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# ANALYSIS OF SOLUTIONS FOR EXTERIOR WALLS IN THE BIM MODEL USING THE AHP METHOD

# ANALIZA WARIANTÓW ŚCIAN ZEWNĘTRZNYCH W MODELU BIM Z WYKORZYSTANIEM METODY AHP

Abstract

This paper presents selected variants of thermal insulation for external walls of single family homes. The main aim of this article is to analyze the technological and economical solutions based on the BIM model. The technical and economic analysis concerns the calculation and evaluation of both the costs of constructing the walls and the energy demand of the model building designed by the authors. The last part of the paper compares and prioritises proposed solutions in regard to the accepted assessment criteria using the AHP method, which allows for selecting the best solution.

*Keywords: AHP method, BIM, cost estimation, exterior walls*

Streszczenie

W artykule przedstawiono wybrane warianty izolacji cieplnej ścian zewnętrznych domów jednorodzinnych. Głównym celem artykułu jest analiza technologiczna i ekonomiczna rozwiązań oparta na modelu BIM. Analiza techniczna i ekonomiczna dotyczy obliczania i oceny zarówno kosztów budowy ścian, jak i zapotrzebowania na energię budynku zaprojektowanego przez autorów. W ostatniej części artykułu porównano proponowane rozwiązania i priorytety w odniesieniu do przyjętych kryteriów oceny z wykorzystaniem metody AHP, która pozwala na wybór najlepszego rozwiązania.

*Słowa kluczowe: metoda AHP, BIM, kosztorysowanie, ściany zewnętrzne*

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## 1. Introduction

The development of energy-efficient construction has become very dynamic in recent years. Care for high-quality thermal comfort in buildings, the desire to minimize the impacts of energy consumption on the environment and the reduction in expenses for heating are all tasks that require computer assistance. In addition, systematically tightening regulations compel the use of modern techniques for improving the facilities built.

This paper presents selected variants of thermal insulation for external walls of single family homes. The main aim of this article is to analyze the technological and economical solutions based on the BIM model. Technical and economic analysis concerns the calculation and evaluation of both the costs of constructing the walls and the energy demand of the model building designed by the authors. Calculation and analysis are based on the BIM model, presenting the possible workflow, which includes an automation of the calculations of the building energy demand and cost calculations.

The last part of the paper compares and prioritises proposed solutions in regard to the accepted assessment criteria using the AHP method, which allows for selecting the best solution.

## 2. Innovative methods for creating buildings – Utilization of BIM technology in modern construction

Progress and the development of computer technology have made it possible to transfer the design process from paper to the computer screen [1]. The foundations of BIM technology date back to the late twentieth century, when programmers tried to develop software allowing one to illustrate the processes taking place in the building designer's imagination. Initially, the exchange of industry data was not possible due to the lack of a common format, and the first versions of the programs only created mock-ups of future buildings on which self-generated drawings were based. After several years of development, the IFC standard (Industry Foundation Classes) was created, which is currently adopted by most leading IT companies creating software for the construction industry. As a result, cooperation between branches is now possible regardless of the software [2].

BIM is defined by the National BIM Standard as "a digital representation of physical and functional characteristics of a facility" and "shared knowledge resource for information." In another words, we could say that BIM means a building, which can be created in the virtual world, from the conceptual stage to implementation. BIM is an organizing concept that contributes in the lifecycle of a facility by creating and managing a building's data in a convenient way [3]. That digital model developed in 5D technology can be used to make design decisions, develop a coherent and complete construction documentation, perform subsequent analysis of collected data for estimating the profitability and investment costs, and ultimately the management of the built object as well [4].

An object created in BIM has all the possible parameters of the actual building (Fig. 1). However, a virtual building created this way is not only an ordinary geometrical model dressed in nice textures, creating attractive visualizations for the client. With BIM technology, each element is a digital prototype of the building's physical components: walls, columns, windows, doors, stairs, etc. As a result, the BIM model allows us to understand the building before its construction even begins, as well as to catch errors in the design before its implementation. Because its energy efficiency is known, it is possible to control the cost of construction and materials, as well as the cost of maintaining the building throughout its life cycle already at the design stage. The database can include a wide array of information about the structure, including geometry, material, manufacturing and assembly techniques, tolerances, costs, and even information to support supply chain management, or it may include only some of these [5].

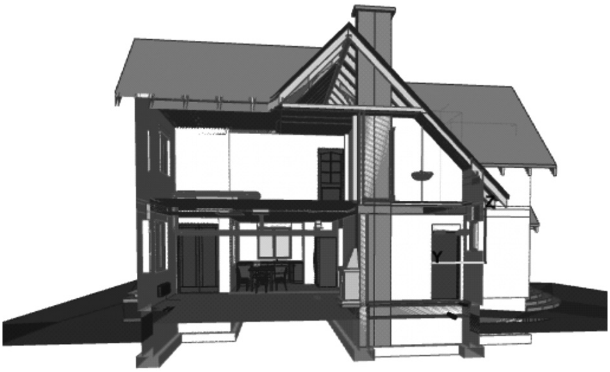

Fig. 1. Model of a building in BIM

BIM technology is used at the stage of design development so that all participants in the investment process may become involved in the creation of the facility. Because cooperation is based on 3D models, changes made by one party are immediately seen by others. This results in saving time that had previously been spent on coordinating and adapting all of the documentation to the changes made in 2D. Therefore, BIM also facilitates the close cooperation of specialists.

The model's level of detail and the ease of sharing information between sectors makes it simpler to introduce design changes, thus enabling contributors to simulate the costs and the energy demand. For these reasons, the universality of the use of BIM models in the world is growing at a dynamic pace, and this technology is already recognized as a worldwide standard.

## 3. Decision-making based on BIM

Decision-making based on BIM technology consists of collecting data from engineering analysis, cost analysis, etc., in a single model. Information from databases is added to the 3D model. It is easy to calculate the energy demand from the designed building or to create a realistic visualization of the facility so that the potential customer can easily imagine the finished product. Such a model can be also loaded into a cost estimation program and present the estimate in a transparent manner (Fig. 2).

Estimating the cost in a program based on BIM technology, equipped with a 3D model viewer, we can save a substantial amount of time. Such a system allows users to move bills of quantities obtained directly from virtual models in order to estimate and obtain a quote at any stage of the project. Therefore the estimate is based on the bill of quantities obtained from a virtual model of the building. Such a system eliminates accounting errors and elements included in the bill of quantities which are related to the blueprints, so it is possible to skip single parts. Dimensional elements appear in the browser as slides (Fig. 3), so there is no need for the estimator to consider whether the given element was already measured. This innovative application is adaptable and can use models developed in any CAD system compatible with BIM.

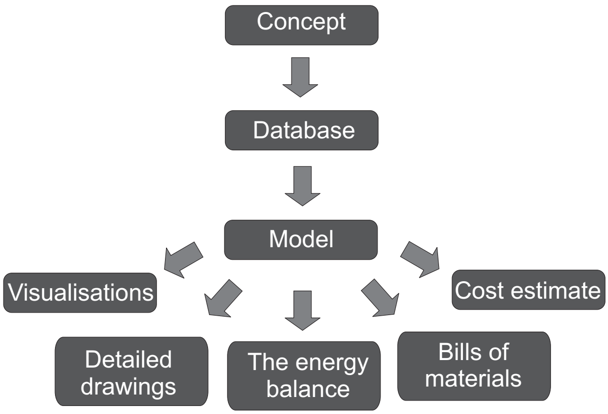


Fig. 2. Diagram of the BIM process

The BIM model can automatically provide a section of data needed to perform cost calculation (bill of quantities, scope of calculation and list of materials), leaving the cost estimator with the remaining elements. The remaining work is dependent on the regulations relating to cost estimation and the individual assessment of the cost estimator [6].

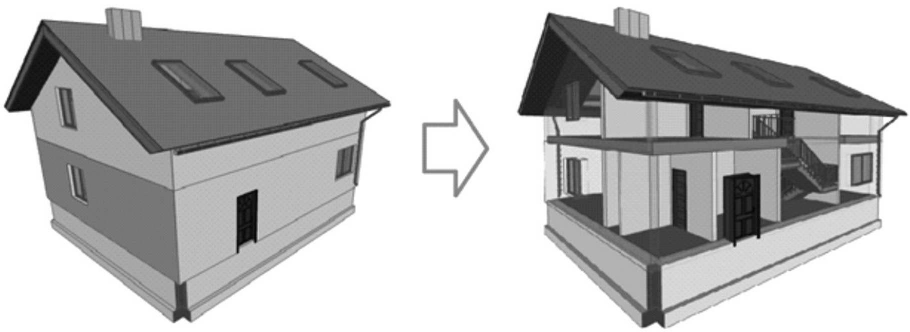

Fig. 3. Presentation of the quantity takeoff process in BIM

The integration of a BIM model with a decision-making tool and sustainability metrics addresses the difficulties of making decisions earlier in the design/build process, and allows for specific sustainability trade-off analyses to be conducted, using the actual building conditions and characteristics [7]. Figure 4 presents the model's architecture for cost calculations with environmental factors. The exemplary model determines the processes for data analysis, considering all criteria and specifications. This analysis is applied to project and sustainable information, environmental factors, environmental performance, and unit cost calculations, using input requirements. The main aim of the presented model is a 3D-BIM sustainable design of the building, which contains a list of the selected sustainable materials and their environmental impacts, as well as cost calculations for the chosen variant.

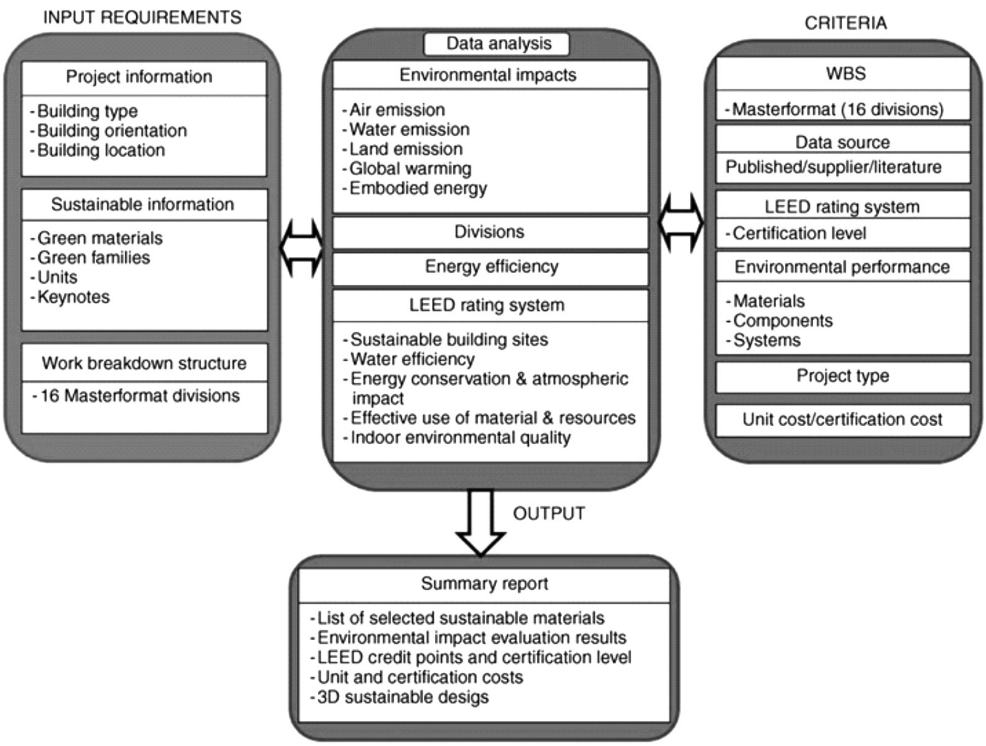


Fig. 4. Model architecture [3]

## 4. BIM based analysis

### 4.1. Basic technical parameters of the analysed building

The model of the building on which the technological and economic analyses of external walls were carried out is a single-storey, single-family house with a habitable attic. The building designed by the authors for the analysis has a rectangular footprint with the dimensions 12.68 m × 10.83 m. Its shape is a truncated rectangular prism with a gable roof. The house consists of a ground floor and a habitable attic, without a basement. The basic data of the building's geometry: total area: 253.2 $m^2$, usable area: 213.4 $m^2$, area of the building envelope: 327.5 $m^2$, volume: 605.57 $m^3$.

The external walls of the building consist of a structure made of clay masonry units Porotherm P+, which are 30 cm thick and contain a 12 cm thermal insulation layer. The total thickness of the envelope is 46 cm.

Individual layers of the external wall include: 2 cm – interior plaster, 30 cm – Porotherm P+W 30 hollow masonry unit, 12 cm – thermal insulation, 2 cm – external plaster.

### 4.2. Thermal insulation of external walls and thermal transmittance of the building

Three variants of insulation have been used for the technical and economic analysis:
- EPS 040 FASSADA foamed polystyrene made by Austrotherm.
- ISOVER TF Profi mineral rock wool.
- EPS 031 FASSADA PREMIUM graphite-enhanced foamed polystyrene made by Austrotherm.

Below is a list of coefficients of thermal conductivity λ and the applied thicknesses of thermal insulation materials, as well as the values of the heat transfer coefficient U, obtained by the external walls of the building after the application of the given type of thermal insulation (Table 1).

Table 1

**Material data of thermal insulation and thermal transmittance values obtained**

| Material | EPS | Mineral wool | Graphite-enhanced EPS |
|---|---|---|---|
| Thermal conductivity coefficient [W/m · K] | 0.40 | 0.36 | 0.31 |
| Thickness [m] | 0.12 | 0.12 | 0.12 |
| Thermal transmittance coefficient U [W/$m^2$ · K] | 0.22 | 0.21 | 0.19 |

Source: Own work

### 4.3. Building energy demand

The values of heating energy and total energy consumption, calculated using ArchiCAD 18, software based on BIM technology, as well as the maximum values of these quantities required for energy efficient buildings and passive buildings are shown in the figure below (Table 2).

As can be seen from the above results, the use of each of the analysed material meets the requirements for energy-efficient buildings, but none of the variants of the solution provides the level required for passive buildings.

Table 2

**Energy demand in relation to the different variants of the building's thermal insulation**

| Type of energy | EPS | Mineral wool | Graphite-enhanced EPS | Permissible value for | |
|---|---|---|---|---|---|
| | | | | energy-efficient building | passive building |
| Heating energy [kWh/m$^2$ · year] | 31.54 | 30.58 | 29.61 | 70 | 15 |
| Total energy consumption [kWh/m$^2$ · year] | 131.29 | 130.33 | 129.36 | 250 | 120 |

Source: Own work

### 4.4. Cost analysis of the building

The cost analysis was limited to estimating the cost of the construction of external walls. The list of the costs of different types of thermal wall insulation is presented in Table 3.

Table 3

**Energy demand in relation to the different variants of the building's thermal insulation**

| EPS | Mineral wool | Graphite-enhanced EPS |
|---|---|---|
| PLN 4433.43 | PLN 6166.23 | PLN 5520.99 |

Source: Own work

## 5. Analysis of the profitability of different variants of thermal insulation using AHP

The Analytic Hierarchy Process (AHP) is a multi-criteria decision analysis method. It is applied in order to find solutions for multi-criteria decision problems. Specifying the importance of the criteria is performed by a pairwise comparison on a 1–9 scale. The scale ranges from 1/9 for 'least valued than' to 1 for 'equal,' and to 9 for 'absolutely more important than,' covering the entire spectrum of the comparison [8]. The AHP method consists of two phases: the creation of a structure and performing an evaluation of the hierarchical structure.

A list of the criteria for particular variants and the evaluation criteria are presented in Table 4.

Table 4

**Material data of thermal insulation and thermal transmittance values obtained**

| Criterion | EPS | Mineral wool | Graphite-enhanced EPS |
|---|---|---|---|
| Thermal transmittance coefficient U | 0.22 | 0.21 | 0.19 |
| Thickness [m] | 0.12 | 0.12 | 0.12 |
| Total energy consumption [kWh/m² · year] | 131.29 | 130.33 | 129.36 |
| Cost | PLN 4433.43 | PLN 6166.23 | PLN 5520.99 |

Source: Own work

Table 5 shows an example matrix of relative significance adjusted to the normalized value.

Table 5

**Matrix of relative significance adjusted to the normalized value – an example for C3**

| C3 | W1 | W2 | W3 | | C1 | W1 | W2 | W3 |
|---|---|---|---|---|---|---|---|---|
| W1 | 1.00 | 0.33 | 0.20 | → | W1 | 0.11 | 0.08 | 0.13 |
| W2 | 3.00 | 1.00 | 0.33 | | W2 | 0.33 | 0.23 | 0.22 |
| W3 | 5.00 | 3.00 | 1.00 | | W3 | 0.56 | 0.69 | 0.65 |

Source: Own work

The hierarchy general ranking table, as a final score of calculations is shown in Table 6.

Table 6

**Hierarchy general ranking**

| GP | C1 | C2 | C3 | C4 | W |
|---|---|---|---|---|---|
| Wg | 0.406 | 0.044 | 0.309 | 0.241 | |
| W1 | 0.083 | 0.333 | 0.106 | 0.633 | 0.289 |
| W2 | 0.193 | 0.333 | 0.260 | 0.106 | 0.223 |
| W3 | 0.724 | 0.333 | 0.633 | 0.260 | 0.488 |
| SUMA | 1.406 | 1.044 | 1.309 | 1.241 | |

Source: Own work

The consistency check in the hierarchy general ranking was calculated: CR for C1 equals 0.063, C2 equals 0.000, C3 equals 0.031, C4 equals 0.031. Therefore, the consistency check succeeds, all CR values are less than 0.1. With the established criteria in the AHP method, variant 3 (Graphite-enhanced EPS) proved to be the most advantageous option.

## 6. Conclusion

The use of solution variants allows for a quick assessment of the solutions. The use of decision-making support using AHP as a module for the BIM model expands the information available to the decision-maker. From the cases analysed in this paper, it can be inferred that:

- The use of EPS 040 FASSADA costs PLN 4433.43, which allows building an exterior wall with the thermal transmittance coefficient of 0.22 W/m2 · K
- The use of ISOVER TF Profi mineral wool reduces the heat permeability by 4.5%, and provides durability to the heat-insulating material, but increases the expense of thermal insulation by 28%
- Construction of thermal insulation using graphite-enhanced EPS 031 FASSADA PREMIUM increases the level of thermal insulation by 13.5% compared to regular EPS and 9.5% to mineral wool, whereas the cost of this solution is 20% higher than the price of regular expanded polystyrene and 10.5% lower than mineral wool.

In summary, it can be said that, depending on the expectations from the building being designed, it is possible to use cheaper materials with average thermal properties (EPS), more expensive materials with better technical parameters such as graphite-enhanced EPS, or expensive – but also more durable materials – such as mineral wool. Using the AHP analysis, however, it is possible to select the best solution, taking multiple criteria into account.

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