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BIM-BASED WORKFLOW FOR ENERGY AUDITS

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Abstract

Energy audits play a crucial role in energy retrofit projects for existing buildings, as the accuracy and completeness of the collected data strongly affect the reliability of the design energy model. The present paper thus proposes a new BIM (Building Information Modelling)-based workflow to better manage data collection in an energy audit process, to minimize data losses and inconsistencies. The proposed framework is based on the use of a simplified BIM Model, linked to an external database (for data storing) and to a webpage (for *in-situ* data acquisition). This can be used as a geometrical and non-geometrical data container to implement a reliable model for energy simulations. The efficacy of the presented BIM-workflow has been successfully validated through a survey on window fixtures for a real case study.

Introduction

The recent interest in energy retrofit of existing buildings is certainly related to the compelling need for reducing energy consumption in the built environment. In this perspective, the Italian Government is promoting, and financing energy retrofit interventions for residential existing buildings via the "Relaunch Decree", which increases the tax deduction rate to 110% expenses for specific interventions in the field of energy efficiency, seismic risk and renewable energy integration ((Legislative Decree 34, Dated 19 May 2020, 2020) and subsequent amendments). Deductions from the gross tax are granted provided that retrofit interventions produce an improvement in energy performance of at least two classes. In this context, the implementation of the BIM methodology in the field of energy retrofit of the built environment is attracting increasing attention lately. The most recent researches on BIM for existing buildings were focused on survey processes, not only aimed at acquiring geometrical data, but more generally aimed at collecting information about the state-of-the-art condition of existing buildings (Ciribini et al., 2015). For instance, Di Giuda *et al.* in 2018 (Di Giuda et al., 2018) proposed the use of the BIM-methodology to make energy audit procedures more efficient. More specifically, Di Giuda *et al.* realized a highly detailed Building Information Model of an existing historical building (the so-called Mandolesi pavilion in Cagliari, Italy). The latter was tested as a "Digital Twin" by storing thermal properties (acquired through instrumental measurements and calculations) of technical elements to manage future maintenance and retrofit interventions more easily and accurately. Desogus *et al.* also proposed the use of an "as-built" BIM model of the "Mandolesi pavilion" to store useful information and to continuously monitor structural and energy performance of the building for predicting the best future interventions scenarios (Desogus et al., 2018). More recently, Desogus *et al.* in (Desogus et al., 2021) proposed an integrated use of low-cost IoT sensors with a BIM Revit model of the aforementioned "Mandolesi pavilion", to monitor indoor conditions and energy consumption of the building in real-time. Similarly, Sanna *et al.* (Sanna et al., 2019) proposed a BIM-based workflow to optimally manage all necessary data for the assessment of comfort or discomfort conditions during the energy audit process of the "Mandolesi pavilion", (still adopted as case study). Tagliabue *et al.* proposed a "BIM (Building Information Model) to BEM (Building Energy Model)" workflow to optimize the Facility Management of existing buildings and implement energy retrofit strategies based on performance analysis by means of dynamic simulations carried out through BEM (Tagliabue et al., 2018). Sanhudo *et al.* in (Sanhudo et al., 2018) also dealt with a BIM-based approach for building energy retrofit, by focusing on optimizing the decision-making process to enable an easy identification of the best solutions in energy retrofitting projects. It can be stated that most of papers dealing with the implementation of the BIM methodology in such projects, have mainly shown the use of "as-built" BIM models to collect and optimally manage information about both real and simulated energy performance of existing buildings, chosen as cases study, during their life cycle. Conversely, the research herein treated, proposes the use of a simplified BIM model to collect early data from energy audits within a BIM to BEM process. The integration between BIM and BEM methodologies has been widely investigated in the recent literature. However, it emerged that full interoperability between BIM and BEM is still far from being achieved due to unsolved issues in data exchange. Spiridigliozzi *et al.* proposed a BIM to BEM workflow where data exchange was accomplished through non-proprietary IFC (Industry Foundation Classes) file format (Spiridigliozzi et al., 2019). Nevertheless, their study confirmed that the flow of information from BIM to BEM was not automatic as some IFC data could not be automatically read by the energy simulation software. Fernald *et al.* (Fernald et al., 2018) attempted several BIM to BEM strategies, based on the gbXML (Green Building XML) file format for data exchange, running into several interoperability issues (*e.g.* geometrical inconsistencies to fix) despite the preliminary BIM model simplifications. O'Donnell *et al.* (O'Donnell et al., 2020) investigated interoperability issues occurring in BIM to BEPS (Building Energy

Performance Simulation) transfer processes, by assessing several different strategies adopting both, IFC and gbXML file formats for data exchange. They found that different transfer routes lead to very different results, due to the lack of standardised processes of data transfer from BIM to BEPS, concluding that improved data transfer workflows and tools are needed. Therefore, having acknowledged the complexity of BIM to BEM processes, as well as some unsolvable interoperability issues, the research herein presented only focuses on optimizing data transfer and management in the earliest stages of a BIM to BEM process. More specifically, this study simply proposes a new BIM-based workflow to digitalize and make more efficient the preliminary survey process (*i.e.*, the preliminary energy audit procedure) to obtain more reliable models for energy analysis in designing energy retrofit interventions for existing buildings. At this purpose, the presented framework introduces the use of a dedicated webpage containing energy audit checklist tables, with in-situ fillable fields, properly linked to an external MySQL Database, as well as to the already-mentioned simplified BIM model. The efficacy of the proposed BIM-based workflow was successfully validated by surveying window fixtures in a floor type of an existing building in Cagliari (Italy) that will be subject to energy retrofit interventions, financed by the Italian Government ((Legislative Decree 34, Dated 19 May 2020, 2020) and subsequent amendments). The content of this paper aims at highlighting the main advantages of adopting, in the earliest stages of a BIM to BEM process, a highly simplified BIM model, linked to an external database and to a web page, to provide a data container and a digital support for *in-situ* data acquisition (*i.e.* the energy audit), in terms of saving time, minimizing inconsistencies and data losses. The rest of the paper is structured as follows: the next section briefly illustrates a traditional approach for energy audits; a new proposed BIM-based workflow for energy audit will be described in "Methods and tools" section; a successful application of the method on a real case study is presented in "Validation of the BIM-based workflow for Building Energy Audits"; concluding remarks about the achieved results are reported in the last section.

Traditional energy audit workflow and data asset

The presented study, started from a comprehensive analysis of a traditional non-digital energy audit workflow to detect its most critical issues. A survey for energy retrofit interventions has got the purpose of collecting qualitative and quantitative information about the building peculiarities that mostly affect its energy performance, such as architectural and constructional characteristics impacting on thermal properties of the building envelope, the installed HVAC and DHW (Heating Ventilation, Air Conditioning and Domestic Hot Water) systems, as well as the building usage (UNI CEI EN 16247-1:2012. Energy Audits - Part 1: General Requirements, 2012; UNI CEI EN 16247-2:2014. Energy Audits - Part 2: Buildings, 2014).

To be more precise, as energy audits aim at estimating energy saving potential of a building to identify the most suitable retrofit solutions, the following information categories are worth collecting (Clement, 2012):

- Dimensional characteristics of internal spaces
- Characteristics of the building opaque and transparent envelope
- Characteristics of the building transparent envelope
- Technical features of HVACW systems
- Information about the building usage (*e.g.* the building occupancy level, data about energy and fluid bills).

In this regard, Dall'O' provided a comprehensive guide to green energy audits including several checklists samples (Dall'O', 2013). It is a common practice in designing energy retrofit interventions for existing residential buildings, to first acquire some general and constructional information about the building (*e.g.* about its geometry, walls and windows location, construction systems) by technical drawings and reports from archives. The crucial next stage of *in-situ* data acquisition aims, on the one hand, at verifying the accuracy of the collected data from archives and, on the other hand, at gathering relevant data for energy analysis (*i.e.,* energy audit). However, it should be noted that the data acquisition on site is commonly accomplished simply by manual annotations and hand sketches on paper checklists and printed drawings.

The traditional survey workflow described above is characterized by the following main drawbacks:

- Paper checklists are not easy to be filled out on site.
- Paper checklists do not provide any kind of alert for incomplete and/or incorrect data.
- Hand sketches and annotations are not often easy to read and understand by anyone
- Data storage and cataloguing after archives and *in-situ* data acquisition is often manually accomplished.

More generally, common survey approaches for buildings energy retrofit can lead to a high level of interpretability and inaccuracy of the collected data, as well as to a high risk of data losses during the whole process.

Methods and tools

BIM-based workflow for a digital Energy Audit

A new workflow for energy audit has been developed, starting from the need to overcome the main drawbacks of traditional survey approaches, around the idea that a simplified BIM model, linked to an external database and to a web page (for *in-situ* data collection), could provide an effective digital support. The proposed method aims at more properly storing and better managing geometrical and non-geometrical input data to implement more reliable energy simulation models of existing buildings to retrofit. The new proposed BIM-based workflow for a digitalized energy audit procedure is briefly illustrated in *Figure 1* and it can be summarized by the following steps:

- **STEP 0 (Digital infrastructure creation)**: the proposed framework requires a preliminary stage (the current STEP 0) to create a digital infrastructure to make it work, which do not need to be reiterated for each specific project. The following sub-steps are necessary:

- **SUB-STEP 0.1 (Data Set Management)**: as shown in *Figure 1,* the whole data asset concerning energy retrofit of existing residential buildings should be properly arranged by identifying and classifying all geometrical, architectural, and thermal features that mostly impact on the energy performance of buildings envelope. The identified datasets should be organized in tables, useful to manage data and develop effective checklists for energy audits. Once datasets are arranged, parameters and related attributes must be clearly codified to uniquely characterize them.
- **SUB-STEP 0.2 (Creation of Dynamo-Slingshot! codes for data exchange)**: Two visual programming codes for bidirectional data exchange between BIM models and their related databases need to be created, through the software Dynamo (*Https://Dynamobim.Org/*, n.d.), integrated with the "Slingshot!" library (*Https://Dynamobim.Org/Slingshot-for-Dynamo/*, n.d.) for connecting to MySQL Databases.
- **SUB-STEP 0.3 (BIM library creation)**: It is suggested by the authors to create a specific BIM-Library of customized parametric walls and floors compound structures, as well as standard windows and doors suitable for simplified BIM models. For this purpose, specific "Groups" of "Shared Parameters" must also be created to store information (as "item" and "type" parameters for BIM entities) related to buildings energy efficiency.
- **SUB-STEP 0.4 (Web page implementation):** A HTML (Hyper Text Markup Language) responsive web page, containing energy audit fillable checklists need to be implemented.

- **STEP 1 (Project Database Creation)**: according with the herein proposed workflow, an empty MySQL Database (DB) must be created to effectively store (at a later stage) all data concerning each specific energy retrofit project. MySQL is an opensource Relational Database Management System (RDBMS) where SQL (Structured Query Language) is used to access, update and handle data in the project Database.
- **STEP 2 (Data acquisition from archives)**: analogously to traditional survey workflows, general geometrical and constructional information about the considered existing building (*e.g.* concerning its geometry, walls thicknesses and location, windows and doors dimensions and location, construction systems) need to be acquired from technical drawings and reports taken from archives of relevance like real estate registries, municipal archives and similar.
- **STEP 3 (BIM authoring)**: as previously disclosed, it has been supposed that a simplified BIM model could be effectively used as a container of energy-related, geometrical and non-geometrical, data acquired from both, archives and in-situ surveys. For this purpose, at this stage, a BIM model of the specific building to retrofit, with a LOD (Level Of Development) not higher than 200, is assumed to be accomplished by the software Autodesk Revit, as it easily allows to be bidirectionally linked to an external Database. The simplified BIM model must preliminarily contain walls, floors, windows, doors and rooms items with generic and approximate shape, dimensions, location, and orientation, derived from archives technical drawings.

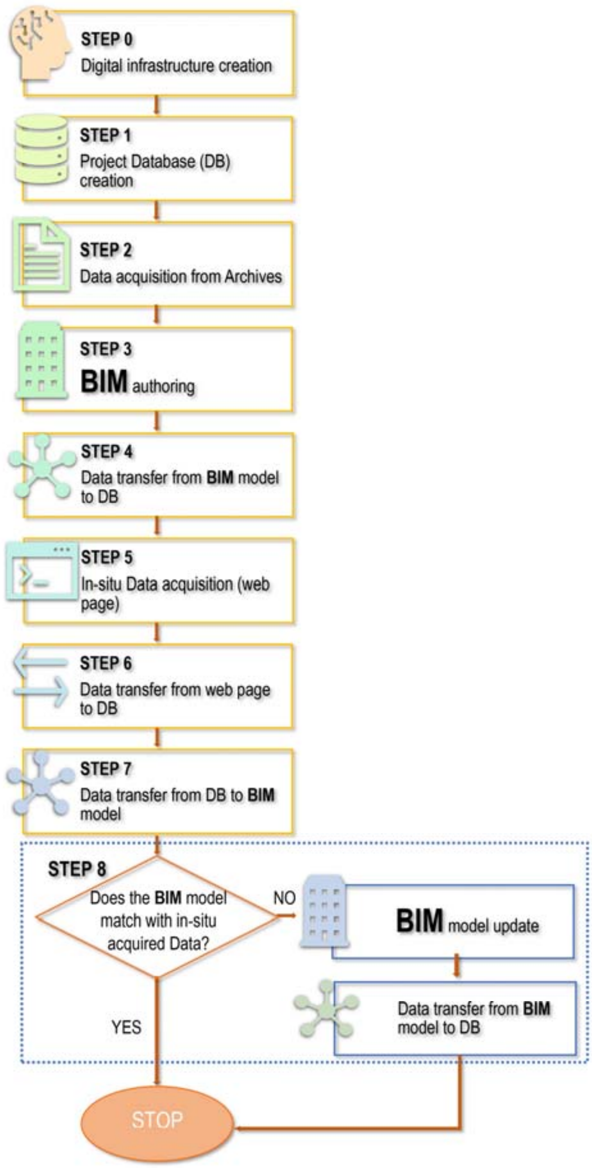

Figure 1: BIM-based workflow for a digitalized Energy Audit procedure

- **STEP 4 (Data transfer from BIM model to DB)**: The Revit BIM model is assumed to be then linked to an external MySQL Database (DB) to transfer and store in it some selected data of the building that are necessary for the *in-situ* data acquisition stage (*e.g.* "ID" of elements, "Family" and "Type" names of walls, floors and windows entities, the related "Level" and "Room" etc.). The chosen data can be transferred from the preliminary building informative model to the project DB by executing one of the two

"Dynamo-Slingshot!" codes, specifically implemented at the **STEP 0**. The proposed "Dynamo-Slingshot!" code allows the user to access the external DB, create specific tables and partially fill them with the selected data deriving from the BIM model items.

- **STEP 5 (*In-situ* data acquisition by web page)**: The process of *in-situ* data acquisition, has been digitalized by introducing the use of a web page with fillable checklists for energy audits. Digital checklists must contain both read-only (containing the selected information, deriving from the simplified BIM model and mined from the project DB) and *in-situ* (mandatory and optional) fillable fields. A suggested web page framework (see *Figure 2*) for energy audit surveys has been conceived based on the previously mentioned information categories that are worth collecting to assess buildings energy performance. A responsive graphical representation of each floor plan of the simplified BIM-model should be also supplied. The visualization of the building floor plans, with proper entity tags, will allow the user to easily identify, during the technical survey, each single building element (such as walls, windows, doors, rooms etc.) to be detected.
- **STEP 6 (Data transfer from Web Page to DB)**: the proposed workflow, also provides that, once all mandatory fields in all checklists have been filled out, the HTML code of the web page allows the related data to be submitted and automatically sent to the project MySQL Database.
- **STEP 7 (Data transfer from DB to BIM model)**: all *in-situ* acquired data need to be sent from the project MySQL DB to the simplified BIM model of the considered building. A second "Dynamo-Slingshot!" visual programming code enables the data transfer by systematically assigning the *in-situ* acquired data to each corresponding element parameter of the BIM model.
- **STEP 8 (Check for information inconsistencies and potential update of BIM and DB data)**: It is worth noting that on site surveys not only aim at acquiring relevant data about the existing building to retrofit, but also at verifying the accuracy of the collected data from archives (*i.e.,* technical drawings and report) concerning the building geometry and construction systems. For this purpose, if some on-site acquired data do not match with the model geometry (based on initial information deriving from archives), the latter and the project DB need to be properly updated. However, it is necessary to specify that the proposed workflow only enables a potential automatic update of limited features of the BIM-model (*e.g.,* walls and floors thicknesses, windows and doors dimensions) whereas more relevant inconsistencies between the original BIM-model and in-situ detected information, (for instance concerning potential missing or redundant internal walls and/or window fixtures), need to be manually updated.

The described workflow attempts to make easier and more accurate the early stages of a BIM to BEM process, by taking full advantage of advanced BIM-based and web-based technologies in digitalizing *in-situ* data acquisition (*i.e.* the energy audit), as well as in optimizing data management to obtain more reliable energy simulation models.

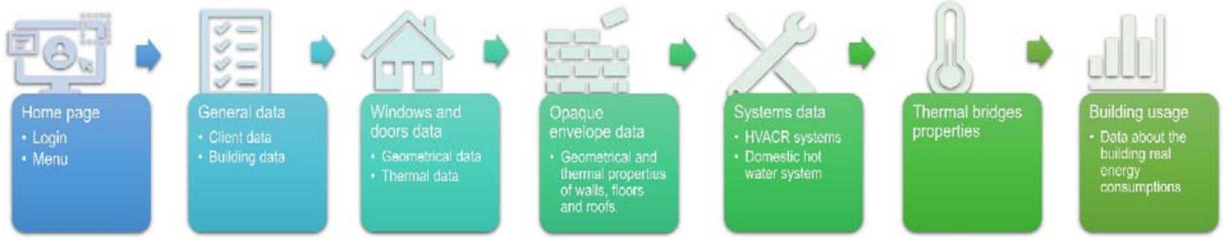

Figure 2: Web Page framework

Validation of the BIM-based workflow for Building Energy Audits

Case study

An existing block of flats, built in the late 1950s in Cagliari (Italy) as a social housing building and then mutated into a private apartment block, has been chosen as a case study among several energy retrofit projects provided by the engineering company DEARIS (partner of the Master PIE, mentioned in the acknowledgments).

The considered building is characterized by a load-bearing reinforced concrete frame with brick walls without any thermal insulation and hollow brick-concrete slabs. The apartment building has got six floors, and it is composed by 18 housing units, of about 110 m^2 each.

Application of the BIM workflow to the case study

The energy audit BIM-based workflow described above has been successfully validated by testing it on the previously described existing apartment building. It will be subject to upcoming energy retrofit interventions, designed by the engineering company DEARIS, and financed by the Italian Government by means of the Relaunch Decree ((Legislative Decree 34, Dated 19 May 2020, 2020) and subsequent amendments). Given the complexity of the proposed method, it was decided to start focusing on a limited portion of the whole information asset involved in a common energy retrofit project, as well as on a single floor type of the apartment block. The energy-related parameters and information, only concerning doors and windows, have been properly arranged and grouped (STEP 0.1 - Data Set Management).

The most common types of window fixtures that can be found in residential existing buildings have been identified and classified. Windows fixtures were classified based on geometrical and technical features that mostly affect their thermal properties (*e.g.,* window dimensions, window frame type and material, type and number of window sashes, glass(es) number, type(s) and thickness(es), shutter box type and size, window air tightness).

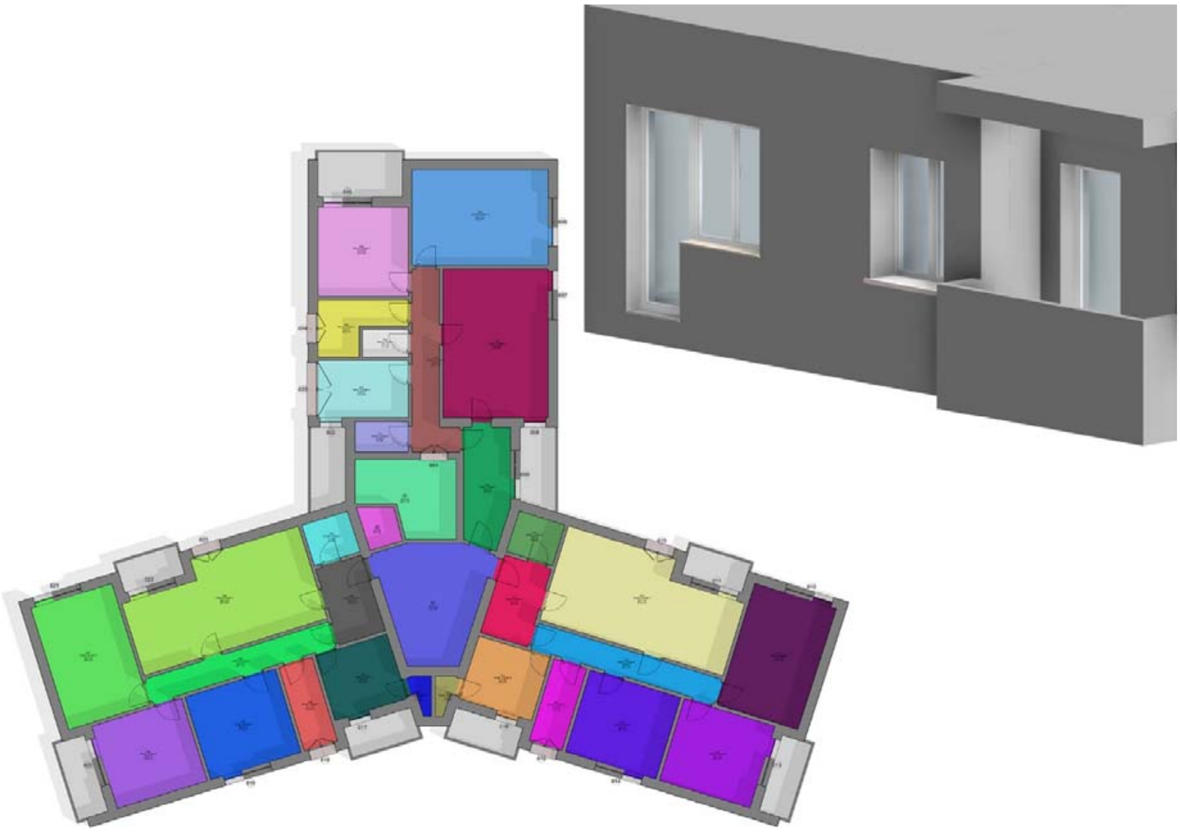

Figure 3: Type floor plan and axonometric portion of the simplified (LOD200) BIM model

According with the proposed BIM-based workflow, a simple codification system for "Family Types" of the Revit BIM model has been conceived for easily identifying windows and doors based on their type (window, French window or door), location (*i.e.* the cadastral subordinate parameter which uniquely identifies the corresponding housing unit where the window fixture is located) and dimensions (*i.e.* height and width). The following syntax has been used to codify "Windows Family Types":

2.1_FN_<Cadastral subordinate name>_Locale <Integer number> - <Window width [cm]>x<Window height [cm]>

(*e.g.,* the code "**2.1_FN_Sub1_Locale1 – 120x130**" refers to a simple window located in the "Sub1" house unit, in the room "Locale1", 120 cm wide and 130 cm high). According with the STEP 0.3 of the proposed workflow, generic customized Revit "Loadable Families" for parametric window fixtures have been created. Moreover, specific "Groups" of "Shared Parameters" have been arranged to be properly identified as "Family Type Parameters" (see *Figure 4*) or "Instance Parameters" to contain energy-related features of windows and doors. As specified in the previous section, Data Set Management and Codification, as well as the creation of a BIM Library will not be reiterated for every project as SUB-STEPS 0.1,0.2, 0.3 and 0.4 aim at implementing an overall digital infrastructure to make the whole workflow work. Based on the STEP 1 of the considered framework, an empty trial MySQL Database, allowing remote access, was created for the specific pilot case study on the XAMPP platform. The latter provides a useful opensource development environment for web designers, also including interpreters for PHP (originally stood for "Personal Home Page", now considered as a recursive acronym for "PHP Hypertext Preprocessor") scripts. Analogously to traditional surveys, general geometrical and construction information about the existing building in Cagliari (Italy), assumed as case study, had to be acquired from technical drawings and reports made available by the real estate registry of relevance (STEP 2). These information (mostly concerning walls, floors and windows dimensions, location and orientation) have been used as input data for the following digital implementation of the simplified BIM model (STEP 3).

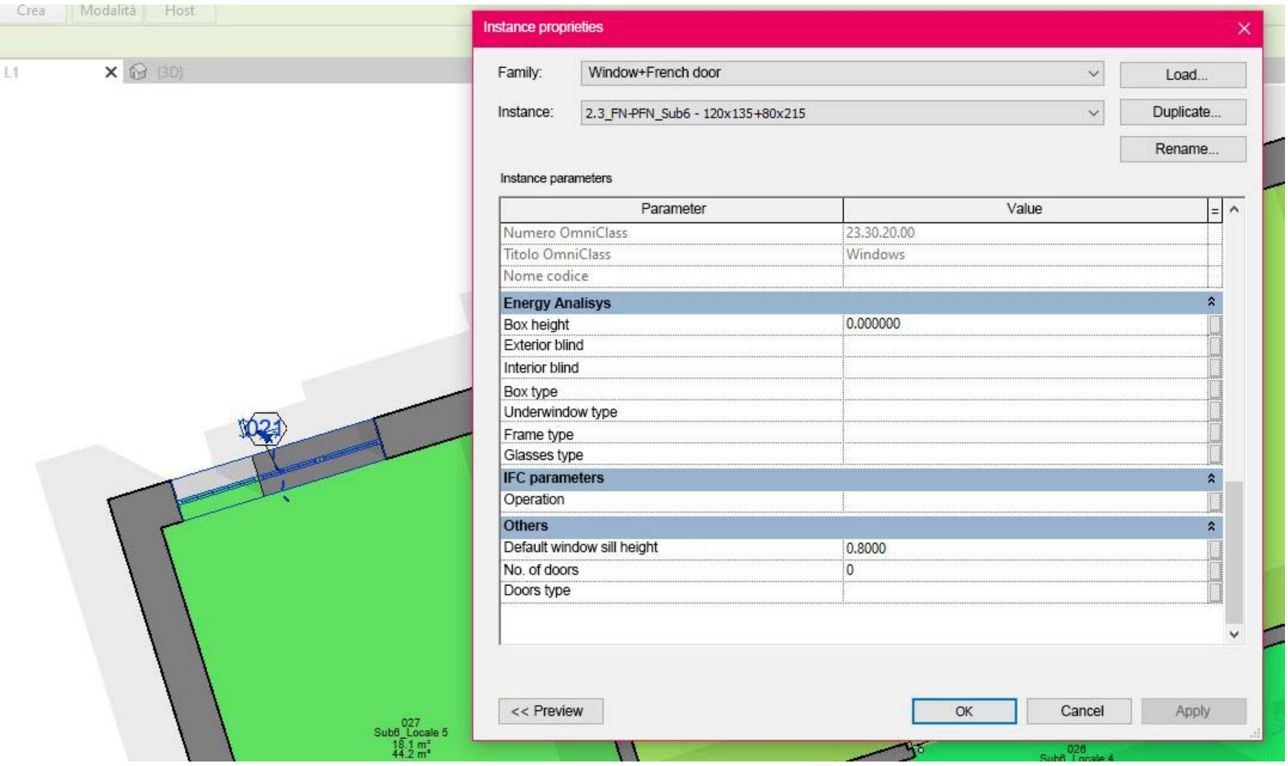

Figure 4: Customized "shared parameters" for Energy Analysis concerning window

Therefore, a BIM model of a single floor type of the building, has been accomplished by means of the authoring software Autodesk Revit (see *Figure 3*). According with LOD200 Level Of Development for BIM items, walls and floor slabs have been graphically represented as generic volumes with approximate dimensions, shape, location and orientation. Non-geometrical information (*e.g.,* walls and floors constructional system and materials) attached to the BIM model elements, have been also considered as an approximation. As shown in *Figure 3*, also windows, French windows and doors have been generically represented, as specific information was expected to be successively gathered during in-situ survey(s). Moreover, it is worth noting, from *Figure 3* and *Figure 4,* that graphical colours in the floor type plan uniquely identify all "Rooms", which are also characterized by unique alphanumeric tags, based on room numbers and apartments (*i.e.* the cadastral subordinate names). The following syntax has been used to codify "Rooms Tags":

<Cadastral subordinate name>_Locale <Integer number>

(*e.g.,* the tag **Sub6_Locale 5** identifies a room in *Figure 4*). A unique "Space" is also associated to each "Room" item as "Space" entities in Revit are conceived to easily store energy-related data about HVACW systems, as well as to evaluate heated volumes for the Building Energy Analysis. As disclosed in the previous section, the presented BIM-based workflow provides that the simplified BIM-model is bidirectionally linked to an external MySQL Database, which has been created at STEP 1. For this purpose, a Dinamo-Slingshot! (*Https://Dynamobim.Org/Slingshot-for-Dynamo/*, n.d.) visual programming code, has been specifically implemented (at SUB-STEP 0.2) to remotely access the project Database (STEP 4), create tables in it and partially fill them automatically (see the *Figure 5*) with already known data from the BIM model (*e.g.* the related "ID", numerical "Tag", "Floor", "Room name", "Family and Type name" identifying the selected windows of the building Revit model). These chosen parameters, deemed useful to identify the building entities during the on-site survey, have been thus transferred to the web-based windows checklist as read-only fields. A responsive web page, only concerning a checklist for window fixtures, has been then implemented at SUB-STEP 0.4 (on the XAMPP environment) by HTML (Hyper Text Markup Language) scripts also including PHP (PHP Hypertext Preprocessor) scripts, both to take data from, and send data to the project Database. The proposed windows web-based checklist has been provided with mandatory and optional fillable fields, most with drop-down menus, to make easier and safer filling them during on site surveys (STEP 5). The developed web page has been also equipped with a floor plan of the BIM-model, viewable in another tab from the web page, to allow the user to easily identify each window to be detected on site. Only once all required fields (marked with a red asterisk, as shown in *Figure 6*) have been filled in, all data have been submitted and automatically sent to the project database (STEP 6). Lastly, it has been verified that, by executing a second Dynamo-Slingshot! Code from Revit Manage Tab, specifically implemented for this stage (SUB-STEP 0.2), the windows data, acquired by the web-based form, were precisely sent to the BIM-model (STEP 7). The effectiveness of the proposed workflow was then validated by checking that data deriving from the web-based form were accurately stored in specific "Type" and

"Item Parameters" of the corresponding BIM-model entities (as shown in *Figure 6*). It is finally worth noting that it was not necessary to update the original BIM-model as any inconsistencies between archives and *in-situ* acquired data have been detected (STEP 8).

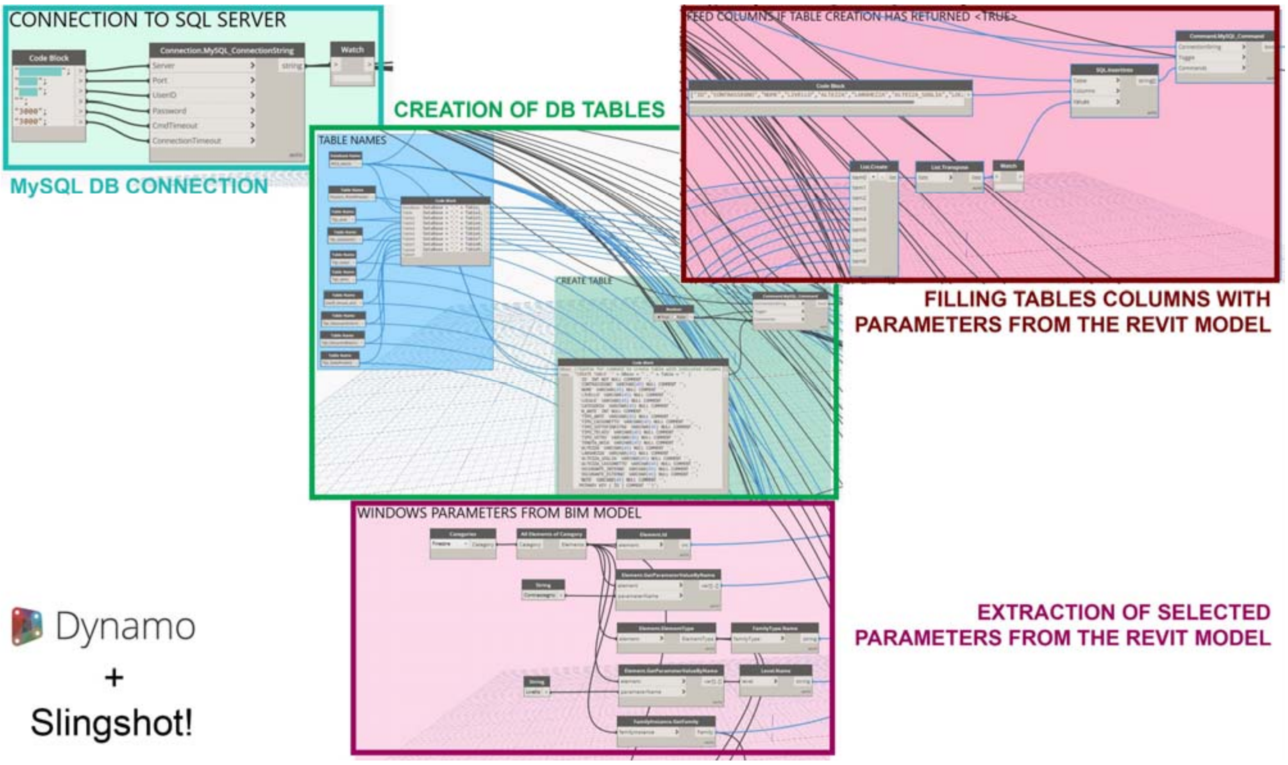

Figure 5: Portions of the Dynamo-Slingshot! Visual Programming code to transfer data from the Revit Model to the project MySQL Database

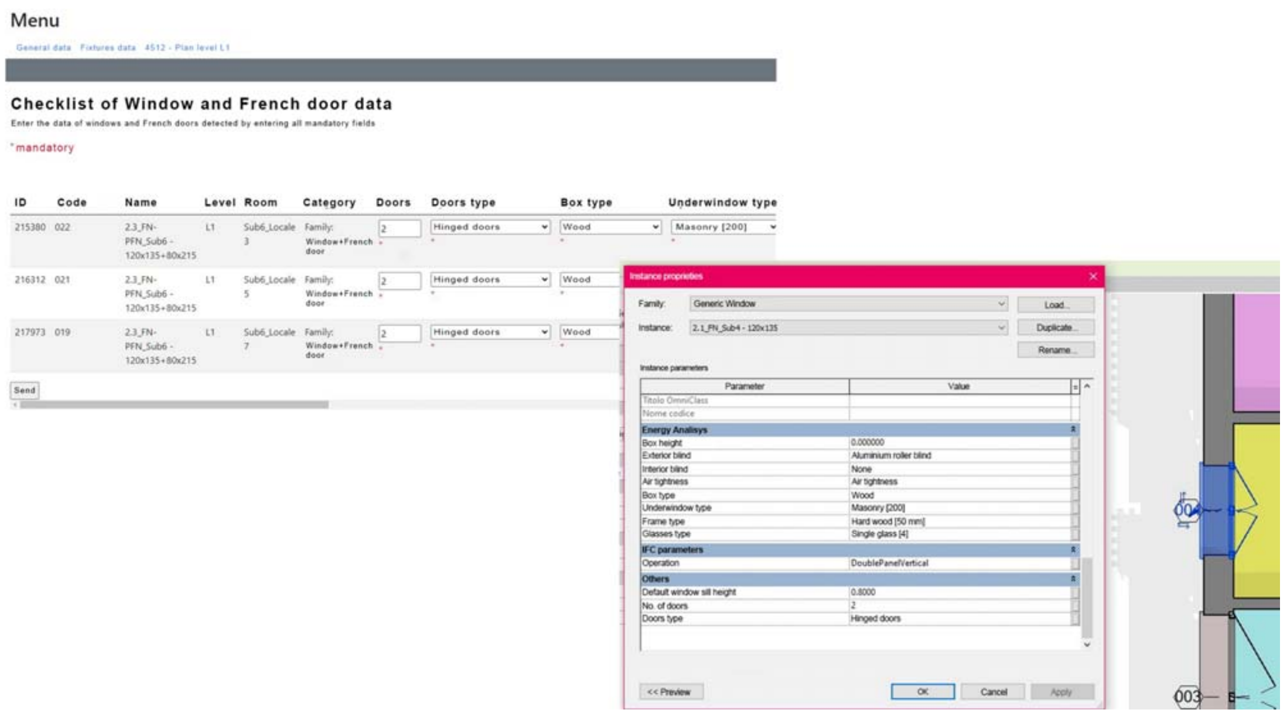

Figure 6: Web-based windows checklist completed (on the left); stored parameters of a detected window (on the right)

Conclusions and future work

The study presented in this paper revealed some significant critical issues deriving from a traditional approach in collecting and managing data in energy auditing, within a BIM to BEM process. As traditional survey approaches for buildings energy retrofit, (mainly based on hand sketches and annotations), can lead to a large margin of inaccuracy of the collected data, as well as to a high risk of data losses, a new digitalized BIM-based workflow for energy audits has been herein proposed. The effectiveness of the proposed workflow has been validated by applying this method in detecting window fixtures of a floor type of the existing apartment building assumed as a case study. The trial application of this method has brought out the advantages deriving from the use of the BIM-methodology in earliest stages of energy retrofit design: the digitalization of the energy audit process by the implementation of a simplified BIM-model to store geometrical and non-geometrical data, (gathered from archives at one time and from in-situ surveys later), made data transfer and management more accurate and safer, leading to more reliable energy simulation models. The use of the proposed web-based tool for *in-situ* data acquisition, whose gathered information are automatically sent to a specific database properly linked to the BIM-model, minimizes the risk of data losses and inaccuracies. Future research will focus on extending the application of the presented BIM-based workflow to the whole information asset concerning energy retrofit interventions, by arranging and codifying the whole involved data set. Furthermore, the web-page framework should be fully accomplished by also including checklists to collect information about the building opaque envelope, the HVACW systems, potential thermal bridges and the building use.

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