Urban Building Energy Modeling Using a Place-Based Approach

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Urban building energy models present a valuable tool for promoting energy efficiency in building design and control, as well as for managing urban energy systems. However, the current models often overlook the importance of site-specific characteristics, as well as the spatial attributes and variations within a specific area of a city. This approach allows for a more in-depth understanding of the interactions behind spatial patterns and an increase in the number and quality of energy-related variables.

Keywords: Urban Building Energy Modeling UBEM ; Urban Scale Energy Models USEM ; place-based approach ; geo-database ; geographic information system ; QGIS ; sustainable citie and communities

1. Introduction

In European urban contexts, where 74.5% of the EU-27 population live [1], buildings account for 36% of greenhouse gas (GHG) emissions [2] and the residential sector for 28% of final energy use [3]. The current issues of climate change, pandemics, wars, and energy price crises highlight the centrality of the energy sector at a territorial level. One of the crucial future challenges that European policies face is achieving energy self-sufficiency in high-density urban contexts, meeting lower energy demand by producing energy by boosting the available renewable energy sources (RESs) [4]. High-energy intensity, combined with the numerous constraints, limited availability, and the associated uncertainties of RESs, shifts the spatial scale of the analysis from a local scale (i.e., building or block of building scale) to an urban or regional scale [5]. In order to ensure a clean energy transition and carbon neutrality by 2050 [6], integrated models and methods that incorporate fine spatial and temporal resolution data from different sources at an urban scale are crucial [7]. Urban building energy modeling (UBEM) is one such method that can be used to simulate and analyze the energy performance of buildings at the neighborhood scale. However, the potential of UBEM to facilitate sustainable development in terms of built environments is limited by its dependence on conventional physics-based inputs [8]. This issue becomes even more critical for district- or city-scale studies, in which data availability is also a concern. To this end, researchers investigate a set of methodologies and models to improve the effectiveness of UBEM to enhance the sustainability of built environments using a place-based approach. In particular, it presents a methodological paper that describes a new energy modeling technique with a place-based approach to provide an effective means of simulating and analyzing energy use in urban built environments, considering fine spatiotemporal resolution data. The energy modeling presented also explains the importance of managing large databases, identifying other variables or surrogate variables, and representing the results. The pre-modeling part is of fundamental importance because it influences the choice and accuracy of the model, and the representation of the data allows for the dissemination of the results.

2. Knowledge Gap and Objectives

Research into building physics and geomatics lacks an integrated approach, which hinders the creation of place-based urban-scale building energy modeling (USBEM). Building physics focuses on the physical phenomena that regulate building energy consumption at a building or block scale. Geomatics deals with databases at the urban and territorial scale and uses open-source geographic information systems such as QGIS to extract and calculate geo-referenced information (e.g., raster or vector data), which can be used for energy modeling at the urban scale. Combining these two fields can create a more comprehensive and effective approach to USBEM.

In order to accurately calculate the energy consumption of a building or block, extensive information on the building envelope, technological systems, and surrounding context must be incorporated into the energy balance equation. However, this level of detailed information is not always available for entire cities. In these cases, QGIS can be utilized to calculate the missing variables and incorporate them into the balance equations. This process ensures a more comprehensive and accurate calculation of energy consumption at the urban scale. This work provides insight into place-based USBEM by explaining the different types of USBEM models, from pre-modeling to energy modeling, result representation, and application fields. The pre-modeling stage is enriched by considering spatial autocorrelation, which identifies clusters or areas with similar characteristics that influence energy consumption. This is a novel improvement, as spatial autocorrelation has not been investigated in energy modeling, even in place-based USBEM. Incorporating this improvement into urban-scale models can be significant, as some information may not be available, and it enables accounting for different energy-use types.

According to the literature, USBEM using a place-based approach offers numerous advantages, such as performing site-specific analyses and considering each building's characteristics that influence its energy consumption. These models can work on various layers and scales, use all the available data, and understand the spatial variations within different areas of a city. They can easily shift from the building to the urban scale and compare different scenarios and analyze them from various perspectives with an interactive interpretation of the results. Place-based USBEM can evaluate the impact of localized interventions on a larger scale. However, it has limitations, including limited data availability on a large scale, language barriers, and privacy concerns. Nevertheless, with expertise in buildings physics and geomatics and experience in locating and managing vast datasets, it is possible to process data or surrogate data to create models for predicting building energy consumption at the urban scale.

3. Place-Based Urban Building Energy Modeling

The implementation of the place-based approach in USBEM is described in detail. In order to treat all of the energy models found in the literature, the place-based approach is implemented into data-driven, process-driven, and hybrid energy models.

The methodology presented here is illustrated in **Figure 1** and described in the steps below:

- Pre-modeling with:
  - Data collection: the collection of input data/geo-databases and geo-localization of urban environment data.
  - Pre-processing phase: correction, integration, and spatialization of databases and evaluation of spatial correlations and local climate conditions.
  - Geo-database creation: the creation of a complete and accurate geo-database for energy modeling;
- Energy modeling with: USBEM using a place-based approach: application of the place-based approach to data-driven, process-driven, and hybrid modeling;
- Calibration: error evaluation and adjustments to input data to minimize errors between the data measured and calculated by the model, making the model more robust.

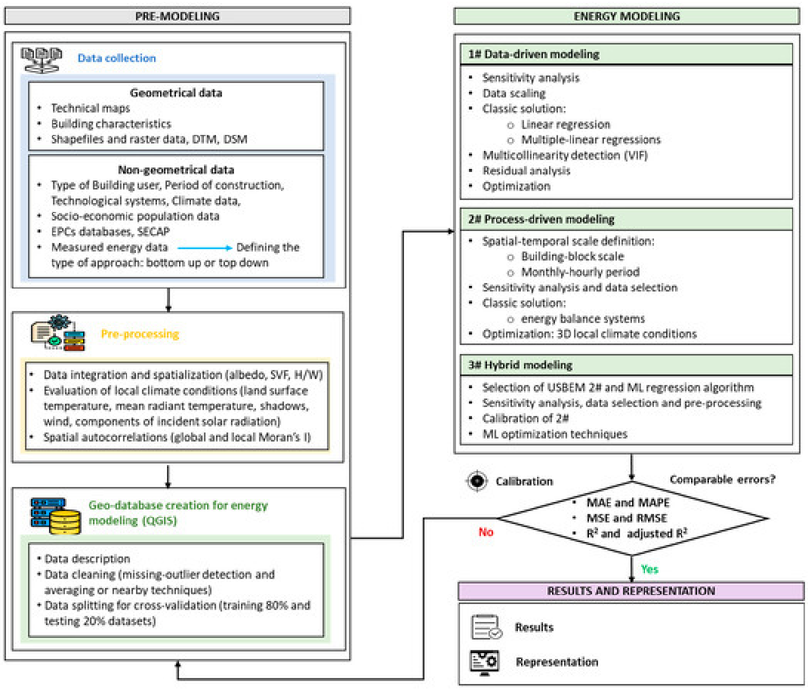

Figure 1. Methodology of USBEM using a place-based approach.

The geographic information system QGIS is used in all phases of the place-based process because it allows the user to upload geo-referenced data, yet it also has various plugins that manage the databases, calculate other data, operate with information at different scales, and helps create data-driven models through specific tools and algorithms.

After collecting the available data and processing the missing data, the geo-database is created, and it provides the information to build USBEM. Then, the geo-database splits into two datasets to train and then test the model. The calibration allows for the minimization of errors and to improve the robustness of the model.

For USBEM using a place-based approach, some of the useful QGIS plugins and tools are “Smart maps”, “R” and “Orfeo Toolbox provider” for statistical analyses and machine learning algorithms.

In **Figure 1** is explained in more detail in the following paragraphs with some examples of the results to explain the different types of outcomes, such as the numerical values, tables, graphs, and maps.

References

1. United Nations. Available online: https://population.un.org/wup/Download/ (accessed on 22 February 2023).
2. European Commission. Available online: https://transport.ec.europa.eu/media-corner/publications/statistical-pocketbook-2022_en (accessed on 22 February 2023).
3. European Commission. Available online: https://ec.europa.eu/eurostat/web/main/data/database (accessed on 22 February 2023).
4. Todeschi, V.; Marocco, P.; Mutani, G.; Lanzini, A.; Santarelli, M. Towards energy self-consumption and self-sufficiency in urban energy communities. Int. J. Heat Technol. 2021, 39, 1–11.
5. Perera, A.T.D.; Javanroodi, K.; Wang, Y.; Hong, T. Urban cells: Extending the energy hub concept to facilitate sector and spatial coupling. Adv. Appl. Energy 2021, 3, 100046.
6. European Commission. Available online: https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en (accessed on 22 February 2023).
7. Perera, A.T.D.; Javanroodi, K.; Mauree, D.; Nik, V.M.; Florio, P.; Hong, T.; Chen, D. Challenges resulting from urban density and climate change for the EU energy transition. Nat. Energy 2023, 8, 397–412.
8. Heidelberger, E.; Rakhahttps, T. Inclusive urban building energy modeling through socioeconomic data: A persona-based case study for an underrepresented community. Build. Environ. 2022, 222, 15.