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COMPARATIVE ANALYSIS OF THE GEOMETRY OF THE ENVELOPE DESIGN ELEMENTS OF BUILDINGS WITH SIMPLE AND COMPLEX FORMS OF STRUCTURE

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Abstract: *The diverse geometric forms of the external envelope areas of the buildings are distinguished by their distinctive geometric characteristics which should be taken into account when providing quantitative assessments of the building materials at the stages of design and construction. Normally, the use of software products to compute and determine the area of the envelope design elements reduces and facilitates the otherwise huge amount of work the relevant experts will do in supervising the building's energy efficiency consistency. The results hereto obtained prove conclusively that the applied software products are capable of meeting the technical requirements for enhanced energy performance of the buildings, both at the concept design stage and the subsequent stages of reconstruction, renovation, repair, etc.*

Key words: *Investigated in the Energy Efficiency Act, applied geometry, 3D modeling, Engineering graphics.*

1. INTRODUCTION

Energy efficiency is a central component of the European Union's 2020 energy strategy with an increased focus on the pursuit of a new 'energy efficiency strategy' providing the means for all the member countries to overcome the strong correlation between energy consumption and economic growth [1].

The objective of a resilient Energy Union that is dedicated to an ambitious climate policy is to provide consumers in the Union with a secure, sustainable, competitive and economically affordable energy, as well as to promote research and innovation through active encouragement of investments, which calls for fundamental changes in the European energy system. These changes are closely associated with the need to preserve, protect and improve the quality of the environment, as well as to promote the prudent and rational utilization of natural resources, particularly through improved energy efficiency and determined energy savings. Such an objective can only be achieved through coordinated actions combining legislative and non-legislative acts at Union, regional, national and local levels [2].

The binding 2030 EU target of at least 40 percent reduction in the total domestic greenhouse gas emissions relative to those of 1990 was officially approved as a intended nationally determined contributions by the Union and its member countries to the Paris Agreement on Climate Change discussed during a meeting of the Environment Council on March 6th, 2015 [2].

To advance the implementation of the national energy efficiency action plan, which is defined as the amount of savings in primary and final energy consumption by December 31st, 2020, measures are taken annually in all heated and cooled state-owned buildings to improve their energy performance of at least –5 per cent of the total built-up area [3].

The energy efficiency requirements laid down in the Energy Efficiency Act and in the Spatial Development Act are mandatory for all investment projects - the construction of buildings; refurbishing, which alters its characteristics and energy performance; reconstruction; major renovation or overhaul (repair) of buildings [4]. In view of the aforementioned, inspection, survey and certification of buildings are made obligatory.

Under Art. 34. (1) of the Energy Efficiency Act of Bulgaria, upon the sale of a new building as a whole the seller shall provide the buyer with a "Certificate of Energy Efficiency" in its original form.

The energy performance of buildings in operation (use) is established by a systematic energy efficiency survey (audit) which is completed with a report and the issuance of a certificate of the building energy performance. "The energy performance certificate" of a building is an official document issued by energy efficiency consultants within the range of their competence in form and order that includes the energy performance of the building, calculated according to the methodology specified in the Directive [5,13].

Fig. 1. Envelope elements with a variety of complex geometric shapes [6-8].

Building surveying under the Energy Efficiency Act necessitates for a significant part of the assessment to be related to the preparation of a quantitative account of the building's envelope elements - outer faces of the walls, roofs, floors. In general, it is necessary to calculate the area of all the elements of the building's envelope. The task becomes too complicated if the building takes a complex symbiotic-geometric shape (Fig. 1.). But how to approach such a task, are there any suitable software products that can be effectively applied? Which are they and which is the most appropriate for the purposes of measurement?

2. EXPOSITION

If the design documentation is created in a digital format, or, as it is the case with older buildings, in paper but with a simple geometric shape of the building, it would be relatively easy for the necessary calculations of these areas to be done through the use of a calculator. However, in the absence of such design documentation, then they should be captured on architectural shots. Architectural photography is necessary in the preparation of constructive projects for house refurbishment plans, reconstruction of old buildings, adding annexes, extensions, projects for changing the use or the purpose of the buildings or in the lack of technical documentation whatsoever. The purpose of photographing is to show the range of the changes that have occurred in the building, relative to the existing situation and is sometimes an essential part of the preparation of construction statements. Photographing is an accurate measurement of all structural and architectural elements – columns, washers, partitions and enclosing walls, space allotment or the size of rooms, beam heights, windows, bay windows, storey heights, openings and other construction details [9]. Carefully considered are also the materials from which the building was built, as well as its structure. The measurements are made at a height of 160 cm from the floor, and the acquired data is used to draw the building plan to scale. Principally, architectural photographing is performed by qualified building construction specialists. Normally, the entire process is managed and certified by an architect.

To achieve the required accuracy, use is made of precision laser devices and a specially tailored survey algorithm. The collected data is used for computer-generated drawing of the building with the aid of object-oriented computing.

The photographing takes place in four stages:

- initial general information gathering;
- processing and preparation of precise construction pads;
- re-photographing with confirmation of key elements and adding extra information;
- preparing the complete construction documents drawing set.

The finished full architectural photographing contains the distribution of all the storey area in square feet and room construction materials, incisions, facades. Attached further might be some additional explanatory notes, specific details and snap shots as required. It is very often combined with aerial photography and geodetic data of the construction plot and approved statement by a chartered civil engineer [10]. Apart from the measurements obtained directly at the site, the architectural photographing can also be undertaken by remote sensing, which is a more modern and sophisticated method - the so-called close-range photogrammetry.

Photogrammetry is generally used for topographic purposes, for creating and updating topographic maps and plans. Similarly, it can be used to solve various engineering problems as well, such as decoding, designing, calculating surface area and volume, examine deformations, documentation of archaeological sites and monuments of architecture, and others, by photo analysis [11,12].

Photogrammetry is primarily a central projection or central perspective of an object, with one of its most important tasks being the theoretical justification and development of practical solutions for the conversion of the central projection (photo-image) into an orthogonal one to the horizontal plane of the plan.

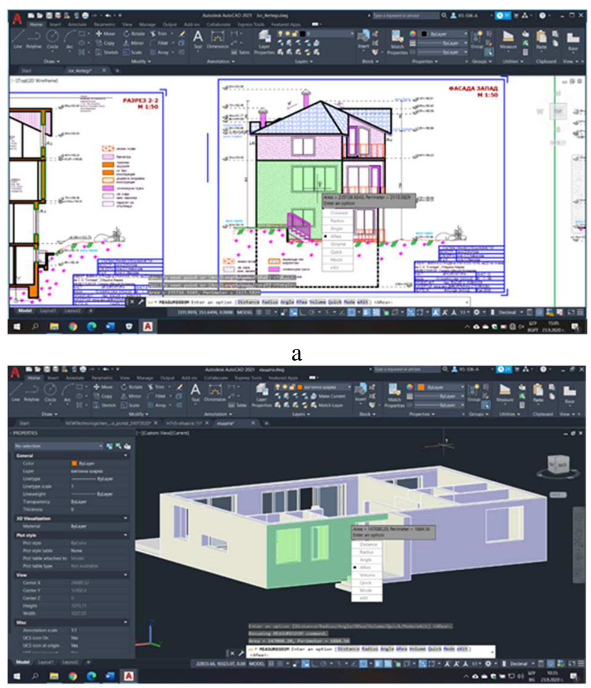
Regardless of which of the two methods of data collection is adopted – architectural photographing or photogrammetry with subsequent architectural design, or ready-made drawings on a digital device or paper, for inspection purposes, the next major and significant step in survey conducting under the Energy Efficiency Act is measuring the external surface area of all the building's envelope elements.

One of the most preferred programs by the architects themselves and frequently used architecture toolset for computer-aided architectural design is AutoCAD. Applying this program will facilitate the process of taking exact area measurements, as demonstrated in figure 2.a.

The surface area is measured by a polyline to enclose the area to be measured. Sometimes it takes a lot of points to measure the area of complex plane shapes, which will greatly complicate the task at hand.

To calculate the area the "Utilities" command is used. The measurement is carried out by enclosing the area with a polyline, and then, selected from the drop-down menu should be one of the suggested options, such as, Distance, Area, Radius, Angle etc. (Fig. 2.).

When measuring surface areas of building's envelope elements of a more complex shape, it is necessary, after enclosing and measuring the surface area with a polyline, to subtract part of the area of those elements that have remained enclosed in the contour and whose area is, therefore, included in the total quantitative account. Such an example is illustrated in figure 2. Enclosed there, with a polyline, is the area of one of the walls but the area of the two window openings is not subtracted. It can be seen from the screen shot that the program automatically calculates and provides the user with a window displaying data related to the surface area enclosed by the polyline including its perimeter, irrespective of whether the drawing is in the two-dimensional or three-dimensional space.



a

b

Fig.2. AutoCAD-based surface area measurement

When calculating the overall heat transfer coefficient of the building's envelope structures and elements, it is also necessary to take into account the minimum regulatorily defined area of the glazed parts of the various types of buildings, which ensures the relevant requirements for sanitary and hygienic conditions [5,14,15].

In practice, the window area is usually calculated through approximation, i.e., computed is the surface area of only one of the normally uniform windows and is multiplied by their number. By all means, this is not entirely correct, since the repeatability in the design and architectural realization is not always present. Next, the result obtained for the entire window area is subtracted from the calculated wall area. Similarly, the same procedure is adopted for calculating the surface area and when the drawings are made only on paper.

Calculating the envelope area of buildings with simple geometry is not such a serious challenge, as distinct from the cases where it is necessary to measure the surface area of buildings with complex geometry such as those shown in figure 1, which would require considerable amount of work and present a serious mathematical problem.

Let us consider an example with the usage of alternative specialized building design software – "Revit". The geometric shape of the building is quite simple, prismatic, and measuring the wall's surface areas and those of the windows is perfectly straightforward (Fig. 3.). Within Revit environment the measurement is done afresh by setting out a specific wall from the building's façade, and in the window "Properties" in the "Dimension" tab displayed automatically is data indicating the Length, Area, Volume and others. But what exactly is different here is that Revit is a software used for creating "Building Information Modeling" or commonly abbreviated to BIM, or in other words, it not only creates geometry, but also attaches essential information to it. The program provides the opportunity to obtain a full quantitative account for each category of elements (external envelope elements, internal partition walls, windows, doors, suspended facades, etc.) on the drawing itself.

The data can be obtained by creating a table from the "Project Browser" panel in the "Schedules/Quantities" tab and right-clicking on the option "New Schedules/Quantities". From the window that opens the designer can select the categories they need to include in the table. The program also provides the opportunity to calculate the "overall heat transfer coefficient" of the envelope structures to meet the energy efficiency requirements, and for the purposes of which the element Walls should be added to the table. A "Schedule Properties" window opens enabling the selection of the columns to be included in the table. If "Type" is selected – this will display the name and type of the wall, "Area" – will estimate the area in square meters, and if a column "Level" is inserted, obtained might be information about the storey on which the wall included in the table is located. Figure 3 features a definite wall in the table, as well as its correlation with the drawing, with that particular wall being highlighted both in the "drawing of the situation" and in the perspective "drawing of one of the facades" in blue.

The table lists the groups of all the walls outlined in the drawing – exterior insulated masonry walls, internal plasterboard walls, foundation walls, etc.

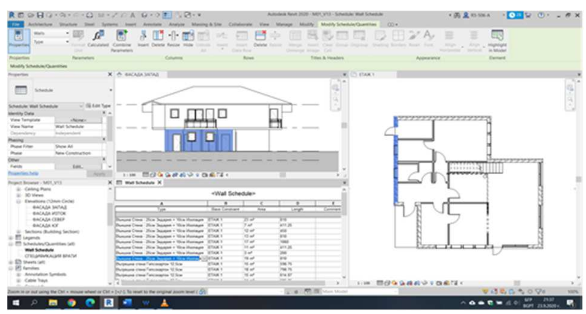


Fig. 3. "Building Information Model" relationship

From the settings panel can be made to prevent all the walls, along with their specific characteristics set against them, listed in the drawing from being visible. Arranged in the table can be all the groups of walls present in the drawing as per their type– external, internal or plasterboard, with the total amount of the selected parameter being visible in the respective columns (Fig. 4.).

Information about various wall parameters can be affixed to the types of walls under consideration, but for the purposes of energy efficiency, the program can also automatically provide information about the "Heat Transfer Coefficient" of the wall, and its "Thermal Resistance and Thermal mass" as well. All that data can be used in the creation of energy analysis or quantitative cost accounting. This is a great advantage over the conventional design

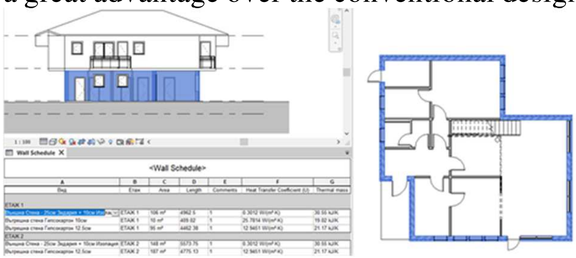


Fig. 4. Quantitative cost accounting

methods, in which the drawings are created in one software program, and a second one is used for conducting detailed analyses of the buildings under survey.

Indisputably, AutoCAD also has the capabilities for three-dimensional modeling of building structures and a great many architects still continue using this particular design software, but calculating the area of the envelope elements is carried out in a way that follows the pattern of the two-dimensional space, namely, by enclosing the area to be measured by a polyline. This, however, proves to be rather inappropriate for inspection reviews [16,17].

3. CONCLUSION

On the basis of the conducted research study, the rigorous selection and results obtained from the comparative analysis into the simple and complex shape geometry of the building's envelope elements, the following inferences can be drawn:

1. The selection and use of appropriate software products in the early stages of schematic design development, facilitates, simplifies and supports the huge amount of work of the specialists in measuring and determining the area of the envelope elements, when surveying the buildings under the Energy Efficiency Act.

2. The usage of computer-aided geometric design with information affixed to the design geometry, or the so-called "Building Information Modeling" products, speeds up significantly the work of specialists who are officially involved in examining the building performance in terms of their energy efficiency.

3. "Building Information Modeling" creates and manages the documentation for a single project throughout its entire life cycle. The design is now object-oriented based on the concepts of objects rather than lines. The created three-dimensional model to scale obtains accurate quantitative accounts and specifications, allowing for the changes in the parameters to generate the entire model of the building and the related construction documents. This enables the corresponding architects and designers to concentrate their efforts exclusively on the process of designing.

4. Through the information affixed to the geometry of the envelope elements, the software can automatically provide data about the "Heat Transfer Coefficient" of the wall in addition to its "Thermal Resistance and Thermal mass".

5. "Building Information Modeling" software tools have a great advantage over the conventional design methods, in which a second software program is used for conducting detailed analyses of the buildings under survey.

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ANALIZA COMPARATIVĂ A GEOMETRIEI ELEMENTELOR DE PROIECTARE A ANVELOPELOR CLĂDIRILOR CU STRUCTURI DE FORMĂ SIMPLĂ ȘI COMPLEXĂ

Diferitele forme geometrice ale suprafețelor exterioare de anvelopare a clădirilor se disting prin caracteristicile lor geometrice, care ar trebui luate în considerare pentru asigurarea unor evaluări cantitative ale materialelor de anvelopare, în etapele de proiectare și de construcție. În mod normal, utilizarea produselor software pentru a calcula și a determina aria elementelor de proiectare a anvelopelor reduce și facilitează efortul de muncă, altfel imens, pe care experții îl vor investi în verificarea eficienței energetice a clădirii. Rezultatele obținute în prezentul studiu demonstrează în mod concludent că utilizarea produselor software este capabilă să îndeplinească cerințele tehnice referitoare la îmbunătățirea performanței energetice a clădirilor, atât în etapa de proiectare conceptuală, cât și în etapele ulterioare de reconstrucție, renovare, reparare etc.etc.

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