4. CONCLUSION

This paper introduced a multiobjective methodology to optimize the design of an insulating cementitious foam combined with phase change material (PCM) in buildings. To address this, the multi-objective Non-dominated Sorting Genetic Algorithm-II (NSGA-II) was dynamically coupled with annual EnergyPlus simulations for the BESTEST 900 from ANSI/ASHRAE Standard 140-2011. Parametric models for the cementitious foam and PCM were implemented in the EnergyPlus simulations to study the optimal thicknesses of the materials along with the PCM melting temperatures.

The optimization results showed that heating and cooling loads have a complex and contradictory relationship regarding the design variables. Therefore, a simulation-based and multiobjective-based optimization approach is needed and highly recommended for performing the optimization of the PCM melting temperatures as well as of the insulation thickness in buildings.

Regarding the cementitious insulating foam, the optimum design for reducing heating loads is achieved for a thickness of 10 cm, while a thickness of 1 cm is necessary to minimize the cooling loads. This latter shows that insulation materials have to be carefully designed by also considering the building typology and local climate.

As for the PCM, all optimum solutions on the Pareto front employ the thickest option of 2.5 cm but were combined with different melting temperatures related to the performance of the design. A melting temperature of 22.66 °C was necessary for reducing the heating loads while a melting temperature of around 28 °C was preferred for reducing the cooling loads.

Regarding the optimal combination of the design variables, there is a design that can reduce the heating loads up to 11.76% and another design that can reduce the cooling loads up to 30%. In terms of total loads, the best design reduced 8.95% of the loads by using 10 cm of cementitious foam combined with 2.5 cm of PCM with a melting temperature of 24.41 °C. Here, it was demonstrated that it is possible to improve the original wall configuration by the optimum combination of a cementitious foam with a PCM. It may be worth noting that an improved performance compared to the original results was achieved by an increased thickness of the cementitious foam. This is because the building typology was dominated by heating loads and the original insulation had a lower thermal conductivity than the employed cementitious foam.

Finally, the proposed methodology showed great robustness to explore the optimum solutions for optimized building designs that use PCMs. Future works will be focused on adapting and employing the methodology to design the NRG-FOAMs panels planned to be tested at a real scale BESTEST 900 buildings of the NRG-STORAGE project.

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PLEA SANTIAGO 2022
Will Cities Survive?

Catalogue of urban surface finish materials

Optimizing solar energy management in Latin American cities located in different climatic zones

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ABSTRACT: The use of surface materials with adequate thermo-optical properties at pavements, facades and roofs is an effective strategy to optimize the management of solar energy in cities, mitigate urban overheating and improve energy efficiency in their buildings. This work presents an analysis of urban surface finish materials in five cities that cover a wide range of geographic and climatic locations along Latin America: Campinas (Brazil), La Paz (Bolivia), Mendoza (Argentina), Santo Domingo (Dominican Republic) and Valparaíso (Chile). One residential neighborhood was selected in each city with special need for urban and building rehabilitation. A unified procedure was defined to examine the in-use urban finishing materials and collect preliminary data affecting their interaction with solar radiation at the five neighborhoods. The results indicate that in-use materials were not selected according to the specific climatic characteristics of each location. These preliminary data were compiled into a catalogue that will be expanded in future research with the experimental thermo-optical properties of the in-use materials and those locally available for urban rehabilitation. The final objective of the research is the proposal of urban surface materials adapted to the local conditions in each city and considering sustainability aspects as well.
KEYWORDS: Solar energy, urban sustainability, surface materials

1. INTRODUCTION

Rising temperatures and heat waves constitute one of the main effects of Global Change on the climate and intensify one of the main current environmental challenges: the warming of urban areas. It is estimated that the percentage of urban population in Latin America is 80% and the forecast is that it will increase to 88% in the year 2050 [1]. It is therefore essential that, both in the rehabilitation and in the development of cities, measures be implemented to mitigate this effect. However, the research papers on urban heat island effect in this area of the world are, for the moment, scarce [2,3].

On the other hand, the high-altitude Andin regions are characterized by a cold weather and a high intensity of solar radiation. In this case, the main problem is not urban overheating, but the need to maximize the use of solar energy to improve indoor comfort and reduce the heating demand in buildings.

The optical and thermal properties of the surface materials in buildings and pavements define the percentage of solar energy absorbed and the speed at which this energy is radiated into the atmosphere. Consequently, these are critical parameters for the temperature of the urban environment and of the indoor conditions in buildings. Therefore, it is possible to mitigate overheating in cities and improve energy efficiency in their buildings by using surface finishing materials with thermo-optic properties that optimize solar energy management [4,5,6].

The general objective of the research pursues the selection of sustainable surface finishing materials with thermo-optical properties that optimize solar energy management at Latin American cities. As a first step, it is necessary to identify and catalogue the materials currently in use in the cities. Latin American countries share a similar history during colonial times and similar languages that provide important cultural, social, and economic links between them. However, they have different climatic conditions and socio-economic evolution throughout more recent times, which have given rise to varied urban configurations. To include these configurations in the research, the cities analyzed must cover a wide range of geographic locations, climatic conditions, and demographic and economic characteristics throughout Latin America. In this context, a cataloging of surface finish materials has been addressed in five Latin American cities: Campinas (Brazil), La Paz (Bolivia), Mendoza (Argentina), Santo Domingo (Dominican Republic) and Valparaíso (Chile). A specific neighborhood has been selected in each city that represents deprived areas with special need for urban and building rehabilitation. The cataloguing methodology has been defined and the catalogue has been initiated with a set of qualitative data that will be complemented with the thermo-optical properties, sustainability aspects and properties related to the material application.

This information will be used to evaluate the potential improvement of sustainability that could be obtained through the substitution of current materials by others available in the local market.

2. METHODOLOGY

The methodology of the research was developed in three steps.

2.1. Assessment of Latin American cities involved in the study

In the first place, the main parameters that define the cities participating in the study were collected and compared. The parameters include those determining the local solar irradiation: latitude, altitude and climatic conditions as defined by the Koppen-Geiger classification [6]. The temperature (minimum, maximum and mean annual values), the mean relative humidity and the mean Urban Heat Island were considered, as parameters closely related to the main problems of urban discomfort and energy inefficiency of buildings in each location. Finally, the population, the surface of the urban area and the Gross Domestic Product characterizing each city was included in the comparison to approach the capability of addressing rehabilitation solutions.

2.2. Selection of neighborhoods to be included in the research

As a second step, one specific neighborhood was selected in each city for the analysis, following consistent criteria in all the cases. The criteria include that the neighborhoods be located at homogeneous areas of mainly residential use and with a clear need for urban/buildings rehabilitation due to discomfort conditions attributable to urban envelope materials. In addition, only safe areas were considered, which may be visited with no specific risk for a detailed analysis and measurement of envelope materials.

2.3. Definition of a catalog of urban surface finishing materials

Cataloguing of surface finishing materials in use at pavements, facades and roofs of the selected urban areas was addressed. A data collection sheet was structured to collect the information corresponding to each material. The sheet is segmented in two parts associated to the two steps of data collection. In the step presented in this work, preliminary data were collected, including the material application, frequency of use, appearance (color and texture), nominal properties, availability and estimated cost. Different types of data sources were allowed, as in-situ sampling, Google Earth images or previous research works.

These preliminary data were compiled in a catalogue that will be expanded in the second step of the research.

3. RESULTS

3.1 Characteristics of the studied cities

Table 1 shows the parameters selected to define and compare the five cities participating in the study. The latitudes range from locations close to equator, as La Paz and Santo Domingo, to the latitudes around 33°S in Mendoza and Valparaíso, with Campinas at an intermediate value. This parameter influences the inclination of solar radiation and consequently its heating capacity of urban surfaces. This capacity is also determined by the altitude, being especially high in the case of La Paz, which is located at an altitude of 3500 m in the Altiplano of the Andes. At the opposite side, two low-altitude coastal cities are analyzed, Santo Domingo and Valparaíso. The distance to the coast and the presence of surrounding mountains, as the Andes in La Paz and Mendoza, determine the cloudiness in each location.

The climatic characteristics of the selected cities are very different as a consequence of the different locations: Campinas (Brazil) is placed in the category of warm temperate climates and specifically in dry-winter humid subtropical climate (Cwa), La Paz (Bolivia) in a polar tundra climate (ET), Mendoza (Argentina) in an arid desert climate (Bw), Santo Domingo (Dominican Republic) in a tropical savanna climate with dry winter characteristics (Aw) and Valparaíso (Chile) in a temperate Mediterranean warm summer climate (Csb). Regarding the demographic and economic aspects, most densely populated cities are La Paz and Campinas, which differ significantly in their Gross Domestic Product (GPD). La Paz, Mendoza and Valparaíso show medium to low density and GPD values.

The data collected in Table 1, confirm that the areas of analysis cover a wide range of geographic and climatic locations and of demographic and economic characteristics along Latin America. This variety justifies the interest in performing a comparative study of the urban surface finish materials in these cities and their behavior under solar radiation.

Table 1:
Characteristics of the cities under analysis.

Parameter	Campinas	La Paz	Mendoza	S. Domingo	Valparaíso
Latitude	22°48’S	16°29’S	32°54’S	18°28´N	33,03° S
Altitude (m)	680	3500	764	14	250
Climate [ref]	Cwa	ET	Bw	Aw	Csb
Direct normal irradiation per year (kWh/m^2)	1781	2425	2189	1750	1966
Temperature (°C)	12/32/22	-2/15/7	1/37/18	20/32/26	11/18/14
Mean Relative Humidity (%)	70		52	83	75
Mean Urban Heat Island (°C)	3-6		6.5		
Population (million people)	1.22	0.86	1.09	1.04	0.30
Urban surface (km^2)	795		168	104	402
% Gross Domestic Product	0.9	28	4	67.9	10.4

Note: Temperatures are given as minimum/maximum/mean annual values.

3.2 Characteristics of the selected neighborhoods

Specific urban areas were selected for the study that comply with the general selection criteria detailed in section 2 and present other peculiarities of interest. The different morphologies of these areas are shown in Figure 1.

In Campinas (Brazil) a neighborhood in the district of Campo Grande was selected. Developed from 1950 without an adequate urban planning and infrastructures, most of the buildings are single storey and distributed in an organic morphology with streets width in the range of 9-12 m and around a 5% of vegetation coverage. The district includes various sectors exposed to high and very high vulnerability with subnormal urban agglomerations, which have become special areas of social interest for regularization by the City Council.

In La Paz (Bolivia), the adjoining neighborhoods Huacataqui and Chualluma were analyzed. While the former is representative of the conventional urban envelopes of the city, Chualluma represents the current transformation of the facades, redecorated with geometric patterns and brightly colored ethnic murals to enhance the identity of the area. These are basically pedestrian areas with 1-2 story houses, distributed in an irregular urban morphology, which adapts to the sloped topography of the site. The streets are narrow, plenty of stairs and without vegetation. They belong to the six “Barrios de Verdad” of the city, a public project for urban rehabilitation of vulnerable neighborhoods with special involvement of the inhabitants.

In Mendoza (Argentina) the analysis was performed at the Cementista neighborhood, which is a peripheral residential area representative of social neighborhoods in the city. It has a homogeneous building typology, characterized by 1-2 story houses. The area is characterized by an orthogonal grid morphology, in the form of checkerboard with rectangular blocks, street widths (vehicular zones) in the range from 9 to 12 meters and a 13% of the surface covered by urban forestry. The high potential of urban rehabilitation is related to the high percentage of built area (80%).

In Santo Domingo (Dominican Republic), the selected area was the San Miguel neighborhood, which is one of the oldest quarter of Santo Domingo´s Colonial City, dating from the 16th century. The current layout, from an intervention made in the 1970s, is a grid with rectangular, square, and triangular blocks. The paved streets have a width of 5 to 6 m, while the buildings are 1 to 4 stories and vegetation coverage is found in a 7% of the space. Urban rehabilitation of the area is expected to be performed in the near future.

a) Campinas. Campo Grande. | b) La Paz. Chualluma - Huacataqui. | c)Mendoza. Cementista. | d)Santo Domingo. San Miguel. | e) Valparaíso. Quebrada Márquez

Figure 1:
Morphology of the neighborhoods studied. Reference: Google Earth Pro, 2022

In Valparaíso (Chile), the selected area was the Quebrada Márquez, housing complex, located within the founding area of the city. The complex was built in the mid-20th century and presents social housing buildings in a block system. The blocks are 5 story buildings developed in a reticular morphology, with an urban grid in the form of checkerboards staggered along the slope. The area is characterized by eminently pedestrian and narrow streets, crossed by stairs and passages and without vegetation. The complex has the category of patrimonial protection called "Typical Zone" and is one of the most representative sectors of this urban singularity.

3.3 Preliminary data collection

Surface finishing materials at pavements, façades and roofs that are in use in each of the urban areas studied were inspected in-situ or using Google Earth images. A first set of data were obtained for the different materials and collected in data sheets as the one shown in Figure 2 (for façade materials). The sheet is divided in a first set of general data to identify the material and the manner and the frequency in which it is observed in the area of analysis.

The second part of the sheet refers to morphological characteristics of the material affecting the interaction of the surface with solar radiation. A third set (not shown in Figure 2) will be completed in future research to include the thermo-optical properties of the surface material. Finally, a set of indicators related to sustainability is added and will be extended in the future.

A catalogue was generated with the data sheets corresponding to all the surface finish materials in use in the studied neighborhoods. This information will be used to perform a comparative analysis, considering the characteristics of each location (Table 1). Optical characterization of surface finish materials will be performed by in situ measurement techniques and laboratory tests.

A. GENERAL INFORMATION	
Reference	**CP F 2**
Image	
Location at facade/wall	Complete
Percent use	20%

B.1. MORPHO-MATERIAL CHARACTERISTICS	
Surface material	Brick
Color	Orange
Tone	Medium
Texture	Smooth
Size of unitary element	Medium
B.3. SUSTAINABILITY INDICATORS	
Cost ($ x m^2)	
Type of technology	Traditional
Range	Economic
Availability in local market	High

Figure 2:
Example of the data sheets used to collect the preliminary set of data from in use surface materials.

Figures 3 and 4 show an extract of the catalogue, including the images of the most frequent surface finishes in the pavements and the façades, respectively, in the areas studied.

A first analysis of the collected data indicates that the most used materials at pavements in all the areas studied are asphalt for vehicular use and concrete for both vehicular and pedestrian use. Soil pavements were also observed in Campinas, La Paz and Valparaíso (Fig. 3.b, 3.e and 3.n, respectively), and stone is used in Mendoza (Fig. 3.i) and more predominantly in Valparaíso (Fig.3.o). Finally, brick as surface finish material in sidewalks was only observed in Santo Domingo (Fig. 3.l)

Pigmented mortars and painted renders are highly frequent surface materials in the façades of the five areas. They are predominantly colored white or in the range from yellow to red. Exceptions are the façades of the Chualluma neighborhood in La Paz, intentionally decorated in a wide variety of bright colors (Figs. 4.d and 4.e). Part of the blocks in Quebrada Márquez (Valparaíso) show a characteristic green render, as observed in Fig. 4.n.

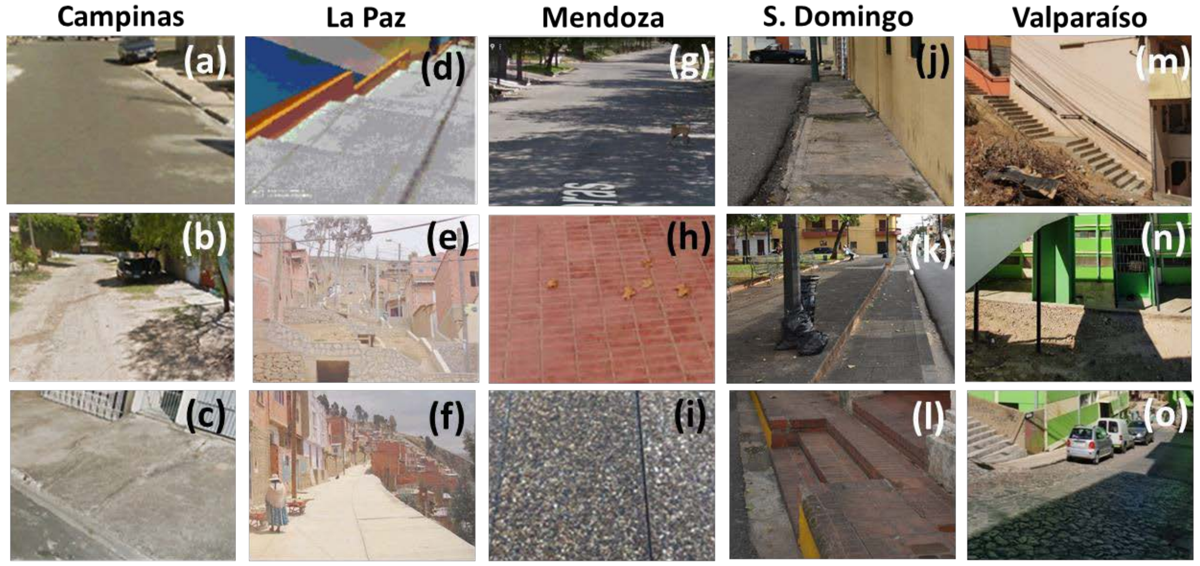

Figure 3:
Predominant surface finish materials catalogued in pavements of the neighborhoods under study.

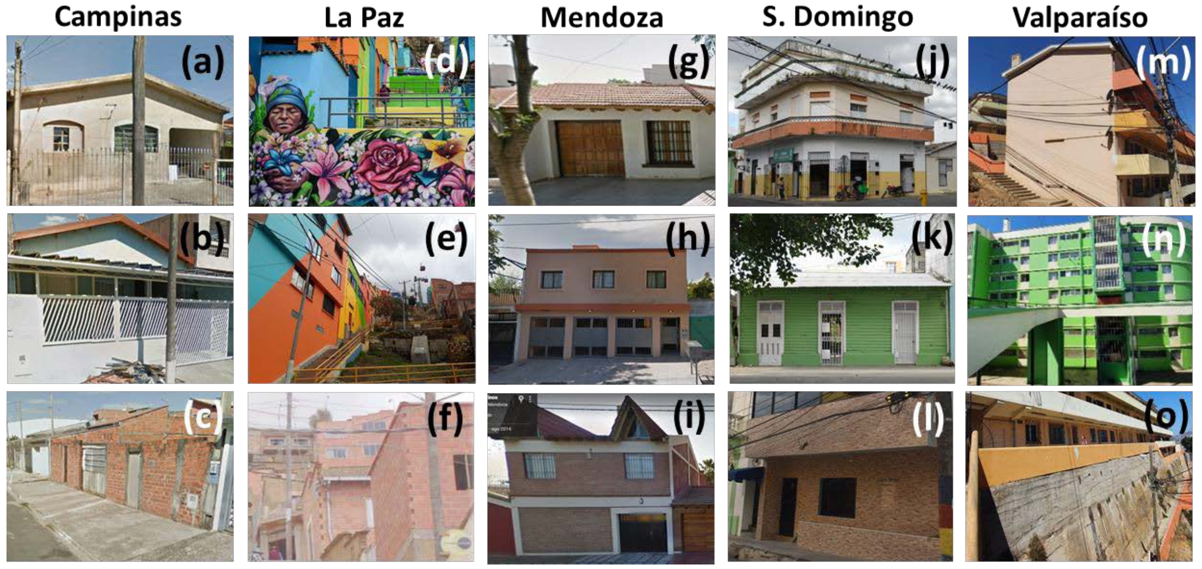

Figure 4:
Predominant surface finish materials catalogued in facades of the neighborhoods under study.

Exposed brick facades were frequently observed as well in the neighborhoods of Campo Grande (Campinas. Fig. 4.c), Huacataqui (La Paz. Fig. 4.f), San Miguel (Santo Domingo, Fig. 4.l) and Cementista (Mendoza, Fig. 4.i). Finally, minority observed materials were wood façades in San Miguel and reinforced concrete walls in Quebrada Márquez (Figs. 4.k and 4.o, respectively).

Regarding the roofs, sheet metal roof was observed as surface finish material in all the urban areas analyzed and was the predominant option in those of Valparaíso and La Paz. Cementitious flat roofs are usual in Santo Domingo neighborhoods and ceramic tiles were observed in inclined roofs in Campinas and Mendoza. Finally, polymeric flat roofs were only observed in the case of Cementista area, in Mendoza.

The results from the preliminary data collection evidence the use of similar materials in the five urban areas analyzed, in spite of the significantly different characteristics and conditions described for each of them in sections 3.1 and 3.2. This means that the choice of surface finish materials in these areas does not correspond to the climatic and environmental conditions in which they are inserted. In fact, they respond to the use of globalized technologies that implement materials with high thermal inertia. These technologies and materials are more suitable for cities more distant from the Equator than those analyzed in this study.

Another evidence obtained from the study and observed in Figs. 3 and 4 is the degradation of the surface finish materials in part of the neighborhoods. This degradation affects the thermo-optical response of the materials and must be taken into account in future research.

4. CONCLUSION

This paper describes the first stage of a research addressing the improvement of urban sustainability in Latin American cities through the optimization of solar energy management.

Preliminary data of the surface finish urban materials were collected with a unified methodology in disadvantaged neighborhoods of 5 cities representing different climatic conditions. The data were organized into data sheets, gathered in a catalogue to ensure an efficient data management and a reliable comparison of the results from different locations.

The results indicate that the materials currently in use in the studied neighborhoods were not selected according to the specific climatic characteristics of each location. This means that a more detailed research is of interest, to analyze the potential substitution of current materials by others adapted to local conditions.

With this idea in mind, the catalogue will be extended in the future with the experimental thermo-optical properties of the surface finish materials. Other properties related to their performance and sustainability (transport properties, thermal properties, carbon footprint, durability, etc.) will be assessed as well. The gathered information will be included in a life cycle analysis of the materials, in which the origin of the raw materials and manufactured elements will also be considered. Similar data of the materials available at the local markets for urban retrofit will be included as well.

From this information, a suitable strategy to improve the urban sustainability will be assessed, based on the substitution of the current urban materials by others with optimized properties for the climate conditions of each area. Strategies to mitigate urban overheating through the reduction of solar energy absorption will be defined for areas affected by high temperatures. On the contrary, solutions to reduce the heating demand of buildings through the enhancement of solar gains will be proposed for colder areas.

The methodology initiated in the present work is intended to be extended to other cities. Specifically, it will be implemented in a similar analysis under progress by the authors in deprived neighborhoods of Madrid (Spain).

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PLEA SANTIAGO 2022
Will Cities Survive?

Automatic mesh generator for urban Computational Fluid Dynamics simulations

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ABSTRACT: Despite the well-known potential of Computational Fluid Dynamics (CFD) to enhance the prediction of Building Performance Simulation (BPS) models, several barriers prevent BPS simulators from actively using CFD. A recognized obstacle is the proficiency required to get a high-quality computational mesh to study the atmospheric boundary layer (ABL) flow in actual urban environments. Hence, this work aims to present and validate an automatic tool to generate and discretize a virtual wind tunnel from an urban geometry model given as an input. The development comprises an unattended procedure that analyzes the buildings and their components (walls, openings, shadings), determines dimensions of the domain and grid refinements that abide by the best practice guidelines, and finally constructs the mesh. Case studies with isolated and non-isolated buildings show the robustness and capabilities of the developed tool. A mesh convergence study is carried out to assess the sufficiency of the spatial discretization for ABL simulations.

KEYWORDS: Urban environment, Atmospheric boundary layer flow, Computational fluid dynamics, Building performance simulation, Computational mesh, Natural ventilation

1. INTRODUCTION

It is well known the need for feeding Building Performance Simulations (BPS) with data computed by Computational Fluid Dynamics (CFD) simulations (Cóstola et al., 2009). For instance, the wind-induced pressure distribution on the building openings is an essential input data for Airflow Network (AFN) models, and highly influential in the Natural Ventilation (NV) results (Gimenez et al., 2018). Moreover, thanks to the growing computing capabilities CFD can obtain detailed information about the urban microclimate, useful to predict the energy performance of buildings, and the comfort and health of citizens in both, indoors and outdoors environments (Toparlar et al., 2017).

The construction of high-quality meshes is a prerequisite for successful CFD simulations. A set of best practice guidelines ensures the reliability and accuracy of the CFD predicted results, including a detailed description of the desired features for the computational grid (Tominaga et al., 2008; Franke et al., 2011; Marzei and Carmeliet, 2013). Among the latest works, Du (2018) has proposed a systematic mesh generation method controlling the mesh quality over the entire domain. However, the effort and difficulties of manually generating proper meshes for geometrically complex real urban environments prevent BPS simulators from being active CFD users.

In this context, Bre and Gimenez (2022) introduced *CpSimulator*, a platform that comprises a set of fully automatic CFD-based tools to perform atmospheric boundary layer (ABL) simulations. In that work, the automatic tool to generate the computational grid from a geometry file given as an input was summarized and applied to the study of simple models. The current work improves the procedure for managing complex urban environments. The geometry of the target building and its surrounding environment, using the EnergyPlus input format (IDF), is processed, reconstructed, and placed in a computational wind tunnel, which is then automatically discretized. The focus is put on computing the characteristic sizes of the building surfaces to assess an adequate local mesh resolution. In addition, the automatic detection of the urban envelope is introduced to ease the split of the spatial domain and improve the calculations in the urban area. Several case studies, involving isolated and non-isolated buildings, show the capabilities of the developed tool. Additionally, the sufficiency of the spatial discretization generated by the automatic tools is assessed through a mesh convergence analysis of ABL simulations.

2. METHODOLOGY

The unassisted procedure to reconstruct the target building and its environment and generate the computational domain involves a sequence of steps described next.

2.1 Geometry Input

The description of the geometry of the building and its environment should accomplish: a) the +z