Catalogue of construction materials for Zero Emission Buildings design based on Artificial Intelligence

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Abstract

Buildings are major energy consumers and emitters of greenhouse gases. Improving their environmental impact requires effective actions. Architectural design with a sustainable approach from the early stages is a viable strategy for this purpose, especially if it is supported by innovative technologies. ZEBAI is a European project that seeks to help in the design of Zero Emission Building (ZEB) with Artificial Intelligence (AI). The project integrates different analyses: energy, thermal, lighting, economic, environmental and regulatory, managed by an AI-tool. The analyses require a catalogue of materials that provides different properties of commercial construction materials. This paper shows the criteria taken into account to create the catalogue: function definition, required properties, information sources, characterization, background databases and updates. The criteria focus on performance analysis (energy and thermal) to be carried out with the well-known EnergyPlus engine. According to the simulation software, thickness, density, specific heat, thermal conductivity, emissivity and thermal, solar and visible absorptances are required. The information will be gathered from datasheets or from measurements and will be included in a standardized way for future updates. Finally, the catalogue will be used for both project analyses and public consultation.

Keywords

Catalogue of materials, Energy simulation, Artificial intelligence, Material characterization

1. Introduction

Energy Efficiency of buildings is an urgent issue. In the European Union (EU), three quarters of all buildings are not energy efficient, using 40% of the energy consumed in the territory. In addition, they are responsible for more than a third of greenhouse gas emissions (GHG) related to the resource [1]. Reducing the energy consumption of buildings can be achieved through different strategies that involve the architectural design itself, linking the building with its context, selecting appropriate construction materials, incorporating passive technologies, using efficient HVAC systems and including renewable energy sources. The architect's efforts aim at obtaining comfortable spaces with minimal energy consumption, low environmental impact and highly cost-effectives. Based on the designer's knowledge, decisions made generally result in a building with positive performance, though not necessarily accurate.

Architectural design involves a huge number of variables that are very difficult to consider and weigh up for one or more people. In this sense, the assistance of current technology opens up new

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possibilities for increasing the precision of building design, optimizing performance at each stage of its life cycle.

Simulation software are becoming increasingly popular and have shaped a new paradigm for building design. These tools allow for energy, thermal, lighting and environmental analyses, among others. Architectural design assistance programs no longer just help your draw or model the building, but also check its performance [2]. By using Building Performance Simulation (BPS) programs, it is possible to predict how well the building would function.

Despite the help that a BPS represent in achieving an acceptable design performance, the improvement process is inefficient. The proposal is modified time after time until the established objectives are achieved [2]. However, the design improvement process can benefit from new technological developments, such as artificial intelligence (AI).

AI is a booming technology that has been incorporated into different sectors, including architecture. There are several applications of AI, such as Machine Learning (ML), which allow managing databases to find answers to different questions, analysing, relating and deciphering information. In [3], a Deep Neuronal Network is used to generate new conceptual architectural designs through coded graphs from architectural designs. In [4], ML and AI optimization algorithms were used to evaluate and improve the energy performance of envelopes at an non-detailed design phase.

The use of AI allows architectural design to have greater scope and contributes to meeting environmental commitments at European level, including the construction of Zero Emission Building (ZEB). Directive (UE) 2024/1275 on the energy performance of buildings states that all buildings built from 2030 onwards must comply with the ZEB concept, a building that requires low energy for its operation, does no emit CO_2 and emits a very low level of GHG [1].

1.1. ZEBAI Project

There are projects such as ZEBAI that represent an effort to optimize the design process of ZEB with the help of AI. Eighteen partners from the EU coordinated by the Universidad Politécnica de Madrid are collaborating on the project "Innovative methodologies for the design of Zero-Emission and cost-effective Buildings enhanced by Artificial Intelligence (ZEBAI)". An AI tool for ZEB design is under development in the framework of the ZEBAI European project (HORIZON-CL5-2023-D4-01, 101138678) [5].

The ZEBAI tool aims to optimize the different constructive systems that compose a living unit or a building, including windows, facades, roofs, and other components. It also considers active elements (HVAC and renewable systems) and passive elements (overhangs and shading controls). The tool streamlines the refinement of building designs through an optimization process driven by an evolutionary algorithm. To assess the quality of the solutions, the tool adopts a multi-criteria evaluation framework that integrates several analyses and simulations:

(a) Energy performance (simulated using EnergyPlus)
(b) Thermal comfort and air quality (simulated using EnergyPlus)
(c) Carbon footprint
(d) Daylight comfort
(e) Cost and
(f) Compliance with local and national regulations.

The tool relies on seven key inputs (Figure 1):

1. **Material Catalogue** – A database of commonly used construction materials, including their properties required for simulations and analyses. This catalogue includes opaque materials, as well as glass and gases. Properties considered include physical, thermal, optical, cost, environmental, and usage characteristics.

2. **Building Configuration Catalogue** – Defines possible design solutions for:
    - *Fenestration solutions*: Following predefined rules for glazing composition and using materials from the material catalogue, the tool automatically generates fenestration options.
    - *Solar control systems*: Predefined solar control solutions.
    - *Wall compositions*: Based on predefined rules and materials from the catalogue, the tool automatically generates facade and internal partition options.
    - *Roof composition*: Using predefined rules and materials, the tool automatically generates roof options.
    - *HVAC systems*: Predefined system configurations with associated selection rules.
    - *Renewable systems*: Predefined system configurations with associated selection rules.
3. **Regulations and Standards** – The tool integrates national, regional, and local building regulations to ensure compliance. Additionally, it considers relevant standard requirements, penalizing non-compliant solutions accordingly.
4. **Design Restrictions** – Various constraints are applied, including glazing size limitations and restrictions on overhang and fin dimensions.
5. **User Preferences** – Customization options include:
    - Weighting of different evaluation criteria (e.g., 50% cost, 30% energy performance, 10% comfort, and 10% environmental impact).
    - Selection of variables for optimization (users can choose to optimize all constructive systems and elements or focus on specific ones).
    - Material selection (users can include or exclude materials from the catalogue).
6. **Environmental and Location Data** – Climate and site-specific data to ensure context-aware optimizations.
7. **Preliminary Building Design** – The initial design serves as a baseline for the iterative refinement process.

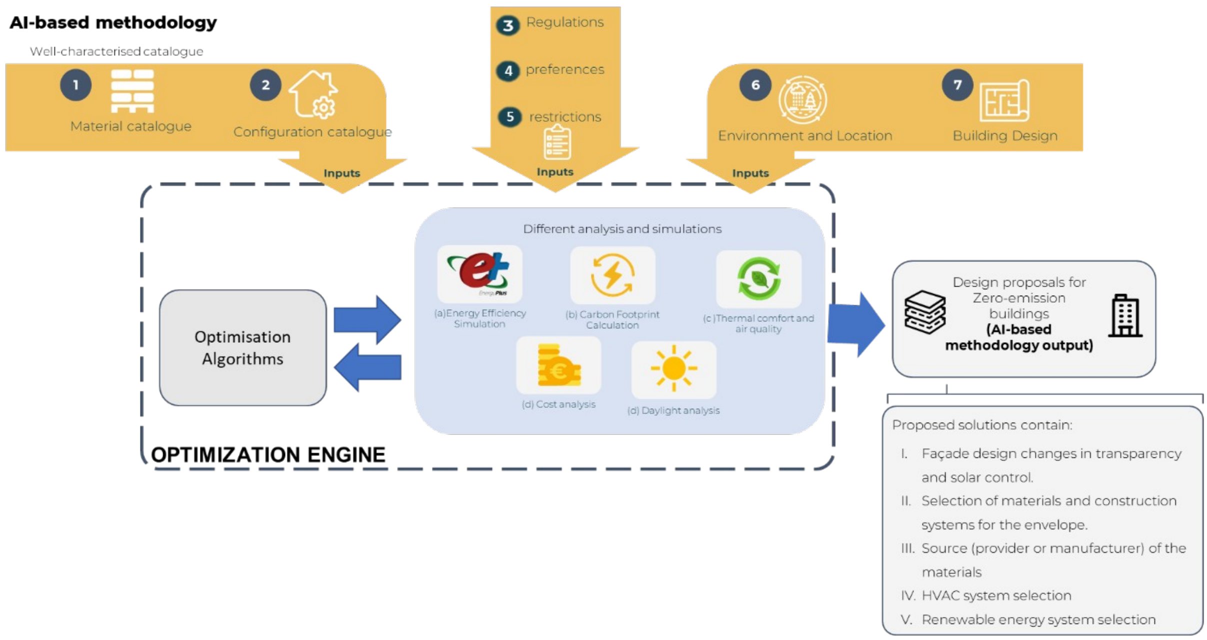

Figure 1. ZEBAI building design optimization methodology

1.2. Optimization and Expert Review

Using these inputs, the tool generates design alternatives, evaluates them through the previously mentioned analyses, and iteratively refines them using an optimization algorithm. Once the optimization process is complete, the tool provides the user with solutions that comply with regulations, user preferences, and given constraints while achieving strong performance in key evaluation criteria. Finally, the expert user can review the generated solutions and selects the most suitable option based on the specific needs of the building project.

1.3. Catalogue of materials

The ZEBAI Project requires a catalogue that provides information on the products that will make up the design proposals. Some BPS contain libraries with the necessary data on the materials to perform the corresponding calculations. The properties included can come from different databases and integrate various types of information: physical, hygrothermal, optical, environmental or economic. However, sometimes the analysis requirements imply to use additional materials, so it is necessary to investigate the mentioned properties of each product to be integrated.

There are different ways to obtain the properties of a building material to configure in a computer model. Technical information on a specific product and even databases of similar products can be consulted. Datasheets usually contain some required data on a commercial product. The information available depends on the type of material. For example, a thermal insulation material can contains thermal conductivity, water vapour diffusion resistance and reaction to fire, while a façade coating can contains bulk density, porosity and water absorption.

On the web, there are catalogues with some information required to configure materials in the computational model. Access to information, whether free or paid, allows you to obtain the properties requested by the software. However, it was found that some of these databases lack commercial identification or a description that allows for precise selection of the items. The selection decision falls on the modeller, choosing the material most similar to what he is looking for.

The modelled-building performance it often different from reality because of several factors that can generate discrepancies, such as geometrical definition, climatic data, calculation methods or materials properties. In fact, it has been accepted that the physical properties of materials have a strong influence on simulation results[6].

Yang et al. state that "A more fundamental solution is to acquire physical property information of several building materials and construct a database so that more practical and realistic property information can be used for simulations" [6].

In this sense and considering the ZEBAI Project requirements, it is necessary to generate a database of construction materials that integrates the information so that a simulation tool can perform energy and thermal calculations. The objective of this paper is to present the considerations taken into account in compiling the catalogue regarding function, updating, properties, information sources, materials characterization, and similar databases. This document focuses solely on the properties that will be involved in the analysis of energy and thermal performances.

2. Method

The catalogue of materials will be created from an understanding of its function and scope. What is for? What should it contain? What similar databases exist? How are the items integrated? How will it be kept up to date? The answer to these questions are expected to consolidate an efficient database.

2.1. Function

The catalogue will have a dual function: as a database for subsequent simulation and optimization processes of the models that will be carried out in the ZEBAI project and as an open source of information for the interested public.

The ZEBAI Project requires the integration of commercial materials data, reducing the degree of error caused by generalization in the selection of materials for construction elements. It is important to note that variations in the properties of a material occur due to various factors: shape, components, application, etc. Taking this into account, commercially identified materials must be used to avoid ambiguity in the selection of elements to be incorporated into the model.

Another important issue is that the catalogue will integrate products taking into account their validity and availability. Initially, priority will be given to materials distributed or manufactured close to the demonstrators, buildings constructed or rehabilitated with the help of the ZEBAI methodology. The proximity of the products will also benefit the subsequent environmental impact and cost-effective analyses. It has been shown that the use of local construction materials brings economic and environmental benefits [7].

2.2. Properties determination

The catalogue must include the properties required by the energy simulation software. Yang et al. analysed the properties considered by some energy analysis tools. Thickness and thermal conductivity are the most requested properties by the programs. Density, specific heat and thermal resistance are requested by the majority, and absorptances (thermal, solar and visible) and roughness are requested less frequently. In the article it can be observed that EnergyPlus was the tool that requests the most information compared to five other programs [6].

EnergyPlus is a building energy simulation software created by the U.S. Department of Energy, the National Renewable Energy Laboratory and other academic and private organizations. Its open code makes it a suitable tool for integration with other programs [8]. EnergyPlus has been used as a tool for building performance analysis in several publications [9][10]. Due to its capabilities and recognition, this software was selected as the tool mainly for the thermal and energy calculation for the ZEBAI project, so the selection of properties to be included must correspond to the program requirements (Table 1).

Table 1. Properties required in the catalogue for thermal and energy analyses

Property	Unit
Roughness	Smooth-rough scale
Thickness	mm
Density	Kg/m^3
Thermal conductivity	W/m.K
Specific heat	J/Kg.K
Water vapor diffusion resistance factor	μ factor
Emissivity	Value 0-1
Solar absorptance	Value 0-1
Visual absorptance	Value 0-1

2.3.Materials Characterization

Most of the data to be included in the catalogue will come from datasheets. However, these documents do not contain all the required information. As mentioned, the type of information varies according to the type of product. Thus, it is planned to obtain the missing properties through measurement. Regarding thermal an energy analyses, measurements of physical, hygrothermal and optical properties will be carried out.

Figure 2 shows the data collection process. Based on the identification of the required properties, data will be collected through the review of technical documents or through the characterization of the materials.

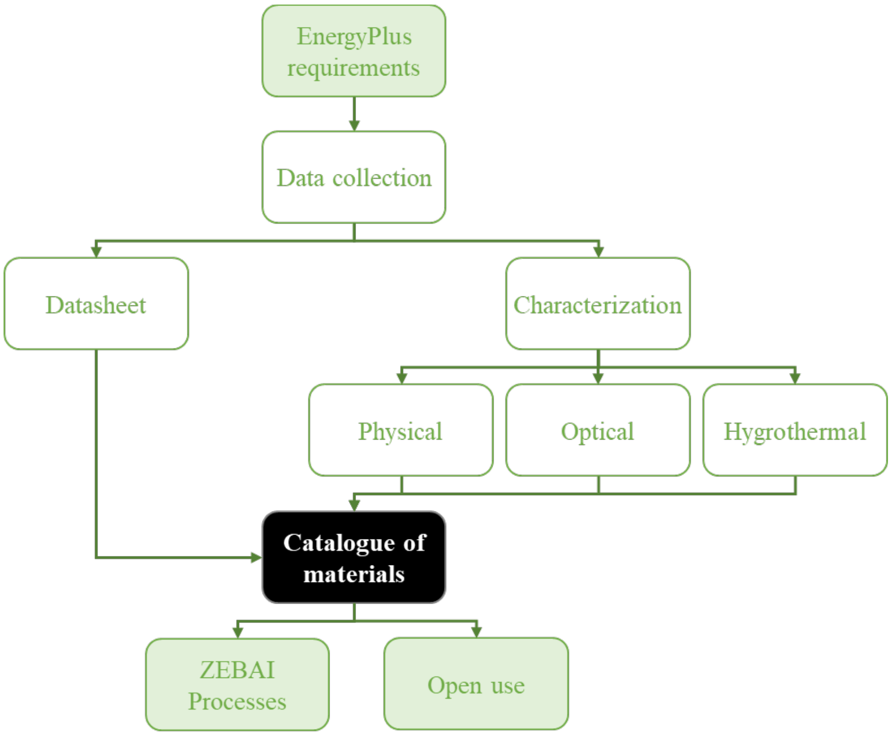

Figure 2: Data collection process

Measurements include obtaining thermal conductivity, water vapour diffusion, emissivity and solar and visible reflectance, compiling with the corresponding standards. Thermal conductivity will be measured using a guarded hot plate method, following standard UNE EN 12667, and hot-wire method, following standard ASTM D5334. The water vapour diffusion factor will be measured following the procedure indicated in standard UNE-EN12086.

The thermal and energy performances of a building depends not only on the thermal and physical properties of the materials, but also on the optical properties. The absorptance or reflectance of the sun-exposed material on an envelope influences the management of solar radiation. From the study by Fabiani et al. the importance of the optical properties of the envelope exterior-materials can be inferred by analysing the performance of a chromogenic material that varies its optical properties depending on its temperatures. The change from high reflectance in summer to a high absorptance in winter allows for better thermal results compared to materials with static optical properties [10]. Antonaia et al. study the use of materials with high solar reflectance and emissivity materials (cool materials) in roofs to reduce heat gains and generate energy savings [11]. Thus, considering the optical properties of the materials, the adaptation of building to it climatic environment can be improved and contribute to the reduction of energy use.

Regarding availability of optical information, it was observed that it is very scarce in the technical datasheets of the products, even in those located on the façade. Therefore, in most cases it will be necessary to determine the solar and visible reflectance and the emissivity of the products. In opaque materials, the absorptance coefficient can be obtained from the reflectance, since they do not transmitting light. The measurements to determine the reflectance will be carried out with spectrophotometers that cover the visible and near infrared ranges, following the UNE EN410 standard. The emissivity will be measure with a portable thermal emissometer, following the ASTM E408 standard.

2.3. Background catalogues

A search was carried out of the material catalogues available on the web to analyse the type of information included, the link with manufacturer or suppliers, the interface and the accessibility to the information. It was found that there is no database that integrates all the properties required by a program such as EnergyPlus, many of the databases did not include commercial information on the materials or an extensive description and some required payment. Therefore, it can be assumed that the creation of the materials catalogue for the ZEBAI project is necessary for the success of the developed Artificial Intelligence tool.

2.4. Maintenance and updating of catalogue

The material catalogue is intended to be kept up to date by including new concepts. Construction materials are constantly developing. Which requires the database to be updated continuously. Therefore, the addition of materials to the catalogue will be done in a standardized way. Including characterization and cataloguing methods, to ensure the homogeneity and quality of the information.

3. Conclusions

The ZEBAI Project aims to develop a methodology that use AI to encourage the architectural design process of ZEB. The process includes different analyses: thermal, energy, regulatory, environmental and cost-effectiveness. To carried out the analyses, a catalogue is required that provides the properties of commercial construction materials. This paper focuses on showing the criteria that were take on create this material catalogue, specifically on the properties necessary for the thermal and energy analyses.

The process for creating the materials catalogue begins with the identification of the properties required for the calculations. EnergyPlus was the program selected to generate the thermal and energy performance results of the building, which later be managed by the ZEBAI AI tool. Thus, the materials catalogue must contain the physical, hygrothermal, and optical information so that the analysis tool can perform the calculations properly. The necessary properties to include were roughness, thickness, thermal conductivity, water vapour diffusion resistance factor, density, specific heat and thermal, solar and visible absorptances.

Once the necessary properties are identified, they are planned to be obtained through the product's datasheets. If the required is not available, a characterization process is initiated, which can include measurements of thermal conductivity, specific heat, solar and visible reflectances, emissivity (thermal absorptance) and resistance to water vapour diffusion.

The ZEBAI materials catalogue aims to fill a gap in current information, providing a data source that, in addition to its use for the project, is of a public nature, available for consultation by anyone who requires it.

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Declaration on Generative AI

During the preparation of this work, the author Lorena Cruz used ChatGPT in order to: Grammar and spelling check sections 1.1 and 1.2. After using this tool, Lorena Cruz reviewed and edited the content as needed and takes full responsibility for the publication's content.

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