SOLAR POTENTIAL AND ENERGY ASSESSMENT DATA IN U-BEM MODELS: INTEROPERABILITY ANALYSIS BETWEEN PERFORMANCE SIMULATION TOOLS AND OPENBIM/GIS PLATFORMS

Carlo Zanchetta, Martina Giorio, Maria Grazia Donatiello, Federico Rossi & Rossana Paparella
Department of Civil, Environmental and Architectural Engineering, University of Padova, Padova, Italy

ABSTRACT: *To evaluate the energy and solar potential of the building stock and address feasibility studies of building retrofit interventions information standards are required to ensure proper data flow from building and urban models to simulation environments. Energy performance data are gathered from different information containers and therefore the result of simulations needs to be shared in BIM/GIS environments to better address energy policies and decision-making processes. Solar potential and energy retrofit estimation, developed by means of urban models (U-BEM) are too rough to support a decision-making process, even if at a feasibility stage. On the opposite, strategic decisions are defined with reference to large building stocks that require a U-BEM approach. To increase the reliability of this kind of simulations the study proposes to integrate U-BEMS with BIM-based data that are aggregated and published at urban scale as average performance indicators of built systems. The interoperability problem is analyzed both for simulation tools that need to manage this kind of data and openBIM/GIS platforms that need to share performance indicators and simulation results.*

KEYWORDS: *Energy potential, Solar potential, IFC, BIM, U-BEM.*

1. BACKGROUND

The necessity to take action in the constructed environment, encompassing both individual structures and entire urban areas, stems from the increasing significance of enhancing comfort levels and energy efficiency. This need arises due to mounting environmental issues and the imperative to reduce energy consumption (Ratti et al., 2005). With urbanization and the increasing impact of buildings on energy demand, there is a crucial demand for accurate predictive models that can guide sustainable urban development (Amado & Poggi, 2012).

Traditionally, urban energy planning and building design analyses have been based on generic models, leading to suboptimal energy performance and inefficient resource utilization (Lan et al., 2022). Due to this reason, it becomes imperative to establish precise information standards that ensure seamless data transfer from architectural structures to urban models, encompassing both geometric and climatic data. These standardized procedures will facilitate, for example, the transmission of initial solar potential assessments within simulation environments. To overcome all the limitations, the development of sophisticated and reliable predictive models has become necessary (Lobaccaro et al., 2019). Such models can provide, in a simulation environment, valuable insights into the solar potential of different urban areas, allowing city planners, architects, and experts to make informed decisions regarding energy-efficient designs, renewable energy integration, and also climate-responsive urban planning (Kabir et al., 2018).

The examination of outcomes from the new solar potential estimation applications, reveals a noteworthy decrease in the computed potential once the feasibility of installing energy production systems like photovoltaics is assessed. Analyzing the solar potential of buildings allows for the swift identification of surfaces significantly impacted by solar irradiation, evaluating the more suitable for incorporating active solar systems. However, if this assessment is conducted on an overly simplistic model, assuming all surfaces possess a uniform level of adaptability, it fails to accurately reflect the true solar potential.

Likewise, concerning the energy retrofit of existing buildings, it is crucial to confirm the practical feasibility of upgrading building envelopes and technological systems with energy-efficient technologies. This verification should occur within a comprehensive information model aimed at identifying transformation barriers that could potentially impact feasibility studies. Such a model would help reference point challenges that might arise during the retrofitting process and ensure a more accurate assessment of the retrofitting potential.

The essence of the issue lies in the requirement for simulations to rely on a dependable information foundation, which necessitates a detailed representation of buildings. However, such detailed data is often unavailable during the preliminary stages of the study. Consequently, it becomes imperative to establish a system that enables the

Referee List (DOI: 10.36253/fup_referee_list)
FUP Best Practice in Scholarly Publishing (DOI 10.36253/fup_best_practice)
Carlo Zanchetta, Martina Giorio, Maria Grazia Donatiello, Federico Rossi, Rossana Paparella, *Solar Potential and Energy Assessment Data in U-BEM Models: Interoperability Analysis Between Performance Simulation Tools and OpenBIM/GIS Platforms,* pp. 1021-1032, DOI 10.36253/979-12-215-0289-3.102

enrichment of urban models with more accurate values for the subsequent calculation of the solar potential data and the energy retrofit. Such models must integrate irradiation conditions on architectural surfaces depending on their exposure and geographical location with a broader range of factors influencing energy production and transformation to ensure more precise and reliable simulations.

In fact, the building sector lacks a method that makes it possible, in a relatively short period of time, to assess the real renovation potential of an existing building and, therefore, to identify, at a preliminary level, the optimal intervention strategy. The lack of information on the transformation of the existing building, on the one hand, and the enormous potential offered by the development of new technologies, on the other, make it necessary to identify a plan for evaluating the renovation potential of buildings.

The literature analysis revealed that, to date, the only tool for formulating energy efficiency design hypotheses is the energy diagnosis. This is a rather time-consuming process, as well as an economic one. Hence, the need to formulate an expeditious methodology for assessing existing buildings. (Mazzarella & Piterà, n.d.)

Some attempts have been made to propose a method for defining a building potential in Italy, but these go beyond the concept of transformability, which is intrinsically linked to the technological element, and outline intervention scenarios that are compatible with the valuable characteristics of a historic building, such as ENEA method. In turn, the intervention is ranked according to a score determined based on effectiveness, durability, compatibility, and cost-effectiveness (Boriani et al., 2011). Other attempts to propose a methodology to analyze buildings are represented by TABULA project and CRI_TRA method. TABULA focuses on the proposal of a census of building types and their optimization by simulating the effects of possible retrofitting interventions (Corrado et al., 2014), while the CRI_TRA method is very close to what is proposed in the rest of this research activity. It is configured as a study of the criticality and transformability exhibited by the public housing sector through the assignment of a numerical score to the two indices, GDC and GDT (Diana, 2017).

2. METHODOLOGY

To achieve the delineated results, the study proposes to integrate simplified models with "transformability coefficients" that considered the adaptability and potential of various building surfaces and technical elements to harness solar energy effectively. By identifying surfaces that are most susceptible to solar irradiation, the integration of this coefficient with the simulated data offers a more precise representation of the real potential within the urban context.

To establish these coefficients, a representative selection of detailed building models was analyzed. These detailed models serve as a basis for deriving coefficients that reflect the unique characteristics of different surface types and facades. The coefficients were identified inside the entire urban area using characteristics such as the age of the buildings and the architectural similarities. Integrating the coefficients into the subsequent simulation process ensures that the data are based on more realistic and specific information.

The geographic information system (GIS) environment plays a crucial role in this methodology, enabling the integration of various data sources, such as climatic data from terrestrial or satellite weather stations, building geometries, and urban morphologies, in the calculation of the solar potential data. Through this integration, the GIS platform acquires data from 3D simulations that take into account solar irradiance, local weather conditions, and the complex interplay of sunlight with urban elements (Bahu et al., 2013).

Moreover, the simulation outcomes do not only focus on solar potential estimation for photovoltaic installations but also extend to solar thermal systems. This broader perspective enables a comprehensive evaluation of the renewable energy potential available in the urban context, encouraging the adoption of different and integrated renewable energy solutions.

By applying this methodology to the North Piovego University area in Padua, Italy, the study demonstrates its applicability to real urban scenarios. The study area selected for analysis covers approximately 50,000 m2 and it is located in northern Italy. By integrating detailed building data, geographic information, and solar simulation techniques, this approach provides a robust foundation for optimizing energy efficiency, promoting renewable energy integration, and fostering sustainable urban development.

2.1 Source data for modeling

Urban data and weather data are closely related to a geographical location and a determined time. Geospatial data can take different forms: raster, vector, and graph data. Raster data is a gridded matrix, organized in rows and columns. Vector data represent information through points, lines, and polygons. Graph data are represented by edge and node and generally take the form of road networks (Lee & Kang, 2015). Since raster data always have a standard dimension, they are considered more basic than vector data, which, on the contrary, are discrete. The union of raster and vector data makes the geographic database. The sources of these data are manifold and in recent years there has been a radical change in the way the maps are created. While maps were previously only created by national land mapping agencies, in the 2000s, thanks to the elimination of intentional GPS degradation, a new way of creating maps was born (Haklay & Weber, 2008). The accuracy of GPS, introduced in all mobile devices, gives any citizen the possibility of entering information into maps. Numerous studies have named this phenomenon differently. They speak of Volunteered Geographic Information (VGI) (Goodchild, 2007), neogeography (Rana & Joliveau, 2009) and crowdsourcing geospatial data (Heipke, 2010). The peculiarities of this phenomenon are:

- data are much more varied than in official cartographies because anyone can add information to the map;
- data are available for any part of the world even for places subject to legal or technical restrictions.

Main producers of information are the citizens who consciously or unconsciously add information to these databases. the most successful project is OpenStreetMap that up to date, counts 10.729.032 users and 23.604.230.005 GPS points (*OpenStreetMap Statistics*, n.d.). Other VGI projects are Wikimapia, Map Maker, Here Map Creator, Map Share and Waze.

Citizens can actively or passively add information to the map. The active mode is when people are aware of updating the map by participating in some campaigns aimed at updating databases. The passive way, on the other hand, takes place thanks to the GPS inside mobile phones, when georeferencing any post on social media, for example (See et al., 2017). These maps also contain so-called 'framework data', that is the 'most common data themes that users of geographic data need', which can 'typically include seven framework data themes: geodetic control, orthoimage, elevation, transport, hydrography, governmental units and cadastre. These data represent relatively static phenomena and are commonly used for administrative programs, wayfinding, geopositioning, geotagging, and other popular services, so they have been a traditional target of government data production" (Elwood et al., 2012).

Regarding the correctness of data, citizens tend to enter or correct only the data they really know, generally related to the area in which they live. Many institutions that produce geospatial data have espoused the cause of OpenStreetMap, such as for Italy Portale Cartografico Nazionale (PCN), since 2010, makes its images available (*Italy/PCN - OpenStreetMap Wiki*, n.d.). Several studies (Borkowska & Pokonieczny, 2022), (Minaei, 2020), (Dorn et al., 2015) have shown that from a geometric point of view, the information contained in OpenStreetMap databases are quite correct, especially regarding buildings and the transport network. Another important fact concerns the accuracy, which increases proportionally to the urbanization of the area. Accuracy of data is one of the requirements also expressed in ISO 19157:2023 geographic Information - data quality. According to this standard, the quality of geospatial data is based on several characteristics:

- Completeness: presence of values describing different characteristics;
- Logical Consistency: degree of adherence to the rules of the data structure (documented and named);
- Positional Accuracy: accuracy of the measurement between the given position and the position accepted as true within a reference system is. For Global Navigation Satellite System (GNSS), it is within 2-3m.
- Thematic Quality: accuracy of quantitative attributes and the correctness of non-quantitative attributes and feature classifications and their relationships.
- Temporal Quality: the quality of temporal attributes and temporal relationships of features

2.2 Open Street Map as a reliable data source

Due to its large diffusion, the study proposes OpenStreetMap as a reliable and scalable data source. The project started in 2004, so it developed right at the same time as the evolution of crowdsourcing concepts. This study takes all the urban data from OpenStreetMap, which can in fact export part of the whole map. The exported file can also be used as a base map within GIS software. The .osm format is proprietary, but it is written in XML so it is interoperable due to an expandable language (Behr & AGSE. 5 2012 Stuttgart., 2012).

Although the idea is that anyone can insert new information into this map, OpenStreetMap is not included in the more than 70 standards of the Open Geospatial Consortium (OGC). Voluntarily OpenStreetMap does not conform to the standards because its purpose is not to be a standard but only to be a map containing geospatial information.

Despite this fact all OpenStreetMap data can be used and possibly even transformed according to the standards, in fact there is third-party software that allows to read .osm files and transform them into shape files.

OpenStreetMap has its own data structure comprising three geometric features (Nodes, Ways, and Relations) plus an object information feature (Tags) (Vargas-Munoz et al., 2021).
Nodes are the main element in the data structure and represent symbols. A node is a transposition of a point of interest on the earth. Several nodes together form a way, which can be open (polyline) or closed (polygon). An example of a polyline can be a road or a river, while the most illustrative polygon is a building. At least two nodes are needed to create a polyline, while three nodes are needed to create a polygon. It is therefore possible to relate several nodes to create a road, but it is also possible to relate geometric objects with information objects (tags).

Tags consist of two items 'key-value' where the key describes the type or category, and the value is the specification of the key. The insertion or modification of tags is free, in fact although OpenStreetMap has a defined structure of tags, it leaves the user the possibility of adding different tags.

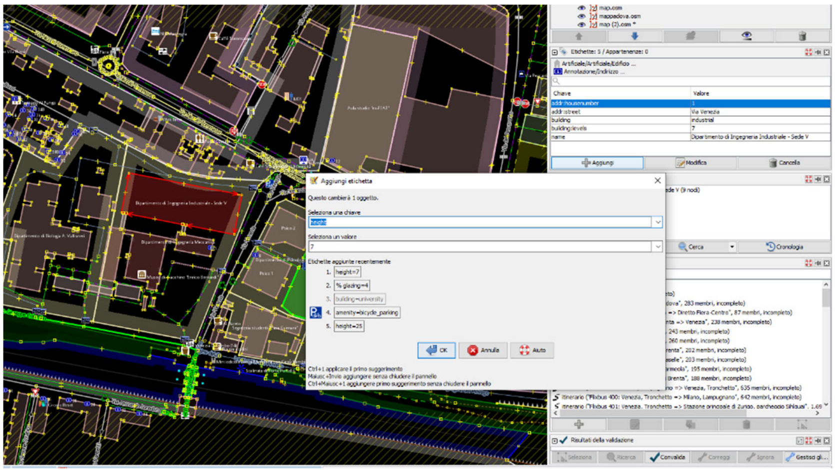

Fig.1: Adding a tag with JOSM.

Unfortunately, the estimates clam that less than 3% of the objects have the height key filled in and very often also wrong. Height is the typical datum that must be entered by the user to be correct, it cannot be taken from satellite orthophotos. Calculating this data could be difficult to obtain especially if the building is tall, which is why the study (Bshouty et al., 2020) of has created an app "OpenStreetHeight" that can calculate the height using a photograph. The height for the buildings, in the selected area, was not present within the .osm file but was visible through the OSMBuildings application. This site, written in Java, shows at the three-dimensional level the 2D map of OpenStreetMap According to what has been said so far, if a data is wrong or missing everyone can change and update it, and that is what has been done. To be able to modify the data there are several editors. There are both computer and telephone applications. The best known and most widely used are JOSM (Java OpenStreetMap) and Potlatch (Neis & Zielstra, 2014), both are computer applications. Through these applications, the map can be viewed and edited. Adding the data, using JOSM, is very simple just import the map and selecting the building polygon add the tag.

2.3 Generation of the model

To create the model of the case study area, the initial step involved the editing of the source OSM file. In fact, certain unnecessary data had to be modified or removed from the starting .osm file. The primary data was generally accurate, except for building heights, which were often incorrect, listed as a default "3 meters" when not available.

To acquire accurate data, several methods were considered, also including LIDAR technology (Manni et al., 2022). LiDAR sensors can gather highly precise and detailed elevation data. These advanced sensors emit laser pulses toward the Earth's surface and measure the time it takes for the laser to return after hitting an object or the ground. By analyzing the return time and the wavelength of the laser, LiDAR systems can calculate the distance between the sensor and the target surface with exceptional accuracy. In any case, it is important to have adequate equipment to carry out these surveys, and for that reason, in this case, building heights were manually calculated by cross-referencing data like the number of floors, using JOSM to modify and delete data. Additionally, two new tags were inserted:

- Transformation coefficient: which represents the percentage of façade or building transformability, indicating the freedom to incorporate new installations on surfaces or interiors.
- % glazing: which represents the total glazed area relative to the total area.

Correct values for these new parameters will be calculated for each building and replaced together with the starting information. Each element in the OSM file has a unique ID number to identify it. The default value is 1 for façade transformability and 0 for glazing.

A generative script developed with Grasshopper's Urban tool generated building volumes starting from OSM metadata and including the urban geometry of roads and external spaces. Each building is represented as an extrusion of its planar geometry. The source file also contains other information, such as the number of levels, function type, and structure identifier, unique to each building.

Climatic and environmental conditions are gathered by .epw file. Ladybug offers a library of data collected from weather stations worldwide, downloadable from their official website (*EPW Map*, n.d.). For the case study, data from the Treviso airport weather station was used due to a lack of specific data for the Padua area. The available data is for year 2020, and the simulations presented focus on the entire month of July 2020.

Before conducting simulations, the presence of greenery and trees must be considered, as they significantly impact solar potential and act as crucial mitigating elements. Therefore, the 3D geometric model was supplemented with the modeling and placement of trees and green elements based on their actual arrangement, height, and leaf density, utilizing a site survey and satellite images for accuracy.

2.4 Solar potential study

Once the basic geometric model is prepared and enriched with additional information, the analysis of solar potential can commence using various available tools, both in GIS environments and beyond. In a comparative study conducted by (Giannelli et al., 2022), five main tools, including GRASS GIS, ArcGIS, SimStadt, CitySim, and Ladybug, were assessed by comparing their simulation data with ground truth data obtained from a weather station (Jakica, 2018), (Peronato et al., 2018). Among these tools, Ladybug was found to be one of the most accurate for solar radiation studies, sky view analysis, sunlight hour modeling, and more (Freitas et al., 2015). Therefore, it was chosen as the basis for the research work in this study.

However, a notable challenge faced by all the tools, including Ladybug, is that the data obtained through simulations are related to simplified surfaces that do not correspond to the real conformation of buildings. Consequently, they may not provide reliable estimates of the exact solar potential, as factors such as surface conformation and the percentage of glazing can significantly impact the results. For instance, certain surfaces may not be suitable for the installation of new energy systems throughout the entire area (Esclapés et al., 2014). The issue arises as simplified models treat all surfaces uniformly, considering them flat and non-glazed facades.

To address this problem, the study aims to introduce coefficients that can account for these specific building characteristics and rectify the results obtained from the simulations. By identifying and incorporating these coefficients into the analysis, the study seeks to obtain more realistic and reliable data with minimal additional complexity. This process involves coding in Grasshopper to automate the identification and application of the coefficients to the simulation results, streamlining the evaluation process (Assouline et al., 2017).

2.5 Energy Potential study

The definition of the energy retrofitting potential of a building is based on the development of a method which allows the cataloguing of technical elements and their subsequent differentiation through the analysis of geometric, aesthetic and technological factors and the relative retrofitting potential. The main objective of this research activity is to develop a simplified type of rapid assessment model about building technical elements, whose horizontality allows the extension of the experimental scheme to the entire building system to evaluate its potential and criticalities and to direct a specific renovation process. The formulation of a percentage score, an indicator of the building retrofitting potential, constitutes the tool for pre-evaluating the effectiveness of its efficiency and for comparing buildings belonging to the same stock to identify a design strategy that is convenient both from an economic and energy point of view.

The structure of the methodology is based on the definition of the upgrading potential, which quantifies the possibility of increasing the performance level of a technical element by implementing specific retrofitting measures. For example, the presence of geometric and aesthetic constraints could significantly limit the building transformability. Although the upgrading potential is directly focused on the element itself, the definition of retrofitting potentials introduces a preliminary assessment of possible interventions.

Once virtual potential for improvement has been defined, it is necessary to introduce the concept of transformability, which indicates the readiness of a technical element or a building to accommodate a technological solution aimed at increasing the energy efficiency. Thus, this parameter represents a tool to moderate the value assumed by the potential according to the real possibility of intervention. The definition of this parameter considers geometric, aesthetic and technological features of each technical element. In fact, the transformability coefficient (T) is the result of geometric mean (Equation 1) of the geometric (T_G), aesthetic (T_A) and technological transformability (T_T).

$$T = \sqrt{T_G \cdot T_A \cdot T_T} \quad (1)$$

Therefore, the combination of the virtual potential and transformability rate into a single index, called effective potential for upgrading, guarantees the moderation of technological element potential as a function of its transformability.

To define effective potential rate, this method involves a careful process of analysis of the specificities that distinguish each item. Both transformability and upgrading potential are subjected to the assignment of a score, a coefficient between 0 and 3 to each index. A coefficient of 3 corresponds to the maximum possibility of intervention to which a technical element can be subjected. On the other hand, a value of zero is determined by the impossibility of intervention: in the case of potential, zero indicates the absence of actions that increase the energy performance of a building component (if it is already particularly performing), while a zero transformability derives from the presence of constraints that inhibit any design strategy. Depending on the type of component, the meaning of the rates changes according to the peculiarities.

The decision to use a classification system with a peer number of coefficients stems from the desire to reduce the possibility of a high percentage of components falling within the median.

At the same time, this research work proposed the decomposition of the building system provided for by UNI 8290 and identifies five technical elements, such as opaque vertical components and windows, opaque horizontal components and heating systems. In addition, the methodology included a census of these elements to determine their profile in terms of energy potential. The entire set of examples is the result of research into sector manuals and direct observation of buildings in nearby cities: in particular, the attempt to grasp the complexity and variety of technical elements is one of the main objectives of this compilation. However, it must be stressed that the definition of building archetypes is a subject that will be further developed to capture the diversity of the building sector.

3. EXPERIMENTATION

The research work, for the solar potential study, involved the analysis of two significant buildings within the study area, focusing on their geometric and solar aspects. The first building, primarily used for offices, had a rectangular floor plan with an overall height of 30m. Its facades featured a series of pilasters, creating a rhythmic pattern of window openings. The second building, with the university department of industrial engineering laboratories, had a rectangular plan with a height of 9m. Its facades were predominantly composed of windows, forming an overlapping grid pattern. The roof of this building had a distinctive stepped pattern.

To analyze the solar potential of these buildings, two models were developed for each, a simplified model, and a more detailed one. Ladybug for Grasshopper was used for the simulations to obtain the solar potential values for each facade. The factors that significantly influenced the actual solar potential were the percentage of windowed and opaque surfaces and the conformation of surfaces susceptible to transformations. The shading factor was already considered by Ladybug, and the presence of elements like balconies would be accounted for in the detailed model.

An equation (Equation 2) was derived to relate the real solar potential value (SP_r) to the simplified solar potential value (SP_s), the percentage of the opaque area ($\%op_{area}$), and the transformation coefficient (T_{coeff}). The simplified solar potential value was obtained through Ladybug simulations on the simplified model. The opaque area percentage was calculated from geometric analysis using software like AutoCAD. The transformation coefficient was derived by using an inverse equation based on the real solar potential value from the detailed model.

$$SP_r = SP_s \cdot \%op_{area} \cdot T_{coeff} \tag{2}$$

The data for the transformation coefficients, opaque area percentages, and glazing percentages were then included within the .osm file to enrich the information for each building. The JOSM software facilitated editing the .osm file to create new categories of parameters and associate their values with each building. For simplicity, a single parameter was associated with each building for the new data categories, taking the average values for each facade and roof to account for varying conformations.

By applying the new coefficients to the data of the simplified solar potential, a more accurate estimation of the solar potential value was obtained, considering the actual building conformation. The additional data calculated using this methodology was inserted into the .osm file for each building using specific identification codes. The file was then exported in .xml format, allowing the GIS environment to read the new data along with the existing data in an open-source format. This approach enables the creation of more realistic territorial models, providing more reliable information on solar potential at a granular level.

The energy potential research activity involves the transformation of the initial qualitative approach, linked to the formulation of a rehabilitation potential index, into a scientifically based methodology. To achieve this, the development of energy simulations made it possible to provide a numerical basis for the initial survey. In this way, the results obtained are crucial to the establishment of the methodology, like the definition of the rehabilitation potential. Specifically, the aim is to quantify the reduction in energy consumption resulting from the implementation of a given retrofitting measure affecting a specific component, leaving the conditions of the other technical elements unchanged. The experimental activity leads to a ranking of the efficiency measures, expressed in terms of energy demand reduction. Thus, it will be possible to relate the actual improvement potential of each technical element to the actual energy footprint assumed by the same. This phase is not an integral part of the methodology, but it is functional to validate its results for subsequent applications.

The verification of the previously assigned virtual improvement potential rates required the development of energy simulations using the EC700 software supplied by Edilclima. Edilclima is one of the main Italian software packages for calculating energy diagnoses. The choice of this calculator is due to the high interoperability between the BIM modelling, carried out in Revit, and the energy simulation software. In fact, the introduction of EC770 (the plug-in provided by the company) makes it possible to derive a large part of the input data for determining the energy performance of a building from the architectural model, speeding up the process.

Moreover, the procedure has introduced a series of energy improvements, each of which is intended for one building component. The decision to use this specific method, which is very different from the usual practice, stems from the desire to be able to calculate the influence of the improvement in the efficiency of a specific technical element on the overall behavior. Several architectural models have been defined in the process to group together the building types studied during the survey phase and, therefore, to evaluate the energy savings percentages by carrying out a considerable number of energy simulations. Specifically, for each macro-category of technical element, a common design state was identified to compare the percentages obtained.

For this purpose, it was considered appropriate to adopt an extremely simplified architectural model. A rectangular building with a side of 10x6 meters, developed on two levels, was implemented in Revit. The floors have the same layout and contain only one room. The construction characteristics are the most common in Italy. It is a load-bearing masonry construction, with brick floors and roofs. The energy performance is particularly poor. To determine the actual impact of a technical element on the overall energy savings, it was considered appropriate to vary the energy characteristics of the considered component, while leaving the other parts of the building organism unchanged. An attempt was made to reproduce the most representative cases of the previous survey.

Four possible types of heating systems were identified: radiators, radiant floors, fan coils, full-air system.

Two boiler variants were associated with each type, such as a traditional boiler and a condensing boiler. The energy retrofit intervention includes the replacement of the central heating system with a heat pump and the installation of a photovoltaic system with a total power of 4.5 kW, while keeping the envelope performance unchanged. The following results were obtained:

Table 1: Schematization of the reduction in energy consumption due to heating system retrofit

Type of plant	Heating generator	EP pre intervention	EP post intervention	Energy saving
Radiators	Boiler	318,86 kWh/m^{2}year	99,00 kWh/m^{2}year	69%
	Condensing boiler	294,06 kWh/m^{2}year	99,00 kWh/m^{2}year	66%
Radiant heating	Boiler	302,93 kWh/m^{2}year	99,00 kWh/m^{2}year	67%
Fancoil	Boiler	305,27 kWh/m^{2}year	118,60 kWh/m^{2}year	61%
	Condensing boiler	281,60 kWh/m^{2}year	118,60 kWh/m^{2}year	58%
Air system	Boiler	319,07 kWh/m^{2}year	67,14 kWh/m^{2}year	79%
	Condensing boiler	290,67 kWh/m^{2}year	67,14 kWh/m^{2}year	77%

Therefore, it can be concluded that the maximum reduction in energy consumption is obtained from the efficiency of the air system, which is over 70%. This result confirms the value of 3 of virtual potential given to the system under consideration. Then, this reasoning was extended to the five technical elements to obtain a complete view of the thermal behavior of a typical building.

Furthermore, the values obtained were used as a tool to calibrate the energy potential values initially assigned based on qualitative assumptions about the energy behavior of each component. This phase was supported by the analysis of the results in Excel. In fact, the formulation of a classification of the reduction in consumption attributable to the improvement of the different types of each technical element made it possible to place the corresponding potential values within four energy saving ranges.

During the experimental stage, the method was applied to a specific case study. The building is one of ATER's buildings of Padua and it is in Ferdinando Coletti Street. It is an apartment block, developed on four levels and divided into three different staircases. Each staircase serves a total of eight residential units, consisting of approximately 45 sqm, whose layout is repeated on all four levels. The size of the typical apartment is rather humble: it consists of a living area with a kitchen and a separate sleeping area, which is served by bathrooms. The building has undergone various renovations over the years, which have not ensured its good state of conservation. In the 1970s, a refurbishment was carried out with questionable results: the total renovation of the facilities allowed the construction of an internal toilet for each flat. Moreover, the energy simulation confirmed its energy-intensive nature. The absence of insulation and technological solutions ensures the veracity of the results.

Established the poor energy performance of the current state, two different intervention scenery could be identified. Specifically, the first is related to maximizing the heating system efficiency, while the second is related to maximizing the insulation of the envelope to reduce dispersion.

The first scenario concentrates almost all resources on the energy retrofitting of the heating system, followed by limited insulation measures. The retrofit action foresees the introduction of renewable energy sources and the installation of a heat pump generator and a radiant floor, after the demolition of the existing flooring with a consequent increase in height, but it is compatible with the functional-spatial characteristics thanks to the high room heights. The autonomous system configurations remain unchanged. The installation of a centralized photovoltaic system on the roof provides a large proportion of the energy required by the new heating plant. Once the retrofit intervention on the installation system had been defined, the discussion focused on evaluating the reduction in energy demand caused by the insulation of the envelope. Thus, it is possible to separate the contribution to the efficiency of envelope structures from the overall behavior. These retrofitting actions include the insulation of opaque components and the replacement of windows to comply with the transmission limits imposed by Italian regulations.

The second scenario focuses attention on increasing the insulation of the envelope and, regarding the systems, replacing the existing generator with a condensing boiler and the existing heating terminals with a radiant floor to ensure proper operation at a lower temperature. The individual system configurations remain unchanged.

4. ANALYSIS AND EVALUATION OF RESULTS

During the final stage, it becomes crucial to evaluate the obtained solar potential data to determine if there are significant differences between the results obtained from simplified models and detailed models, and whether the simplified data is adequate for the evaluation purposes, especially when considering the inclusion of a new system. For instance, upon analyzing the data regarding the total solar potential of some of the buildings present in the area, it was measured a considerable difference corresponding to a potential drop of about 25%. The discrepancies in the results are quite significant, emphasizing the importance of model enrichment to avoid overestimation of solar potential when relying solely on basic models for evaluation. The detailed models provide a more accurate representation of the solar potential, making it evident that the use of simplified simulations alone may not suffice for precise assessments and decision-making regarding the implementation of new energy systems.

The application of the EP method to the case study made it possible to identify its main weaknesses and to optimize its use. In particular, the conversion of the numerical scale with values between 0 and 3 into percentages required various experiments and subsequent adjustments. The initial approach was to proportionally convert the numerical indices of transformability and upgrading potential: however, the implementation of the method highlighted that situations characterized by low transformability were particularly disadvantaged in the calculation of potential for energy redevelopment. The reason can be found in the series of multiplicative operations that lead to the definition of the upgrading potential: in fact, a low potential value is obtained starting from average values assumed by the transformability and the virtual potential. The further multiplication between the effective potential and the technical element weight contributes to a further reduction of the achievable energy savings, making it incompatible with the results of energy simulations. The first attempt to transpose the transformability and the virtual potential was carried out independently of the type of technical element, disregarding the results of the energy model. For this reason, it was necessary to completely revise the entire transformability allocation matrix, calibrating the percentages for each technical element. To facilitate the implementation of energy retrofitting measures, it was appropriate to shift the entire numerical scale to values greater than 70 per cent, thus projecting values in the range between 70 and 100 per cent. The agreement between the results of the fast method and the energy simulations was the basis for the choice of the percentage range.

The graphs below show a comparison between the results obtained by using the methodology, the energy model and the projection of the energy savings obtained by the efficiency of a model type (with construction characteristics very closed to the case study), representing the research building. In the first scenario, the analysis of the deviations shows a maximum deviation of 11%, related to the heating system.

On the other hand, in the second scenario, a maximum deviation of 24% is reported for the insulation of the vertical perimeter walls. The reason for this difference can be found in the proposed interventions: in fact, the walls of the case study have external aesthetic reliefs that are incompatible with the installation of an external insulation system. The insulation is therefore provided internally. On the other hand, the simplified model proposes the external technological solution which, for the same thickness, leads to a better energy performance thanks to the correction of thermal bridge. Where:

- A represents the gap created between the reduction in consumption derived from the methodology and the energy simulations.
- B represents the gap created between the decrease in consumption derived from the methodology and the projected decrease in consumption.

– C represents the gap between the reduction in consumption derived from the energy simulations and the projected reduction in consumption.

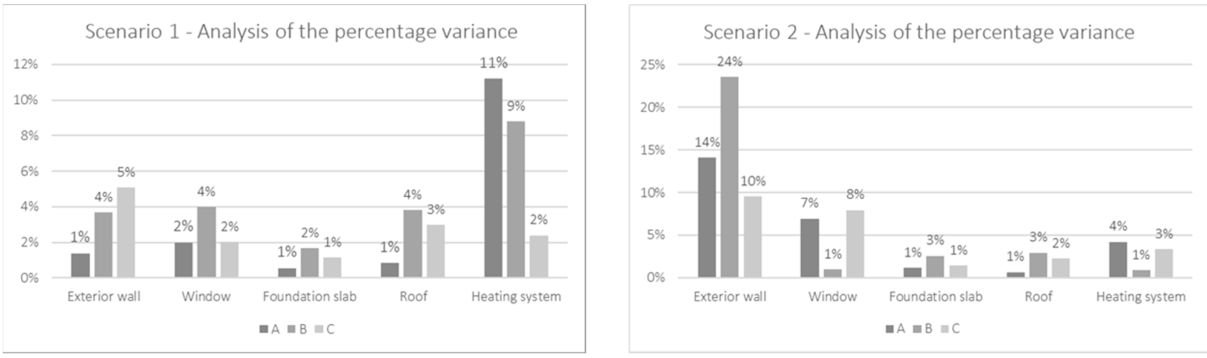

Fig.2: Comparison of methodology results of heat pump systems (scenario 1) and condensing boiler (scenario 2)

5. CONCLUSION AND FUTURE WORK

The innovative aspect of this process revolves around information-related elements, as modern tools process geospatial data that can't be modified based on typological criteria to enhance analysis results. The provided proposal delineates the methods to attain these objectives, approached from two key angles. Firstly, from a disciplinary standpoint, it involves the establishment of transformation coefficients. Secondly, from an informational perspective, it revolves around fostering the interoperability of solar potential reduction factors.

To apply this methodology to various building contexts and urban environments, it becomes crucial to categorize different case studies of typical facades and roofs, examining the similarity between buildings. This allows for the creation of a set of moderating coefficients and parameters associated with the urban environment, considering the structure's form and glazing percentage. For scalability, the process of creating a solar map at the neighborhood level should be as automated as possible to establish urban environment parameterization standards.

One limitation of this approach is that when selecting corrective coefficients on a large scale, it requires more time for context analysis and relies on source materials such as aerial photographs or files that identify the differentiation between glazed and opaque surfaces, which may be challenging to obtain. Moreover, it would be interesting to extend the study further by assessing how much energy could be generated from various PV systems to determine the percentage of energy needs that these systems could cover for the buildings in the area.

The study was conducted in a small area of Padua, but with the necessary adaptations, the data could be replicated across the entire city map. This would enable the integration of the findings into the OpenStreetMap project, expanding the database with valuable information on Solar Potential for the entire city. It is evident that the results show that the methodology is validated by the energy simulations by analyzing energy potential method. In fact, the percentage deviation of the values is around 10%, a percentage that can be considered acceptable in a preliminary assessment. Therefore, the application of the method allows a quick screening within a building stock, identifying the buildings responsible for greater energy savings.

Specifically, it was possible to highlight that heating systems constitutes the most decisive factor in the process of formulating the design hypotheses: thus, it is not possible to disregard the evaluation of plant transformability that, in the first instance, governs the declination of the retrofit intervention. This assumption derives from the fact that, with the same envelope, the replacement of a traditional generator with a heat pump, the installation of a radiant floor system and a photovoltaic system cause a decrease in energy consumption of approximately 70%. The discriminating factor is the possibility of installing renewable energy production systems, which make the thermal behavior of the envelope take second place since the energy produced is largely free. Therefore, it can be said that maximizing plant efficiency is the winning strategy. Where systems are characterized by good performance, it is more convenient to intervene on the envelope insulation.

REFERENCES

Amado, M., & Poggi, F. (2012). Towards solar urban planning: A new step for better energy performance. *Energy Procedia*, *30*. https://doi.org/10.1016/j.egypro.2012.11.139

Assouline, D., Mohajeri, N., & Scartezzini, J. L. (2017). Quantifying rooftop photovoltaic solar energy potential: A machine learning approach. *Solar Energy*, *141*, 278–296. https://doi.org/10.1016/j.solener.2016.11.045

Bahu, J. M., Koch, A., Kremers, E., & Murshed, S. M. (2013). Towards a 3D spatial urban energy modelling approach. *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *2*(2W1), 33–41. https://doi.org/10.5194/isprsannals-II-2-W1-33-2013

Behr, F.-J. 1957-, & AGSE. 5 2012 Stuttgart. (2012). *Geoinformation - catalyst for planning, development and good governance.* AGSE Publishing.

Boriani, M., Giambruno, M., & Garzulino, A. (2011). *Studio, sviluppo e definizione di schede tecniche di intervento per l'efficienza energetica negli edifici di pregio*.

Borkowska, S., & Pokonieczny, K. (2022). Analysis of OpenStreetMap Data Quality for Selected Counties in Poland in Terms of Sustainable Development. *Sustainability (Switzerland)*, *14*(7). https://doi.org/10.3390/su14073728

Bshouty, E., Shafir, A., & Dalyot, S. (2020). Towards the generation of 3D OpenStreetMap building models from single contributed photographs. *Computers, Environment and Urban Systems*, *79*. https://doi.org/10.1016/j.compenvurbsys.2019.101421

Corrado, V., Ballarini, I., & Corgnati, S. P. (2014). *Building Typology Brochure-Italy Fascicolo sulla Tipologia Edilizia Italiana nuova edizione*.

Diana, L. (2017). *Metodo CRI_TRA: un metodo di valutazione comparativa delle criticità e della trasformabilità edilizia del patrimonio residenziale pubblico in Italia.* https://www.researchgate.net/publication/317002914

Dorn, H., Törnros, T., & Zipf, A. (2015). Quality evaluation of VGI using authoritative data-a comparison with land use data in southern Germany. *ISPRS International Journal of Geo-Information*, *4*(3), 1657–1671. https://doi.org/10.3390/ijgi4031657

Elwood, S., Goodchild, M. F., & Sui, D. Z. (2012). Researching Volunteered Geographic Information: Spatial Data, Geographic Research, and New Social Practice. *Annals of the Association of American Geographers*, *102*(3), 571–590. https://doi.org/10.1080/00045608.2011.595657

EPW Map. (n.d.). Retrieved August 7, 2023, from https://www.ladybug.tools/epwmap/

Esclapés, J., Ferreiro, I., Piera, J., & Teller, J. (2014). A method to evaluate the adaptability of photovoltaic energy on urban façades. *Solar Energy*, *105*. https://doi.org/10.1016/j.solener.2014.03.012

Freitas, S., Catita, C., Redweik, P., & Brito, M. C. (2015). Modelling solar potential in the urban environment: State-of-the-art review. In *Renewable and Sustainable Energy Reviews* (Vol. 41). https://doi.org/10.1016/j.rser.2014.08.060

Giannelli, D., León-Sánchez, C., & Agugiaro, G. (2022). Comparison and evaluation of different gis software tools to estimate solar irradiation. *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *5*(4), 275–282. https://doi.org/10.5194/isprs-Annals-V-4-2022-275-2022

Goodchild, M. F. (2007). Citizens as sensors: The world of volunteered geography. *GeoJournal*, *69*(4), 211–221. https://doi.org/10.1007/s10708-007-9111-y

Haklay, M., & Weber, P. (2008). *openstreetMap: User-Generated street Maps*. www.openstreetmap.

Heipke, C. (2010). Crowdsourcing geospatial data. *ISPRS Journal of Photogrammetry and Remote Sensing*, *65*(6), 550–557. https://doi.org/10.1016/j.isprsjprs.2010.06.005

Italy/PCN - OpenStreetMap Wiki. (n.d.). Retrieved August 7, 2023, from https://wiki.openstreetmap.org/wiki/Italy/PCN

Jakica, N. (2018). State-of-the-art review of solar design tools and methods for assessing daylighting and solar potential for building-integrated photovoltaics. *Renewable and Sustainable Energy Reviews*, *81*. https://doi.org/10.1016/j.rser.2017.05.080

Kabir, E., Kumar, P., Kumar, S., Adelodun, A. A., & Kim, K. H. (2018). Solar energy: Potential and future prospects. *Renewable and Sustainable Energy Reviews*, *82*(1), 894–900. https://doi.org/10.1016/j.rser.2017.09.094

Lan, H., Gou, Z., & Hou, C. (2022). Understanding the relationship between urban morphology and solar potential in mixed-use neighborhoods using machine learning algorithms. *Sustainable Cities and Society*, *87*. https://doi.org/10.1016/j.scs.2022.104225

Lee, J. G., & Kang, M. (2015). Geospatial Big Data: Challenges and Opportunities. *Big Data Research*, *2*(2), 74–81. https://doi.org/10.1016/j.bdr.2015.01.003

Lobaccaro, G., Lisowska, M. M., Saretta, E., Bonomo, P., & Frontini, F. (2019). A methodological analysis approach to assess solar energy potential at the neighborhood scale. *Energies*, *12*(18). https://doi.org/10.3390/en12183554

Manni, M., Nocente, A., Kong, G., Skeie, K., Fan, H., & Lobaccaro, G. (2022). Solar energy digitalization at high latitudes: A model chain combining solar irradiation models, a LiDAR scanner, and high-detail 3D building model. *Frontiers in Energy Research*, *10*. https://doi.org/10.3389/fenrg.2022.1082092

Mazzarella, L., & Piterà, L. A. (n.d.). *Efficienza Energetica attraverso la Diagnosi e il Servizio Energia negli Edifici Linee Guida*.

Minaei, M. (2020). Evolution, density and completeness of OpenStreetMap road networks in developing countries: The case of Iran. *Applied Geography*, *119*. https://doi.org/10.1016/j.apgeog.2020.102246

Neis, P., & Zielstra, D. (2014). Recent Developments and Future Trends in Volunteered Geographic Information Research: The Case of OpenStreetMap. *Future Internet*, *6*(1), 76–106. https://doi.org/10.3390/fi6010076

OpenStreetMap Statistics. (n.d.). Retrieved August 7, 2023, from https://planet.openstreetmap.org/statistics/data_stats.html

Peronato, G., Rastogi, P., Rey, E., & Andersen, M. (2018). A toolkit for multi-scale mapping of the solar energy-generation potential of buildings in urban environments under uncertainty. *Solar Energy*, *173*, 861–874. https://doi.org/10.1016/j.solener.2018.08.017

Rana, S., & Joliveau, T. (2009). NeoGeography: An extension of mainstream geography for everyone made by everyone? In *Journal of Location Based Services* (Vol. 3, Issue 2, pp. 75–81). https://doi.org/10.1080/17489720903146824

Ratti, C., Baker, N., & Steemers, K. (2005). Energy consumption and urban texture. *Energy and Buildings*, *37*(7), 762–776. https://doi.org/10.1016/j.enbuild.2004.10.010

See, L., Estima, J., Pődör, A., Jokar Arsanjiani, J., Laso Bayas, J.-C., & Vatseva, R. (2017). Sources of VGI for Mapping. In *Mapping and the Citizen Sensor* (pp. 13–35). Ubiquity Press. https://doi.org/10.5334/bbf.b

Vargas-Munoz, J. E., Srivastava, S., Tuia, D., & Falcao, A. X. (2021). OpenStreetMap: Challenges and Opportunities in Machine Learning and Remote Sensing. *IEEE Geoscience and Remote Sensing Magazine*, *9*(1), 184–199. https://doi.org/10.1109/MGRS.2020.2994107