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Formal simulation model to optimize building sustainability

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ABSTRACT

In this work, we present a simulation model that makes it possible to find optimal values for various building parameters and the associated impacts that reduce the energy demand or consumption of the building. In the study, we consider several situations with different levels of thermal insulation. To define and to integrate the different models, a formal language (Specification and Description Language, SDL) is used. The main reason for using this formal language is that it makes it possible to define simulation models from graphical diagrams in an unambiguous and standard way. This simplifies the multidisciplinary interaction between team members. Additionally, the fact that SDL is an ISO standard simplifies its implementation because several tools understand this language. This simplification of the model makes it possible to increase the model credibility and simplify the validation and verification processes. In the present project, the simulation tools used were SDLPS (to rule the main simulation process) and Energy+ (as a calculus engine for energy demand). The interactions between all these tools are detailed and specified in the model, allowing a deeper comprehension of the process that define the life of a building from the point of view of its sustainability.

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1. Introduction

In response to the new European directive 2010/31/CE [1] related to the energy efficiency of buildings and the data published by the International Energy Agency [2], which predicts a consumption increase of greater than 40% over the next 2 decades, we propose the use of a simulator that addresses the problem comprehensively from the initial concept design of the building to its eventual demolition for the development of a Net Zero Energy Building (NZEB), see [3] or [4]. During the modeling process, we will consider the energy cost optimization environmental impacts (energy, CO_2, NOx, etc.) and the economic and social impacts. We can analyze the model year after year to observe how it changes over time. This makes it possible to introduce changes to the environmental model (climate data, the built environment, base model data, etc.).

For the model development, we define 4 basic modules:

1. Climatic and environmental module.
2. Sustainability optimization of the building.
3. Waste produced by the model
4. Energy compensation.

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In this project, we analyze the process related to the energy optimization model. The energy needs of a specific building depend on the phase the building is in. We can categorize the building phases as follows:

1. The *initial design* (envelope development). In this phase, the use of parametric architecture [5] to define the shape of the building can be useful. In that sense, the use of a simulation model helps in the definition of some different alternatives that can be considered to analyze, among other parameters, the wind, the temperature, the maximum use of the climate zone, the sun, and the vegetation (using the existing local resources).
2. The *construction process*, which considers the rehabilitation process, the demolition process (in a rehabilitation case), environmental impacts, CO_2 consumption, the economic cost (the reuse of the demolition materials), and so on.
3. The *life of the building*, a process that optimizes the energy demand and consumption of the building by the standards for indoor comfort.
4. The *deconstruction process* and the reuse of the materials.

In this paper, we focus on the simulation model related to the *life of the building*, which facilitates the development of multiple scenarios automatically to determine a feasible solution. For each scenario, we determine a typology based on the shape of the envelope, the climatic zone and altitude, and the best insulation to use in response to the need for minimum energy demand, minimum cost and minimum production of CO_2 (taking into account the materials used). This makes it possible to obtain an optimum level of insulation for a specific building to minimize the energy demand.

2. State of the art

Conceptually, NZEB "It is a building with a high level of efficiency, where the little amount of required energy should come from renewable sources, so that the energy balance is zero" [6]. Hence, the NZEB are connected to networks and import (or buy) energy to be consumed and export all or part of the energy produced. The expression that defines a NZEB [6] is

$$\sum_i e_1 \cdot w_{s,i} - \sum_i s_i \cdot w_{s,i} = E - S \geqslant 0$$

where e = exported energy; S = energy supplied; w = conversion factors that are applied to each power source (i); E = weighted energy exported; S = weighted energy supplied.

The EU directive 2010/31/CE, with the initiative to incorporate concepts of reduction in the impact on the environment, regulates, in article 9, which on December 31, 2020 the new buildings need to be energy consumption almost null – nNZEB, nearly NZEB – [7].

To know more related to NZEB some interesting works are [3,4,8] or [9].

Today, every building is connected to energy and social networking, which has changed the rules of the game. We now have to address these concepts to complete the cycle (an idea already introduced in Cradle to Cradle [10] and in which we face a new paradigm of design (see Fig. 1)).

We examine the building energy performance using numerous resources for modeling the prototype. The designer spends a significant amount of time designing the virtual model. Only after studying several iterations of the design can a good solution be identified. Without analyzing all possibilities, the designer cannot ensure that the solution adopted is the best, or at least one of the best, solution. Most commercial simulation software packages allow us to calculate the annual energy analysis of the building but do not optimize the process. Neither the results nor the previous steps, such as the design, construction or final demolition processes, are optimized.

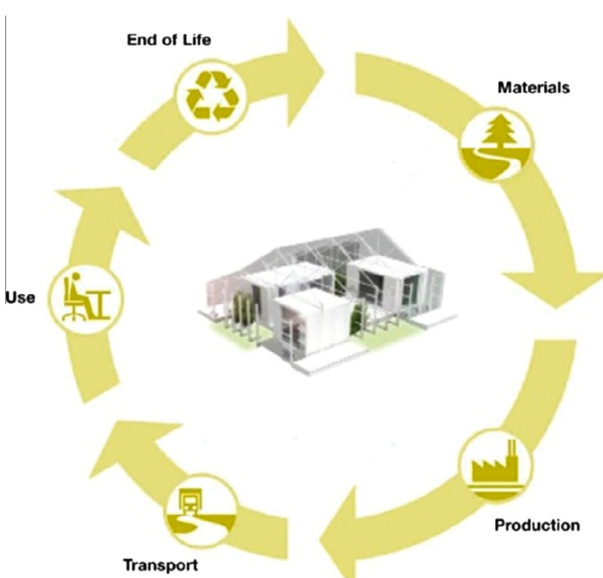

Fig. 1. Cradle to Cradle cycle.

Currently, efforts have been made to develop approaches and methods for assessing buildings [11], methods to integrate daylight and thermal efficiency [12–14], photovoltaic systems [15] and systems of multiobjective optimization for urban design [16] that take various aspects into account when we create an energy optimization system. Some systems address parts of the optimization problem posed above, such as GenOpt [17], an optimization program for minimizing a cost function that is evaluated by an external simulation program, or OptEPLus [18], an application focused on the tertiary sector. In line with these applications, BEopt [19] uses a sequential search technique to automate the process of identifying an optimal design regarding energy use, and Dakota [20], Design Analysis Kit for Optimization and Terascale Applications, is a toolkit that is intended to perform an optimization of the design in a multilevel C++ object-oriented framework.

Commonly used languages for programming simulators or optimization tools are Java, Fortran, C++ and Delphi, among others. The use of different languages can cause problems of integration, model definition and understanding among the researchers who come from different disciplines. One of the proposals of this work is the use of a formal language to simplify the model definition and its use.

Using formal languages, such as Discrete Event System Specification (DEVS) [21], Specification and Description Language (SDL) [22] or Petri Nets [23], is without a doubt the best solution to easily integrate and communicate ideas about the model with the other members of the team, improve interoperability with other models (Co-simulation) and encourage collaboration. An example of a recent work that explores the use of formal languages in this area is [24], or [25], that explores the uses of Co-simulation approach to calculate the HVAC (heating, ventilation and air-conditioning) systems in a building.

In this paper, we use SDL as a formalism to define the model behavior and structure. SDL [26] is a visual and easy-to-understand language. It can detail the processes and the procedures that define the model behavior, which allows engineers, architects and researchers to integrate and understand the models easily without learning a specific and more time-consuming programming language.

Defining the model is not enough; it is necessary to perform several calculations. To do this, we identified different calculation engines capable of analyzing the building from an energy standpoint [27], such as DOE-2.1, BLAST, TRNSYS and IES ⟨VE⟩. The use of EnergyPlus [28] with DOE-2.1 and the BLAST calculation engine (a combination that has passed the BESTEST –Building Energy Simulation TEST) [29] gives us the computing power to analyze many factors that influence the energy required by a building. Thus, DOE-2.1 has become one of the most widely used and internationally recognized calculation engines and has been adopted as the base engine in many commercial software interfaces and eQuest [30].

3. The model

One of the aims of this research is to be able to describe, as formally as possible, the structure and the behavior of the lifecycle of a building. This goal is crucial in this project because the people involved are diverse and come from many different backgrounds. To address this issue, we use SDL [22] to formally define the model.

The use of SDL language gives us maximum flexibility to integrate new processes and procedures to the system. Using a formal language is an advantage for programming and for enabling non-specialized technicians to access programming to design their

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