A value-based framework from Building Stock Model to Retrofit Model

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Abstract

Buildings play a crucial role in global decarbonization efforts to reduce energy consumption. Building Energy Retrofitting (BER) is a highly effective strategy for meeting Green House Gas (GHG) reductions. Building Stock Models (BSM) are typically oriented toward reducing operational emissions. However, achieving energy reductions through retrofit and refurbishment has specific embodied environmental impacts to consider.

This document represents the synthesis of Ph.D. research chapter one, which establishes the "Problem Statement" concerns, such as approach, delimitation, theoretical framework, methodology, and hypothesis. The study has as its original database the decarbonization process initiated in Mexico by the National Commission for the Efficient Use of Energy (CONUEE) as part of its "Savings Program of Electric Power in Buildings of the Federal Public Administration" (PAEIAPF) of 1999. The primary purpose of PAEIAPF was to reduce the levels of electric power consumption in Federal Government buildings. The program has operated for 20 years; however, its scope only reaches operational carbon.

Since 90% of existing buildings will be in use by 2050[1], the Retrofit Models will be the base to determine solutions for a more resilient living environment that fortifies and extends the grid's capacity and meets climate change mitigation targets.

Secondly, significant socioeconomic and profound environmental impacts are not calculated explicitly in existing tools and are often referred to as "secondary" or Non-Energy Benefits (NEB). "The goal is to give them a measurement value to be considered in the decision-making calculus. It is assumed that soon, such factors will enter the general climate change economy, not unlike carbon in the past decade.[2]"

In this context, the proposed research is to develop a value-based framework that will support a Building Stock Model and subsequent Retrofit Models, documented in a web-tool platform, which has three main steps:

a) BUILDING STOCK MODEL: Mapping of selected buildings of the program PAEIAPF in a GIS system. Documentation of the baseline energy consumption, embodied CO2-eq of the existing building, and energy required in the supply process;

b) RETROFIT MODELS: Involving a Whole Life Cycle Assessment (WLCA) and Non-Energy Benefits (resilience coefficient, health, productivity);

[1] Ksenia Petrichenko, policy analyst in the International Energy Agency (IEA), 2020.
[2] Michael Jemtrud. Associate Professor School of Architecture, McGuill University (Interview).

c) WEB TOOL PLATFORM: Application and Toolset that allows for the consistent documentation, environmental impact evaluation of existing building stock, and solution design in identifying energy reduction concepts.

Background

IEA[3] data shows that the global floor area is expected to increase by 75% mid-century. This is equivalent to adding an area the size of Paris every week for the next 30 years. If this happens with today's energy consumption patterns, more is needed to achieve climate targets. To reduce direct emissions from buildings by more than 95% by 2050, we need to face three things in this order: efficiency, renewable energy electrification, and decarbonization.

Energy efficiency must come first. And in buildings, it should be improved in two ways. First, improving the building envelope's energy efficiency with better materials, design solutions, insulation of walls, roofs, basements, and energy-efficient windows; second, improving the energy efficiency of all appliances and equipment used in the building for space heating and cooling, water heating, lighting, cooking, working, and entertainment.

Improving energy efficiency will result in significant energy savings, reduced CO2 emissions, lower energy bills, and enhanced comfort, productivity, and health of people living in them.

The second step is a shift towards decarbonized electricity produced from solar, wind, and other low-carbon sources; however, in some countries like Mexico, the transition to renewable energy resources needs to be seen Mexico cautiously. Even though Mexico has one of the highest levels of solar radiation on Earth, it gets more than 80% of its total energy supply from fossil fuels, and it started to import natural gas as a source of electricity generation. So there is a climate imperative and a solid geopolitical and energy security imperative to electrify and decarbonize our buildings and make them as efficient as possible.

The evolution of existing building stock to curtail energy consumption by upgrading building structures is a proven, highly effective climate change mitigation and adaptation strategy (1-10).

Operational emissions (using buildings for Energy Efficiency and on-site production of renewable energy) are critical in the clean energy transition. BER strategies aim to achieve reductions, which implies meaningful, environmental, energy, and societal aspects.

More critical than operational emissions are the Embodied Emissions that arise from producing, procuring, installing, maintaining, and eventually disposal of the materials and components that make up a building.

The amount of embodied carbon dioxide equivalent (CO2-eq) in a typical building outweighs operational CO2 emissions throughout its lifecycle (69% in residential, 76% in warehouses, 67% in commercial) (11, 12).

[3] https://www.iea.org/

To achieve a net-zero carbon building stock by 2050, the IEA estimates that direct building CO2 emissions would need to decrease by 50% and indirect building sector emissions decline through a reduction of 60% in power generation emissions by 2030. These efforts must see building sector emissions fall by around 6% annually from 2020 to 2030. For comparison, the global energy sector's CO2 emissions decreased by 7% during the pandemic.

Most efforts are designated to new constructions; however, to reach energy demand-decreasing targets by 2050, savings may be primarily achieved by renovating the existing building stock rather than new buildings.

Generally, the typical energy renovation rate is 12% of the building stock per year, with average energy intensity reductions usually less than 15%. To achieve the Sustainable Development Scenario (SDS), however, energy renovations need to reduce energy intensity by 30-50%.

Refurbishment actions based on moderate efforts in existing buildings could contribute the most to decarbonizing the building environment.[4]

Although refurbishment is necessary to reach the ambitious energy and decarbonization targets for 2020 and 2050, which require an eventual reduction of up to 90% in CO2 emissions, the renovation rate still needs to be higher. There is an increasing demand to upgrade both the physical condition and the performance of the building, with the minimum disturbance to the interior, so that the occupants do not have to be relocated during construction. Thus, the role of the user and the owner becomes essential not only in terms of performance during the post-refurbishment phase but also in the design and planning of the refurbishment.

Research Problem

Several countries are now introducing stringent regulations to retrofit existing buildings. For instance, the Building Technology Program of the United States Department of Energy and the European Union Directive of Energy Performance of Buildings are two significant initiatives introduced in the past to promote the construction of new net-zero buildings and retrofit the existing ones. In the case of Mexico, there are some isolated efforts to have more energy efficiency in buildings, for example, the PAEIAPF of 1999.

However, to be a scalable and replicable instrument in other contexts, there needs to be a digital database of this information where the baseline data and improvement in the energy efficiency performance of buildings can be transparent.

One way to have control of energy efficiency strategies and renewable energy measures for existing buildings is designing a Framework and evaluation method where it will be possible to map the main characteristics of sample buildings, such as baseline energy consumption and embodied carbon, identifying the emissions that can be avoided and calculated in an Environmental Balance Sheet.

[4] Loga et al.2015.

That information must be the base for designing Retrofit prototype solutions. The result must be classified and documented strategically to reply to and scale the sample and the scope for future analysis.

As a reference, some similar projects have shaped the research framework. The most influential authors in this exploration have been Hollberg et al. 2020; Hester et al.; Claudio Nägeli, Martin Jakob, Giacomo Catenazzi, York Ostermeyer; Soust-Verdaguer, Bernadette. However, some conclusions regarding state of the art so far are that most tools and methodologies are implemented for the design and pre-design phases but for new buildings, some of the most used Instruments, tools, and Methods for retrofit proposals are BSM, WLCA, and the use of Algorithms. Regarding the BSM for retrofit, research is increasing, especially in the residential sector, European countries, and North America, but it still needs to be in LATAM.

Most existing studies focus on devising retrofit solutions on a case-by-case basis rather than approaching the problem in a standardized way.

Therefore, the scope of this research is to develop a framework that can help to retrofit a specific building or a set of buildings on an urban scale. The selected sample is a group of Office Buildings property of the Mexican Government located in Mexico City, which are part of the PAEIAPF, specifically, the ones located in Cuauhtémoc District (68 Office Buildings).

It is essential to quantitatively manifest the advances made so far in the PAEIAPF program, set a digital platform, and, most importantly, curate the baseline information through the framework that contemplates the whole life carbon vision to integrate the WLCA, Operational Carbon, and Embodied Carbon in the retrofit design strategies.

Additionally, the framework will contemplate the stakeholders, such as the owners and especially the users, and make clear the benefits, not only from an environmental perspective but also economically.

Research Objective

Design a digital system to document and verify buildings' baseline regarding energy consumption, embodied carbon, and energy required in the supply process. Said Digital Platform will be the repository of retrofit models based on the information collected. The performance of the sample buildings will be documented with future projections, incorporating possible scenarios of renewable energy supply (out of initial scope). The reference framework for the retrofit proposals will be based on the Whole Life Carbon Assessment vision; it will include the Non-Energy Benefits (resilience coefficient) measurement.

Methodology

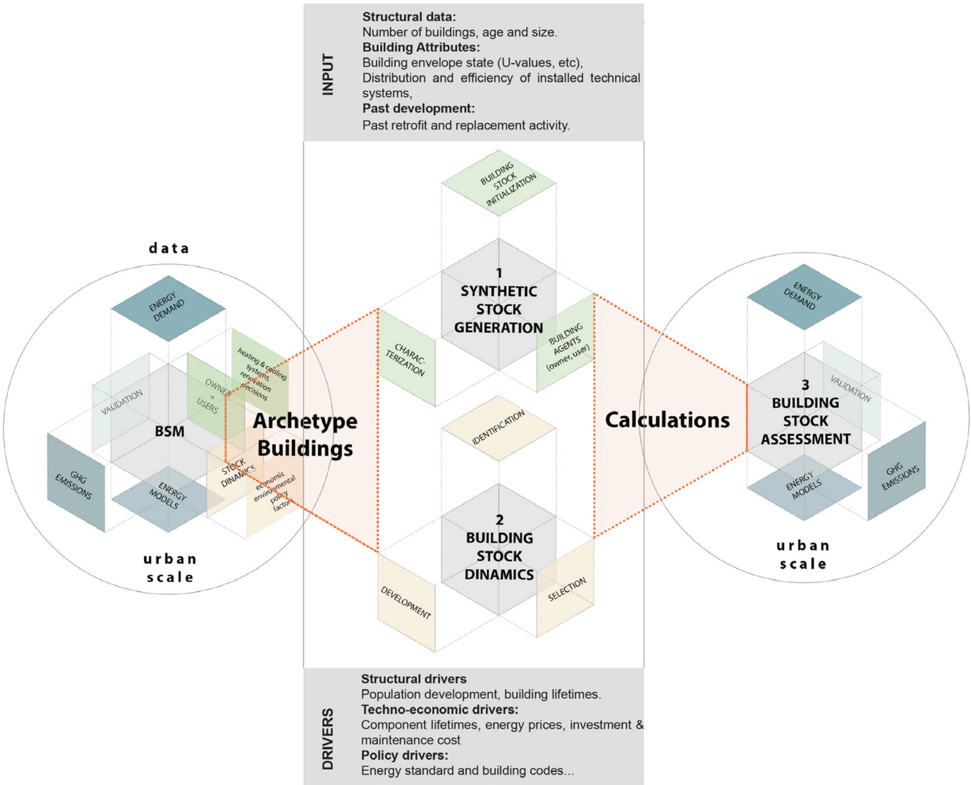

Figure 1: Schematic Methodology

A Building Stock Model (BSM) will be used as the starting point of the methodology for assessing the energy demand and environmental impact of the representative sample of buildings that conform to the building stock and that, through retrofit strategies, can determine pathways for reducing GHG emissions and energy demand. However, typical BSM usually does not consider variables such as the probability that users and owners want/should retrofit their properties, as well as dynamic concepts like economic and environmental policy factors, which can be determining factors in the strategies to be proposed.

On an urban scale, more information regarding the baseline is needed. In this case, CONUEE (National Commission for the Efficient Use of Energy), a Mexican Institution, has shared the energy consumption record of Buildings properties of the Federal Government that are part of their program “Savings Program of Electric Power in Buildings of the Federal Public Administration,” where a selection of 68 buildings located in Cuauhtémoc district, in Mexico City, is part of the scope of the analysis.

Even though the energy consumption record is a critical baseline aspect, the characterization of the buildings requires more information with which to fill the proposed template for their documentation. The research will follow the methodology for generating synthetic building stocks tailored for Mexico City buildings (22).

The method for generating the initial building stock per se comprises four steps: (1) building stock initialization, (2) characterization, (3) retrofit proposals, and (4) synthetic building stock assessment in terms of its energy demand and GHG emissions.

“An extension of the approach will be to combine the synthetic building stock with a synthetic population. This would make it possible to model occupant behavior in greater detail or estimate the impact of changes in the building stock on the population, including social sustainability indicators.” (22).

VARIABLES	INDICATORS
V1. Specific buildings that are property of the Federal Government. Those buildings were part of the “Savings Program of Electric Power in Buildings of the Federal Public Administration,” carried out by CONUEE.	I1. Reduction of final energy consumption in public office buildings (kWh/year).
V2. Poor availability and quality of data. The baseline of Buildings’ Energy consumption and their characterization.	I2. Reduction of Operational Carbon Emissions (CO2eq).
V3. Building Performance	I3. Reduction of Embodied Carbon Emissions (CO2eq).
V4. The user, the owner, and the stock dynamics (economic, environmental policy factors).	I4. Reduction of primary energy consumption in public office buildings (kWh / year). (Non-renewable supply primary energy consumption values (kWh / m2 • year). (Out of initial scope).
V5. Buildings Resiliency as a national security matter.	I5. Estimated annual reduction of greenhouse gases (GHG) (equivalent tons of CO2 / year).
V6. Renewable Energy Sources and the Independence of Buildings from the Grid. (Out of initial scope).	I6. Estimated annual quantification of NEB and Resilience factor (units and measurement criteria TBD).
V7. Business model to buildings retrofit. (Out of initial scope).	I7. Standardized retrofit strategies by similar cases.
	I8. Independent Buildings of the energy network. (Out of initial scope).

Table 1: Variables and Indicators

Hypothesis

1. Developing a value-based framework will give continuity to the retrofit strategy projects in the building stock model selected as a sample, which considers some specific buildings property of the Federal Government. To achieve energy efficiency, those buildings were part of the “Savings Program of Electric Power in Buildings of the Federal Public Administration,” carried out by CONUEE, but this time will consider the WLCA and NEB.

2. The **lack of buildings data documentation** at an urban scale can be saved with the synthetic building stock method to identify the **energy consumption baseline and their characterization**.

3. The digital resource of a Web Tool will serve as a repository for the information collected, both for the baseline and to record the different scenarios of the retrofit strategies, and thus be able to monitor **Building Performance.**

4. To ensure the framework's success, even synthetically, the user, the owner, and the stock dynamics (economic and environmental policy factors) must be included.

5. As long as a measurement of the Non-Energy Benefits (NEB), especially the Resilience factor (regarding how buildings can facilitate the regeneration of natural resources), can be determined quantitatively, they will not be a priority or a matter of national security.

6. As part of the retrofit proposals, incorporating renewable energy sources will make the sample **building stock independent of the grid** (out of initial scope).

7. This value-based framework can develop a **business model for buildings to retrofit** the sample building stock (as a further study).

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