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# USE OF TECHNOLOGY BUILDING INFORMATION MODELING (BIM) IN THE DESIGN HIGH BUILDING BASED ON INNOVATIVE APPROACH DESIGN CAE/CAD

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Abstract

BIM – Building Information Modeling is the fastest growing branch of modern design and execution of buildings. In the United States there is a requirement for the design of public investment based on BIM technology. Similar legislation has been in force since 2016 in the United Kingdom. In the near future also in Poland, it becomes necessary the use of BIM technology in the implementation of investments co-financed from European Union funds. The most important part in the design of a new approach is the treatment of structural parts of geometric models, as information which can be changed as desired at any stage of design. A comprehensive approach to design using BIM technology allows to carry out a series of analysis and collision detection at the design stage, in order to reduce costs at the stage of execution of the investment. The paper presents the design of the structural part of a reinforced concrete building, multi-storey in BIM technology. It uses an innovative design approach, enabling the analysis of the object using CAD (Computer Aided Design), which previously was based BIM method and a new approach based on the method of CAE (Computer Aided Engineering), which permit the object generated in BIM, static-strenght analysis. The article presents opportunities and benefits of BIM methods, using innovative design CAE/CAD.

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## Introductions

### BIM development

The use of BIM technology in the design stage of a construction project helps to reduce the total cost of the investment (TOMALA 2016). BIM technology with the ability to assess the quality of the solutions already at the modeling stage, the preparation of project documentation, significantly improves the quality of documentation and reduce errors. Several studies carried out in the US (TOMALA 2016) for various types of construction, showed a significant decrease in the overall cost of construction, in the case of an increase of 2–3% of the costs aimed at improving the design documentation. Despite the increase in initial costs, it contributes to the reduction of the cost to the value forecast, calculated as the difference between the value of fixed investments, and the actual costs in relation to the value predicted at the time of completion of the entire project (Fig. 1).

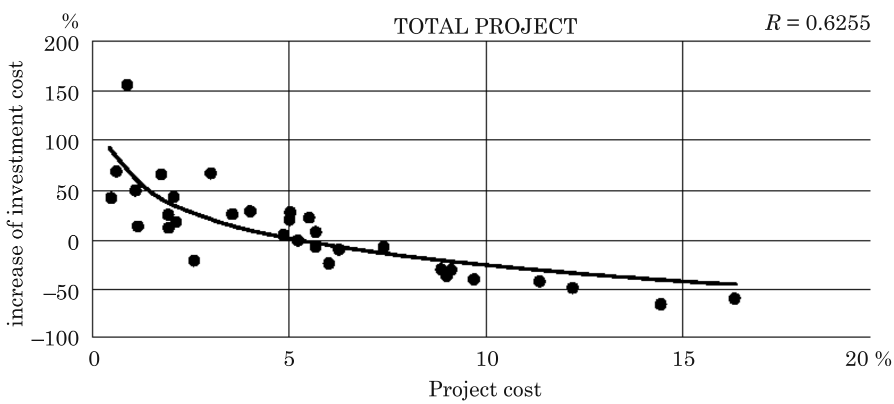


Fig. 1. The dependence of the increase initial costs, to the total cost of the project
Source: based on TOMALA (2016).

The use of BIM in the construction industry, will play an increasingly important due to the advantages of accurate design documentation. The dynamic development of the design using BIM can be observed in the US market in 2007–2012 (BIM 2012). For the past four years the share of use of BIM technology in the development of projects increased by 28% in 2008, up to 71% in 2012. This is related to the obligation to draw up documents in public procurement in the US, realized in BIM technology. In the UK, Germany and

France, the level of implementation of BIM in the public procurement system is similar and represented 36% (KIVINIEMI 2010).

## BIM assumptions

BIM Technology is a building information model. It is also understoodas a parametric, computational representation of the model, combined with the various structural, finishing and installation elements. Made by designers, engineers, architects, contractors and subcontractors (TOMALA 2016). Also, the concept of BIM is defined as building information modeling, concerning its geometry, space, or estimating the cost of its construction. Means the process of creating and managing data from the whole life cycle of the project. Starting from the design phase and ending with the restoration of the object, or its liquidation. With each step, under the premise of BIM data should be provided to enable a comprehensive assessment of the behaviour of a building. Figure 2 illustrates the steps of data management of the different stages of life design. In addition to the existing management scheme 3D data also appear requirements for information management, the collection and processing in terms of

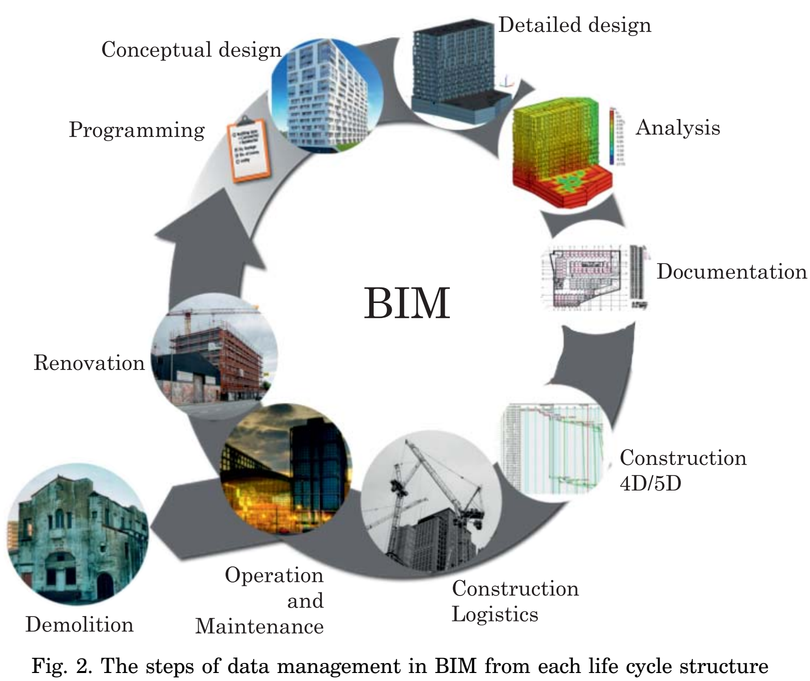


Fig. 2. The steps of data management in BIM from each life cycle structure
Source: own elaboration.

time associated with the analyzed object construction [4D models]. Also included data on cost management [5D models]. Also mentioned is the use of modeling 6D and 7D BIM technology in the management of the data appearing on the construction site (TOMALA 2016).

In BIM, an important role is played by the level of complexity of projects in construction (TOMALA 2016). The levels are the following:

– level 0: traditional concerns for the design, based on an manual preparation of project documentation, in the form of 2D drawings;

– level 1: Currently used in the preparation of project documentation, based on 2D and 3D models, developed specialized software, without sharing made them models;

– level 2: Development of design documentation occurs in electronic form and as BIM models for every industry project, which cooperate with creating construction project. Shared files for data exchange including 3D models, also taking into account the time duration of the construction process;

– level 3: It includes comprehensive documentation and documentation of BIM model, resulting from a combination of data from the models developed by individual industries. This represents the highest level of complexity of the project.

Follows from this that the use of BIM technology requires a comprehensive account of building structure, shape elements. It is associated with precise representation of building.

An additional assumption method of BIM is the level of detail of the object, determined by the document (BIMFORUM. 2013) according to the model drawn up on the basis of 5 criteria LOD (level of development). It is selected from the range LOD100 for graphically depicting a simple model, or by means of a symbol to LOD500 characterized highest degree of detail. Which take into account the actual dimensions of the object on the site, geometry, shape, orientation. Also, it is important here distinction between the use of project documentation, depending on the destination (visualization, simulation, calculation of static and endurance). The basic premise of BIM technology is also the possibility of free exchange of data files between the participants of the construction process, hence the requirements for data recording format in IFC standard (TOMALA 2016, Polish Ministry of Infrastructure and Construction. 2016).

The reason for the wider use of BIM in the design, and the whole process of the project construction, the legal provisions and European requirements governing the use of this method in the Member States (Directive 2014, TOMALA 2016). Arrangements laid by the European Commission, will need to implement investments co-financed from EU funds, using BIM technology. In the US, and also from the beginning of 2016 in the UK (Industrial Strategy

2012), all investments in the public procurement must be implemented using BIM technology.

A major problem is data exchange in the form of files. BIM uses among other the IFC format for recording and reading data. IFC format (Industry Foundation Class) is a format for data exchange between applications AEC (Architectural Engineering & Construction). Allows to save the same standard information about the project components. This format is obligatoryin public procurement, in many countries using this technology (including the US, Denmark, the Netherlands).

## BIM in Polish conditions

In Poland, there are no clear regulations on the requirements, standards, and laws of governing investment implementation with the use of BIM technology. Taking the trend of the development BIM in other countries of the European Union and its popularity in the US, it is necessary to develop design standards with the use of BIM technology in Poland. Recent research carried out on behalf of the Polish Ministry of Infrastructure and Construction (2016) showed that more than half of the designers are interested in the implementation of BIM during create projects for the purposes of public procurement (Fig. 3).

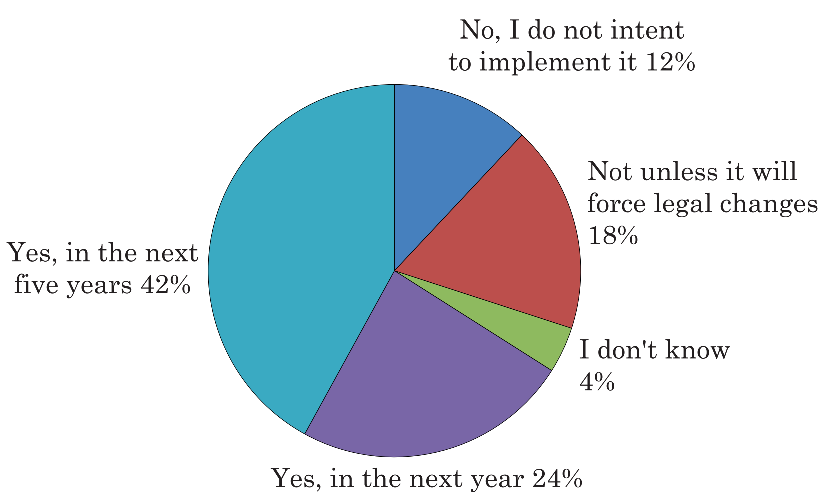


Fig. 3. Responses from a group of designers to the question: Does company considering investing in BIM technology in the future?
Source: based on *Building Information Modeling* (2016).

In the case of contractors, the majority of respondents also expressed interest in BIM technology. The main limitation is for contractors insufficient knowledge about new technology in the construction process (Fig. 4).

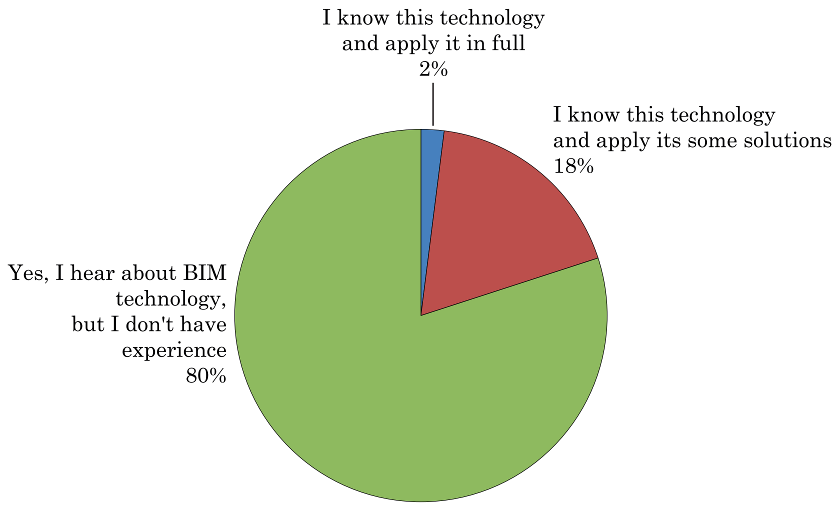


Fig. 4. Responses from a group of contractors to the question: Do you know the opportunity to use the BIM technology in the construction process. It is the technology of building information modeling, with the ability to design in 3D

Source: based on *Building Information Modeling* (2016).

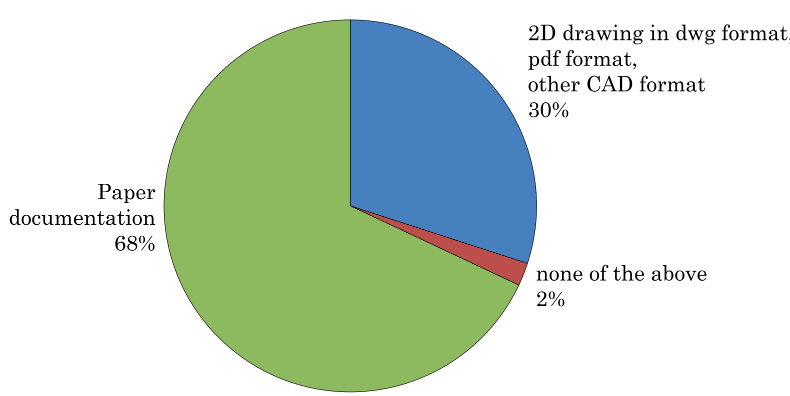


Fig. 5. Responses from a group of contractors to the question: In which form is most commonly transmitted design documentation in Mr./Ms company?

Source: based on *Building Information Modeling* (2016).

Also a major problem in the conditions of the Polish is a form of communication between designers and contractors. The research shows that the majority of respondents from the group of contractors said that dominates the paper documentations. Also 2D documentation in dwg format (Fig. 5).

From the data compiled in the research (*Building Information Modeling,* 2016) it shows that BIM technology has a good chance to improve the design process and cost management at all levels in the implementation a construction project. In the planning stage it is to use the experience of the UK and Finland (TOMALA 2016), in the correct definition of the model, data availability, interoperability between all participants in the construction process. The estimated cost of implementing BIM technology associated with the training of the participants a construction project (designers, contractors, sector specialists) will: 4.5 mld PLN. The costs of projects in the public procurement system in 2014 amounted to 133.2 mld PLN. Advantages of BIM confirmed in other countries where the technology has already been implemented, creating huge opportunities for effective use of funds from the state budget. This will allow the relocation of funds previously frozen on a particular investment.

## BIM in high buildings

High buildings in the Polish regulations (PAWŁOSKI, CAŁA 2013) are constructions from 25 to 55 m height. The use of BIM in the design and da management with the implementation of high buildings, enables the capture of data from each cycle the emergence of a building. Take into account fixed and variable loads over time, staging construction, repeatable and unique segments. Define additional loads of scaffolding, masts, machines or stiffeners. BIM technology enables the collection and management of huge amounts of data from the construction process. It allows to take into account the orientation of the reinforcement element in reinforced concrete or seismic loads. The article presents of the possibilities of using BIM technology in the design of high buildings, based on a novel approach takes into account in a single project, both CAD models and analysis of static-strength CAE models based on the finite element method.

Conducted static and strength calculations of the building along with the analysis of the eigenvalues of the constructions. Analysis includes only the structural elements object. The application of BIM technology, along with a new approach to the design of CAE/CAD, realized on the example of the planned building “Mogilska Tower” in Cracow (Semaco Invest Group).

## Material and methods

The analyzed building "Mogilska Tower" in Cracow, is a 15-storey building, with 3 additional underground levels, intended for car park. As one of the few in Cracow will be equipped with three-level underground car park. The planned investment has started in the spring of 2016 at the Mogilska street in Cracow. Construction has got a total height of 45 m a.s.l. The object serves as a multifamily residential building, with a separate service part on the ground floor. The building has a skeleton structure made of monolithic reinforced concrete supporting walls, pillars, floors and stairs as well as non load-bearing elements: walls of silicate blocks. Each floor plan is similar to each other. The values of material parameters, considered in the project were selected based on the standard (EN 1991-1-1:2002). The building visualization in presented at work SZWARKOWSKI, PILECKA (2017).

The adopted design assumptions in the model:

I. Geometry dimensions:
- the length of the building plan: 51 m; building width: 19.5 m,
- the length of the underground building plan: 51 m; underground building width: 56 m,
- supporting walls with monolithic reinforced concrete, 15 cm, 20 cm, 30 cm, 60 cm,
- walls of silicate blocks, 10 cm, 15 cm,
- slabs of monolithic reinforced concrete, 15 cm,
- stairs of monolithic reinforced concrete, gr. 15 cm.

II. Live loads (EN 1991-1-1:2002):
- living quarters, category A, qk1 = 2.0 kN/m$^2$,
- stairs, qk2 = 4.0 kN/m$^2$,
- balconies, qk3 = 2. kN/m$^2$,

III. Material properties (EN 1991-1-1:2002):
- volume weight of reinforced concrete elements, $\gamma$c = 25 kN/m$^3$,
- volume weight of steel element, $\gamma$s = 78 kN/m$^3$,
- volume weight of masonry elements from silicate blocks, $\gamma$sil = 18 kN/m$^3$,

IV. Type of analysis

The modeling includes the analysis of linear-elastic model and eigenvalues. Results of the analysis will be used to generate internal forces in elements of the structural walls, lintels, beams and slabs and allow for the design of reinforcement by standard requirements (EN 1996-1-1:2005), (EN 1992-1--1:2008). According to the recommendations contained in (EN 1996-2:2006), elements of the structural walls, lintels, should be calculated taking account of the vertical loads, second order effects, eccentrics, depending on the location of walls cooperating with the slabs and walls stiffening. The project includes eccentric of individual components at the level of detail LOD3. The analysis was conducted in the Midas nGEN approach combining modeling with building CAD analysis (CAE method). FEM analysis of the object was carried out on the basis of flat finite elements. Adopted mesh size equal to 0.5 m. Adopted at the level of the foundation unmovable boundary conditions.

***a*** ***b***

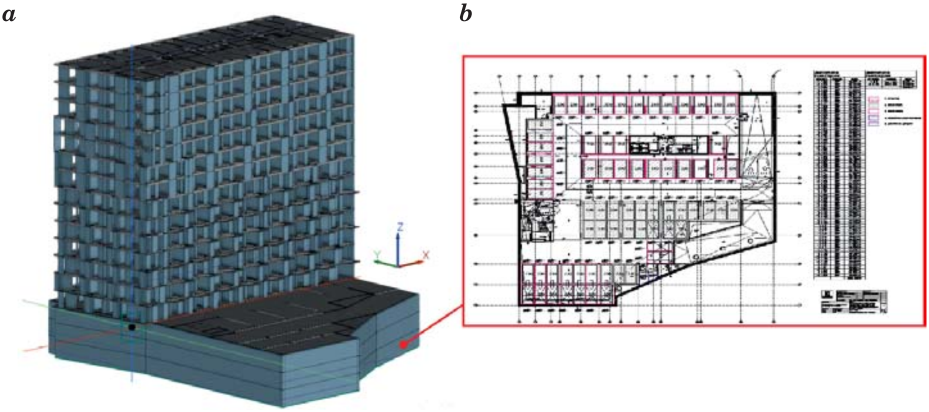

Fig. 6. Visualization model in program (*a*), underground floor of the building (*b*)
Source: own elaboration.

V. Dimensioning reinforcement

Elements of reinforced concrete, reinforced steel rods, designed based on (EN 1992-1-1:2008). The following assumptions:

– structural elements the aboveground part, $f_{ck}$ = 25 MPa, for concrete class C25/30,
– structural elements the underground part, $f_{ck}$ = 30 MPa, for concrete class C30/37,
– modulus of concrete, $E_{\mathrm{cm}}$ = 31 GPa, for strain $\varepsilon_{c1}$ = 2.1%.
– reinforcing steel, $f_{yk}$ = 400 MPa,

In the analysis of linear-elastic model was adopted reinforcing steel by Figure 7*a*.

At full nonlinear analysis, we should take advantage of the full characteristics of the stress-strain behavior of reinforcing steel and concrete. The building modeled in the Midas nGEN has the ability to export the model FEM programs take into account the full material nonlinearity.

– modulus of reinforcing steel, $E_s$ = 200 GPa,
– minimum thickness of concrete cover, $c_{\mathrm{nom}}$ = 40 mm,

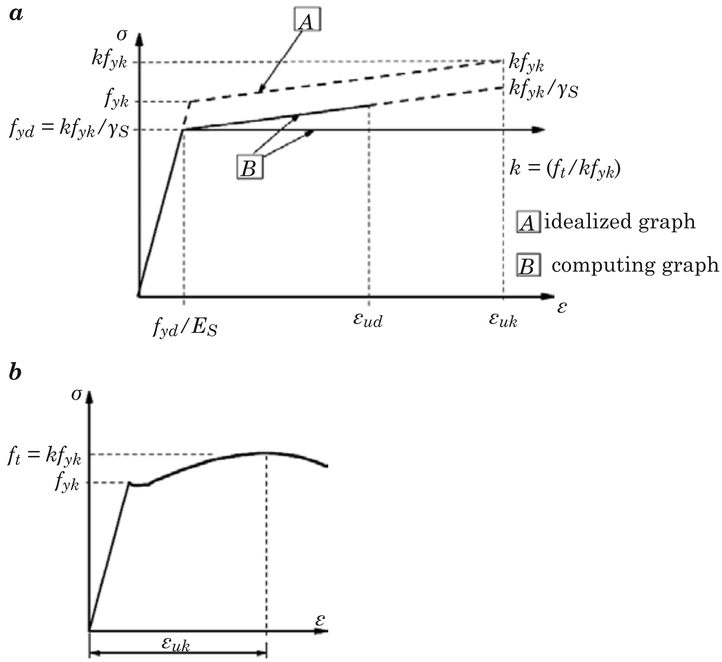


Fig. 7. Stress-strain graph of reinforcing steel, model in program (computing graph) (*a*), Stress-strain graph of a typical reinforcing steel (*b*)
Source: based on EN 1992-1-1:2008.

– the selection of the spacing rebar's was performed based on included requirements in EN 1992-1-1:2008.

VI. Serviceability Limit State (SLS)

Maximum deflection of model elements types: beams, plates, brackets, quasi static load should not be more than $f \leq L/250$, where $L$ is the span element. Arrow deflection values can be determined on the basis of formulas contained in Eurocode 2 (EN 1992-1-1:2008). The maximum deflection of the highest parts of high building should not exceed $L/500$ (PAWŁOSKI, CAŁA 2013).

VII. Snow load

The characteristic values of snow load for a building modeled determined based on the standard (PAWŁOSKI, CAŁA 2013). The object is placed in Cracow, located in zone 2 of snow loads. The characteristic values of snow load of the building was set on the basis of the formula 1 with standard (EN 1991-1--4:2008):

$$s = \mu_i C_e C_t s_k = 0.96 \text{ kN/m}^2 \tag{1}$$

where:
$\mu_i$ – ratio of the roof shape, $\mu_i = 0.8$, flat roof,
$s_k$ – characteristic value of snow loads, $s_k = 1.2$ kN/m$^2$,
$C_e$ – exposure ratio, $C_e = 1.0$,
$C_i$ – thermal ratio, $C_t = 1.0$.

VIII. Wind load

Wind load of the building was determined based on the standard (EN 1991-1-4:2008). It was assumed that wind direction operates in accordance with angle of 27 degrees to west elevation (Zone IX according to standard), and at an angle of 151 degrees to the south elevation (zone 6) (Fig. 8). The height of the building is equal 45 m. Overground floor plan has dimensions of 51 m × 19.5 m.

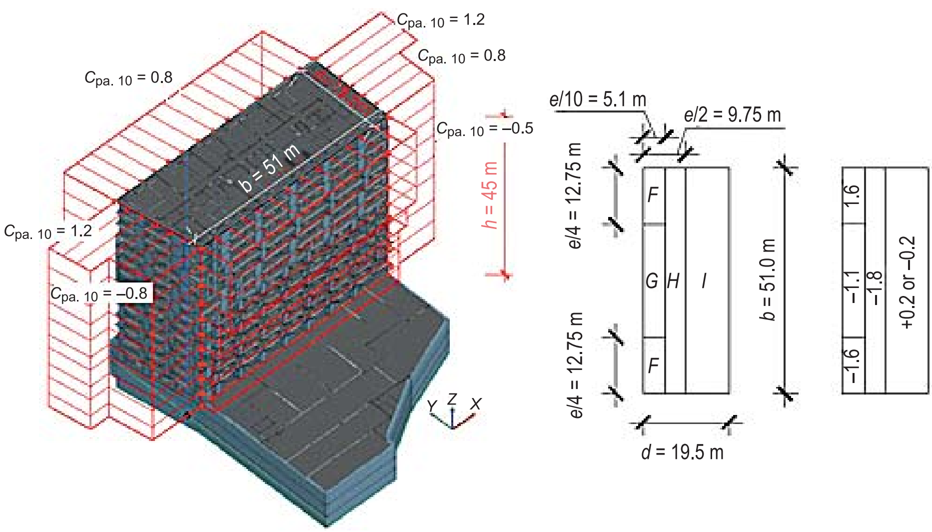


Fig. 8. Pressure peaks of wind speed, together with the distribution of external pressure $c_{pe,10}$
Source: own elaboration.

Calculation of the wind load object made according to standard (EN 1991-1-4:2008). Structural factor determined on the accordance with the logarithmic equation with standard (EN 1991-1-4:2008) and Article (ŻURAWSKI, GACZEK 2010) It assumes a fourth category of land for the urban area and the logarithmic decrement for concrete buildings equal to $\delta = 0.10$.

## Results

Frequency and oscillation period of construction were chosen based on the first the form of vibrations generated by modeling (Fig. 9). Following show displacements of the building obtained for the first and second form of vibration.

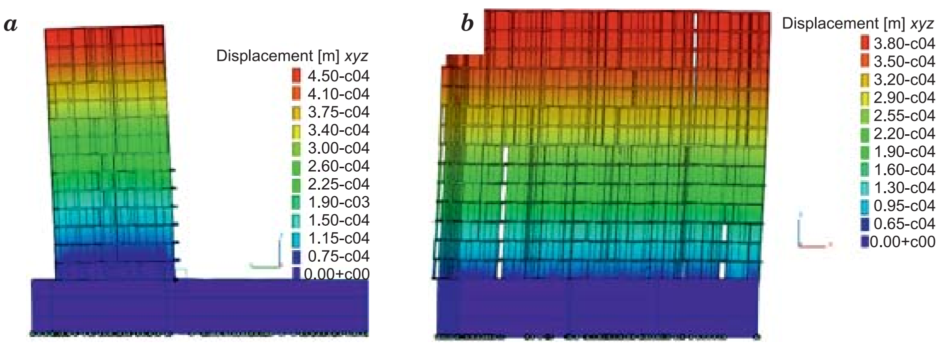


Fig. 9. First form of vibration model in the plane *zy*, for 2.71 Hz (*a*), second form of vibration model in the plane *zx*, for 3.01 Hz (*b*)
Source: own elaboration.

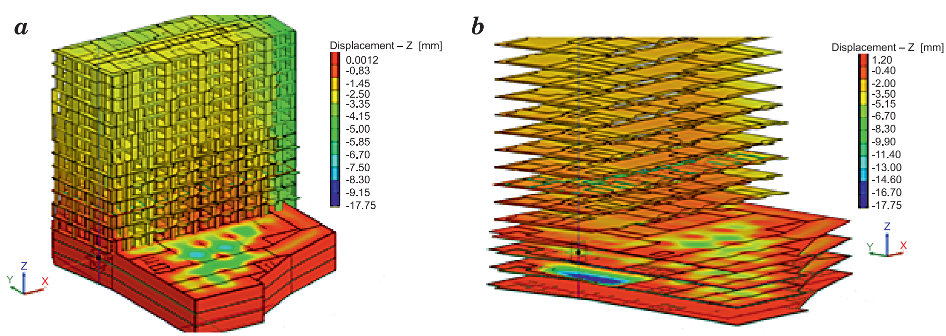


Fig. 10. Maximum vertical displacement building (*a*), maximum vertical displacement of slabs (*b*)
Source: own elaboration.

Figure 10*a* shows the vertical displacement of the building loaded with its own weight, live load and wind and snow loads. The obtained maximum vertical displacement slabs are equal 17.75 mm, and are lower than the limit value $L/250 = 30$ mm. In Figure 10*b* shows the maximum vertical slabs displacement.

Maximum vertical displacements lintels and substrings are equal 6 mm, and also meet the requirements of the SLS ($L/250 = 27$ mm).

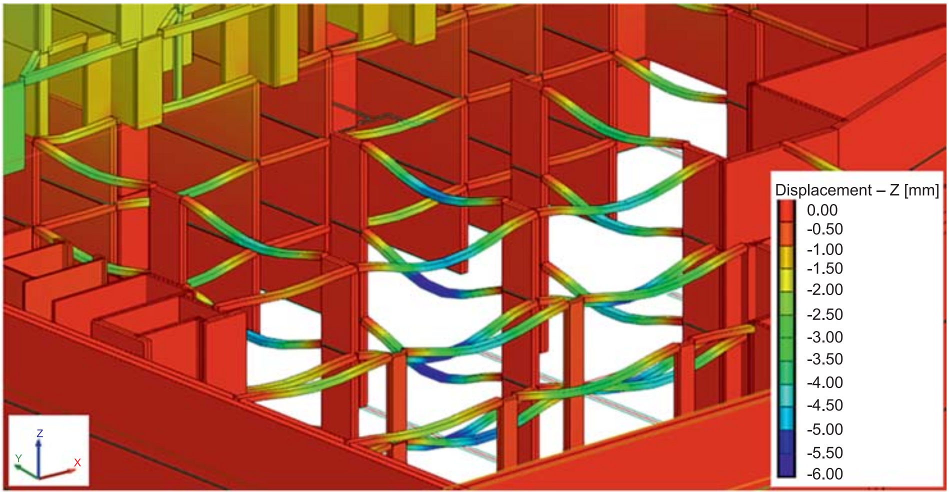


Fig. 11. Maximum vertical displacement of lintels and substrings
Source: own elaboration.

Figure 12*a* shows the horizontal displacements in the direction of $x$, in line with the greatest strength of wind pressure. While in Figure 12*b* shows the horizontal displacements in the direction of $y$. The value of horizontal displacements amounted to 2 mm in $x$-direction and 3.2 mm in the direction of $y$. Horizontal displacement value is less than the maximum value amounting to $H/900$ = 46 mm.

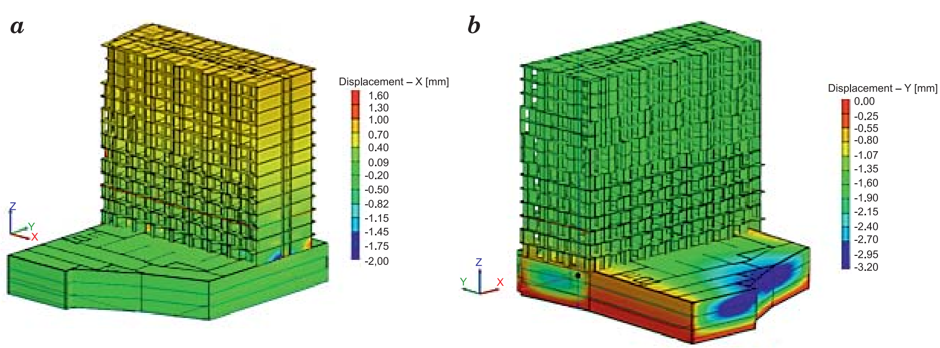


Fig. 12. Maximum horizontal displacement of construction in direction $X$ (*a*), maximum horizontal displacement of construction in direction $Y$ (*b*)
Source: own elaboration.

BIM technology allows the automatic generation of reports on the reinforcement and components used in the model. Parametric modeling of objects allows the changes made to the drawings are automatically included in the model space. Each element is defined in the project by the reference number (ID) to enable explicit definition of the model relative to other. This allows to optimize the structure of the arrangement of and the amounts of the reinforcing rebar sections or size of components.

## Conclusion

The article highlighted the need for the implementation of the public procurement BIM in the design and preparation of project documentation and documentation which is updated at each stage of the construction process. The application of BIM technology shown on example model of high building "Mogilska Tower" in Cracow, which was modeled using a new approach taking into account both traditional modeling 3D CAD as well as direct analysis of static-strength using BIM. The application of design methods discussed in the article creates a lot of opportunities in the process faster and more efficient data management implemented building. Additional possibility of this technology is the ability to use dynamic data. The individual elements can be optimized at every stage of the project and are automatically included in the model. In addition, any change in dimension, cross section, reinforcement is also changed throughout the project. Due to the volume of the article, not included the possibility of optimal development of reinforcement for individual components, and it is also advantage of BIM. The enormous amount of data collected at each stage of the construction process offer opportunities for their M in Polish conditionsoptimal use. BIM technology allows their use. However, large amounts of data may cause that the site managers instead of being proficient engineers of construction, more time will have to spend an extra obligation to enter information into the database of the building.

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