From parchment to BIM, standards and example of use

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Abstract. The paper contains a detailed discussion of the history of computer support from the first computers to the current revolution, which is BIM. BIM or Building Information Modeling is the hottest topic in global construction. The author presented the advantages of using this technology. Project levels are given and discussed. The concepts of "internal and external BIM" were introduced and described. The second part of the work presents an example of using Revit to model a single-family home. Insolation analysis, compatibility of Robot and Revit programs are shown, and other design tools are described.

1. From parchment to BIM – a historical outline of computer design
The history of the development of computer aided design methods is not long. It is preceded by a hundreds of years period of manual design, where all projects and ideas were written down manually on parchment, paper, and decals. Design offices looked the same for many decades. The rooms filled with rows of drafting stands, where the constructors worked, carrying out a number of the same activities. The first sketch was drawn in pencil on drafting sheets, and then outlined with ink. Everything was done by hand, and the number of mistakes extended the working time and, consequently, the duration of the entire construction process. It wasn't until the 1960s that the first computers appeared and there was a slow development in designing for today. Although the then developed finite element method (FEM) was at the center of the work of introducing computer support, it was very much separated from the current possibilities of its use. In the mid-1980s, PC – personal computers became commonplace, and thus programs for interactive support of drawing documentation creation were created. It was not as widely available as it is today, but the support tools found their way to the jobs of engineers and increased their capabilities. The dissemination of computers made it possible to transfer some of the information used in the construction process to a computer, and thus more and more often the documents were printed, edited and drawn automatically. The hours needed to manually create documentation gradually decreased over time.

The real breakthrough came in November 1982 in Las Vegas, United States, where Autodesk's AutoCAD program was presented. A month later the program went on sale. AutoCAD (Computer Aided Design) – is currently the most popular program for two-dimensional design support. Although AutoCAD has a 3D design function, it is not as popular as Revit or even other architectural modeling programs. AutoCAD sold and still sells great. Autodesk is gradually expanding its offer with overlays or completely new programs based on AutoCAD. CAD works well among engineers, designers, architects, mechanics and students. The advantages of the program include, above all, a huge library of materials available for free. While there are several libraries with Revit files around the world, CAD files can be found almost everywhere. There are many websites on the Internet with files posted directly by construction companies or users who have created, for example, an interesting texture or drawn the exact element of the structure. One of the fastest growing pages is [1]. Two years after the
launch of AutoCAD, in 1984, a rival Hungarian company, Graphisoft, creates the first version of Archicad. At the beginning, designing in this program consisted of creating a virtual mock-up of the future building, and now it is possible to take a virtual walk around the created structure.

Almost thirty years before Archicad, in 1957 Dr. Patrick J. Hanratty developed the first commercial computer-aided software (CAM). Shortly thereafter, he took up computer-generated graphics, and in 1961 he developed DAC (Design Automated by Computer), which became the first CAM / CAD system that used interactive graphics. Two years later, Ivan Sutherland developed the first computer-aided (CAD) project with a graphical user interface - Sketchpad. In general, he was a pioneer in the field of human-computer interaction and was a significant breakthrough in the development of computer graphics. However Sketchpad despite its breakthrough, had to give way to programs that modeled solids by giving them shape information. In 1975 Charles Eastman published an article describing the prototype called the Building Description System (BDS). Ideas for parametric design, high quality computable 3D representations with 'a single integrated database for visual and quantitative analyzes were discussed. Eastman’s article basically described BIM as we know it now. It should be mentioned that BDS was one of the first projects in the history of BIM, which successfully created the building database \[2\].

Let’s return to AutoCAD, which is a program more often used in structural design, not architecture. It allows to transfer files to other formats. These are basic formats such as PDF or JPG, as well as it is possible to export files to, for example, Robot Structural Analysis Professional. Thanks to the AutoCAD 360 Pro overlay, it is possible to draw, edit and display 2D CAD drawings on portable devices. And since the AutoCAD 2017 version, it is possible to store and display files in the cloud. AutoCAD has replaced manual drafting, and transferring all the project drawing to the computer is undoubtedly its greatest success. CAD has well displaced manual drawing and all drawings at construction sites are both designed and printed from computer programs. This saves time and is undoubtedly more effective than drawing each drawing by hand. Despite the above-mentioned advantages of AutoCAD and its enormous success, we are at the next turning point in the history of computer design. This technology is called BIM.

| 1957 | 1961 | 1975 | 1982 | 1984 | 1987 | 2017 |
|------|------|------|------|------|------|------|
| hand drawing | DAC - the first CAD system using interactive graphics | Eastman publishes Building Description System basically described BIM | Graphisoft publishes the concept of Virtual Building - the beginning of the development of BIM technology | start of creating files in the virtual cloud in AutoCAD |

**Figure 1.** The most important events in the development of computer aided design

**2. What is BIM?**

Currently, the abbreviation BIM is most often developed as the Building Information Model, i.e. the Building Information Model (Digital). However, at the source of the term BIM, i.e. innovative technology of digital construction, is the term Building Information Modeling. Building Information Management is a common development of the BIM abbreviation. The building information model is a database of information about this building. Modeling building information is a process. It is designed to collect information, manage it and make it readable and accessible to every participant in the construction process. Building management means analyzing, estimating costs, planning construction, setting schedules and providing information in a construction team. Authors in [3] presents a study on the implementation of four key aspects for successful development of BIM models. An example of the effectiveness of the implemented BIM-based system for communication in a team is in [4].
2.1. BIM – Building Information Modeling

BIM or Building Information Modeling is the hottest topic in global construction. In 2010 it became the main element of the UK strategy, and while the world's largest economies are investing huge amounts in BIM [5], many misunderstandings and legends have accumulated around BIM in Poland and not only. They mainly result from a lack of knowledge among participants of the construction process and especially among investors. BIM is another revolution in design. After the implementation of CAD software, BIM is the next step to transfer all the information used in the construction process to computers. One of the biggest advantages of BIM modeling is the ability to work in a virtual cloud. This process allows the simultaneous work of specialists from many industries on the same project and almost immediately eliminating collisions or editing elements. The scheme developed by M. Richards and M. Bewa in 2008 [5] is the best graphic presentation of the BIM maturity levels.

![Diagram of BIM maturity levels](image_url)

**Figure 3. Diagram of BIM maturity levels [6]**

Description of abbreviations used in the drawing:
- CAD - Computer Aided Design, Computer Aided Design
- 2D - two-dimensional modeling
- 3D - three-dimensional modeling
- AIM - Architecture Information Model - architecture information model
- SIM - Structure Information Model - structure information model
- FIM - Facilities Information Model - equipment and management information model
- BSIM - Building Service Information Model - information model for services related to facility maintenance
- BRIM - Bridge Information Model - information model for bridge structures
- iBIM - Interoperable Building Information Model - an interoperable digital object model
Level 1 BIM introduces a 3D model. The basic documentation is still 2D documentation on paper. The three-dimensional model is introduced at the concept stage by architects and is used for better communication with the investor. Builders do not work on a 3D model. Despite the visualization of the design in space, only a small percentage of the possibilities offered by 3D modeling are used.

BIM level 2 is already a milestone from CAD design. The integrated 3D model becomes the basic information carrier. By the word 'integrated' I mean a model containing almost a complete set of industry information. They are architecture, construction and all kinds of installations. At this level, you can simulate the facility implementation process, i.e. accurately plan the delivery and implementation schedule (4D). The next step is to create an estimate and plan expenses (5D).

BIM also means greater awareness of the ecology and processes that shape our environment. Therefore, at level 2, an environmental impact analysis (6D) can be carried out. The final stage is collecting and organizing data so as to create an object management system (7D).

Level 3 is the biggest challenge. This is a huge leap between CAD modeling, or even level 2. While in level 2 specialists can work on separate files, so at level 3 all the above-described data (3D, 4D, 5D, 6D, 7D ...) are collected in one file. This model is iBIM. The term "interoperable" means that all participants in the construction process can use the data contained in the file as well as edit it. This model is updated on a regular basis and all changes are visible at the time of their introduction.

As can be seen from the figure above, construction has been at "level 0" for years. This is the level at which paper documentation is the main information carrier. Inter-branch coordination takes place via traditional channels. Each specialist works on his 2D model. Noticing and eliminating collisions in the design phase is hard to see. It is possible to switch from a 2D (CAD) model to a BIM model. The standards are described in [7].

2.1.1. Who is BIM for and is it worth investing in software?
In modern times, information is the key to success. After the fact it is easy to think "if I knew about it before...". BIM is a tool that lets you know in advance and avoid costly and problematic errors. Each construction process contains hundreds of information, drawings, calculations, permits. During the now more and more common project and build system, some activities are performed and changed on an ongoing basis. Communication between the construction site and a number of design offices is time consuming and often the office only works on its project, e.g. installation. Loss of some information, its incorrect determination, or work on updated data, causes errors of bills of quantities, errors in bill of materials, cost estimates, schedule errors as well as design and implementation collisions. In the Reinventing Construction: A Route to Higher Productivity report published in February 2017 created by McKinsey Global Institute [8], an analysis of the construction industry from 1994-2014 was included. Each year, construction investments consume 10 trillion $, accounting for 13% of global GDP, and construction is a sector that employs 7% of the world's population. Given the above, and the fact that 41 countries generate 96% of global GDP, it is not surprising that construction investors are looking for a system that will save them huge amounts. Because often the largest investments concern public construction, it is not surprising that governments of many countries decide to introduce BIM into the public procurement sector. An extensive study and implementation process of the BIM strategy in Peru is presented in [9].

To answer the question "who is BIM for?" just analyze how you can use information about a building, who can use it, and pay attention to whether such information can be lost. The most important BIM users include: investors, construction designers, architects, specialists in various industries, building companies, facility owners, managers, tenants, users, customers, media supply companies, facility maintenance companies, renovation and demolition companies, public administration and also emergency services. The number of advantages of working in BIM technology is so long that it should be described in a separate article. However, can a number of advantages and savings resulting from them cover the costs of purchasing software? Assuming only one part of the whole structure is designed, it's hard to talk about cost savings. However, this technology becomes...
extremely useful when calculating the cost of maintaining a facility in 30, 40 or 50 years. The longer the time line, the more accurate the calculated renovation costs decrease, and the number of factors difficult to capture increases. Therefore, the investor should consider the cost of construction, as well as the expenses that will have to be obtained during the entire life cycle of the building. In this case, BIM allows to simulate investment efficiency throughout the entire life cycle of the facility. In addition to the costs that must be incurred (the cost of purchasing a plot, design, utilities, construction, utility costs and other costs resulting from daily use), in a project based on the BIM model, it can be include, for example, renovations that will definitely happen in the future, also indicators, e.g. the amount of greenhouse gases generated in the production of materials used during construction, can be included in the design. [10] Describes the possibility of integrating ecological assessment tools within BIM software systems. BIM can create a common language for all participants in the construction process and system departments in the project and make them an integrated team [11]. [12] Presents a multiple case study that understands the barriers encountered during building information modeling (BIM), enabling the monitoring of the impact of various barriers on various organizations (from management to project teams) and combining these barriers with BIM maturity limiters. Figure 4 shows the benefits of comprehensive office design. To this end, it is necessary to provide appropriate software and the correct organization of activities, development of drawing file templates, training of personnel, and many other guidelines that should be met. If it is necessary to change the software, select such that all industries can work on it. The article [13] presents a solution in the case of data transfer from one software to another.

VALUES GENERATED BY USING BIM

| Internal BIM | External BIM |
|--------------|--------------|
| Used inside the organization: improves her work, reduces costs, i.e. increases competitiveness, e.g. by reducing design or construction time, | Used inside the organization: to improve work, external entities generating value added that the organization can sell for additional consideration. |
| Used in design offices to improve their own work efficiency, increase revenues and reduce costs, e.g. by: | Some contractors use BIM even if they are implementing a contract in which the investor did not expect BIM. 2D drawings themselves create a 3D model, only to better plan the construction: |
| acceleration of design due to the use of our own internal libraries of ready-made elements used in creating the 3D model | prepare a schedule |
| preparation of very accurate 3D models of complex industrial facilities | make an estimate |
| accurate design of buildings requiring many design works throughout the entire life cycle of the facility (renovations, modernizations, extensions) | estimate the amount of materials needed |
| preparation of three-dimensional computational models accelerating the work of designers | the ability to build faster |

Figure 4. Benefits of comprehensive office design
3. Creating an easy BIM project

3.1. The modelling process

In the presented work, the whole project has been modeled in the AutoDesk Revit 2018 program - free student license. Modeling the project in 3D allows for much faster creation of documentation compared to 2D modeling. No matter what view, plan or cross-section we currently create, we work and observe the same model. As a consequence, every change introduced in a specific view will be visible throughout the entire project and guarantees the timeliness of all documentation. The first stage of creating the project was setting the scale, parameters of the entire project such as units, and setting graphic styles (line thickness, line styles, fill patterns in individual materials). In addition, boards for printing were developed at the beginning of the model creation. At first, a family of sheets was created, tables were added, and legends and summaries were created at a later stage. The second step in creating the project was to set floor levels. The object location data was loaded using CADtoEarth. These data are needed to analyze the exposure of individual rooms and to determine the position of the sun. The design view and north orientation has also changed. At the level of 2_Parter, the axes of the walls were drawn, in the visibility settings the visibility of the axes was set for each plan. This stage finished the initial preparation of the document for further work. At the construction stage, it began with modeling the load-bearing and partition walls. Each material used in the design has real physical, thermal and strength properties. The materials were downloaded from the producer's websites. There are three types of walls in the design, selected according to current pig guidelines. The designed building meets the conditions required for a passive building. Hygrothermal calculations according to [14]. Also, information from [15-20] was used in the calculations.

Wall axes are located in the middle of the bearing layer of the wall (in the middle of a block of aerated concrete) and not in the default program setting, i.e. in the geometric center of the wall cross-section. The walls were pulled up to the flat roof level. The foundations were created as a foundation bench under a ground foundation made of C20 / 25 concrete. Another element of creating the project was the creation of floors and ceilings. Due to the limited resources of materials made available by manufacturers, it was decided to make a floor based on Leca expanded clay. The flat roofs were created using materials from the same company. The structural layer of the ceiling above the ground floor and roof is the Teriva ceiling. Teriva ceiling beams modeled by hand as a family of concrete beams. Arranged on load-bearing walls, they contact the wreaths. In the model, the beams are located in the ceiling.

Figure 5. Building with visible ceiling beams above the attic

Lintels and wreaths were inserted using X-Rev Xella. The program detects the material used to create the walls and selects the appropriate wreath and lintel based on loads and design. Windows and doors were downloaded from [1]. This site is a free designer platform where you can find original products.
added by manufacturers. Stairs were inserted automatically using the "stairs" tool. Gears, platforms and supports can be modified independently, so the automatically generated stairs were easily adapted to the project. Thanks to the wide range of architectural tools, balustrades and handrails can be changed and modified as individual elements, so you can directly control their appearance. Chimneys were created as a family of chimneys. Each family can be modified and can have a different height. The chimneys were founded on a footing modeled as a reinforced concrete slab. Load factor values according to [15-20]. In addition to static and strength calculations, room exposure analysis was performed. Free overlay for the program - Insight student version, made it possible to carry out the analysis. The analysis was made based on the actual location of the building: Ostrów Wielkopolski, Poland Figure 6. The whole project can be easily transferred to Robot. The "Robot Structural Analysis Link" function was used. This function automatically updates program changes Figure 7.

![Figure 6. Comparison of the position of the sun on January 28, 2019 and July 15, 2019](image)

![Figure 7. Building view in Robot Structural Analysis](image)

Elements marked in Revit as structural elements in Robot have the same properties as given in Revit. Loads and supports were added and returned to Revit. At this stage, work in the programs was completed.
3.2. Placing the project in the cloud
Autodesk® ReCap is the default Revit drive. However, outside the free trial period, the subscription is payable. The program itself is a great help for design offices. When sharing a project, the files take up a lot of disk space. Thanks to the cloud drive, files can be viewed and organized without having to download the entire file. This saves space on the local disk. By placing the project in the cloud, users can work on the model at the same time. The program prevents two users from editing the same item at the same time. The project can be placed in the Google Drive File Stream cloud. This is Google's free drive. After creating an account, you can upload the project file to disk and make it available to colleagues.

3.3. Collision and error detection
Another application that facilitates work in Revit is Revit-Navisworks Manage. It is this application that allows you to collect in one file 3D models from various industries (e.g. architecture + construction + MEP systems + development) exported from various applications, not necessarily Autodesk. Although Revit itself has a collision detection tool, it is not as accurate as Navisworks. The default tool allows you to check the correctness, but firstly only between family categories (e.g. between ventilation and substring), and secondly without the option of indicating the parameter that the program should check for collision. That is, for example, whether the ventilation duct does not pass through the boom center on the third floor. After checking the collision, you cannot save or change the collision. Navisworks Manage, on the other hand, enables precise analysis of the project with indication of specific parameters against which we expect collisions. You can save the place of these collisions. Thanks to the additional Switchback application, it is possible to find the element selected in Navisworks and to apply corrections (including by another user).

4. Conclusions
The main concept of BIM is to integrate information sources and, consequently, to minimize losses that can be incurred during the design and life cycle of the facility. Despite the numerous advantages discussed in this paper, as those not mentioned, the BIM concept still raises doubts and fears among both designers, architects and investors. We are at an important moment in the history of construction and it depends on us whether we will find ourselves in a new reality, from which there is no turning back. A historical outline of computer design is presented. Project levels are given and discussed, and the concepts of "internal and external BIM" are introduced.

This article shows both the basics and more advanced applications of the most popular BIM modeling program - Revita. In the presented example, creating families, editing types of individual elements, changing default program settings, adding products from dedicated pages were used.

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