World of Real Estate Journal
ŚWIAT NIERUCHOMOŚCI

Analysis of the BIM Documentation Usefulness in the Field of Planned Multi-family Residential Area (building) – Case Study

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ABSTRACT

Purpose - The purpose of the article is to conduct a multi-criteria analysis of the BIM project documentation usage in the field of planning the implementation of a multi building design on the example of a specific project.

Design/methodology/approach - The collisions in the IFC model were verified in Tekla BIMsight software. The cost estimation and the construction works schedule of the planned investment were prepared in a software enabling the bill of quantities and the cost estimation creation in accordance to the BIM philosophy assumptions. BIMestiMate version 4.1 made by Datacomp company was used.

Findings -Based on the BIM model analyzed in this work, several conclusions were noted. Cost analysis using 3D, 4D or 5D models has many advantages over the analysis based on 2D documentation. Despite not the highest level of detail in the model, a collision analysis along with verification of the IFC file correctness, as well as the planned investment costs estimation were carried out for analyzed project.

Research limitations - The findings of this study have to be seen in light of some limitations. The primary limitation is that the study is based on the only one example. For the purpose of the results generalization, further studies are needed.

Research implications - Construction investors and developers can be informed through our study about the advantages of BIM software usage during the building investment planning process.

Keywords:	BIM; development investment; multi-family residential area
JEL codes:	R330; L740; O310
Article type:	research article
DOI:	10.14659/WOREJ.2020.112.05

INTRODUCTION

The development market is constantly growing on the real estate market in Poland. The developer at the investment planning stage should adapt an investment plan with its stages looking for answers to questions that may facilitate his/her choice, such as:

- to which customer group the investment is addressed to,
- what type of investment is appropriate in the given location,
- on which social group the investment will have direct and indirect impact?

After analyzing the above questions, the investor should consider the key issue of the economic profitability of the planned investment. However, not only the developer has an impact on the cost-efficiency of the investment. Actions such as the desire to reduce the duration of considered development investment, thorough market analysis and proper investment execution can minimize the investment risk level and also make the customer satisfied with the way their assets are located.

The use of Building Information Modeling (BIM) technology can help in achieving the investors goals. The possibilities offered by BIM in the civil engineering area are enormous. Currently there is a software which significantly shorten the entire investment documentation preparation in comparison to the traditional way of preparing it. Nowadays, many industries can work based on one model while co-creating it. This allows - with good work organization - to limit the number of problems that may appear during the construction on the building site.

The aim of the article is to conduct a multi-criteria analysis of the BIM project documentation usage in the field of planning the implementation of a multi building design on the example of a specific project.

LITERATURE REVIEW

The nature of real estate market makes it an attractive and lucrative asset for many investors (Awa, Nnametu & Emoh, 2019). Return is the basic motivating force and the principal reward in any investment process. In turn the development market becoming a bigger part of the whole real estate market (Peca, 2009). The development investment is a complex process and has a long lifecycle from initiation to completion. This is the process of investing capital, time, material and expertise to transform a piece of raw land or changing the usage of an existing property (facility) into a usable space that meets the demand of the tenants who are then welling to pay money for using it over a specific period of time. The value creation of this process is achieved by providing a usable space that meets the market demand at competitive price while it is profitable and sustainable. The transforming and usage changing processes in real estate development are achieved through initiating and completing successful well-coordinated projects within 3 parameters: 1) shortest time to market; 2) within the specified budget; and at 3) highest quality (Fayadh, 2020).

Therefore, at the investment planning stage, an attempt should be made to analyse the market in terms of inflation, expected demand for real estate, loan costs and possibilities of obtaining them by potential buyers. The type of object should also be adapted to the area in which it is designed. The risk in this industry may depend on many factors. The macroeconomic situation is crucial, but the global market situation is also non-negligible. Long-term decisions of potential clients often depend on the abovementioned conditions. It is also crucial to know the preferences of potential buyers (Plebankiewicz & Biel, 2017; Powichrowska & Prokopiuk, 2019).

The investors and clients pay more and more attention to environmental aspects. Sustainability principles become more popular in design, assessment, construction, exploitation and demolition of the buildings (Raslanas, Stasiukynas, & Krutinis, 2012; Trinkunas et al., 2018; Fan & Hui, 2020). Green building, as one of the solutions to reduce building energy consumption and construction waste, becomes a growing tendency. However, various barriers to green buildings adoption have emerged, among which cost barriers are often mentioned (Darko & Chan, 2017).

A developer can use various tools to achieve the abovementioned goals. One of them is the use of BIM technology. According the United States National Institute of Building Sciences (NIBS) "A BIM is a digital representation of physical and functional characteristics of a facility. As such it serves as a shared knowledge resource for information about a facility forming a reliable basis for decisions during its lifecycle from inception onward" (US National Institute of Building Sciences, 2007). The task of the BIM technology is therefore to support the activities performed during the entire life cycle of a building by providing information on the geometry of the building as well as descriptive information on the building and its individual elements. The main advantage of BIM is the possibility to collect data in one place, namely in the BIM model, together with the method of geometric presentation of the building structure in a three-dimensional view. Collecting data through the design, construction, and operational phases would allow for further analysis of these data, generating new insights and simulations to identify clashes and interdependencies (Zima, Plebankiewicz & Wieczorek, 2020). Moreover, creating new methods of data visualization using visual and mixed reality improves communication and provides on-site information (Elagiry et al., 2019; Hamidavi, Abrishami & Hosseini 2020).

Unexpected events nearly always occur during construction projects, i.e., design errors, reworks, and schedule delays (Ham et al., 2018). Uncertainty and the unexpected events themselves can lead to additional transaction costs (Lee, Park & Won, 2012). Advantage of BIM is the possibility to check the geometry and information included in the model easily and quickly. Revising the possible clash detection which can make works difficult to implement in order to discuss other solutions or remove errors occurring already at the pre-execution stage, is a significant advantage of the BIM technology.

Many studies confirm the advantages of using the BIM technology in the entire investment process (Lee, Cha & Lee, 2018; Won, Cheng & Lee, 2016; Lee & Lee, 2020). These studies reported that the design review has effects on various tangible or intangible benefits, such as preventing rework, reduction of errors and omissions, construction cost overruns, schedule delays, safety, and quality. Khanzode, Fischer& Reed (2008) reported that the rework costs were reduced to 0.2% of the work costs by using BIM; as a result, the schedule of the project was reduced by 6 months and the costs were reduced by about $9M for the overall project. Lee, Park and Won (2012) proved that 22-97% was derived by converting 709 design errors detected by BIM into rework cost savings. Won, Cheng amd Lee (2016) estimated the amount of construction waste prevented by a BIM-based design validation process based on the amount of construction waste that might be generated because of design errors. Lee et al. (2018) estimated the BIM impact on preventing rework in their case study and determined that approximately $314,000 was saved by BIM adoption. In several cases, return on investment (ROI) results have been proposed without details about data collection and analysis methods (Ghaffarianhoseini et al., 2017).

RESEARCH METHODOLOGY

The analyzed investment property is located in Łódź Province, in the Bełchatów County. The proximity of well-developed road infrastructure, together with the property location in the center of Poland, enables to reach many places in Poland, as well as the whole Europe easily and quickly. The location, in the nearby of Bełchatów town and large workplaces such as, among others, the coal mine in Bełchatów and the power plant PGE Bełchatów, increases the potential of real estate. Due to the fact that large workplaces are located in this area, the society is relatively rich. It is shown on the Fig.1 the purchasing power in different Counties in Poland, which was published by the Polish Central Statistics Office (GUS).

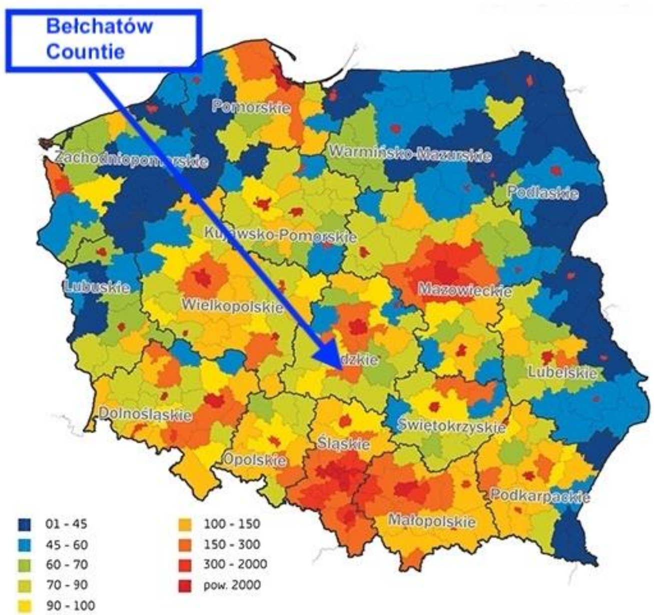

Figure 1. Purchasing power in different Counties of Poland
Source: the Polish Central Statistics Office (GUS).

Unfortunately, factors affecting favorably from an economic point of view, are very negative from the ecological point. According to the Environmental Protection Plan of the Kluki Area, there are adverse aero-sanitary conditions. The main sources of air pollution in this area are:

- power plant dust particles emission,
- dust particles and gases emissions from local furnaces and production plants,
- gas emissions from transportation due to the location of a national road in this area.

The pollution share coming from the power plant in Bełchatów in the total Łódź Province pollution emission was: 86% of the total SO_2 emission, 78% in the case of NO_2, 69% in the case of CO and 30% in the case of dust (PM 10 and PM 2.5). [1]

[1] Report on the environment condition in the Lodzkie Voivodship Jubilee Edition, Regional Environmental Inspectorate in Łódź, Łódź 2018; https://www.wios.lodz.pl/files/docs/raport_2017.pdf (29.05.2020r.)

In November 2019, during an inventory of the planned investment, an interview with the owner of building lots – the potential investor - was carried out. The owner described the initial plans for this property. Figure 2 shows the expectations of the investor in planning the housing area on the property.

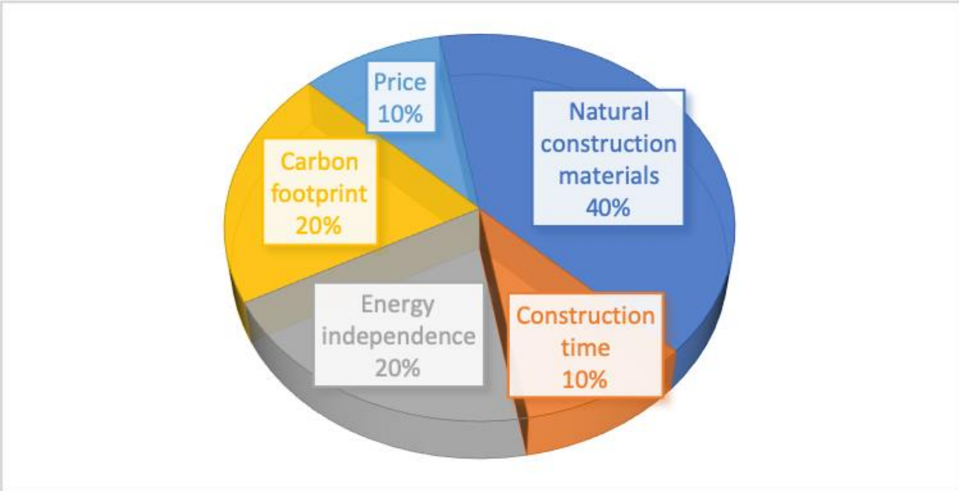

Figure 2. Investor's expectancy based on the interview
Source: own elaboration.

The planned investment consists of 15 building lots with one common mortgage register. The lots areas are ranging between 1362.9 m^2 and 1161.3 m^2. The status of the farm land has been changed, the investor obtained building conditions for residential buildings. The property has now the building lot status, excluding the separated part where the access road is planned. Fourteen semi-detached houses are planned to be erected on these lots. In addition to houses, the investment will include land development together with the car park on the lot number 15.

All houses are designed in the same way and shall be sold after the building completion. Prefabricated walls and ceilings in the Holz 100 system from Austrian producer has been designed. The envelope is composed of 36,4 cm Holz100 wall core and 12 cm soft wood fibre, 5 cm unventilated air gap and 2,4 cm external formwork. Northern part of the building which consists of garage, boiler room, WC and the entrance is designed to be built from Ytong forte system. External envelope of this part of the building is composed of 30 cm Ytong forte, and 15 cm mineral wool thermal insulation. The dilatation wall separating both parts of the building is a double load-bearing Ytong forte wall (30 cm) with a 5 cm mineral wool insulation in-between.

The building was designed in the BIM level 2, which provides the information in the so-called 4th and 5th dimension. These dimensions relate to information about time and costs. It gives the opportunity to estimate the duration of the construction works and its anticipated costs much faster. ArchiCAD software was used to make the documentation, in which both the 2D projections as well as 3D model were created. One of the most important functions offered by the ArchiCAD software is "2D documentation creation simultaneously with the model preparation. Each designer decision can be checked on a model of the object, which is shown on a 1:1 scale." (Ślęk, 2013). The model was then exported to an IFC file, which enabled further planning of the project.

The model was exported to the IFC file and checked for its preparation correctness in Tekla BIMsight software. It is a software enabling inter-branch coordination in the process of creating a BIM project. This software is available for free and acts as a kind of model viewer for the IFC files. It gives the opportunity to find collisions in the model so that the errors of the designer or a group of designers are eliminated in an easier and faster way than before. The abovementioned features show the manufacturers commitment to the openBIM philosophy.

In the software described above, a model analysis of one building of the development estate was performed. This analysis can be useful in the future for any of the buildings because they are multiplicated along the entire street length of the planned investment. The collision search option allows the software user to define criteria of one or more models that the program will find and define as collisions.

The user defines tolerance intervals for considered conflicts between model elements. After the collisions detection in Tekla BIMsight, the user can see the number of them occurring in the project. In addition, it is possible to select a given collision from the list and display it while at the same time dimming the visibility of other objects. This option significantly speeds up the checking procedure for design errors contained in the given project.

The next stage of the investment planning procedure is determining the cost and the construction time. For this purpose it is necessary to prepare a bill of quantities. Considering the usability of BIM technology for the bill of quantities process, it should be noted that this technology "allows the user to increase control over the work progress, facilitate access to objects' specific data, notice the scope and scale of individual works. This has a direct impact on reducing the time needed to prepare the bill of quantities, as well as minimizing the risk of errors at this stage of the investment process." (Orlińska-Dejer, 2018).

There is a lot of software helping to perform the bill of quantities available on the Polish market, which are more or less developed depending on the manufacturer. In practice, three of them are the most popular on the market: BIMestiMate, Norma Pro and Rodos.

BIMestiMate is the new version of the ZUZIA software. It is produced by Datacomp company. It combines the functions originally available in the ZUZIA and the latest trends, which gives the user opportunity to measure objects, perform bill of quantities and the construction works schedules using traditional techniques as well as BIM technology by uploading IFC file to this software. BIMestiMate has uploaded over 300 KNR catalogues and standards. This program is flexible and open in terms of data exchange with other programs due to the fact that it gives the ability to save and import the cost estimation or the bill of quantities in many file formats.

Norma Pro is one of the software from the Athenasoft family. In addition to Norma Pro, which is a very well-developed software that allows the user to perform bill of quantities in a traditional way, the manufacturer has created a new program that is a natural development of Norma Pro - Norma Expert. The Norma Expert software, like BIMestiMate, provides the possibility of cost estimation using BIM technology.

Rodos is a standard cost estimation software. What distinguishes it from other manufactures is the access to a very extensive database of over 400 standards and KNR catalogues.

The new versions of abovementioned software types are constantly updated and adapted to the market requirements. The manufacturers pay attention to new technologies, thanks to which the cost estimation process is becoming more and more transparent and precise. During the past few years it has also become one of the components of the building planning process in the modern BIM technology.

The cost estimation of the planned investment was prepared in a software enabling the bill of quantities and the cost estimation creation in accordance to the BIM philosophy assumptions. BIMestiMate version 4.1 made by Datacomp company was used. This software allows also the user to prepare a construction works schedule after the bill of quantities creation.

While creating the construction works schedule, there is a possibility to select an appropriate level of detail in the BIMestiMate software. The user can choose to generate a schedule based whether on groups or elements. In the schedule configuration options there is also a possibility to choose the number of hours the construction team will work during one day, the number of employees in the team and the number of working days during the week. The last possible aspect is the selection of the leading parameter.

RESULTS & DISCUSSION

The collisions in the IFC model were verified in Tekla BIMsight, the software has found 600 collisions in the building model (Fig. 3). Most of them are collisions related to the building walls, slab and the curtain wall. Some collisions were found between the building elements and the group called "Space". These are intangible elements designed only for computational purposes such as determining the volume and making an inventory of the rooms.

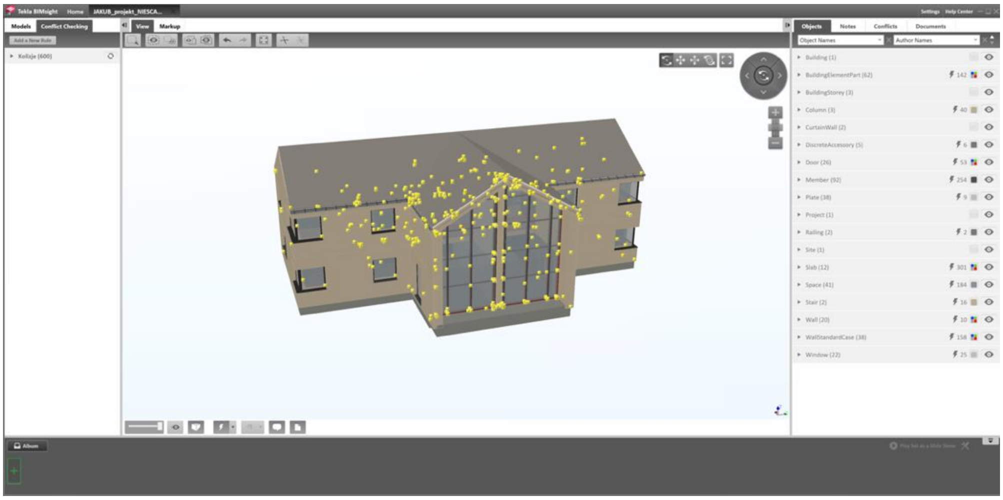

Figure 3. View of the building model collisions
Source: own elaboration.

As an example, the wall case is described. Three groups consisting of walls has been created in this IFC model. (Fig. 4) Such dispersion of elements is not correct. The Thoma Holz 100 system wall element has been assigned to one of three groups of elements in which the walls are located. The wall has the name given by the designer - "Wall - external insulated thoma". The element belongs to the load-bearing object part, which is correct. The sum of the thickness of the described layers corresponds to the thickness of the layers in the model. Not all layers in the design are described correctly, for example, to one of them the material "Timber - Roof" has been assigned. Besides all walls, also slab over 1st floor is assigned to the groups of walls, which is presented at the Figure 4. This is another designer’s mistake. Other layers are described correctly. In addition, it is not possible to verify the correctness of the wall length and width graphically with its description, because such information were not included in the IFC file.

Figure 4. View of the groups of wall elements
Source: own elaboration.

As an example the verification of one, specific wall collisions was conducted and the result is presented (Fig. 5 and Fig. 6). It is a wall located on the ground floor in the eastern part of the building. It has 2 collisions, both with elements from the "slab" group of elements. One of them is the collision with the foundation slab and the other one is a collision with the slab between ground - and the first floor. The situation is caused by improper connection design and it is the designer's mistake. In BIM documentation design it is very common that collisions in a form of various kind of elements' overlap appear.

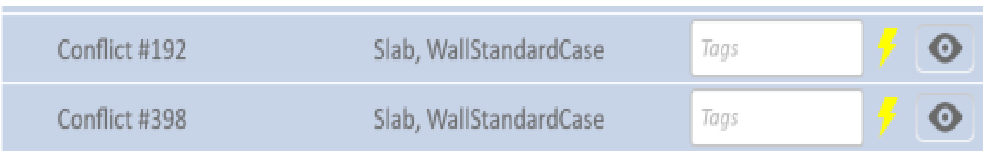

Figure 5. Number of collisions in the selected wall
Source: own elaboration.

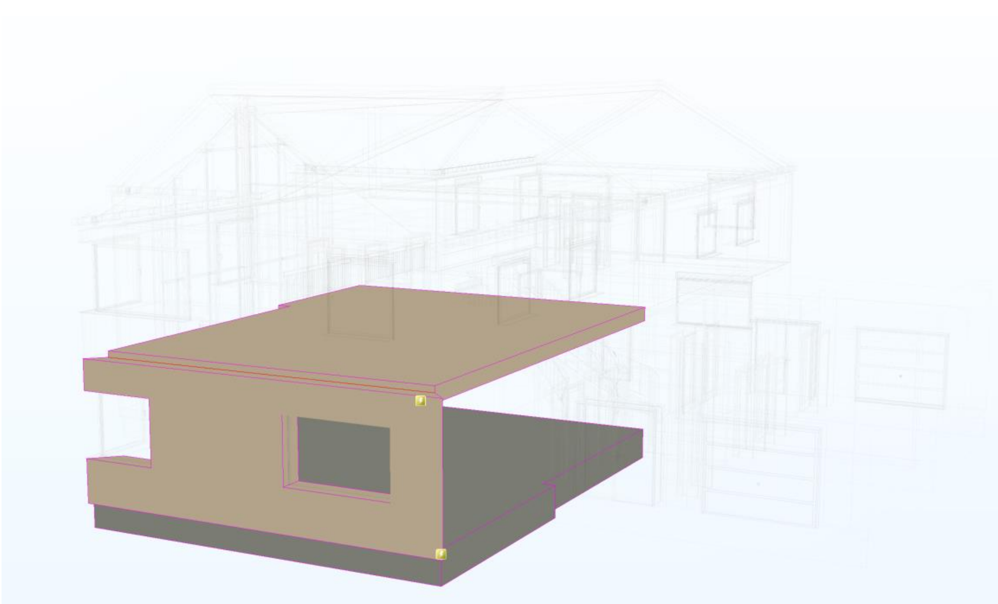

Figure 6. View of the selected Thoma Holz100 wall and its collisions
Source: own elaboration.

The analysis allows to conclude that the BIM model of the designed house is not 100% completed. There are no significant structural elements included in the model, the best example is the lack of information regarding reinforcement in the foundation slab. Technological solutions of details were not designed, however they are necessary in the building permission design. Information about building parts such as stairs, doors and windows was also omitted in the checked IFC file.

Grouping of some elements was not done correctly. For instance, the foundation slab, floor slabs and roof elements were classified together, into one group, however they should be diversified due to the transparency of the design and their different construction character. The slab between first floor and the unheated attic was grouped together with the walls, in a different category from the other slabs. In the design, wall elements with various technological solutions have been assigned to three different groups without appropriate division. The lack of transparent grouping method can lead to further problems in elements identification and can also create mistakes generating additional costs.

Additionally information, such as the element material type, descriptions of properties or product names contained in the project is missing. Windows and doors have their graphic reflection, but their manufacturer together with their technical parameters have not been delivered. However, it is possible to measure both the surface and the volume of given elements based on their graphic reflection.

The model does not meet the requirements for advanced BIM levels of detail. Based on the analysis of selected parts, it can be seen that the model meets all the LOD 200 level requirements. This level of detail corresponds to the architectural concept of the object. There are also elements in the model whose presence indicates the so-called general level of detail - LOD 300. The considered model level of detail can be assessed as uncompleted general and named "LOD 250", which would correspond to an advanced architectural concept, without some specific structural solutions.

The appropriate activities coordination in the process of creating an investment is extremely important. Starting from the architectural concept, ending with the building service, all these tasks shall be interrelated to each other. Many activities in the object design process were originally duplicated. This led to an unnecessary increase of the documentation amount, introduced chaos and made it difficult to use the content. When preparing the cost estimation, KNR Catalogs and BCO - Bulletin of Construction Objects were used, as well as prices obtained directly from producers.

The building model did not contain complete information about it. Due to this fact, elements such as reinforcement of the foundation slab or installations were calculated based on assumptions. The reinforcement was estimated as a percentage of the concrete volume in the foundation slab, while the installation costs were assumed on the basis of the BCO catalogue for a similar project of a timber semi-detached building. The cost estimation was prepared for the building in the so-called developer standard, therefore elements such as interior doors, were not included in the estimation of the planned construction costs.

The BIMestiMate software allows to create a construction work schedule after creating an estimation. In the case of a multi building investment, this is unfortunately difficult due to the fact that the multiplication factor, which defines the number of buildings (14) and calculates the costs of the entire housing estate, indisposes the staging process of planned construction works. Additional problems described in the previous part of the article reveal another obstacle. In practice, in order to reliably create a schedule of construction works, the designer should use another software, specially dedicated for this activity. It is much more time-consuming and more expensive. Unfortunately, it is also inconsistent with the BIM philosophy that everything that has already been done can be used in the further steps of planning and using the designed building.

There are computer software for cost estimation that allow the user to upload an IFC file, as well as software for creating construction works schedule. Unfortunately, in many cases, the BIM 4D and BIM 5D software are not compatible with each other. In practice, the bill of quantities and the cost estimation created in one software do not shorten the time needed to prepare the schedule and vice versa.

Limited capabilities of computer software unable the preparation of the construction works schedule and the cost estimation of the modeled multi building investment in one cohesive computer software.

CONCLUSION

Based on the BIM model analyzed in this work, following conclusions were noted. Cost analysis using 3D, 4D or 5D models has many advantages over the analysis based on 2D documentation.

Table 1. BIM parameters

Dimension	Information included in certain BIM dimension	Advanatages of certain BIM dimension implementation
3D	3 dimensional model	Possibility of quick collisions finding.
4D	+ time	Improved control of construction works schedule.
5D	+ cost	Higher precision of the bill of quantities and reduced preparation time.
6D	+ energy demand parameters	Possibility of environmentally sustainable design introduction.
7D	+ Life Cycle	Life cycle cost analysis as well as possibility of BIM usage during operation stage.
∞D	+ „?” D	BIM can deliver much more possibilities.

Source: own elaboration.

Traditional (2D) documentation is often ambiguous and due to the lack of the object visualization, there is a certain uncertainty level in relation to the actual designer’s concept . The traditional drawings interpretation, not necessarily consistent with the vision of the designer, may be fraught with errors causing incorrect determination of the construction costs. In this case, both underestimation and overestimation of the costs can generate unnecessary problems. However, the 3D model allows the user to estimate the construction costs with greater accuracy. The introduction of the 5D model in the development investment planning process means that the investor will receive at the early designing stage all information regarding materials and their costs. In this way, the most price determining factors can be identified, as it was in the analyzed investment with the Thoma Holz 100 system.

Despite not the highest level of detail in the model, the analyzed project carried out a collision analysis along with verification of the correctness of the IFC file, as well as the costs estimation of the planned investment. The conceptual model, which did not contain detailed design solutions, was very useful. Despite finding deficiencies in the subsequent phases in the IFC file, it was possible to prepare a complete cost estimation of the entire investment. The time spent on creating this cost estimation was disproportionately shorter than the time needed to create a cost estimation based on traditional, 2D documentation.

Based on abovementioned cost estimation, no construction works schedule was created. Due to the primitive nature of the schedule creation option, based on the cost estimation created in this software, multi building investments cannot be properly planned in time. This is not a positive conclusion, but definitely interesting one. Certainly, in the future, along with the development of BIM and the IT progress, the compatibility of individual BIM dimensions will be increasing.

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