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3. Requirements for BIM model

Maciej Major[1], Jacek Nawrot[2], Izabela Major[3]

[1] *Czestochowa University of Technology, Faculty of Civil Engineering, Częstochowa, Poland, mmajor@bud.pcz.pl, orcid.org/ 0000-0001-5114-7932*

[2] *Czestochowa University of Technology, Faculty of Civil Engineering, Częstochowa, Poland, jaceknawrot@o2.pl, orcid.org/0000-0002-9581-1388*

[3] *Czestochowa University of Technology, Faculty of Civil Engineering, Częstochowa, Poland, imajor@bud.pcz.pl, orcid.org/ 0000-0003-1234-9317*

Abstract: The paper discusses the requirements that should be met by a properly designed BIM model of a building structure in the phases of design, construction and use. The scope of potential information contained in the model in the context of its multidimensional character was presented. The knowledge of BIM modelling was reviewed, with particular emphasis on barriers and problems related to the use of this technology in different areas of the investment process. The factors that should be taken into account to create a BIM model that can be effectively used at all stages of the life cycle of a building were discussed.

Keywords: BIM model, interoperability, IFC standard

3.1. Introduction

The building information modelling (BIM) technology is increasingly being used in the implementation of construction projects, also in Poland. Its application allows for a reduction of costs associated with the construction and use of the building and effective management of its entire life cycle, from design through construction to the phase of use. In order to make it possible, a virtual model of a building (the BIM model) should be a perfect reflection of the actual building at every stage of the investment process and use, the so-called detailed model. The digital model should be updated on an ongoing basis and take into account all possible corrections in relation to the design and changes resulting from repairs and modernizations made after the facility has been put into service.

An important issue related to the model quality and the way it is created is the so-called BIM maturity levels (Fig. 3.1).

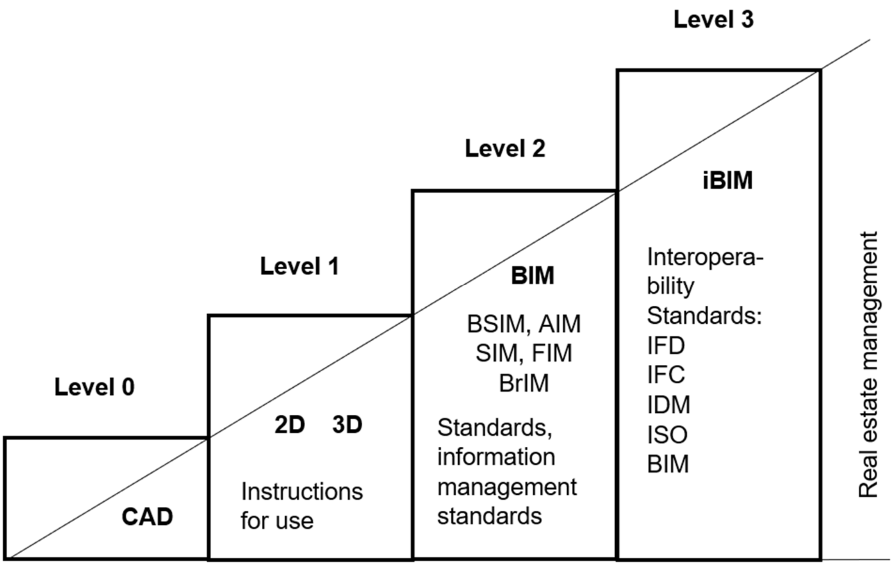

Fig. 3.1. BIM maturity levels: author's own elaboration based on "A report for the Government Construction Client Group", 2019; acronyms used in the figure: CAD - computer-aided design, 2D - two-dimensional modelling, 3D - three-dimensional modelling, BIM - building information modelling, BSIM - building services information model, AIM - architecture information model, SIM - structural information model, FIM - facilities information model, BrIM - bridge information model, IFD - international framework for dictionaries, IFC - recording and exchange format for virtual building models, IDM - documentation guidelines for information exchange

Level 0 is the stage preceding the application of BIM. The primary carrier of information is the paper design documentation (2D), which is prepared with the use of CAD programs. Level 1 BIM is characterized by the creation of spatial models for individual disciplines (architecture, structures, installations), but there is no exchange of information between individual participants of the design process, the design documentation (2D drawings) is also in paper form. Level 2 BIM means the creation of an integrated 3D building model that contains information on architecture, construction, installation and building management, without the need for this information to be contained in a single file. Based on the resulting model, it is possible to detect possible collisions between individual disciplines and automatically create 2D documentation. BIM Level 3 is characterised by the generation of a model containing all required information about the building in one file, linked (if necessary) to external databases, while two-way communication between the model and external data is ensured. All participants of the investment process (within the framework of their authorization) have continuous access to the model, which allows for obtaining information, updating data and cooperation, termed model interoperability. At the moment, due to the high requirements of the appropriate IT infrastructure, data transmission speed, database security, etc., level 3 is the objective currently being pursued by BIM.

The requirements for BIM models can be classified according to the two general concepts, LOD (Level Of Detail or Development) and LOI (Level Of Information). However, there are also many other additional requirements related to the prepared model and the objectives of its development. It should be stressed that, depending on the needs, the BIM model may be the basis for coordination and verification of solutions adopted during the design process. Furthermore, it may be used during the construction process, as well as serve other purposes, such as those related to the development of visualization critical at the stages of planning and implementation of the investments serving marketing purposes.

Due to the nature of the information contained in the BIM model, its multidimensionality can also be highlighted (Fig. 3.2). The acronym 3D refers to data concerning spatial geometry of the building (architecture, structure, installations). By adding another dimension i.e. time, a 4D model is obtained, which can be used to create schedules for the progress of works and deliveries. Supplementing such a model with construction costs yields the 5D model, which allows for preparation of cost estimates and construction budget. By adding information about the environmental impact of the investment (noise level, amount of waste generated) one can move on to the 6D model, which, supplemented with information on the use (utility consumption, data on repairs and maintenance) becomes the 7D model.

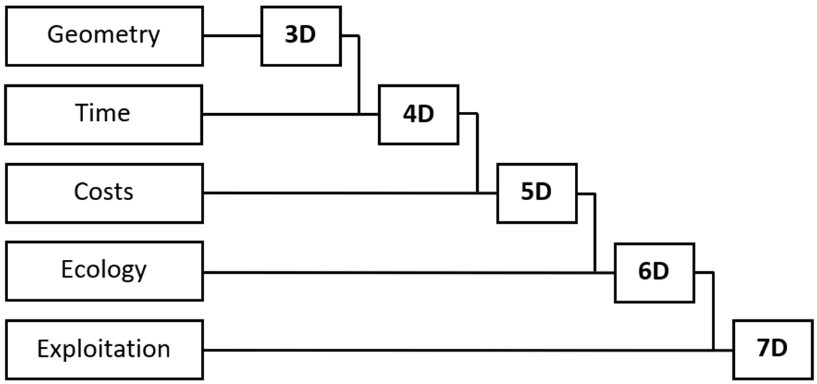

Fig. 3.2. Individual dimensions of the BIM model depending on the scope of information: author's own elaboration

Effective implementation of BIM technology in Poland requires the development and implementation of regulations that would regulate underlying issues such as the creation and management of BIM documentation, the scope of responsibility of the parties in the investment process, exchange of information, etc. Despite attempts being currently made by various institutions (e.g. PZITB and Polish Association of Construction Employers), no such regulations have been developed and implemented yet. Consequently, BIM users are to some extent based on Western standards (e.g. British standards covering PAS 1192-2) and the details of the complexity of the model (the scope of the information contained in the model) are governed by contractual agreements. Apart from formal and legal problems, a critical issue is to determine the requirements that should be met by an adequately construed model of BIM building in order to be effectively used by all participants of the investment process. In this paper, an attempt has been made to specify such requirements for particular stages of the life cycle of a building.

3.2. Literature review on BIM

BIM modelling can be used for different purposes by different participants in the investment process, but it is essential to define the principles of communication and cooperation between all stakeholders of the process (Papadonikolaki *et al.*, 2019). The benefits of using this technology in the design, construction or management of a building are well known (Ghaffarianhoseini *et al.*, 2017). An interesting proposal is to use the BIM model in building sustainability assessment (BSA). Carvalho *et al.*, 2019, proposed the SBToolPT-H (Sustainable Building Tool) method to assess the sustainability of new and renovated buildings. The process takes into account the assessed 25 criteria (e.g. use of recycled materials, water demand, thermal comfort, etc.), of which as many as 24 criteria can be obtained directly or indirectly from the BIM model itself. The actions taken at this level aim to develop an automated BSA method in order to identify and compare different sustainability design scenarios as early as at the concept choice stage. It is worth emphasizing here that in certain situations the BIM model created in the design phase and used in the implementation phase requires the necessary modifications in order to be further used for various analyses (e.g. energy performance analysis of a building). This is the case, for example, if a more complex building geometry is used, when the problem may occur with the transformation of the IFC (Industry Foundation Classes) file containing information about the BIM model to the building energy model (BEM). This situation occurs, among others, in objects with curved surfaces. Ying and Lee, (2019), proposed an algorithm for the automatic transformation of curved wall geometry into polyhedrons, which can be further processed by available transformational approaches. With this algorithm, arched surfaces are converted into multi-walled geometries while maintaining correct geometric proportions and a new IFC file is generated, which can be imported into the BIM model of the designed building using the available transformation tools. The use of the BIM model to assess the energy consumption of buildings was also discussed in the paper of by Andriamamonjy *et al*., 2019, where a set of tools needed to obtain information from the BIM model to the so-called grey box model used to optimise the energy performance of a building is presented. Since the highest cost component in the entire life cycle of a building is its operating costs (accounting for ca. 80% of total costs), (Kasznia *et al*., 2019), BIM models should be developed in such a way that they can be effectively utilized in facility management (FM) (Pishdad-Bozorgi *et al*., 2019). Nowadays, this becomes a necessity and should be developed during the preparation of the BIM model. In addition to economic aspects, the BIM modelling used in FM improves the quality of life (QOL) by ensuring a higher level of functionality of the environment built through integration of people, place, processes and technologies (Aziz *et al*., 2016). Another issue related to building management is the integration of BIM and the Internet of Things (IoT). Tang *et al*., (2019) indicated the objectives of research that should be undertaken in order to establish BIM-IoT integration standards, solve problems with interoperability and cloud computing. Barriers related to the adoption of the BIM model for the needs of building management by large organizations of owners were presented in the paper of Cavka *et al*., 2017. A method of identification and characterization of owners' expectations was developed in order to adjust the information contained in the BIM model to their individual needs, which sometimes constitute the essence of things to the extent that it unequivocally forces the final solutions. In some cases, the solution preferred by large contractors is to outsource the implementation of the BIM model to external entities, i.e. specialized IT companies with experience and competencies enabling them to obtain target solutions that guarantee their high level. This approach helps avoid potential model errors or imperfections due to the insufficient experience of the contracting entities in BIM modelling. However, the results of research conducted for the US market showed that outsourcing of such services is less efficient than internal BIM (Fountain and Langar, 2018), because a common phenomenon during BIM modelling is making further adjustments to the model, and these should be preferably implemented in an internal team directly involved in the construction process. Furthermore, Juszczyk *et al*., 2016 discussed problems related to change management in the BIM model and presented tools dedicated to this process since BIM in the phase of building construction (realization of the investment process) can be used not only at the construction site but also in the structure prefabrication plant. The issue of applying BIM modelling in manufacturing of prefabricated building components was discussed in the paper of Tan *et al*., (2019), which indicated the major barriers to the implementation of this technology and proposed a three-level strategy for its implementation in order to achieve the intended final results. The BIM modelling, which is focused on the digital representation of buildings (construction objects) at the micro level, is complemented by the geographical information systems (GIS) system, which ensures representation of the external environment of buildings at the macro level (Wang *et al*. 2019). Correct BIM-GIS integration is the key to the next stage of building digitalization, enabling the creation of a virtual model of not only individual buildings but also the entire urban space covering both the housing estate and the entire city in the future.

3.3. Requirements for BIM models

A problem that concerns all phases of the life cycle of a building is the adaptation of the scope of information contained in the model to the needs of individual users, while an important issue is a certain unification of the complexity of the models due to the set of information assigned to them. This issue was resolved by the American Institute of Architects developing a classification of the levels of development (Level of Development - LOD) of BIM models, as already mentioned in the introduction. This classification implies that each level of LOD is assigned an appropriate level of detail of the information contained in the BIM model (Table 3.1).

Table 3.1. LOD classification for different degrees of detail of information in the BIM model; author's own elaboration based on Level of Development (LOD) Specyfication, Part I & Commentary, For Building Information Models and Data 2019

LOD	Data content
100	A model element is represented by a symbol and does not need to have a real shape, size or precise location. All information contained in the LOD is approximate. It does not meet the requirements of LOD 200 (without geometric data).
200	An element of a BIM model is graphically represented in the model as a general system, object, or assembly with approximate size, shape, position, and orientation.
300	A model element is graphically represented in a model as a specific system, object, or assembly in terms of quantity, size, shape, location, and orientation. Its quantities can be directly measurable from the BIM model, from which project documentation can be generated.
350	A model element is graphically represented in a model as a specific system, object or assembly in terms of quantity, size, shape, location, orientation and connections with other building systems (supports, connectors).
400	A model element is graphically represented in a model as a specific system, object or assembly in terms of size, shape, location, quantity and orientation along with details, and information about manufacturing and assembly. The quantity, size, shape, position and orientation of the designed element can be measured directly from the model.
500	A model element is a representation verified in a real object in terms of size, shape, location, quantity and orientation (e.g. through a 3D geodetic inventory). This level does not involve a higher level of detail of the model geometry, whereas LOD 500 does not have to be a detailed upgrade of the LOD 400.

As a general rule, the higher the level of detail of the model, the higher the LOD level. Of course, this classification was prepared by taking into account the realities of the US market, but in the absence of similar regulations in force in Poland, it is used by national operators using BIM technology to carry out the construction process, even though, as mentioned above, there is currently no internal standardization in this respect.

3.3.1. Design in BIM technology

Since the BIM model is mainly developed at the design stage, it is essential that it is properly developed from the very beginning. Any mistakes made in this phase of the investment project will have consequences on further stages of working with the model. The first and most important issue is to ensure interoperability, i.e. the possibility of exchanging data contained in the model between the individual participants in the design process. Designers of individual areas and disciplines (architecture, construction, installations) work using different programs and save information in native files. In order to integrate this information into a single, multi-discipline project, a standard is needed to enable communication between native files of programs used in individual disciplines. The most popular standard for exchanging this data is the IFC (Industry Foundation Classes) format. A program for a given discipline working in a BIM environment has the capability to convert native files to IFC format so that the information contained in them can be read by programs from other disciplines, which translates into the effectiveness of the project process (Fig. 3.3).

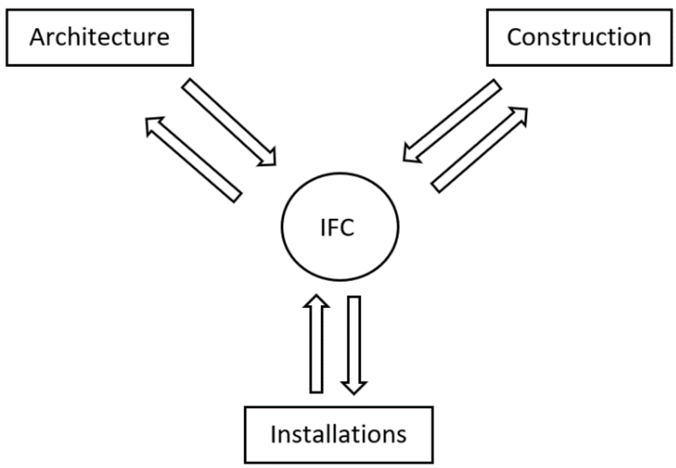

Fig. 3.3. Diagram of data exchange between individual areas and disciplines using IFC format (author's own elaboration)

Another factor equally important for the correctness of the design process which significantly determines the correctness of the model is the lack of design collisions between individual areas and disciplines. Overlapping the area and discipline projects yields a complete model of the building, so it is possible to capture all potential incompatibilities at the interface between architecture/construction/installations. An example diagram of this process is illustrated in Fig. 3.4.

Designers from a given area of the project implementation as well as discipline designers save their projects in source files of programs they use and then export them to IFC format. Based on the information contained in IFC files, a target model is created for all participants of the design process, commonly known as a multi-discipline project, allowing for the detection of possible collisions. After discussing how to solve (eliminate) the collision, feedback is provided to the designers who make the respective corrections in the source files, and the design process is continued. In the case of further collisions, the entire operation is repeated in the same way.

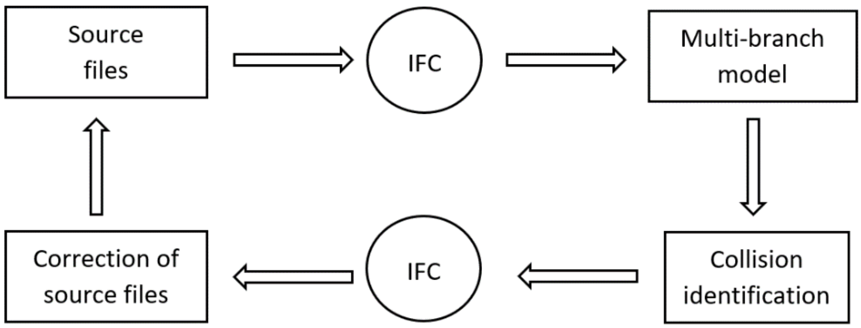

Fig. 3.4. Diagram of the process of identification and elimination of design collisions based on the area and multi-sector BIM model: author's own elaboration

Another issue to be considered when developing the BIM model is the definition of the types of individual elements in accordance with the IFC standard. If, for example, the thermal insulation layer of the ceiling is incorrectly defined as a floor slab, then during the cost estimation based on the IFC file with such data, errors in the cost estimation may occur. Another problem that should also be addressed is the correct determination of the geometry of individual elements - cutting off walls at the floor level, a proper definition of ceiling/wall and wall/wall contacts, verification of beam and column cross-sections after performing static calculations in relation to the initially accepted sections, etc. All errors resulting from incorrect modelling of individual elements (according to both type and geometry) do not allow for effective use of the model during the implementation of the investment and may lead to making unintended mistakes by its subsequent users. Such a situation is not only undesirable but should be eliminated at the level of project creation.

Furthermore, the model should be made in such a way that it can automatically "refresh" itself after changing its properties in terms of geometry, materials, etc. Such parameterization of the model allows for its immediate modification at low labour intensity, which is extremely efficient and therefore necessary for implementation in the design process.

3.3.2. Construction based on the BIM model

The factor necessary to maintain consistency between the actual status and the design is the ongoing updating of the BIM model as discussed above. During the implementation of an investment (due to factors that could not have been predicted during the design phase), a situation often arises that requires changes to be made during the construction process. Therefore, continuous verification of the digital model of the building is necessary. It should be carried out at strictly defined intervals and cover all introduced changes, whether in terms of the geometry of the building, the materials used, the equipment installed, changes of location, etc. This will ensure that the model remains entirely usable throughout the construction period and during the final use of the building.

Another equally important requirement from the standpoint of the contractor is a properly constructed BIM model, which will allow for proper development of schedules, bills of quantities or cost estimates. This is extremely important for the implementation of the entire investment process and should be taken into account by all participants in the implementation of the project with due diligence. If the BIM model being implemented (or already implemented) is prepared in accordance with the principles described in 3.3.1, it will be possible to fully utilize the opportunities offered by BIM technology, e.g. automated bills of quantities, scheduling and cost estimation. Any mistakes made at the stage of design and creation of the model will potentially imply executive errors. One should avoid such situations because they are or can be very expensive and often also time-consuming. The importance of this aspect of the implementation of future investment and the consequences of mistakes made at the stage of the project implementation should be emphasized. The BIM project prepared for implementation must guarantee the correctness of the construction process - the implementation of the investment project. Figure 3.5 shows an erroneously defined wall corner, which results in the common part of the wall being included in both elements at the stage of the bill of quantities, which leads to overestimating the quantity of material and the resulting inflated material costs.

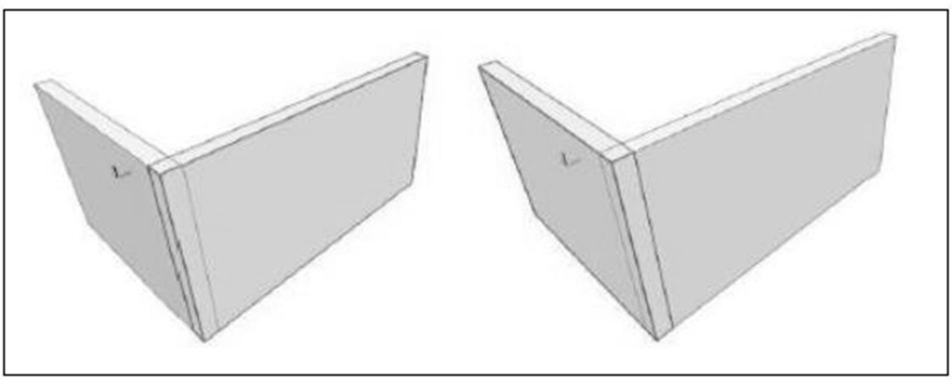

Fig. 3.5. Erroneous definition of the wall contact resulting in an incorrect bill of quantities: author's own elaboration

3.3.3. Operation and management of the building

Due to the fact that the costs of building use in a certain time perspective are many times higher than the costs of its construction, all the tools that contribute to their reduction are extremely desirable for owners and managers of real estate. One of the main reasons for the excessive increase in operating costs is insufficient knowledge about the building, especially in the case of large-size buildings, where the amount of data generated during their use is enormous. Efficient and fast access to all necessary information is critical for effective property management. The answer to these needs can be a properly construed BIM model, which, updated with operating data, becomes digital documentation of the building operation (Building Owner Operations Model - BOOM). This effective way of working of the owner or manager of the building translates into financial and time dimension related to the implementation of operation-related tasks.

Moreover, while construing such a model, the specificity of the building and the resulting needs of the owner/manager should be taken into account. The scope of the data should include:

- technical information (data about the building, equipment, systems, installations, etc.),
- financial data (receipts, expenses),
- information about the employees employed in the facility (personal data, courses, training),
- information on tenants,
- data concerning repairs, breakdowns and maintenance,
- other information resulting from the nature of the facility.

In a correctly made model, the individual elements of the 3D model should be associated with relevant documents (e.g. devices - warranty cards) and external databases (e.g. temperature sensors - temperature readings). This is necessary to maintain the effectiveness of the implementation of maintenance tasks because the availability of a record of the operation of equipment included in the individual systems and installations allows for rapid detection of possible irregularities, immediate corrective actions and actions to prevent potential negative effects of failure. Thanks to the knowledge of the current condition of the property, it will be possible to prepare energy and economic analyses, etc., which will allow effective management of the facility and will eliminate to a large extent the risks resulting from the lack of sufficient technical condition of individual systems and elements.

3.4. Conclusions

In order to take full advantage of the possibilities offered by BIM technology in the entire life cycle of a building, from concept implementation through design to final operation, special attention should be paid to the correctness of the digital model of the building. Such a model should be free from any errors. It is unacceptable for the element to be improperly modelled so that geometric inconsistencies, poorly defined contacts and collisions etc. might occur. Only then will the BIM model be fully useful for all participants in the investment process and guarantee the correct implementation of the construction projects at every stage. Otherwise, the errors contained in the model will lead to collecting false information, and thus any actions taken based on this information will lead to duplication of erroneous results having a negative effect on the process of investment implementation.

Constant ongoing updating of the aggregated data in the model is necessary so that the digital image of the object reflects its real state at any time. This is a prerequisite for making the right decisions at every stage of the investment as well as during the operation of the completed construction project.

The level of detail of the model should be adjusted to the needs of stakeholders and precisely defined, e.g. by using the LOD classification. This will help avoid possible discrepancies in the expectations of individual users of the developed BIM model regarding the scope of information contained in the model.

Unfortunately, a certain barrier in the development of BIM technology in Poland is the lack of standards regulating the basic issues related to the use of this technology. This encourages entities using BIM in their activity to follow the standards used in other countries (e.g. in the UK or the USA) or to develop their own guidelines. Such internal guidelines are implemented at the level of the enterprise, which may lead to some interpretation problems concerning the obligations of particular parties in the investment process concerning the principles of creating and managing BIM documentation. This also applies to the type and content of BIM data contained in the model.

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