Integrated Energy Design - a new way of teaching, with the use of modern tools to support the design process

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ABSTRACT: The article is based on the author's experience with the organisation of *Integrated Energy Design* workshops, conducted for three years on the basis of a student exchange scheme between Kraków (Poland) and Strasbourg (France). The article describes a new way of teaching architectural design of energy-efficient buildings, with the use of modern supporting tools. Designing a building as an energy-efficient structure has become common today, for environmental, economic and social reasons, as well as being a reaction to legislation. The problem is that the traditional way of designing, taught to this day at many universities does not allow for the design of such buildings. For this reason, there is a need to develop a new method of teaching, which requires a reorganisation of the design process. This is connected with the need to use appropriate tools to support the design process and to shift the main burden of decisions to the earliest stage of design. These tools include computer software in the BIM (building information modelling) standard and related programmes, through which it is possible to perform a series of simulations for a virtual model of the building concerning its energy efficiency.

Keywords: Building information modelling, building energy model, analysis of energy efficiency, final energy consumption, integrated energy design

INTRODUCTION

This article is based on the author's experience from the organisation of workshops devoted to integrated energy design, held for three years in Kraków, Poland, and Strasbourg, Germany, according to the principles of student exchange, and addressed to students from the Faculty of Architecture of Cracow University of Technology and students from Licée Le Corbusiere.

The methodology of teaching architectural and construction design applied broadly today in faculties of architecture should be radically modified and adjusted to meet contemporary needs. The need to introduce changes in the system of educating future architects is justified by two factors:

- First, there is the growing demand connected with energy efficiency in the construction engineering sector. The effort should aim at improving the valid standards of architectural and construction solutions towards increasing the energy efficiency of buildings. The goal of the changes is to reach the standard of *nearly zero energy buildings*. The design of buildings as energy-efficient ones differs from the previously applied traditional design methods, whereas it would be a valid standard for students who commence their education at faculties of architecture today, and when they graduate and enter the professional job market.
- The second factor is the IT revolution, connected with the introduction of design supporting tools in the BIM (building information modelling) standard into general use, enabling the construction of a virtual, fully parametrised model of a building being designed, and software that allows for energy efficiency analyses of virtual models of buildings designed using the BIM software.

The design of energy-efficient buildings by means of the BIM software in connection with energy-related simulations is referred to as integrated energy design.

DESIGNING ENERGY-EFFICIENT BUILDINGS

Soon, designing energy-efficient buildings will not be just an exclusive alternative to much less demanding normative buildings, but a necessity, resulting from environmental, economic and social reasons, as well as from relevant legislation. Designing energy-efficient buildings is difficult as these are technically advanced buildings that require a well-thought-out combination of architectural and construction solutions with installation solutions, as well as detailed simulations and calculations referring to their energy efficiency. Most design solutions recommended for energy-efficient buildings differ from the standard solutions applied so far. Determined by the greater problem of energy efficiency, the rules of shaping the surrounding area, the building itself and its functional system change, and the set of energy-efficient architectural and construction components that form a building become correlated with the adopted installation solutions to a great extent.

The problems connected with designing energy-efficient buildings call for a reorganisation of the design process towards the integrated energy design approach [1], in which the early stage of design and the introduction of appropriate design-supporting tools in the form of specialist computer software are particularly important. The principles and standards of energy design have been already implemented in Austria, France, the United Kingdom and Germany, for example [2].

FIRST STEP - BUILDING INFORMATION MODELLING - BIM

The first change that needs to be implemented in the teaching syllabus is the application of the BIM standard and a tool supporting the architectural and construction design, and the adjustment of the order of activities in the design works appropriate to the use of this tool.

Building information modelling (BIM) stands for the creation of an enormous database - by means of relevant software - which precisely defines each part of the building (its structure, materials and their properties, fittings, etc) and is arranged in the 3D space in the form of a virtual 3D model [3]. A design prepared in the BIM standard comes into being by means of three-dimensional elements, such as walls, ceilings, roofs, floors, windows, doors, etc, which apart from geometrical dimensions are assigned with relevant parameters (physical, technical properties, etc). Information integration within one database allows for automatic identification of introduced changes and identification of collisions, if any.

Designing a building as a virtual spatial model with all parameters of the actual buildings introduced, such as the layers of partitions with specific materials and their physical properties, technical parameters, prices, etc, allows for all types of analyses and simulations to be conducted at an early stage. This is quite impossible in traditional designs developed in CAD-2D software in the form of flat projections, sections and elevations [4].

A characteristic feature of designing in design supporting software in the BIM standard is the shift of the main workload to the early stages of the design process (stage of the concept), thanks to which the opportunities to influence efficiency are the greatest, at the lowest costs and with the least difficulty.

The concept of *shifting the effort* was presented for the first time by Patrick MacLeamy (USA); thus, the graph of this relationship is known as the *MacLeamy curve* and shown in Figure 1:

- The curve the *2D CAD workflow* represents the traditional design effort from the conceptual stage through construction. The heavy work effort (and costs) comes at the construction documentation stage.
- The MacLeamy curve *BIM workflow* suggests that if one moves the design effort to an earlier stage in the project (to the left), this should be more efficient than the traditional design process.

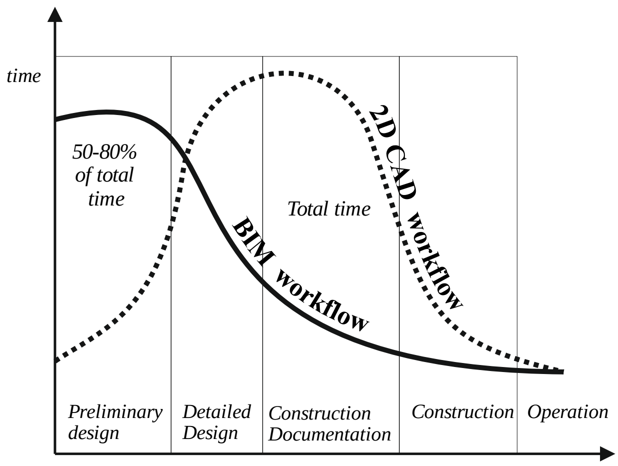

Figure 1: Comparison of the effort for different phases of the designing process in BIM and CAD-2D (source: Patrick MacLeamy, buildingSMART, US).

SECOND STEP - BUILDING ENERGY MODEL - BEM

The second change necessary to be incorporated in the syllabus of teaching architectural and construction design is broadening of the scope of design-related studies, and including the implementation of climate and meteorological data that refer to the specific location of a designed building and the introduction of internal temperatures in the designed interiors along with the schedule of use.

Energy efficiency of the designed building can be tested at the early stage of the designing process and long before all solutions are implemented and applied in reality, by means of simulations referred to as *energy modelling.* Conducting such simulations requires a three-dimensional virtual model of the building in the BIM standard, where all construction and installation solutions are parametrised precisely. When one enters data pertaining to the designed service temperatures, the temperature zoning of individual rooms, the use schedules, etc, in the virtual model of the building, one can say that the BIM model has been transformed into the so-called *building energy model* (BEM) [5].

In the building energy model, one can examine the effect of different design variants on energy efficiency [6]. The BEM building model is situated in a specific geographical location, for which a set of meteorological information is used. In addition to the quantity of energy divided into various components (heating, cooling and ventilation) and different energy carriers, it is possible to analyse the heat comfort (PPD, PMV) to examine the operation of energy recovery systems, etc. Running all sorts of variant analyses and simulations enables optimum energy efficiency to be reached, and for correct the adopted solutions to be verified.

The building energy model should be developed in the following way:

Geometrical analysis of the model has been run on the basis of the so-called *zones,* that is, usable areas along with the clear height, placed in each room in the building. For the purposes of energy assessment, these zones are grouped into so-called *thermal blocks.* Thermal blocks are a group of one or several rooms in the building of a similar arrangement, profile of use and requirements as to the inside temperature (requirements of the thermostatic control with a 24-hour schedule). These zones do not have to be interconnected and be strictly adjacent to each other in order to be combined in one thermal block. After configuring the thermal blocks, the virtual BIM architectural model is transformed into the building energy model.

The following principles of defining zones in the building have been adopted:

- For multi-storey internal spaces (e.g. stairs, atriums), separate zones are modelled on each storey;
- The walls of the body of the building, which separate heated rooms are the so-called adiabatic walls that do not transmit heat;
- Determination of the threshold of the minimum surface area of elements enables to filter out small elements, insignificant to the energy balance, and to obtain a more transparent list of elements;
- Parametrisation of openings specifies outlines of the zones in internal and external openings (reveals) of the building along with physical properties essential for the energy simulation.

A specific location with strictly determined parameters of the environment, climate and the surrounding area have been incorporated in the design:

- Location;
- Weather data:
    - Air temperature;
    - Relative humidity;
    - Insolation;
    - Velocity and direction of the dominating winds;
- Type of soil;
- Direct surroundings of the building;
- Land altitude;
- Exposure to wind;
- Degree of horizontal overshadowing.

For the purposes of the energy assessment, the following data with an essential effect on the energy efficiency have been determined:

- Type of installations in the building:
    - Heating - district heating or local appliances (renewable/non-renewable fuels);
    - Cooling - type and parameters of cooling devices;
    - Domestic hot water - target temperature expressed in ^{o}C;
    - Ventilation - natural or mechanic (without or with recuperation – heat recovery);
- Energy sources and energy costs - data enabling to calculate demands for the main energy sources (renewable or non-renewable), CO_2 emission and annual costs per unit of usable floor area;

- Profiles of use of thermal blocks - each thermal block is assigned with a separate profile of use. Each profile of use is connected with the daily schedule containing the following data, according to the time of the day, for the entire year (8,760 hours in total):
    - Type of use - residential or non-residential premises and the relevant required range of internal temperature:
        - Internal temperature - admissible range of the temperature inside (maximum and minimum) during the day;
        - Internal heat gain - factors, which cause energy emission (internal heat gain) during the day per m^2 of usable surface area [W/m^2]:
            - Number of users;
            - Illumination - type of illumination (value of the power of the selected illumination type);
            - Equipment - value describing the number of appliances (e.g. TV sets, computers, household appliances);
    - Heat gain from people - quantity of heat generated by people staying in the building (W/person);
    - Demand for hot water - quantity of hot water necessary for one person, corresponding to the associated function of the building (l/day per person);
    - Humidity load - quantity of water steam, which permeates the air inside as a result of the use of the building (l/day).

THIRD STEP - INTEGRATED ENERGY DESIGN - IED

The third change that needs to be implemented in the teaching syllabus of architectural and construction design is the shift of the highest intensity of the design works to the earliest possible stage and adoption of an appropriate strategy in the order of the selection of design solutions.

The methodology and principles of integrated energy design are becoming a standard in the modern design of buildings [7], defined as:

- Process of organisation of design works with the shift of the balance point to the early stages of the designing process, in order to achieve better efficiency and minimise costs;
- Prioritising energy-efficient integrated architectural, construction and installation solutions;
- Close cooperation between the investor/customer and the future user on one hand, and the architect, consultants, experts and discipline-specific designers on the other hand since the very beginning of the designing process to the implementation stage [7].

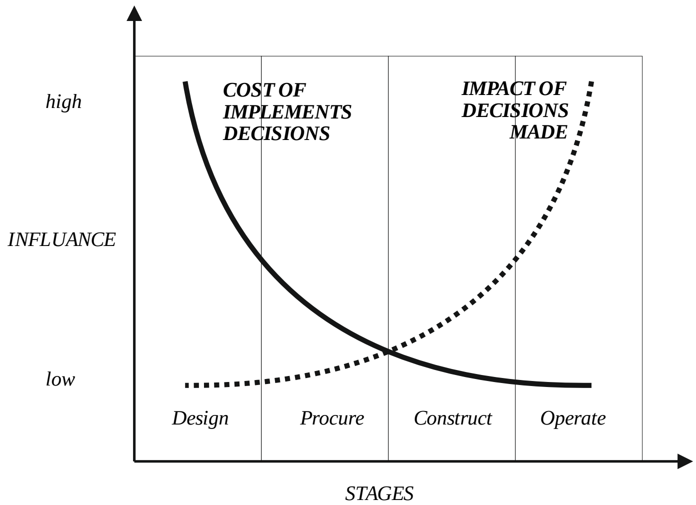

Figure 2: Effectiveness, costs and difficulties at different stages of the design works.

The descending curve represents the declining ability to impact cost and performance - early changes can be implemented cheaply, reduce costs efficiently, and this declines as the design is developed into construction drawings. The ascending line illustrates that, as the project proceeds, the cost of making changes goes up and up.

Integrated energy design of energy efficient buildings also stands for a relevant strategy of selecting architectural and construction solutions, as well as the technical furnishings of the building. The guidelines of this strategy - the so-called energy efficiency pyramid *Trias Energetica* [9] - contain information on the appropriate order and hierarchy of activities in the process of architectural and construction design and installation solutions, connected with economic and energy-related analyses:

- The first step in this strategy is the reduction of the demand for energy by the application of relevant means (optimal shape and position of the building, appropriate functional layout and temperature zoning, very high thermal insulation and air tightness, supply and exhaust ventilation with heat recovery and ground-couple heat exchangers).
- The second step is the use of renewable energy, which is connected with the application of technologies based on local sources of renewable energy, such as systems of solar collectors, photovoltaic cells, ground source heat pumps, technologies making use of wind energy, etc.
- If design analyses demonstrate that there is still some demand for usable energy, the third step leads to the use of fossil fuels that pollute the environment as little as possible, applying methods that will be the most effective.

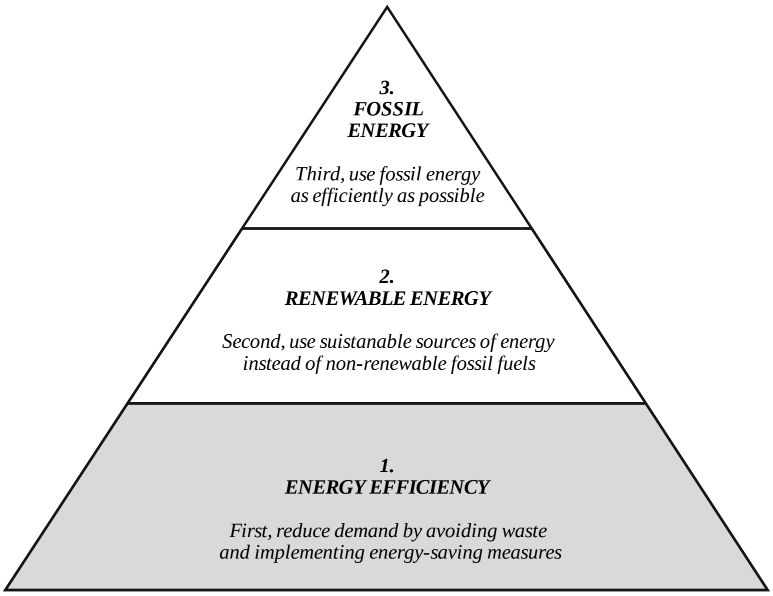

Figure 3: Energy efficiency pyramid *Trias Energetica*.

CONCLUSIONS

Classes conducted with students during the design workshops were based on five subsequent stages:

1. A preliminary architectural and functional concept or rather its outline, was drawn up in a simple intuitive programme Skechup.
2. Next, the virtual model was imported to ArchiCad, which is the BIM software and in which precise parameters of all partitions in the buildings were specified at an early stage of designing, with physical properties of the construction products assigned to them.
3. After defining internal temperature zones, climatic conditions and the surroundings of the building, the virtual model was automatically converted into the energy model.
4. In Ecodesigner Star, the software integrated on the digital platform of ArchiCAD, the parameters of installation appliances were entered and, then, simulations of energy efficiency were run.
5. If the results of the analyses were unsatisfactory, corrections were implemented in the design solutions.

Due to the fact that the workshops for students were quite short, obviously, the designs were not final and polished, but they did teach the recommended order of the designing works and enabled the sensitive elements to be considered when making design-related decisions. All participants declared that in all the designs they would prepare over the course of their studies, they would use this configuration of the order of the design works and the acquired design supporting tools.

The conclusions from the workshops can be described as follows:

1. The final level of energy efficiency of the building is affected by numerous mutually complementing and interrelated architectural and construction solutions, which are recommended for energy-efficient buildings. The more such solutions are applied in the design and during its implementation, the better the final energy-related parameters of the building will be.
2. As to verifying the design of the building in terms of its energy efficiency, it is necessary to change the approach to the design principles adopted so far towards the integrated energy design. It is connected with the application of appropriate design supporting tools. These tools are - first of all - software in the BIM standard, enabling the creation of a virtual precisely parametrised and programmed building. Second, it is the appropriate software enabling simulation of energy efficiency for a virtual model of the building to be run and, therefore, allowing for analyses of the consumption of end energy, energy gains and losses, and the level of comfort and overheating.

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BIOGRAPHY

Przemysław Markiewicz graduated with a Master of Science in Architecture from Cracow University of Technology, Kraków, Poland, in 1995. His PhD dissertation was entitled *Selection of Advanced Construction Technologies for Housing Purposes* and was defended in 1999. He is an Assistant Professor in the Institute of Construction Design in the Faculty of Architecture at Cracow University of Technology. Dr Markiewicz is a professionally active architect, the author of a number of design studies of one- and multi-family houses, office buildings, public utility buildings, and a member of the Małopolska Chamber of Architects. His scientific activity is connected with the Section of General Construction of the Committee of Urban Planning and Architecture of the Polish Academy of Sciences (Kraków Branch). Within the scope of his didactic activities, he conducts classes with students in the Faculty of Architecture of Cracow University of Technology in the General Construction subject. He is the author of a series of books devoted to general construction, and architectural and construction design, including, for example, Interior Design with the Application of Drywall Partitioning Systems of Plaster - Cardboard Panels (2001), Glazed Shell Walls (2007), Shaping Architecture by Changing Construction Solutions (2006), General Construction for Architects (4th Edn, 2011), Design Details for Architects (2010), Architectural and Construction Project - Graphic Standards for Design Studies (2014), Building Construction (2014). Dr Markiewicz is also the author of a number of technical catalogues and information/educational publications for architects, developed for the leading construction companies, including - without limitations - Rigips Systems, Assembly of Rigips Systems (RIGIPS), ISOVER - Catalogue of Architectural and Construction Solutions for Designers and Investors, Catalogue of Architectural and Construction Solutions - Essence of Insulation, PFLEIDERER - URSA Insulation Materials, BRAAS - Technical Solutions - Pitched Roofs, WIENERBERGER - Structural and Construction Design of Walls in the POROTHERM System, XELLA - Principles of Designing in the YTONG System. He is the organiser of courses devoted to designing and modelling virtual buildings in ArchiCAD, and the co-organiser of the exchange of students with France and workshops entitled *Integrated Energy Design*.