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Integration of sustainable design issues from the first stage of the education process of architecture students

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ABSTRACT: Due to the propagation of the concept of *sustainable development* in recent years, the idea of *sustainable design* is being introduced into the field of architecture. The definition of *sustainable development* postulates meeting the current needs of people without adverse consequences for future generations. Decisions that are made during the process of *sustainable design* should be the result of the analysis of multiple criteria, of a so-called multi-criteria analysis of the influence that structures have on people and the environment during their construction, operation, demolition and recycling phases. During their first year of study at the Faculty of Architecture of Cracow University of Technology, students are being tasked with the development of a design of a medium-sized commercial pavilion within a given area, which is to be a sustainable building. The introduction of design support tools in the form of BIM-standard software during the first year of study makes it possible to set a series of important parameters and perform analyses with the aim of making design more sustainable. The results of these analyses allow one to tune design assumptions and optimise them.

INTRODUCTION

The concept of *sustainable development* that is being introduced in the field of architecture is described as *sustainable design*. Architectural designs that are developed in accordance with this concept need to meet the condition that while they should meet people's needs, they should not cause negative consequences for the environment, the economy and the society of future generations. In practical terms, this means that design decisions that are made during the process of sustainable design should be the result of a multi-criteria analysis of the influence of a building on people, as well as the environment, during the construction, operation, demolition and recycling phases [1].

The amount of information and the various parameters that need to be introduced into a design and taken into account at the conceptual design stage is much larger than in the case of traditional designs, many facets of which are developed in an intuitive manner. Modern architectural designs, thus, require the carrying out of numerous precise analyses and simulations, which verify previously accepted design solutions. This, in turn, requires the use of proper design support tools in the design process in the form of BIM software. These revolutionary changes in the approach to design place new challenges in front of universities that teach future architects. In short, university curricula need to be profoundly altered and tuned in the direction of sustainable design.

AN INNOVATIVE TEACHING SYSTEM BASED ON BIM SOFTWARE

In the second semester of the first year of study at the Faculty of Architecture of Cracow University of Technology, Kraków, Poland, students are tasked with developing a design of a medium-sized commercial pavilion located on a square in an urban environment, with the pavilion being a sustainable and, thus, an energy efficient building [2].

As a result, it is recommended that first year students use the BIM computer-aided design software. The use of this type of software makes it possible to introduce and define important parameters at the conceptual design stage and carry out preliminary analyses that aid sustainable design. The results of these analyses allow designers to modify design assumptions and optimise them. One of the more important qualities of a sustainable building is energy efficiency, which is why these analyses are focused chiefly on those aspects of a given design, which influence the final level of this parameter. The elements of sustainable design that are recommended for introduction into the design documentation during the conceptual design stage through the use of BIM software are:

- The geographical location of the site:

  The BIM computer-aided design software makes it possible to enter the precise location of the site of a project (geographical longitude and latitude, and its elevation above sea level). The value of the latitude is associated with the height of the sun and its incidence angle. This makes it possible to conduct a daylighting analysis for the building that is being designed.

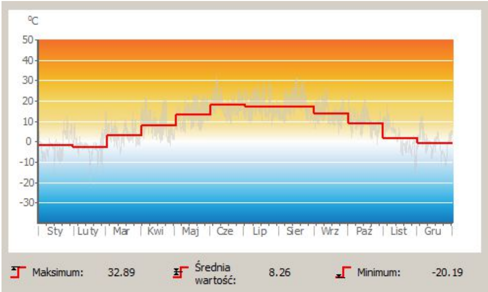
- Climate data:

  In order to carry out energy efficiency analyses of the designed building during the further stages of design, it is imperative that proper climate data are available. The external temperatures are provided in accordance with the appropriate standard, which means that for a designed building located in Kraków, such a structure will be located in the III climate zone.

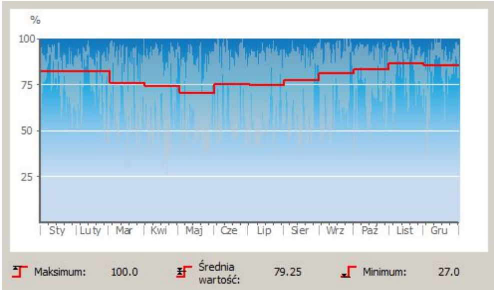
  In the case of the designs that are being developed by students as a part of their design classes, it is required that the location of the designed building, along with precise climate data, be introduced into the design at the conceptual design stage. These data should include:

  – Air temperature;
  – Relative humidity;
  – Insolation;
  – The speed and direction of the dominant winds.

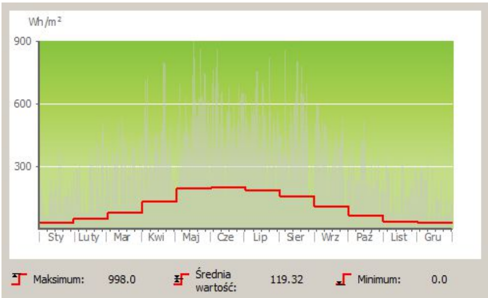
Air temperature



Relative humidity



Insolation



The speed and direction of the dominant winds

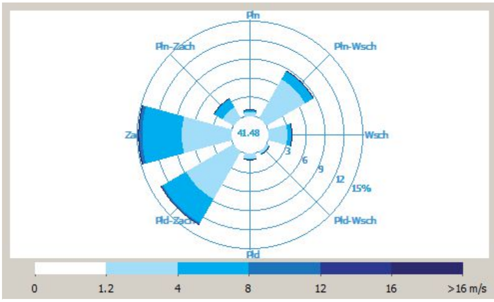


Figure 1: Weather data over an average yearly cycle, provided for a building located in Kraków (Source: Archicad 19 - Ecodesigner Star module).

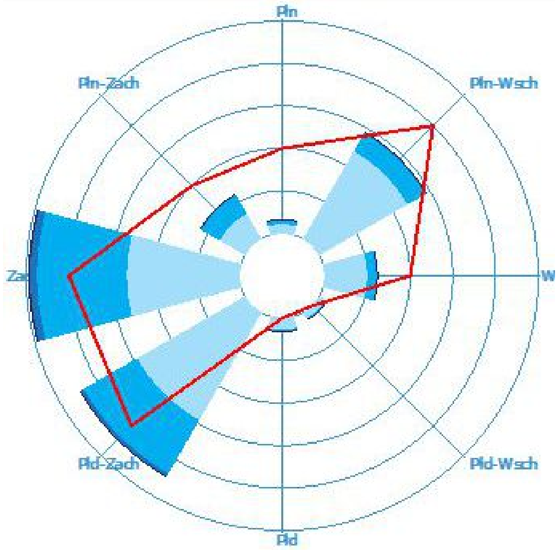
- The intensity, speed and direction of the dominant winds:

  The energy performance of a building is heavily influenced by wind or to be more precise, by the speed and direction of the dominant winds for a given site. The precise location of a designed building and said location's distinct winds should be an indicator in the planning of appropriate wind barriers or *openings* for each of the buildings' façades.

- The trees or buildings in the vicinity of the site which can affect its sunlight exposure:

  The designed wind barriers have an effect on the level of so-called horizontal shade, which is the level of shadows that are cast by external elements on non-translucent elements of a building. Sources of horizontal shade of a building are a result of the placement of a building on a given site, the type and number of elements, which are located in the vicinity of the building and the structure of the shape of the building itself.

  The evaluation of the level of shade cast onto a building or its immediate surroundings should be performed for two seasons of the year: winter and summer. The winter period level of shadow cast on the walls and windows from the southern side makes it impossible to make use of solar energy, while shadow during the summer, especially from the western side, can prove beneficial, as it prevents the overheating of a building. Should the need arise, the surroundings of a building should be appropriately modified in order to increase or decrease the amount of shade in order to affect the level of accessibility to solar radiation.



Orientation	Wind exposure	The level of a building's shielding from the wind
Northern	1.5%	Partially shielded
North-eastern	9%	Shielded
Eastern	4%	Partially shielded
South-eastern	1%	Unshielded
Southern	1.5%	Unshielded
South-western	13.5%	Shielded
Western	15%	Shielded
North-western	3.5%	Partially shielded

Figure 2: An example of an analysis regarding wind exposure and the designed wind barriers for a building located in Kraków (Source: Archicad 19 - Ecodesigner Star module). The figure shows a depiction of wind data in the form of a wind rose. The polar plot is divided into the eight cardinal directions. The length of each segment represents the frequency of the incidence of wind (over the length of a year) from a given direction and its speed. The red lines indicate the degree of designed shielding.

- A daylighting analysis:

  In accordance with legal regulations, rooms within buildings should be provided with an appropriate period of exposure to daylight, which is determined for conditions present during equinoxes (between 21 March and 21 September) [3]. This can be verified with a so-called daylighting analysis, which allows one to observe the designed building in a real situation in order to evaluate the sunlight exposure conditions within a particular area (geographical location) and over a distinct period of time [4].

  Daylighting analyses for students' designs that feature various sets of variables are carried out in Archicad, while taking into account the parameters associated with the geographical location of a model and the associated position of the sun. The day for which the daylighting analysis is performed is 21 March. The time intervals between each frame of the analysis are standardised to reflect each hour of the day.

  Due to the legally required degree of energy efficiency, the maximum and minimum area of allowable glazing should also be defined during the conceptual design phase. The proportions between the size of the glazing within a building are defined in the Ordinance Regarding the Technical Conditions to be Met by Buildings [3].

  - The minimum allowed surface of glazing - in a room meant for human occupation, the ratio between the surface area of windows, calculated inside the jambs, to the surface area of the floor should be no less than 1:8.
  - The maximum allowed surface area of glazing - within a commercial building, the surface area A_0, expressed in m^2, of windows and glazed or translucent barriers with a heat transfer coefficient no smaller than 0.9 $W/(m^2K)$, calculated in accordance with their modular dimensions, should be no larger than the value of A_{0max}, calculated in accordance with the formula: $A_{0max}= 0.15\ A_z+ 0.03\ A_w$,, where A_z - is the sum of the

surface areas of the horizontal floor plan of all floors above ground (measured along the external outline of a building) within a belt of 5 m wide along their external walls. A_w is the sum of surface areas of the remaining part of the horizontal floor plan of all floors after the subtraction of A_z.

There are currently no separate guidelines regarding the recommended size of glazing for low energy (NF 40) and passive (NF 15) buildings, which should be verified through analyses of energy gains and losses for the entire building [5]. However, when designing an energy efficient building, one needs to take into account that the windows of energy efficient buildings play a very important part, because the introduction of daylight through windows is the simplest form of passively obtaining energy from solar radiation.

Research conducted at the Passivhaus Institut in Darmstadt, Germany, has shown that only those windows that are located on the southern, south-eastern and north-western side of a building can positively affect a building's energy balance [6]. Thus, it is recommended that windows in energy efficient buildings be concentrated on their southern façade. At the same time, windows facing the south should be fitted with shading mechanisms, which allow the interior of the building to be protected from overheating during the summer season. On the other hand, it is recommended that placing windows on the northern façade be avoided, and their number be limited on the eastern and western façades [7].

Furthermore, it needs to be taken into account at the conceptual design stage that in geographical locations, such as Poland, the amount of solar radiation during the heating season is relatively small in comparison to the amount of radiation, which affects a building during the warmer months. Energy efficient buildings with large window surface areas from the south can suffer from the problem of the overheating of their interiors. In order to preserve thermal comfort during the summer season, it is recommended that shading mechanisms be used.

Internal Infrastructure Guidelines that Take into Account Renewable Energy Sources (RES)

During the conceptual design stage of the design of an energy efficient building, students need to outline preliminary solutions regarding a building's infrastructure and technical equipment. These should include the following types of infrastructure and equipment:

- Infrastructure providing ventilation and thermal comfort **-** buildings designed in a traditional manner have fresh air provided by a system of natural ventilation. Energy efficient buildings cannot achieve the required, much higher level of energy efficiency than the ones in normative buildings without the use of mechanical ventilation with heat recuperation. Among the types of equipment that are effective in providing thermal energy for the purposes of heating energy efficient buildings are heat pumps. A ground heat exchanger is a recommended form of supplementing the ventilation and heating systems of energy efficient buildings.
- Infrastructure providing hot water - in traditional buildings, the main component of their energy balance is the need for heat that is used for heating the building, while the energy required to prepare domestic hot water is only a small part of it. In energy-efficient buildings, these proportions are reversed and, as a result, one should strive to keep the amount of thermal loss in domestic hot water infrastructure at a minimum, limit the need for domestic hot water and use renewable energy sources to heat it (for instance through the use of solar collectors).
- Electrical infrastructure - energy efficient buildings should have a highly effective electric energy efficiency, while the illumination of their rooms should be carried out with as much natural light as possible.
- Automation and intelligent building systems - the term *intelligent building* describes a structure, which is highly advanced in terms of technology, which is fitted with a system of sensors and detectors and a single, integrated system of managing the entirety of its infrastructure. The use of automatics associated with intelligent building systems allows one to reduce energy expenditure greatly - the cost of installing an intelligent building system amounts to around 1-2% of the total cost of a building's construction, while providing a reduction in operating costs as high as 75%.
- The use of energy from renewable sources:

  - Passive solar systems - a reduction in the amount of energy used for heating can be achieved through the use of passive solar systems. Such systems are created by elements of buildings, which are designed in an appropriate manner to absorb, filter or store solar radiation passively.
  - Active solar systems - active solar systems are systems in which the use of special mechanisms allows the conversion of the energy derived from solar radiation into usable heat. Solar collectors are an example of such a system.
  - The conversion of solar radiation into electricity; for instance, through the use of photovoltaic cells.
  - Heat pumps - machinery that gathers energy from a low temperature source (the lower source) and transfers it to a source with a higher temperature (upper source), where it is used to heat rooms or domestic hot water.
  - Other sources of renewable energy, like biomass, wind energy, etc.

The designs are developed during the second semester of the first year of studying architecture at the Institute of Urban Design in the Faculty of Architecture at Cracow University of Technology, during the functional and architectural conceptual design phase. During the successive semesters, the design is to be developed further at the Institute of Construction Design as a technical and detailed design. Taking into account the abovementioned elements of sustainable design during the conceptual design stage makes it possible to continue developing the designs during the technical and detailed design stages without the need to introduce far reaching modifications associated with the orientation of a building, its exposure to sunlight, function, etc. This approach to teaching design during the conceptual design stage makes it possible to develop design decisions effectively. After assigning all the construction materials used in each element of the building based on their physical properties, further analyses can be carried out, such as an analysis of the gains and losses of final energy used for the purposes of heating a building, a thermal comfort analysis, an overheating analysis, etc.

CONCLUSIONS

Architectural and urban design, as well as the technical design that follows the concept of sustainable development, requires coordination at all stages, as well as the integration of the efforts of all of the participants of the design process. Sustainable design is based on predetermined rules, which are logically tied together. The carrying out of proper analyses and the introduction of solutions that can be labelled as *sustainable* into a design does broaden the overall scope of the design documentation, in addition to increasing the probability of making a mistake. It seems that currently, the most efficient support tool for sustainable design is the BIM software.

This is due to the option of introducing various parameters into a design, such as geographical location, climate data, the position of the sun, etc., as well as the carrying out of the associated analyses, such as a daylighting analysis. Without aid in the form of proper software, such analyses would be exceedingly tedious or even impossible to carry out. Computer technology has risen to the challenge of steeper requirements placed before designs and their authors in a time of sustainable development. The teaching of sustainable design with the use of these technologies is of great aid to architects and engineers, while in the future it could become a necessity. This is why education in this field, as well as the coordination of urban, architectural and technical design appears to be necessary from the first year of study.

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