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Use of bim technology in transport infrastructure projects

Abstract: This paper describes the possibilities of using BIM (Building Information Modeling) technology based on object modeling in transport infrastructure projects. The main focus was on investments such as roads and railways. The objectives of implementing this technology were presented and its benefits for participants of the construction process were discussed. The basic principles, norms and documents related to the BIM methodology have been outlined. Then it was described at what stage the introduction of this technology is on the Polish market. Finally, examples of "implementation" projects currently implemented by the main managers of the rail and road network in Poland, ie PKP PLK and GDDKiA, were shown.

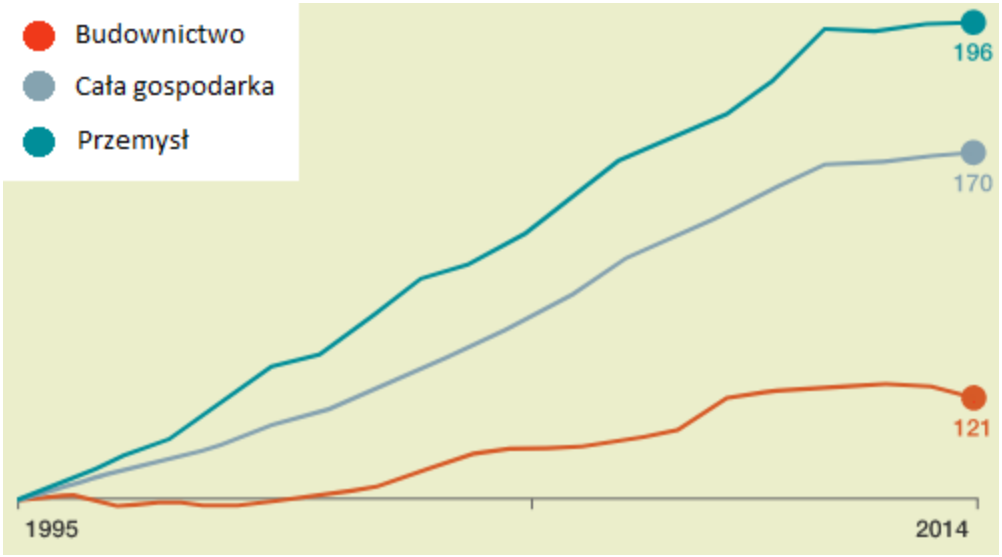
Keywords: civil engineering, BIM, infrastructure.

Introduction

Building Information Modeling (BIM) technology was invented at the end of the 20th century when computers became more and more common. Thanks to electronic devices, it was possible to transfer some of the information about the designed building or structure from paper to the electronic environment.

Initially, it was only geometric information - that is, the dimensions of the elements and their descriptions. In CAD (Computer Aided Design) programs, 2D drawings were created in electronic form, which could then be printed and sent to the construction site. Then another dimension was added to the CAD drawings. This is how 3D modeling was born. Originally, 3D models were used for the purposes of project visualization, which made it easier to present the work to the investor. However, over the years, 3D models have been supplemented with information about objects. Thanks to this, in the model there was no longer only one type of element with specific dimensions, but it was possible to distinguish different elements with their features (e.g. pillar, window, door, wardrobe) along with the necessary dimensions. Such models could already have the character of BIM models.

However, a question should be asked, why is the use of BIM technology in construction pursued? The main problem in construction is the efficiency of designers and contractors. As shown by research from Europe and the world [11], labor productivity in the economy and industry has been growing steadily since the beginning of the 21st century. Unfortunately, the productivity in the field of construction has remained at a similar level for years. Despite the enormous technological progress and the use of computers in the design and construction process, there is no visible increase in labor productivity in this area of the economy. Figure **1** shows the actual value added generated by employees of various sectors of the economy. And so for industry and as a whole in terms of the economy, labor efficiency almost doubled, while for construction the increase was only insignificant (around 20%).



1. The real added value generated by hired employees within one hour [11]

Public and private investors, in order to increase efficiency, and thus increase profits and reduce costs, began to look for new systems and technologies. The answer to their problems was BIM, in which information plays the most important role. Each construction process contains a lot of data, i.e. information - maps, calculations, drawings, diagrams, tables. Information in the construction process should be there [7]:

- Up-to-date, i.e. consistent with the actual state at a given moment in the construction process,
- Complete, that is, containing all the necessary information,
- Legible - verifiable by every participant in the construction process,
- Available - readable or easy to edit regardless of the device on which it is viewed or edited,
- Easy to modify, so that every participant in the construction process can keep it up-to-date and complete,
- Protected - available only to authorized persons and archived.

If the above conditions are met, the construction process may become more effective. Thanks to this, the investor will spend less money and receive a finished object in a shorter time with fewer design and implementation errors.

In addition to information, important in the BIM process, cooperation also plays a key role. The cooperation of all participants in the construction process may be easier thanks to the information that will meet the requirements set out above. The cooperation of all parties involved allows the creation and effective use of the BIM model.

Goals and advantages of implementing BIM

The goals that may be achieved thanks to the implementation of BIM technology in investments can be divided depending on the participants of the construction process. The investor, other designers and industry specialists, contractors and owners or managers of the building or structure set themselves different goals. The same applies to the advantages of implementing this technology - each participant in the construction process will benefit from different advantages. However, it is possible that the goals and advantages may be common to different participants.

BIM for the investor, owner and manager

For the investor, BIM is primarily better information. Thanks to this information, making decisions about starting investment and its shape is easier. The use of BIM makes it possible to accurately assess the planned costs and the feasibility of the schedule. At the design stage, the investor can actively participate in the design process. Design changes at the investor's request are faster and cheaper. Despite the higher initial project implementation costs at the design documentation stage, the subsequent stages (construction and operation) are characterized by a lower investment implementation cost. In addition, thanks to this technology, the investor has the ability to monitor the progress of works and costs on an ongoing basis [15].

The owner of a building made with the use of BIM technology may receive the so-called Digital Twin ("virtual copy of an object"). Thanks to this, he/she has access to the model of his building and can enter their data on the current management of the building - maintenance, renovation and reconstruction costs [14]. The building manager also uses the advantages of Digital Twin, when the object model can be supplemented with the technical data of all fittings and devices in the building. The facility administrator then has the ability to accurately plan repairs and maintenance works and has information on the service life of each element in the facility. In addition, access to documentation of all parts of the building is possible during the lifetime of the facility.

BIM for the designer and contractor

The added value that BIM brings to the designer and contractor depends primarily on the "type" of BIM that is used in the enterprise. Very often there are situations where investors do not require BIM in their project, so the companies implementing the contract limit themselves only to using this technology within their organization - it is the so-called "Internal BIM" [8]. BIM used inside the company can improve its work and reduce costs. The company is thus more competitive. He may propose to the investor the implementation of the project or construction in a shorter period and at a lower price. In the case of "external BIM", its use is not limited only to the organization, but also to the client - the investor, ordering party or manager, and other external entities cooperating with the organization.

The main advantages of implementing BIM for the designer are:

- Better communication within the team and inter-branch communication,
- Less iteration of corrections on the project,
- Easier detection of collisions and their removal,
- Easy to implementation of changes later in the project.

For the contractor, the use of the BIM model is primarily:

- Possibility to better estimate the price of the offer for the investor thanks to an accurate 3D model,
- Facilitated access to complete and up-to-date documentation through the use of computer hardware,
- Significant reduction of assembly and design conflicts, which reduces costs for the contractor,
- Managing and controlling the work of subcontractors,
- Possibility to use construction machines that use data from the 3D model.

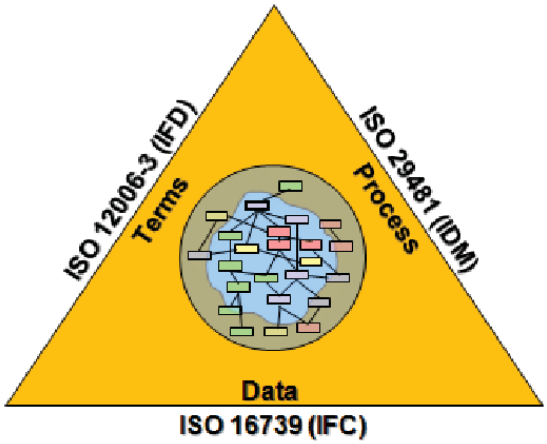
Information and its processing as a key in BIM technology

For BIM technology to be useful in the construction process, the exchange of information between participants in the construction process must be effective. The information that is provided should be standardized and include only the necessary elements that will allow for legible reading of this information.

At the stage of design documentation, companies use software that works on native files, i.e. files that can be edited and saved only in dedicated programs. This situation contradicts the idea of BIM, which should be open to all participants of the construction process.

To achieve this, at the beginning of the 21st century, the buildingSmart organization was established, which aims to promote the idea of OpenBIM, i.e. a universal approach to cooperation in the design, implementation and operation of buildings based on open standards and information exchange [4]. BIM foundations according to buildingSmart are shown in Fig. **2**. Their reference is implemented standards, which can be divided into three areas [7]:

- Data (included in the ISO 16739 standard) - IFC (Industry Foundation Classes),
- Processes (included in the ISO 29481 standard) - IDM (Information Delivery Manual),
- Terminology (included in the ISO 12006-3 standard) - IFD (International Framework for Dictionaries).



2. OpenBIM foundations [5]

IFC

IFC is a standard for recording a digital 3D model of an object. It is an open data recording format used to transfer information between participants of the construction process, based on semantic data structures [7]. Semantic data allows you to link individual elements in a building with each other. An IFC file contains complete geometric information about an object, as well as its position in space, the structure of the object and its attributes. The IFC format is developed by buildingSmart, its elements are described in the ISO 16739 standard.

IDM

IDM is a document that describes the principles of information exchange between participants in the construction process, as well as the requirements for the information provided. An important element of IDM is the process map, which should show who takes part in the project, how tasks are divided for participants and how the information exchange between them should look like. Moreover, it is important to define the level of detail of the project at individual stages of the project implementation. According to the buildingSmart requirements, IDM should comply with the ISO 29481 standard.

BIM standards and the investment process compliant with them

In 2019, two European standards came into force that constitute the foundation of BIM: PN EN 19650-1 and PN-EN 19650-2. These are documents based on the British 1192 series standards. They describe information management through building information modeling. They cover

basic concepts and principles as well as elements related to the implementation of the facilities. On the basis of these norms, efforts are being made to create universal standards in Poland that could be the basis for the implementation of public projects.

According to their content and on the basis of the Public Procurement Law [16], the following stages of project implementation can be distinguished:

- Tender for design / construction or design and construction - preparation of the Terms of Reference together with the Employer's Information Requirements (EIR),
- Selection of the contractor,
- Preparation of the contract with the BIM Performance Plan (BEP),
- Signing the contract and preparation by the Contractor of the Master Information Delivery Plan (MIDP),
- Execution of works or design.

Ordering Party Information Requirements (EIR)

The EIR document is a key element of the Terms of Reference. In this document, the Employer should describe what goals he wants to achieve through the use of BIM technology, as well as what the Contractor's requirements are. The EIR should consist of three subject areas: technical, management and commercial [1]. The technical part should describe the required data exchange formats, methods of coordination, levels of LOD accuracy. The management part should include the roles and responsibilities for process participants and the information exchange strategy. The commercial part should consist of the requirements for data dumps as well as the objectives and expectations of the Employer.

The BIM Performance Plan (BEP) and the Master Information Delivery Plan (MIDP)

The BIM Performance Plan is prepared by the Contractor as a response to the Employer's EIR. In this document, the contractor should propose an implementation plan for the project tasks, outline the roles and responsibilities for his staff, and execute the MIDP. The Master Information Delivery Plan is primarily a schedule for creating an information model containing detailed information on who, how and when will produce its subsequent fragments [7].

BIM in cubature and infrastructure facilities

When talking about projects in BIM technology, one should distinguish between infrastructure design and cubature objects. In infrastructure projects, we mainly deal with objects of irregular shape, with much longer elements. Often there are also point elements at great distances from each other [2].

The method of modeling and presenting the current state plays a key role in projects, in particular infrastructure projects, implemented on the basis of BIM technology. It is, therefore, crucial to properly reflect the topography, individual layers of soil, and underground and above-ground installations. They allow, among others for accurate estimates of construction costs, as well as for the detection of collisions [2].

For the proper development of a project in BIM technology, it is necessary to use the most precise tools possible during the preparation of inventory documentation or examination of the state of the works being carried out. In addition to traditional total station measurements, for this purpose are used:

- terrain measurements using the UDAR technology (e.g. ground scanners);
- measurements of artifacts and underground layers using GPR, electrofusion tomography or magnetometry;
- photogrammetry (e.g. based on drone raids).

The above-mentioned data is then processed in the design software into point clouds from which meshes are created [10].

BIM in Poland

Until now, the overwhelming majority of investments carried out with the help of BIM technology were cubature investments. Line infrastructure projects based on BIM are currently underway. There are several reasons for this. The most important of them are listed below.

BIM education

The Polish higher education system is still based on the class-lesson system. Any changes to the core curriculum, modifications to the education system, introducing innovations and new solutions are not simple things. There is also often a lack of practical classes that allow students to acquire skills directly used in the engineering profession, incl. such as support for 3D modeling programs. There are also hardware limitations, problems with obtaining actual output data for the implementation of projects within the classes, as well as shortages of student licenses of some software.

Another problem is the low salary rates for university employees, which in no way encourage engineers/designers and practitioners to cooperate with a university in the field of transferring knowledge about new technologies.

The offer of first and second degree studies usually does not deal with the subject of BIM, or it only touches it to a small extent. There are only a few universities that implement BIM specialization programs in second-cycle studies (Cracow University of Technology). The development of the subject takes place only during paid postgraduate studies, the offer of which is growing more and more.

All this contributes to the lack of training of young staff in the spirit of innovation and practical approach to the profession.

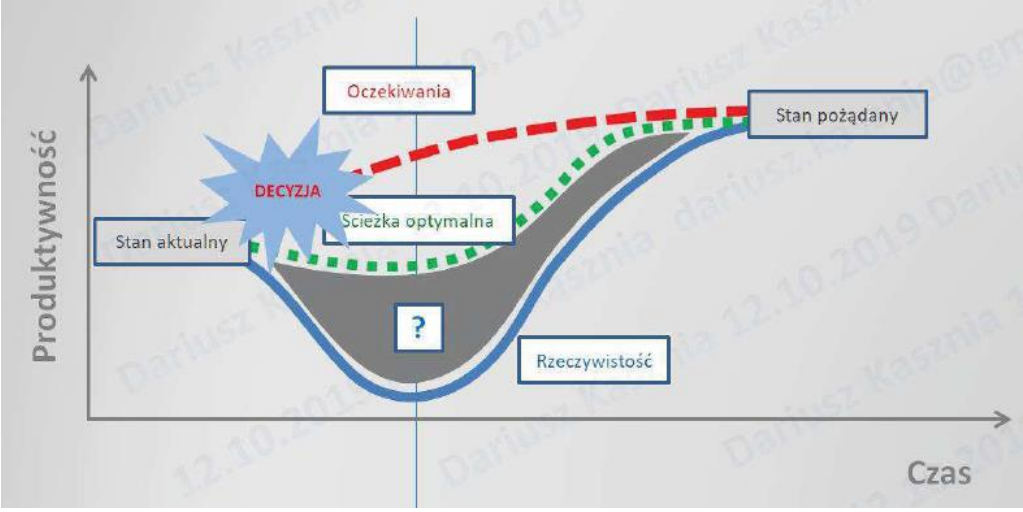
Costs and risks

Each new technology requires an investment. This, in turn, is associated with a temporary reduction in efficiency, and thus a reduction in profits. First of all, it is necessary to devote time to exploring the subject, defining goals, and then appropriate training of staff and employees. In addition, it is necessary to invest in new software, work tools (e.g. high-performance workstations) and IT support, and often also increase the performance/size of servers. The graph of the dependence of the increase in productivity with the passage of time in the following variants: expected, optimal and real, are shown in Figure **3.**

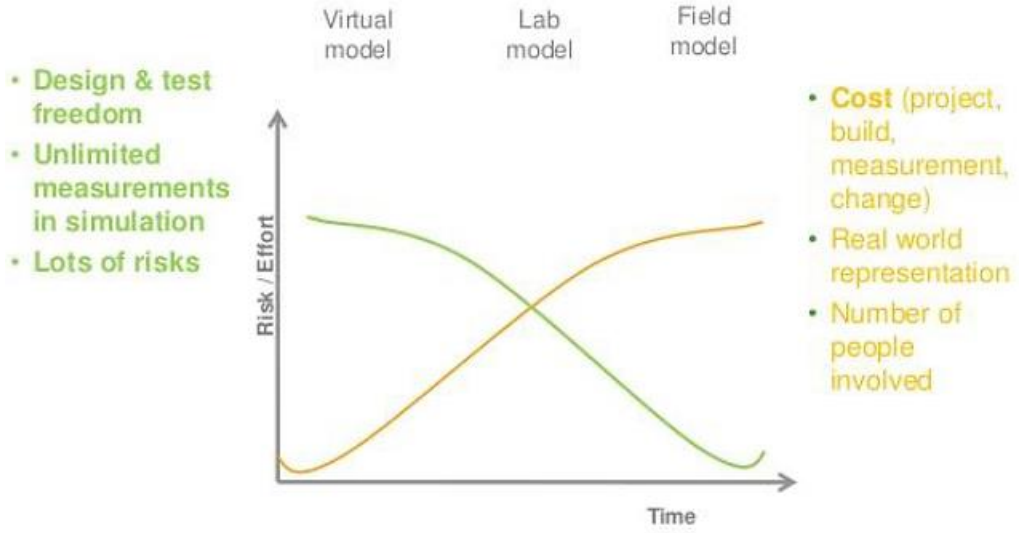
It should also be borne in mind that even after a well-planned and conducted BIM implementation, problems and challenges will appear on the first projects. It is essential at this point to learn from your mistakes. These, in turn, may lead to a failure to meet the project cost reduction expectations. As a result, the expected increase in productivity (and thus cost reduction) may appear much later than expected [3].

Figure 4 shows the relationship between the level of risk and effort, and the duration of investments carried out with different methods. The investment carried out in a standard manner is marked in orange. The investment carried out with the use of BIM is marked in green. At the beginning of BIM implementation, the risk and effort are very high. This is mainly due to the high costs of generating a model of the existing infrastructure, assigning it the appropriate parameters and deciding on the appropriate level of detail. Over time, risk and workload decrease. A properly built base model allows for much easier changes. Risks are identified much earlier (e.g. collisions with foreign infrastructure), and the number of details allows for a much more accurate estimation of investment implementation costs. In the case of an investment carried out in a traditional way, the risks and workload are initially much lower. The

risk increases only at the stage of physical implementation of the investment - previously undetected elements of underground infrastructure, local weakening of land and other factors that increase the initial investment costs appear.



3. The dependence of productivity on the duration of BIM implementation [9]



4. The dependence of productivity on the duration of BIM implementation [17]

Standards

At the moment, there are no unified standards in the field of BIM application in Poland. On the initiative of the Polish Association of Construction Employers and the Polish Association of Construction Engineers and Technicians, the BIM Standard PL agreement was signed in 2018. This agreement was aimed at starting the development of BIM standards for the needs of construction investments carried out in Poland under public procurement. Several of the largest construction companies in the country have joined the project. The implementation was planned for 2019 [13]. Industry consultations on the document are currently underway.

Infrastructural investments implemented with the use of BIM in Poland

The first pilot infrastructure projects with elements of BIM implementation in the public procurement sector have appeared recently. The first tender procedure was announced by the General Directorate for National Roads and Motorways, and then also by PKP Polskie Linie

Kolejowe S.A. In both cases, EIR, i.e. the Employer's BIM information requirements, were created.

GDDKiA pilot project - Construction of the Zator bypass along the national road No. 28

At the end of 2017, GDDKiA Branch in Cracow decided to conduct a pilot project with the use of BIM. In June 2018, the first tender was announced for the construction of the Zatora bypass along national road No. 28 [6].

The subject of the investment was the construction of the Zatora bypass connecting the national roads No. 28 and No. 44. The project included a 2.1 km long road. In addition to the bypass, a section of provincial road No. 781 was to be reconstructed along the national road No. 28. As part of the bypass project, two viaducts, a bridge and two culverts were to be built [6].

The investment was planned in the "design and build" formula. The design and construction were to be completed within no more than 36 months from the date of the contract. The winter periods were to be included in the deadline at the design stage, while in the case of execution of works, the winter period (from December 15 to March 15) was deducted from the completion date [6].

In February 2019. the submitted bids were opened. 6 Contractors took part in the procedure and each of them offered a price higher than the contracting authority's budget. The lowest of the submitted bids exceeded the budget by approx. 45%. The most expensive was more than twice as high as the contracting authority's budget [6].

Importantly, in the tender, the price was only 40% of the evaluation criterion. The contracting authority saw the need to take into account also other criteria, which in the case of the pilot project seems to be a very important aspect. Ultimately, the tender was canceled. A moment later (August 2019), GDDKiA announced another tender procedure for the investment in question. This time in the "design" formula along with the author's supervision [6].

Offers were opened in September 2019. 7 contractors joined the procedure. This time the contracting authority's budget allowed to make a choice and the final offer amounted to PLN 2,214,369 gross (approx. 47% of the contracting authority's budget). Sweco Engineering Sp. z o.o. from Cracow (company headquarters - Sweden) [6].

The pilot project of PKP PLK S.A. - Demolition and construction of a railway viaduct at km 33,994 on the railway line No. 140 Katowice Ligota - Nędza

In April 2019, the main manager of railway infrastructure in Poland - PKP Polskie Linie Kolejowe S.A. also announced a tender for a pilot project using BIM technology. The scope of the project included the demolition and construction of the railway viaduct, so it was much smaller than the GDDKiA project. The procedure was divided into two separate contracts - separate design and construction. On August 1, 2019, a contract for the preparation of design documentation was signed. The contractor was BBF Sp. z o.o. It is worth noting that PKP PLK S.A. previously announced an order for a BIM Consultant, who developed the procurement methodology, helped the Employer understand BIM processes, advised at the stage of preparing tender documentation and selecting offers, and now conducts constant supervision over the project [12].

Summary

Undoubtedly, BIM technology is a big step towards a technological leap in design and construction processes. As noted, however, it is associated with a large number of risks and costs, which in the initial phase of its implementation may lead to a temporary reduction in efficiency, minimization or even no profits. Therefore, the main reason for the lack of rapid implementation of technologies is the lack of sufficient financial resources for innovative

projects, both in the public sector and in private enterprises. However, in the long run, implementing BIM technology will reduce investment costs and accelerate their implementation.

Infrastructure construction is a particularly difficult construction sector in terms of implementing BIM. The reason is both the size of the linear investments and their irregular shape. The large size of the investment also generates very high costs of preparing base data on the existing state. Seemingly, at the beginning of the investment, these data seem too expensive, but due to the greater degree of detail of the projects, they allow for cost reduction at further stages of the investment implementation.

The Polish market in the line infrastructure sector is just beginning to take the first steps by introducing smaller pilot projects. The coming years will show whether the path of construction development in Poland is right.

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