BIM BASED RATING OF URBAN AND ARCHITECTURAL SURFACES TO REFINE SOLAR POTENTIAL ANALYSIS

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Abstract

The study exposes an analysis of effective transformability of building surfaces on detailed information models developed at the architectural scale, then transfer this information from building BIM models to simplified urban models, using a transformability coefficient as a moderating factor to estimate the solar potential.

The process model illustrated in the study addresses the disciplinary issues related to the calculation of the solar potential as well as the issues of information standardization useful for the activation of these tools in an openBIM environment interoperable with 3D GIS file formats.

Introduction

The need to intervene on the built environment, at building and urban scale, to improve comfort conditions and energy performance entails the necessity to produce predictive models.

For this reason, it is necessary to define accurate information standards aimed at ensuring proper data flow from building to urban models that exhibit geometric and climatic data, to simulation environments aimed at transmitting a preliminary estimate on the solar potential.

The analysis of the results of the applications for solar potential estimation, developed using urban models, show that there is a significant reduction in the calculated potential when the effective possibility of installing energy production systems (such as photovoltaics) is verified. In fact, by analyzing the solar potential of buildings, it is possible to identify very quickly what are the surfaces that are most affected by solar irradiation and therefore, more useful for the insertion of active solar systems. However, if this is done on an oversimplified model, which considers all surfaces with a homogeneous degree of transformability, it does not reflect what is the actual solar potential.

Similarly, from the point of view of the energy retrofit of existing buildings, the effective possibility of retrofitting building envelopes and technological systems with more energy-efficient technologies needs to be verified on a consistent information model pointed at focusing transformation barriers that could possibly affect feasibility studies.

The core of the problem is that the urban solar potential simulations need a reliable information base that should stand on a detailed representation of buildings, and this is not available at preliminary phases of the study. It is, therefore, necessary to set up a system that allows to fill in the territorial models (OSM) that serve as the basis for the calculation of the solar potential, values that are more relevant to the actual potential for energy production and transformation for energy retrofit. These systems must be drawn up according to logic that does not depend exclusively on the irradiation conditions on the architectural surface depending on its exposure and geographical location.

The methodology proposed in the study aims to introduce a great innovative factor, defining a "transformability coefficient” of building surfaces and technical parts. The coefficient is determined in a representative selection of detailed models and then populated at urban scale using geographic area, age and geometry similitudes. The collection of these indicators and its refinement in a GIS environment allows to obtain more realistic simulations and feasibility studies and acts as a solid basis for a decision-making process aimed at improving the system efficiency. For the design of sustainable urban structures, solar radiation plays a particular important role and, through its use, it can significantly contribute to the energy sustenance of the buildings. In fact, the energy associated with solar radiation is among the main sources of free, clean, and inexhaustible energy that can be stored and harnessed in different ways depending on the type of absorption system.

In technical terms, irradiance refers to the radiant power affecting the unit area, which can be expressed in W/m^2, and it is maximum in the case of a perpendicular surface to the sun's rays, while solar potential, expressed in kWh, refers to the amount of solar radiation incident on the building’s surface that can be transformed into electricity by photovoltaic systems or into heat by solar thermal systems (EURAC Research, 2015).

These systems, in the attempt to exploit the most of solar energy, can be installed not only on roofs, but also on facades, sunshades, skylights, balustrades, canopies, and noise barriers. The use of these less conventional surfaces represents a very effective exploitation of available surfaces, allowing more energy to be generated directly inside the urban context, where high energy demand tends to be concentrated (Scognamiglio, 2016). At the same time, however, the urban environment can be complex and not always suitable for systems applications, due to urban morphology or the conformation of the actual buildings, given the increasingly limited area available and the consequent vertical building development, creating quite a few obstacles to the incoming sunlight. For this reason, it is necessary to consider not only individual buildings but to extend attention to entire neighborhood areas and cities as a whole.

In the evaluation of existing buildings and territorial contexts, it is therefore of fundamental importance to try to understand what the total result of the solar potential of the various available surfaces could be, in order to propose evaluations on the implementation of new photovoltaic systems applied, when possible, to roofs, facades, outdoor spaces, etc. This type of analysis can be developed by simulations carried out on 3D models containing a range of information, obtained by the implementation of climatic data, from terrestrial or satellite weather stations that measure the global irradiation received in the horizontal plane, and geospatial data processed in a 3D environment. Thanks to the analyses carried out on city models, it is then possible to arrive at an energy model of the building and the spatial context, which represents the basis for analyses such as solar potential estimation (Bahu et al., 2013). Mapping the solar potential of existing buildings can also be useful in order to be able to make future predictions of the changes that might occur as a result of the construction of new structures or the modification of the existing context.

For the development of the methodology and the related simulations, the North Piovego University area was chosen as the study area. This is an area of approximately 50,000 m^2 located in Padua, in northern Italy, in which there are mainly buildings used for student classrooms, laboratories, offices and the university canteen with all the dedicated outdoor spaces. Since these are very large-scale analyses, the models on which such simulations will be carried out will necessarily have to be simplified. However, starting from this assumption, the simulation data that will be obtained, relating to each building, cannot perfectly correspond to the reality, precisely because each structure has its own conformation characteristics that can negatively influence the obtained data. At the same time, it is impossible to produce detailed models of larger or smaller contexts to have a result that is as reliable as possible. Therefore, to take into account all these factors, it was considered essential to identify a methodology that would be able to return a real result of the solar potential of the surfaces starting from analyses carried out on simplified models, multiplying a series of corrective coefficients for the simplified figure obtained initially.

Source data for modeling

To generate the simplified model, an analysis was carried out to find the best information system suitable for the needs of the research.

In recent years, with the affirmation of BIM, the AEC industry has faced the problem of standardization and open format, so at the basis of the research was the desire to use data that was easily available but above all that could be easily exported and readable by all applications. The choice fell on Open Street Map (OSM) for two main reasons:

- the map contains spatial information that is always up to date thanks to the many volunteers participating in the OSM project;
- the concept of providing free maps that are not constrained by legal or technical restrictions underpins the project.

Although widely used as a base map, OSM is not an ISO-mapped international standard like GML, but nevertheless has a well-defined structure that is easily accessible at the following link: *https://wiki.openstreetmap.org/wiki/Map_features*.

OpenStreetMap has its own data format, mirroring the structure of nodes, ways, relations, and tags in its own XML-based markup language, so that it is easily transmitted over the Internet but, above all, easily interrogated. Conversion programs support the transformation in other formats and the bulk loading into geo-databases. Some Geographical Information Systems already support the import of OSM data (Behr et al., 2012).

Open Street Map

Open street map is a huge collection of volunteered geographic information stored in different types of files. Steve Coast, a British entrepreneur, created this project in 2004 and the main aim was to build a freely available database with geographic information based on the UK's community (*OSM - OpenStreetMap File Format*, n.d.).

OpenStreetMap is the oldest Volunteered Geographic Information (VGI) project. The VGI acronym (Goodchild, 2007) identifies the activity done by individuals who, using the Internet, can contribute to expanding information related to geographic position. Other VGI projects are Wikimapia, Map Maker, Here Map Creator, Map Share and Waze.

The difference between OSM and other maps on the web, as mentioned above, is that most maps have legal or technical restrictions on their use, OSM instead, is free and represents the cheapest source of geographic information, and the only source in areas where access to geographic information is regarded as an issue of national security web. The updating of this global map takes place thanks to the input of the people registered. They have also formed an affiliation with the OpenStreetMap Foundation (OSMF), giving them a link to the legal and copyright governing body. Up to now, OSM counts 9.827.840 users and 15.109.170.404 GPS points(*OpenStreetMap Statistics*, 2022).

The development of OSM allowed more and more information to been tered, for example, complete road data for the Netherlands and trunk road data for India and China were contributed to OSM in April 2007 by Automotive Navigation Data (AND). In December 2007, Oxford University was the most prominent organization that integrated OpenStreetMap data within their main website *https://docs.fileformat.com/gis/osm/*.

There are four different types of data: nodes, ways, relations, and tags (Vargas-Munoz et al., 2021).

While the first three present geometric characteristics, the last corresponds to additional information related to the node or to the way.

- Nodes: They are points represented by symbols. It is one of the core elements in the OpenStreetMap data model. It consists of a single point on Earth's surface defined by its latitude and its longitude. Nodes can be used to define points of interest, like bus stations, features but are more often used to define the shape or "path" of a way.
- Ways: An ordered list of nodes that normally also have at least one tag or are included within a Relation. A way can have between 2 and 2,000 nodes[1], although faulty ways with zero or a single node may exist. A way can be open or closed.
    - Closed ways (polygons) are lines that end at the same point. For example, buildings.
    - Open ways (polylines) are like roads and rivers.
- Relation: represents one of the core data elements. It is a special structure used to represent polylines and polygons with more than 2000 nodes, it consists of one or more tags. An example of a relationship is a bus route, which links the ways of the roads traveled by the bus and the nodes of the bus stops.
- Tag: is a key through which it is possible to describe the objects. The tags are always formed by two names: the key and the value. Keys describe a family of features, while value is more specific. For example, the key highway indicates a family of roads of any type, from highways to footpaths and the same tags can describe both nodes and lines. The key highway has like values for both bus stops (nodes), and traffic signals (way).

A list of tags can be found in the OSM's schema[2].

The collected data is processed and used to create a 2D map, but through various web or desktop applications it is possible to visualize the three-dimensional model of the OpenStreetMap data.

Some of the most important visualisers include OSMBuildings and Esri OpenStreetMap 3D Scene Layers. These two have one major difference, the first one is written in an open format (JavaScript), and the second one is in a proprietary format, in fact, it is mainly used within Esri products including Scene Viewer and ArcGIS Pro.

With OSMBuildings, it is possible to both view a three-dimensional map and query buildings. However, it is not possible to download the map, in fact, the OSM organization also presents a "3D development" with which, using data from OpenStreetMap, it is possible to create the three-dimensional model of the area of interest.

Figure 1 view of the interest area from OSMBuildings

One of the limitations of the use of this starting data concerns the building's heights, that in some cases doesn't reflect reality. In fact, according to the statistics[3], only 3 percent of the 544 million buildings stored in OSM have an assigned value for the tag 'height'. Furthermore, even if the input data is present, it isn't always precise because, unlike the building footprint that is reported from satellite orthophotos, the height could only be derived from an approximate analysis of the building made by any volunteer (Bshouty et al., 2020). To try to solve this problem, Bshouty has developed an Android app "OpenStreetHeight" in which some photographs can be used to identify the average height of a building.

In order to modify this data, the volunteer can proceed through many different editors available for multiple mobile devices, or through the long-established editors' Potlatch or JOSM (Java OpenStreetMap Editor). These two are preferably used by more advanced members(Neis & Zielstra, 2014).

Generation of the model

For the creation of the model of the area selected as a case study, it was started by editing the source OSM file.

Before proceeding with the analysis, it was necessary to act on the .osm file to delete or modify some data. The main data were correct except for the building heights which were not always accurate, in fact many buildings had a height of "3 meters" which corresponds to the height used by default by OSM when that data is not available.

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[1] *The limit of 2000 nodes per way was established in 2009 with the changes from version 0.5 to 0.6 of the OSM API*

2 https://wiki.openstreetmap.org/wiki/Map_features

[3] https://taginfo.openstreetmap.org/compare/building/height

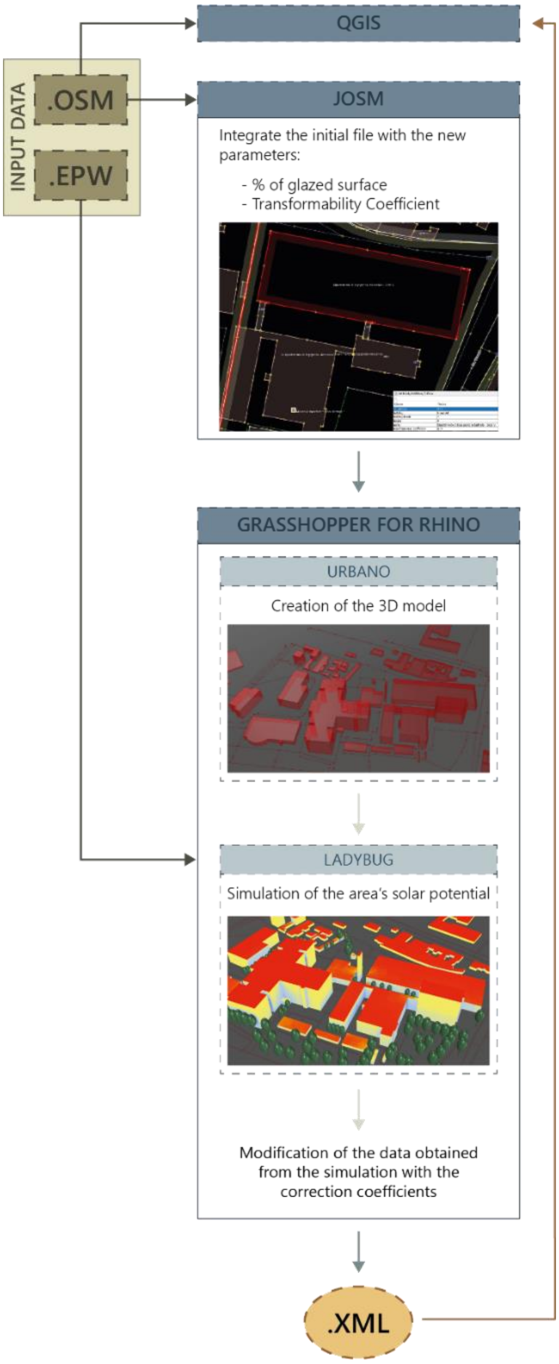

Figure 2: Workflow

To obtain the correct data, various methods were considered, including acquisition using LIDAR technology. Although compared to traditional surveys, LiDAR sensors collect more detailed and highly accurate elevation points, at the time of data acquisition the university did not have the appropriate tools to obtain this type of information, so building height was calculated manually by cross-referencing data such as the number of floors.

For this aim, JOSM was used to delate data, modify the height information and also to insert two additional tags:

- transformation coefficient: that represents the percentage in which the different façades are subject to transformability and thus consequently with what freedom we could intervene with the insertion of new installations applied to the surfaces. The default value of this geometric parameter corresponds to 1;
- % glazing: represents the total glazed area in relation to the total area. This default value corresponds to 0.

The correct value for both of these two new parameters will then be replaced for each building once calculated, as will be explained later in the paper. In addition to the inclusion of the new parameters, a cleaning of the existing ones was done, and the heights of each building were verified based on direct surveys or through satellite photos of the area. Inside the OSM file every node, way or relations have An ID number that uniquely identifies it.

By reading the metadata related to the height of the building, it was possible to start creating the 3D model. After the open street map file has been imported into Grasshopper environment, with a generative script developed with the Urban tool, the creation of the buildings' volumes was permitted also with the reconstruction of the urban geometry of the road system and that of the external spaces of the area. Each building turns out to be an extrusion of its planar geometry. There is also numerous other information contained within the source file that defines other characteristics, geometric and otherwise, unique to each building such as the number of levels, the function type, the structure identifier, etc.

In order to proceed with the simulations, however, a whole range of data on the climatic and environmental conditions of the area are required in addition to geometric information. These input data are contained within an .epw file and consist, for example, on the air temperature, the relative humidity, and the irradiance, for each hour of each day of the year. This file represents the source starting point and can be downloaded from various databases available online. Ladybug provides an official library of data collected at various weather stations around the world, which can be downloaded directly from the official website (*Epwmap*, n.d.). Through this portal, it isn't possible to select the year of interest, but only to download a single available data package. For the case study that is investigated in this paper, the weather station present at the Treviso airport was taken as a reference, because there is a lack of data for the Padua area inside this library and this was considered the area with the most similar environmental and climatic characteristics, among the available neighboring ones (Venice, Vicenza, and Treviso). Specifically, the data available are for the entire year 2005, and the simulations that will be presented below are for analyses carried out in the time window of the entire month of July 2005, taken as a borderline case following an evaluation of the hourly and average temperatures reached.

Before proceeding with the simulation, however, there is also another critically important aspect that has to be evaluated. The presence of greenery and trees has to be considered in the study of solar potential as it represents a fundamental mitigating element. For this reason, it is very important to supplement the 3D geometric model obtained with the modeling and positioning of the trees and green elements according to their actual arrangement and the real conformation in terms of height and leaf density, in order to be able to obtain results as real as possible. A site survey of the area and the use of satellite images were helpful in this regard.

Solar Potential Study

Once the basic geometric model is obtained and enriched with the necessary additional information, it is possible to start the analyses related to the solar potential. There are numerous tools available to obtain such results, operating in a GIS environment and beyond. Several studies (Giannelli et al., 2022) have compared five of the main tools used nowadays, such as GRASS GIS, ArcGIS, SimStadt, CitySim, and Ladybug, showing how much the data obtained deviate from those collected by a weather station, considered as ground truth. As a result of the data comparison, it was found that Ladybug is one of the most accurate tool among the ones that provide this kind of simulations, and therefore, also for this reason, it was decided to proceed by basing the research work on the simulations obtained through it. The Ladybug Tools are a collection of free and open-source applications for environmental design that run in Grasshopper, a visual programming language that runs within Rhino software. The Ladybug module allows to perform solar radiation studies, view analysis, sunlight hour modeling, etc.

However, one of the problems that are not currently addressed, in a direct way, by any tool is related to the fact that the data obtained through these simulations are related to simplified surfaces that don't correspond to the real conformation of the buildings and for this reason are not reliable to identify the exact amounts of solar potential. In fact, there are factors such as the conformation of the surfaces and the percentage of glazing present in them, which negatively affect the results as they are surfaces that perhaps don't allow the application of new systems in the whole area. This, for simulation purposes, is a major problem since, within the simplified model, the surfaces are all treated in the same way as flat and non-glazed facades. For this reason, it would be necessary to supplement the results obtained with coefficients that can track these particularities for each building. Through this work, therefore, one of the aims was to identify a methodology for finding these coefficients, verifying their key role in obtaining realistic data that required as few steps as possible and were developed by coding on Grasshopper.

To test the hypotheses, two particularly significant buildings present within the study area were specifically analyzed, from a purely geometric and solar point of view. These are, in the first case, a building dedicated mainly to offices with a rectangular floor plan and an overall height of 30m. Its peculiarity lies in the external conformation of its facades, in fact, in them there are a series of pilasters, of 0,35m, which create a cadenced rhythm between each column of 1,25m window openings (Figure 3 - a). The second building analyzed has a different conformation from the one just described and contains the laboratories of the university department of industrial engineering (Figure 4 - a). It is an extended structure, also with a rectangular plan but with a height of 9m, which is characterized by its peculiar facades. In fact, in this case, the facades are predominantly with windows, and the wall structures form a kind of overlapping grid pattern. The roof also has a particular conformation because it consists of a series of repeated parallelepipeds forming a stepped pattern.

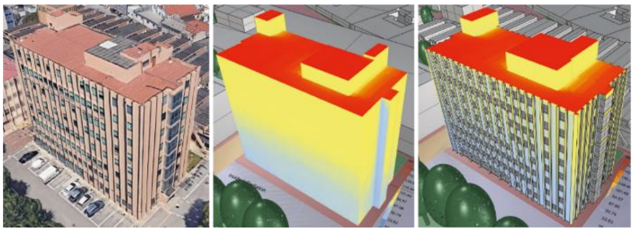

Figure 3: a) Existing building; b) Simplified model; c) Detailed model

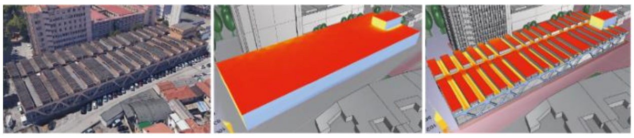

Figure 4: a) Existing building; b) Simplified model; c) Detailed model

These two examples were chosen, for their particular conformation, as case studies in which to analyze the differences in solar potential calculated through simulations performed in a simplified model (Figure 3 - b, Figure 4 - b) and a detailed one (Figure 3 - c, Figure 4 - c). Two models were then developed for each building and, using Ladybug for Grasshopper, the results for each facade were obtained.

As pointed out earlier, the factors that most influence the actual result of solar potential are given by the percentage of windowed and opaque surfaces and the conformation of the surfaces that may be more or less subject to transformations. Ladybug already considers the shading factor which could be given by the presence of other nearby objects so it isn't necessary to add it among the reduction coefficients, and it couldn't be necessary to include a shading coefficient given by the presence of balconies or other elements, because they will be present in the detailed model and considered during this phase. Based on these assumptions, an equation was developed that relates all the factors listed:

$$SP_r = SP_s \cdot \%op_{area} \cdot T_{coeff} \tag{1}$$

SP_r: real solar potential value

SP_s: simplified solar potential value

$\%op_{area}$: opaque area percentage

T_{coeff}: transformation coefficient

This equation was written, developed and solved directly within the script on Grasshopper, thanks also to the reading of the various parameters that had been added in the previous phase within the starting .OSM file. To explain specifically how each coefficient was achieved, the simplified solar potential value is obtained with the Ladybug simulation, through the analyses performed on the simplified model. For the percentage of the opaque area analyses of purely geometric results were carried out and, starting from the calculation of the total area, with the help of the software AutoCAD, the relative amounts and percentages of the opaque and windowed area were calculated (Table 1). The transformation coefficient will be calculated, for each surface area, by the use of an inverse equation, using the value of the real solar potential which comes directly from the simulation script made with Ladybug and applied to the more detailed model.

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

This data, which defines the way in which we can intervene in the buildings, should be included within the .OSM file to enrich the information initially present for each building. Through the JOSM software, it is possible to edit the file directly, with the creation of new categories of parameters and the addition of their values associated with each building. For the simplification of the processes, it was decided to associate a single parameter for each building, for each new category of data entered, averaging the values for each facade and roof, for the transformation coefficients, and the percentages of glazing and opaque surface. To obtain this data, mathematical averages were carried out in order to consider the particular conformations, more or less restrictive, of all surfaces. The use of average values is also important for the implementation of coefficients in similar buildings in terms of date of construction and usage, to simulate realistic buildings. This allows for territorial models closer to the real calculated solar potential value.Table 11 presents the final results obtained through the first equation. Analysing the data obtained, it can be observed that in one case the transformability coefficient is greater than 1. This happens because in this specific case the roof area in the simplified model is smaller and consequently returns a lower solar potential result. In fact, the detailed model takes into account not only the different roof slopes but also the volumes that are present above such as the staircase term that can be used.

Returning to the initial simplified geometric model, and starting the simulations to calculate the solar potential, the new coefficients will be multiplied with the data of the simplified solar potential, in order to return a new estimation of the solar potential value that considers the real conformation of the buildings. Each building is characterized by a unique identification code within the starting .osm listing file and, through a script on Grasshopper, the additional data calculated with the methodology just described for each surface of each building, were inserted as new "solar_potential" parameters.

Table 1 Study of Solar Potential's corrective coefficients

OFFICE BUILDING	LAB. BUILDING
NORTH	NORTH
Total area: 996,54 m^2	Total area: 884,19 m^2
Glazed surface: 267,90 m^2	Glazed surface: 560,75 m^2
Opaque surface: 728,64 m^2	Opaque surface: 323,44 m^2
$\%glz_{area}$: 0,27	$\%glz_{area}$: 0,63
$\%op_{area}$: 0,73	$\%op_{area}$: 0,37
SP_s: 36644,17 kWh	SP_s: 34105,59 kWh
SP_r: 21432,30 kWh	SP_r: 11021,56 kWh
T_{coeff}: 0,80	T_{coeff}: 0,88
EAST	EAST
Total area: 453,07 m^2	Total area: 318,57 m^2
Glazed surface: 101,78 m^2	Glazed surface: 233,24 m^2
Opaque surface: 351,29 m^2	Opaque surface: 85,33 m^2
$\%glz_{area}$: 0,22	$\%glz_{area}$: 0,73
$\%op_{area}$: 0,78	$\%op_{area}$: 0,27
SP_s: 36485,28 kWh	SP_s: 28080,08 kWh
SP_r: 24632,78 kWh	SP_r: 6848,99 kWh
T_{coeff}: 0,87	T_{coeff}: 0,91
SOUTH	SOUTH
Total area: 978,65 m^2	Total area: 884,15 m^2
Glazed surface: 272,30 m^2	Glazed surface: 560,75 m^2
Opaque surface: 706,35 m^2	Opaque surface: 323,40 m^2
$\%glz_{area}$: 0,28	$\%glz_{area}$: 0,63
$\%op_{area}$: 0,72	$\%op_{area}$: 0,37
SP_s: 70990,47 kWh	SP_s: 33250,90 kWh
SP_r: 41441,80 kWh	SP_r: 11672,68 kWh
T_{coeff}: 0,81	T_{coeff}: 0,96
WEST	WEST
Total area: 452,33 m^2	Total area: 371,77 m^2
Glazed surface: 122,09 m^2	Glazed surface: 173,44 m^2
Opaque surface: 330,24 m^2	Opaque surface: 198,33 m^2
$\%glz_{area}$: 0,27	$\%glz_{area}$: 0,47
$\%op_{area}$: 0,73	$\%op_{area}$: 0,53
SP_s: 29686,07 kWh	SP_s: 18631,45 kWh
SP_r: 18601,88 kWh	SP_r: 9856,47 kWh
T_{coeff}: 0,86	T_{coeff}: 0,99

ROOF	ROOF
Total area: 567,32 m^2	Total area: 4188,04 m^2
Glazed surface: 0,00 m^2	Glazed surface: 0,00 m^2
Opaque surface: 567,32 m^2	Opaque surface: 4188,1 m^2
$\%glz_{area}$: 0,00	$\%glz_{area}$: 0,00
$\%op_{area}$: 1,00	$\%op_{area}$: 1,00
SP_s: 101878,40 kWh	SP_s: 708487,68 kWh
SP_r: 105592,77 kWh	SP_r: 600875,56 kWh
T_{coeff}: 1,04	T_{coeff}: 0,85
Average value	Average value
$\%glz_{area}$: 0,21	$\%glz_{area}$: 0,49
$\%op_{area}$: 0,79	$\%op_{area}$: 0,51
T_{coeff}: 0,87	T_{coeff}: 0,92

As can be seen from the exportation of the file in .xml format (Figure 5) the new data and those previously present will be catalogued following a specific protocol for each building. This will allow the new file to be read in a GIS environment with the totality of the data in an open-source format.

```
<way id='131991989' action='modify' timestamp='2021-02-09T11:26:42Z' uid='12632017'
  <tag k='solar_potential' v='19530.184555 KWh' />
  <tag k='solar_potential' v='536.120082 KWh' />
  <tag k='solar_potential' v='427.865958 KWh' />
  <tag k='solar_potential' v='9096.336383 KWh' />
  <tag k='solar_potential' v='20387.776982 KWh' />
  <tag k='solar_potential' v='614.396396 KWh' />
  <tag k='solar_potential' v='11868.079635 KWh' />
  <tag k='solar_potential' v='330571.707481 KWh' />
  <nd ref='1452152563' />
  <nd ref='1452152564' />
  <nd ref='1452152565' />
  <nd ref='1452152581' />
  <nd ref='1452152579' />
  <nd ref='1452152578' />
  <nd ref='1452152537' />
  <nd ref='1452152550' />
  <nd ref='1452152551' />
  <nd ref='1452152563' />
  <tag k='%_glazing' v='0.49' />
  <tag k='building' v='industrial' />
  <tag k='building:levels' v='2' />
  <tag k='height' v='9' />
  <tag k='name' v='Dipartimento di Ingegneria Industriale - Sede V' />
  <tag k='transformation_coefficient' v='0.92' />
```

Figure 5: Exportation of the listed file in .xml format

Analysis and evaluation of results

It is important, at the end of all these considerations, to evaluate the data obtained, to understand whether there are relevant differences or whether the simplified data is sufficient for the evaluation of purposes for the inclusion of a new system.

Taking for example the buildings presented above as a case study (Figure 3, Figure 4) and analyzing the data regarding the total result of solar potential, it can be seen that, in the first case, with a simplified model the amount turns out to be 275,684.39 kWh, while the result obtained by applying the simulations to the detailed model is 211,701.53 kWh. There is a difference of 63,982.86 kWh between the two results, which corresponds to a potential drop of 23.21%. Similarly in the second case there was a total solar potential for the simplified model of 822,555.70 kWh and for the detailed model of 640,275.26 kWh. In this case, the difference between the two results is 182,280.44 kWh, corresponding to a potential drop of 22.16%. These represent very significant data because they demonstrate that simplified simulations can benefit from model enrichment in order to avoid having a solar potential surplus estimation by evaluating only data obtained with basic models.

Conclusion and Future work

The innovative factor of this process relates to informational aspects since the tools available nowadays process geospatial data that cannot be modified according to typological criteria in order to refine the analysis results. The contribution presents instead how this can be implemented both from a disciplinary point of view, through the determination of transformation coefficients, and from an informative point of view, by promoting the interoperability of solar potential reduction factors.

However, in order to make this work applicable to different building contexts and city environments, it is very important to categorize different case histories of typical facades and roofs by analyzing the similarity between buildings, so that a set of moderating coefficients and parameters can be listed and can be associated with the urban environment, according to the conformation and the glazing percentage of the structures. To create a solar map at the neighborhood level this process should become as automatic as possible to allow the creation of urban environment parameterization standards. A limitation of this approach to the problem could be that when the corrective coefficients have to be selected on a large scale, it takes more time for the context analysis and this work also requires some source material such as aerial photographs or source files that allow to identify the differentiation between glazed and opaque surfaces, which could be difficult to find.

It may be interesting, also, to continue the study to see how much energy could be produced from the various PV systems installed to assess in what percentage the systems can cover the energy needs of the buildings in the area.

The study was carried out in a small area of the city of Padua, but with the necessary implementations, it is possible to replicate the data on the entire city map. In this way, it would be possible to embrace the OpenStreetMap project and expand the database with information on the Solar Potential.

References

Amado, M. & Poggi, F. (2012) Towards Solar Urban Planning: A New Step for Better Energy Performance, Energy Procedia, vol. 30, pp. 1261-1273.

Angelis-Dimakis, A., Biberacher, M., Dominguez, J., Fiorese, G., Gadocha, S., Gnansounou, E., Guariso, G., Kartalidis, A., Panichelli, L., Pinedo, I. & Robba, M. (2011) Methods and tools to evaluate the availability of renewable energy sources, Renewable and Sustainable Energy Reviews, vol. 15, Issue 2, pp. 1182-1200.

Assouline, D., Mohajeri, N. & Scartezzini, J. L. (2017) Quantifying rooftop photovoltaic solar energy potential: A machine learning approach, Solar Energy, vol. 141, pp. 278-296.

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., Rahman, A. A., Zimmermann, M., Pradeepkumar, A. P., & Malaysia, U. T. (2012). Geoinformation-Catalyst for planning, development and good governance Applied Geoinformatics for Society and Environment FOSS4G Southeast Asia AGSE 2012-FOSS4G-SEA.

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

Ehsanul, K., Pawan, K., Sandeep, K., Adedeji, A. & Ki-Hyun, K. (2018) Solar energy: Potential and future prospects, Renewable and Sustainable Energy Reviews, vol. 82, part 1, pp.894-900.

epwmap. (n.d.). Retrieved January 13, 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, vol. 105, pp. 414-427.

EURAC Research. (2015). SOLAR TIROL Potenziale solare nel Land Tirolo e nella ... https://www.eurac.edu/it/institutes-centers/istituto-per-le-energie-rinnovabili/projects/solar-tirol.

Freitas, S., Catita, C., Redweik, P. & Brito, M. C. (2015) Modelling solar potential in the urban environment: State-of-the-art review, c, vol. 41, pp. 915-931.

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. In GeoJournal (Vol. 69, Issue 4, pp. 211–221). https://doi.org/10.1007/s10708-007-9111-y

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, vol. 81, no. May 2017, pp. 1296-1328.

Jusuf, S. K., Mousseau, B., Godfroid, G. & Jin Hui, V. S. (2017) Integrated modeling of CityGML and IFC for city/neighborhood development for urban microclimates analysis, Energy Procedia, vol. 122, pp. 145-150.

Kabir, E., Kumar, P., Kumar, S., Adelodun, A. A. & Kim, K. H. (2018) Solar energy: Potential and future prospects, Renewable and Sustainable Energy Reviews, vol. 82, no. October 2017, pp. 894-900.

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, vol. 87.

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, 3554.

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, vol. 10.

Mauree, D., Perera, A. T. D. & Scartezzini, J. L. (2017) Influence of Buildings Configuration on the Energy Demand and Sizing of Energy Systems in an Urban Context, Energy Procedia, vol. 142, pp. 2648-2654.

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. (2022). https://planet.openstreetmap.org/statistics/data_stats.html

OSM - OpenStreetMap File Format. (n.d.). Retrieved January 13, 2023, from https://docs.fileformat.com/gis/osm/

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, vol. 173, pp. 861-874.

Ratti, C., Baker, N. & Steemers, K. (2005) Energy consumption and urban texture, Energy and Buildings, vol. 37, no. 7, pp. 762-776.

Scognamiglio, A. (2016). “Photovoltaic landscapes”: Design and assessment. A critical review for a new transdisciplinary design vision. In Renewable and Sustainable Energy Reviews (Vol. 55, pp. 629–661). Elsevier Ltd. https://doi.org/10.1016/j.rser.2015.10.072

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

Vassiliades, C., Kalogirou, S., Michael, A. & Savvides, A. (2019) A Roadmap for the Integration of Active Solar Systems into Buildings, Applied Sciences, vol. 9, no. 12.

Wieland, M., Nichersu, A., Murshed, S. M. & Wendel, J. (2015) Computing Solar Radiation on CityGML Building Data, AGILE2015: 18th AGILE International Conference on Geographical Information System.