment cost:	108’284 €
d) Retrofit cost:	222’925 € (~75 €/m^2)
e) Annual saving:	17’299 €/year (~ -38%)
f) Payback time:	~ 5 years

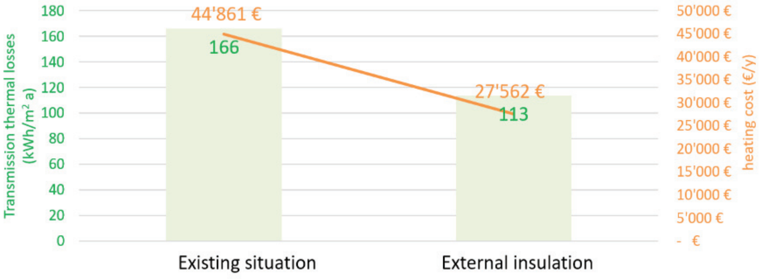

Fig. 6 Economic results comparison: Thermal losses and Cost.

6. Conclusion

Considering the result of energy assessment as a true, unique and unchanging value is a harsh simplification definitely not consistent with the real existing building behavior. The “performance gap” between simulation and actual consumption should be reduced to assure an efficient energy management through model tuning with real monitored data. The accuracy and reliability of the energy result of an energy calculation performed with a continuous chain of information can help the integrity and transparency of the assessment. For that reason BIM model is an assurance of congruence of the results to design and cooperation and information sharing in the project team (in this case architectural team, MEP engineers and energy analysts) is crucial. Moreover the BIM model can provide the repository for useful information for technical and economic evaluation in multi-criteria framework for an informed decision make process. The approach refers to the six leverages of the circular economy that could transform the AEC sector: regenerate, share, optimize, establish loops, virtualize and exchange, applied to schools towards a smart renovation for social development.

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