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besos: Building and Energy Simulation, Optimization and Surrogate Modelling

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Software

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Summary

The buildings sector is one of the largest contributors to CO_2 emissions, comprising up to 33% of the global total (ürge-Vorsatz et al., 2007). Improved computational methods are needed to help design more energy-efficient buildings. The Python library besos along with its associated web-based platform BESOS help researchers and practitioners explore energy use in buildings more effectively. This is achieved by providing an easy way of integrating many disparate aspects of building modelling, district modelling, optimization and machine learning into one common library.

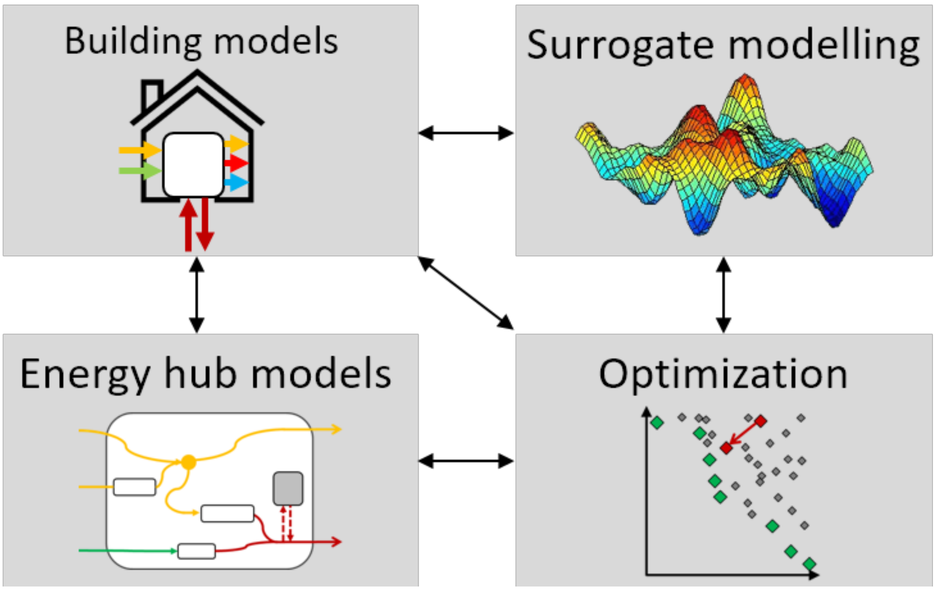

Figure 1: analysis domains encompassed by BESOS.

Statement of Need

As in many domains, computational tools for exploring building energy use are currently fragmented, requiring users to manually integrate many different tools, each with their own

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installation and configuration issues. This is particularly arduous when using machine-learning models together with building energy models, each requiring extensive domain knowledge to implement from scratch. To alleviate this, besos interfaces with the following approaches to modelling and optimization of buildings in one common library.

- A parametric interface to the popular building simulation software EnergyPlus (https://energyplus.net/) (Crawley et al., 2001), built on EPPy (https://pypi.org/project/eppy/).
- District-scale operational and capacity optimization using the Energy Hub (https://pypi.org/project/pyehub/) (Evins et al., 2014) model.
- Large-scale parametric analyses with easy results exploration (using Pandas DataFrames and standard plotting libraries).
- Machine learning based surrogate models that approximate detailed physics-based simulations (P. Westermann & Evins, 2019) using scikit-learn (Pedregosa et al., 2011) and TensorFlow.
- A pipeline to run building design optimizations (Waibel et al., 2019) using meta-heuristics like genetic algorithms (using Platypus), either over EnergyPlus directly or over a surrogate model.
- A set of data structures for handling the different parts of the approaches above: a Problem consisting of Parameters, and Objectives is associated with a building model, then sampled and passed to an Evaluator.

The first key contribution of the besos library is the ease with which the above features can be interlinked. For example, hourly energy demands for a year can be calculated for a set of buildings using a parameterized EnergyPlus simulation, then linked to an Energy Hub model to find the optimal operation and sizing of a district system. This coupled model can then be linked to a multi-objective genetic algorithm to find the trade-off between investment cost and carbon emissions by manipulating both building and district-level variables.

The second key contribution of the besos library is in facilitating surrogate modelling, where machine learning models are trained on many samples of simulation input and output data so that the resulting model can be used as a fast but approximate surrogate for the computationally-intensive simulation. This allows users to rapidly explore the entire 'design space' of possible buildings, rather than optimizing for pre-specified objectives. The besos library provides a complete set of scripts for deriving and using surrogate models of building energy simulations, including problem definition, sampling and batch processing of simulations, and machine learning model training and testing.

To facilitate the use of besos, we have created example notebooks and a supporting BESOS platform. A multitude of example notebooks can be found in the repository which serve as tutorials, and can be copied and adapted to accomplish new tasks. These cover all the besos library functionality, like optimizing building designs, deriving surrogate models (inc. uncertainty analysis and sensitivity analysis), and running coupled EnergyPlus and Energy Hub models.

The BESOS Platform (Faure et al., 2019) provides executable Jupyter Notebooks (https://jupyter.org/) via the Jupyter Lab interface that implement many of the features of the besos library in a web-interface with no set-up required. These notebooks mix executable code, visual outputs and formatted explanations, making them ideal for non-expert programmers who want to get on with running building energy models without navigating a huge codebase. Expert users have full control of their environment, with terminal access to pip install packages or to pull from git repositories. The platform is made freely available to scholars associated with an academic institution after signup and approval.

Associated research and projects

- The besos library is the foundation for the Net Zero Navigator (https://netzeronavigator.ca/) tool which provides interactive visual design-space exploration for net-zero ready buildings based on surrogate models.
- Surrogate modelling research using the besos library includes using convolutional neural networks (CNN) as climate-independent building energy surrogate models (P. Westermann, Welzel, et al., 2020), the use of active learning to derive surrogate models with fewer samples (P. W. Westermann & Evins, 2020), and the use of a surrogate model to analyze the key parameters of ground-source heat pumps (P. Westermann, Deb, et al., 2020).
- Energy Hub applications of the besos library include storage sizing (Rahimzadeh et al., 2021) and photovoltaic potential analysis (Christiaanse et al., 2021).

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