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Conceptualisation of simulation platform for assessing residential construction code impacts

Angela M Rojas[a], **Chi-Hsiang Wang**[a], **Anthony Wright**[a]

[a] *CSIRO Energy, Clayton, Victoria, Australia*
Email: angela.rojas@csiro.au

Abstract: Residential buildings in Australia account for 24% of electricity consumption and over 10% of carbon emissions. Energy-efficient building codes could reduce consumption by 4% to 50%, but challenges in compliance and a lack of thorough evaluations impede effective policymaking. This proposal presents an integrated hybrid framework for assessing the impacts of building codes on energy use and affordability. By combining computational modelling with real-world data, the approach improves simulation accuracy and supports empirical studies. This framework aims to help policymakers, researchers, and energy providers evaluate energy policies and retrofit options, supporting Australia's climate goals through evidence-based building codes.

Keywords: *Energy performance, residential, code, grid, simulation*

1. INTRODUCTION

Residential construction codes aimed at improving energy performance are essential for decarbonisation, and research shows these can reduce residential energy use. However, energy savings range from 4% to 50%, influenced by factors such as location, code standards, building types, and heating methods (Jacobsen & Kotchen, 2010; Zabalza et al., 2022; Kellogg & La Cumbre-Gibbs, 2022). The variety of methodological approaches in these studies makes it hard to draw broad conclusions. Additionally, simulation tools and empirical data are highly context-specific. Real-world results almost always differ from model predictions, and although discrepancies are normal and not always problematic, they must be closely monitored to ensure that policies are delivering the intended outcomes. Australia could utilise local tools, data, simulation techniques, and best practices in research design and analysis to create a comprehensive evaluation framework for code impacts. We propose an integrated hybrid "in-silico" and "in-vivo" building-grid framework to thoroughly examine how energy performance standards in construction codes affect energy consumption, power grids, affordability, and resilience. The in-silico model supports hypothesis development, while in-vivo data calibrates and confirms simulations. This method helps uncover causal effects, quantify uncertainties, and align design ratings with utility demands. It also provides a platform for virtual experiments and sensitivity testing, enabling policymakers, researchers, and energy providers to assess policies, retrofit options, and grid impacts, ultimately supporting Australia's climate goals through evidence-based decision-making.

2. METHODOLOGY CONCEPTUALISATION

Figure 1 conceptualises a simulation platform with two modules: the in-silico (right) includes physics-based building and power grid models, and the in-vivo (left) uses real-world data. Ideally, evidence is gathered through natural experiments; however, this is often impractical, so modules rely on quasi-experimental methods, such as difference-in-difference (Lechner, 2011; Vocht et. al, 2021), regression discontinuity, and matching. To manage uneven code implementation and control confounders, it focuses on a single jurisdiction at a time, using clear building code changes and treatment based on construction year.

The in-silico module uses building stock data, including NatHERS star ratings, Chenath hourly thermal requirement simulations, and appliance information, along with GIS data such as building age, floor area, roof height, and proximity to the city. It incorporates construction codes, compliance, policy, and demographic data, applying statistical methods to estimate star ratings and thermal needs (Wang & Rojas, 2025). This creates synthetic loads for analysis, experiments, causal inference, effect sizing, and uncertainty quantification. It also utilises power grid GIS data, including network topology, asset parameters, and standards. The power grid model converts GIS data into a physics-based format for validation and power flow studies. The Building-Grid model integrates synthetic loads with power grid models for virtual testing, stress assessments, and further analysis. This module helps identify data gaps, refine methods, guide data collection, and validate strategies. The in-vivo module utilises historical smart meter data, gas data, appliance inventories, DER installations, and household surveys, directed by its synthetic counterpart. Power grid data comprises measured load, generation, and electrical parameters. Empirical analysis with Building-Grid data helps validate and calibrate models. This framework supports iterative policy testing and evidence integration, incorporating complex system models such as agent-based and system dynamics models to assess technology adoption and learning.

3. CONCLUSIONS

We provided the conceptualisation for a simulation platform that effectively integrates in-silico and in-vivo approaches to improve our understanding of building performance and power grid impacts from residential construction code changes. By employing quasi-experimental methods and focusing on specific jurisdictions, the framework not only facilitates causal inference and uncertainty quantification but also supports the empirical validation of models. This iterative process can help test, refine, and enhance policies and strategies for better energy performance, network planning, and affordability assessments.

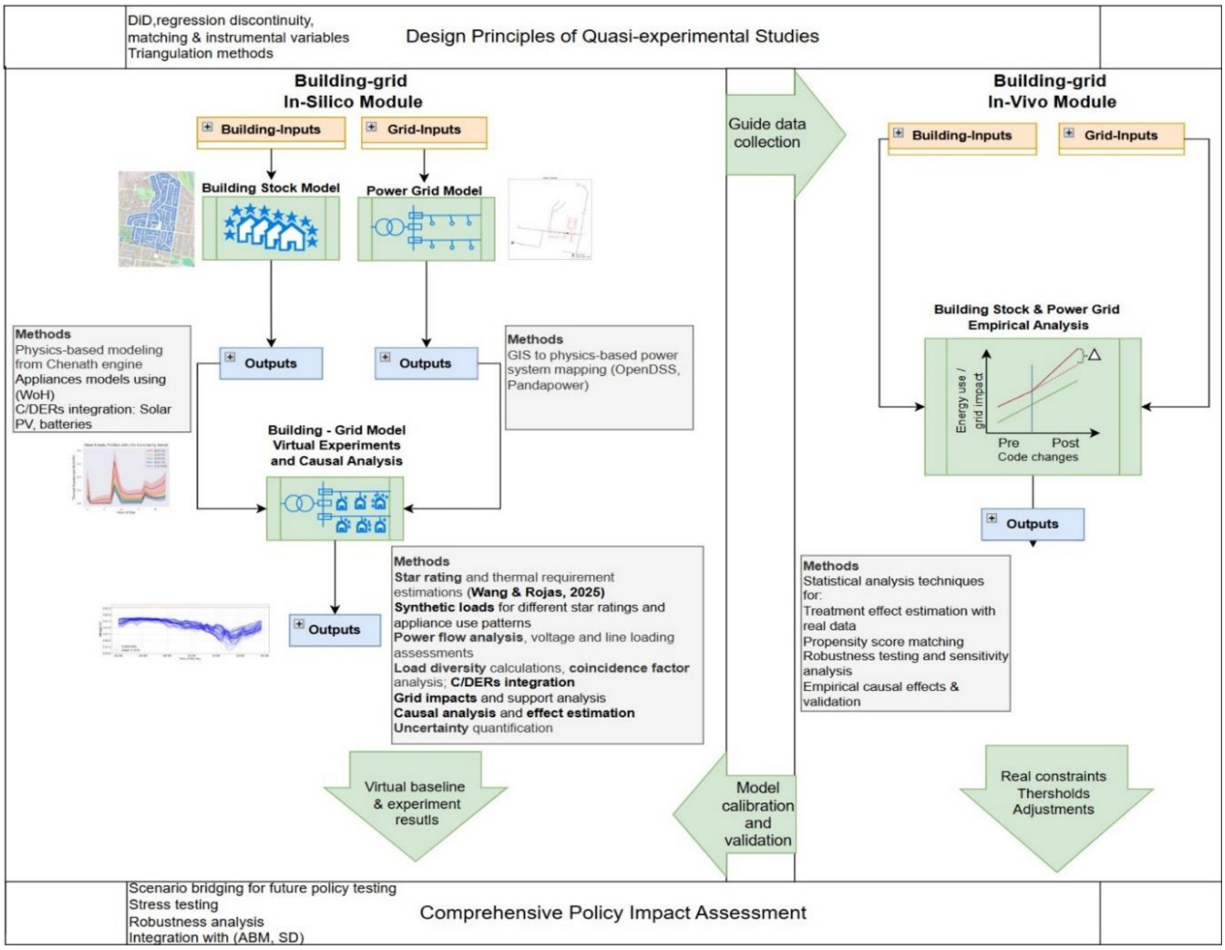

Figure 1 In-silico (right) and in-vivo (left) quasi-experimental and simulation framework for construction code testing of grid affordability impacts.

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