

Benchmarking research work of development state of BIM in Germany

LAB University of Applied Sciences
Bachelor of Engineering, Civil Engineering
2022
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Abstract

Author(s) Artem Patrin	Publication type Thesis, UAS	Completion year 2022
	Number of pages 30	
Title of the thesis Benchmarking research work of development state of BIM in Germany		
Degree Bachelor of Civil Engineer (UAS)		
Name, title and organisation of the client LAB University of Applied Sciences		
Abstract <p>This thesis was carried out in order to find out the level of development of the application of BIM technologies in the German construction industry. At the moment, BIM technologies are innovative and rapidly developing information technologies. Most construction companies and design organizations use these technologies for various purposes.</p> <p>The purpose of the dissertation is to determine the level of development and use of BIM technologies in Germany in various fields. The areas under consideration are: modeling of infrastructure, structures, houses, cities.</p> <p>When writing the work, information obtained from current standards, scientific publications, materials of reports of specialists was used.</p> <p>An analysis of the data results shows that Germany is one of the leaders in the implementation of BIM technologies in the construction industry and the vast majority of design organizations are proficient in working with BIM and actively use this technology in design.</p>		
Keywords Building information modeling, Germany, House modelling, OpenBIM, Structural Modeling		

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1 Introduction

It is impossible to imagine modern life without all the technologies that surround us. The technology allows to automate, improve and improve many production processes.

Construction is an industry that requires precise calculation and attention to every detail, which is very difficult when erecting large buildings with a large number of elements. The emergence of the latest IT technologies has completely changed the structure of the construction industry in a short period of time.

The use of modern technologies has significantly improved the quality of construction products, reduced construction and design time. A variety of technologies makes it possible to automate the process of calculating structures and designing elements of buildings and engineering structures, to systematize the characteristics of structures, data on the scope of work, the properties of a building or an engineering structure as a whole. Data collection allows you to accurately calculate the amount of necessary material, labor, financial and time resources.

One of the key technologies has become BIM (Building Information Modeling), which allows creating a building information model with a full set of characteristics necessary for planning, designing and building an object.

Before the advent of BIM, the entire array of data about an object was presented only on drawings and specifications, which greatly complicated the process of making changes and changes, since even with a slight change in the design of a building or structure, the data had to be updated and recalculated independently. The advent of BIM has made it possible to significantly automate both the design process and the process of making changes to the project.

But BIM is not only a set of data about the building and structures, it is also 3D modeling, which allows you to avoid collisions, inaccuracies in element mating. In addition, 3D modeling allows you to visually see the building at the design stage, gives the construction company an understanding of how the structures should look after completion of work and their exact location in the coordination axes.

BIM allows you to monitor changes in the project in real time, which significantly reduces the process of information transfer between architects, designers and builders. The problem of joint work of organizations involved in construction projects is dealt with by the AEC industry (Architecture, Engineering, Construction). It was BIM that gave a huge boost to the industry.

Currently, many construction companies from different parts of the world are mastering BIM technologies for construction, in some countries the use of BIM is mandatory in the construction of various facilities, including Germany.

The actions of German government authorities in the construction sector have significantly accelerated the pace of BIM implementation, which in turn brought Germany to the list of leaders in terms of the level of development of BIM technologies on a par with such countries as Great Britain, Norway, Switzerland.

This thesis is devoted to the level of application and development of BIM in Germany, demonstrates the use of BIM technology in various fields and assesses the general situation. This thesis is devoted to a comparative analysis of the level of development of BIM in Germany. The thesis was conducted as a part of the benchmarking research of the project BIM-ICE (BIM-Integration of Higher and Continuing Education) which is co-funded by the European Union.

2 Benchmarking research rationale

Benchmarking research will allow many BIM professionals to learn about the technologies and their applicability in Germany. The work pays special attention to the solutions and national standards used in Germany and their results. The work was conducted as a part of the benchmarking research of the project BIM-ICE (BIM-Integration of Higher and Continuing Education) which is co-funded by the European Union. The logo of BIM-ICE project is shown in figure 1.



Figure 1. BIM-ICE logo (BIM-ICE Project 2021).

2.1 Project goals

The two main goals of the project are:

1. Determine the level of development of BIM technologies in Germany.
2. Determine the applicability of BIM in the German construction industry.

2.2 Expected results

The high level of development of industrial technologies in Germany allows us to put forward a hypothesis about the high level of development of the level of BIM technologies in Germany and the widespread use of BIM in various areas of the construction industry.

3 Theoretical data about BIM (Building Information Modelling)

3.1 Definition of BIM

Building Information Modeling is an information technology for a simultaneous work method based on a digital model. The digital model is used to gradually create, supplement and edit databases and information that characterize the properties of an object and its life cycle. Also, the digital model performs the function of a transparent transfer of information between performers. Transparent transmission means that each of the participants can follow the changes in the digital model, by whom and when they were made. (Federal Ministry of Transport and Digital Infrastructure 2015.)

3.2 BIM maturity levels

Due to the introduction of BIM around the world in the construction industry, there are various criteria for measuring the development, dimension and use of this technology. One of the methods for determining the development of BIM is to determine the BIM maturity level. The criteria cover a large number of BIM development parameters and can greatly help in determining the strategy for introducing and further deepening the technology into production processes. (ACCA software S.p.A. 2019.)

There are various definitions of the BIM maturity level in the normative documentation, the criteria are presented in ISO 19650-1 widely used throughout the world, and also presented in PAS 1192 preceding ISO 19650-1 document.

3.2.1 BIM maturity level according to PAS 1192

BIM levels define the level at which BIM technologies are used in a project or organization. The level depends on the degree of interconnectedness of the data, the availability of various project participants, the elaboration of the sections of the project. BIM levels according to PAS 1192 are summarized in Figure 1.

There are 4 levels of BIM in total

Level 0: The project consists only of 2D drawings using computer-aided design software. The exchange of documents, drawings, etc. is carried out using electronic printouts and papers by direct mail. There is a large number of collisions, and errors during construction and design due to misunderstanding of the participants and untimely updating of data. (ACCA software S.p.A. 2019.)

Level 1: The project uses 3D CAD to create the concept, but other sections of the documentation are sent in 2D, with no direct data link. Each participant (organization) manages only its own data, the number of collisions and errors is reduced compared to the previous level due to the presence of a common concept in 3D, however, only slightly. (ACCA software S.p.A. 2019.)

Level 2: The project uses a 3D model to work with, which is sent by the participants when changes are made. The 3D model is transferred via a common file format such as IFC (Industrial Foundation Class) or COBie (Building and Maintenance Information Exchange). Cooperation at this level allows you to detect collisions and errors at the stage of receiving an IFC or COBie file and eliminate them in advance, which significantly reduces the number of edits and changes in the project and track problems before construction begins. (ACCA software S.p.A. 2019.)

Level 3: The design is one general model with a complete list of the necessary design data about the elements, which can be accessed and modified by anyone. This means that each organization is able to observe the project in real time and report changes without having to send additional files. In addition, the model includes data on the cost, calculation of the duration of the durability of the building. The possibility of collisions and errors is minimal, each organization acts as a controller for the other. (ACCA software S.p.A. 2019.)

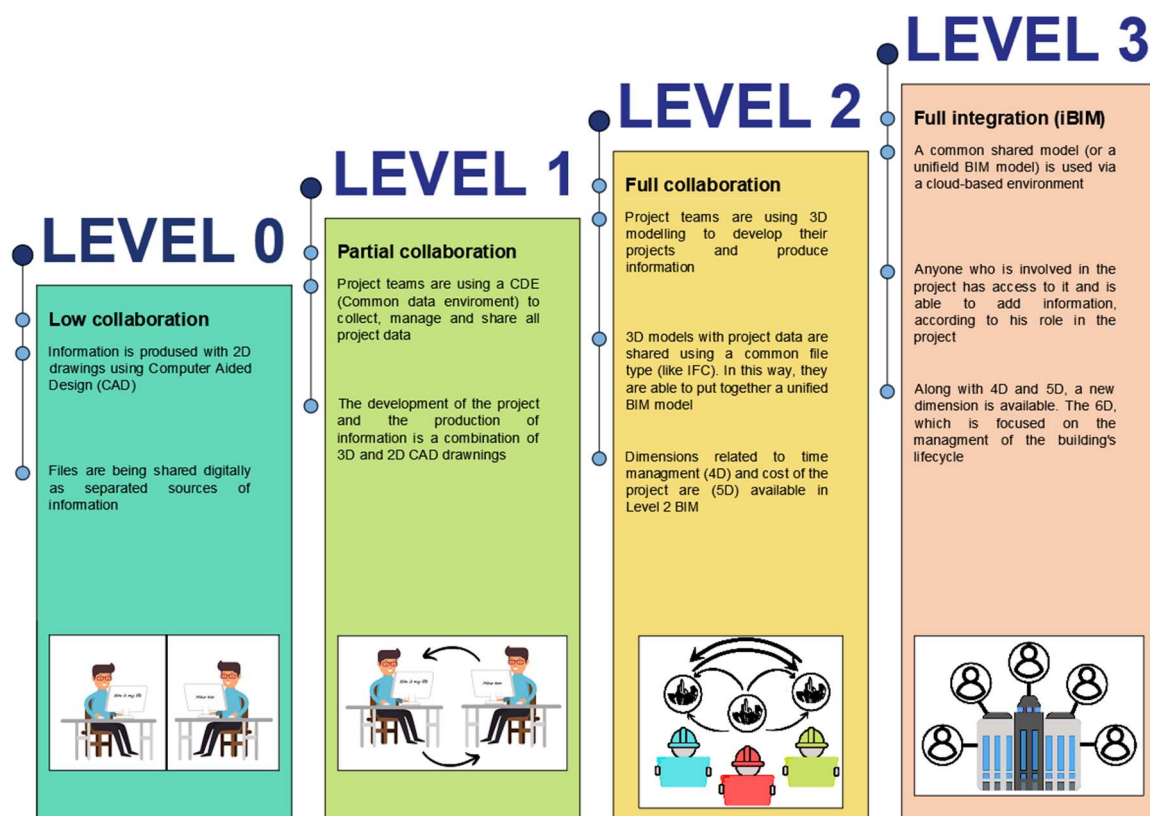


Figure 1. BIM maturity levels according to PAS 1192.

3.2.2 BIM maturity level according to ISO 19650-1

To date, the ISO 19650 standard (parts 1 and 2) is the main information source for the regulation of BIM in various countries and associations. Based on this standard, national applications are developed.

ISO 19650-1:2018 proposes the following requirements for BIM maturity levels:

BIM stage 1: 2D CAD and 3D BIM model results are combined in accordance with national regulations for project development and management. (ACCA software S.p.A. 2019.)

BIM stage 2: information models of individual sections of the project (architectural solutions, structural solutions, engineering systems, etc.) are combined and comply with international ISO 19650 standards, providing the development and management of a construction project. (ACCA software S.p.A. 2019.)

BIM stage 3: Organized databases of information models requested from various project stakeholders allow the implementation of OPEN BIM for project management and further commissioning. In addition, there is a system of solutions for the management of various, simultaneously implemented objects. (ACCA software S.p.A. 2019.)

The levels of BIM can best be seen in the sequence of maturity stages for information management shown in Figure 2. (SFS-EN ISO 19650-1, section 4).

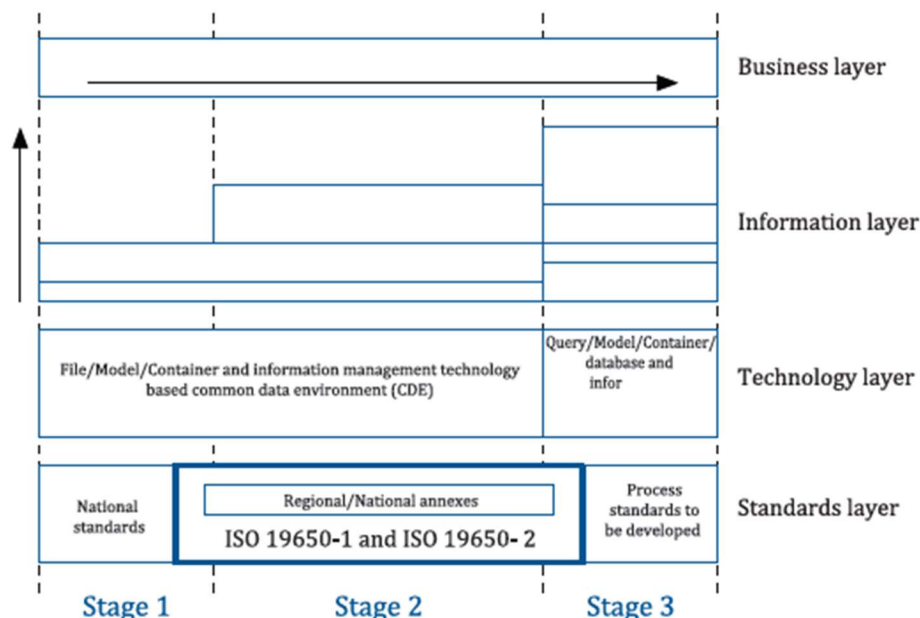


Figure 2. Sequence of maturity stage according to ISO 19650 – Matrix scheme (SFS-EN ISO 19650-1, section 4).

3.3 The using of BIM

When working in the construction industry, most engineers face many different challenges in sharing information about an object. Managing and sending information becomes a big problem. BIM is one of the best information technologies in many aspects of construction. (Liucci 2021.)

3.3.1 Troubleshooting and visualization

The main part of the project in which work is carried out using BIM is the 3D model. When building a model, you can observe the appearance of the building, structures and individual elements. In addition, when building a 3D model, it is easy to notice intersections and avoid mistakes in advance, before it becomes a significant waste of time and money. (Liucci 2021.)

3.3.2 Project management and coordination

When using BIM, all data about a building or structure is stored in the model. Quick access to the model to any interested person can be provided by sharing cloud storage built into the program interface. Each project participant can access important data and change it at any time. The changes you make in the project will be visible to all participants in the same second. (Liucci 2021.)

3.3.3 Project cost calculation

Modern BIM software allows you to estimate the cost of building a project with confidence. Since this process is completely automated, a large amount of time can be saved, which usually takes cost calculation. If you make changes to the design of a building or structure or add additional materials, the cost will be updated automatically. (Liucci 2021.)

3.3.4 Maintenance of buildings and structures

The developed 3D model of the building can be used in the future during operation, restoration, reconstruction, demolition. The task of building maintenance is greatly simplified using BIM, since we can visually assess the location of all engineering networks, elements in advance and compile a list of possible problem areas. (Liucci 2021.)

3.4 Benefits of BIM

BIM technologies have become widespread in the construction industry due to the many benefits they provide. These include (percentage data is relative to the use of BIM in Russia):

BIM technologies have become widespread in the construction industry due to the many benefits they provide. The full list of benefits is shown in Figure 3. The percentage data refers to the use of BIM in Russia.

A large number of different software makes it possible to accurately determine the most rational solutions according to the characteristics of the object. (Rybin et al. 2019, 98-105.)

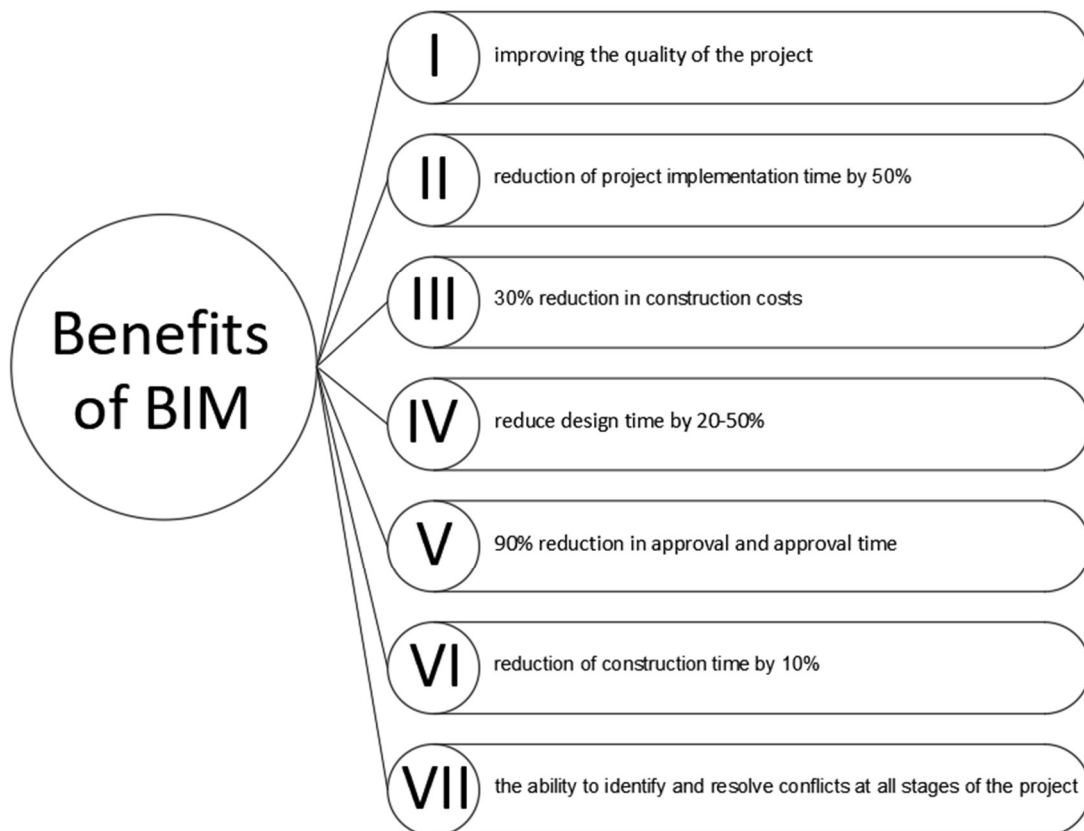


Figure 3. Benefits of BIM.

3.4.1 Benefits for structural engineers

BIM enables engineers to select the most cost-effective elements due to a complete list of design properties and parameters, to avoid discontinuity of structures and elements, and to assess the viability and feasibility of a design. Moreover, this can be done at any of the

design stages. Changes are automatically displayed to all engineers, which helps to avoid errors and design inconsistencies.

Due to the continuous contact between specialists, we reduce the design time. In addition, designers have the ability to use point clouds to obtain the exact dimensions of existing structures, their location and attachment, which allows to obtain the exact configuration of the surrounding buildings and neighboring structures. (BIM Design Hub.)

3.4.2 Benefits for architects

The main criterion when choosing an architect's solutions is the visual appeal of the building. BIM tools allow architects to change the configuration of a building, its shape, materials without spending a lot of time, due to which, in the same period of time, a specialist using BIM is able to consider a greater number of options and choose the best one than a specialist who does not use data in his work instruments. BIM allows you to create renders without resorting to graphic editors, and in case of dissatisfaction with the result, you can change the appearance of the building or the direction from which the view falls on the render. At the same time, the client receives a wide range of solutions and can choose the most attractive one.

BIM allows architects to follow the work of engineers to be completely sure that the decisions made are consistent with the original design. (BIM Design Hub.)

3.4.3 Benefits for MEP engineers

A big advantage of using BIM for MEP engineers is that many tools for creating and calculating structures are included in the software. This allows MEP engineers to improve the efficiency of the applied systems and create the optimal layout of the system elements.

In addition, BIM makes it possible to create a universal digital model, which will later be used in working drawings, wiring diagrams, purchasing lists, and manufacturing schemes.

Since all data about the digital model is structured and can be accurately tracked, any change in the systems will be immediately available to all project participants with automatic data updates in all documentation. (BIM Design Hub.)

3.4.4 Benefits for managers

Using BIM, managers can greatly simplify the process of obtaining information about the current state of the project, its properties, and decisions made. BIM enhances the role of the manager through the use of standardization processes and control tools. BIM standards

enable a manager to evaluate employee productivity, track project progress, and use project data to manage facilities. (Rybin et al. 2019, 98-105.)

3.4.5 Benefits for clients

As a result, the client receives a high quality building product at a reduced cost, in comparison with competitors who do not use BIM technologies in their activities. The most important decisions can be agreed with the client, because of which he will get the desired result. (Rybin et al. 2019, 98-105.)

4 Methods of research

For a detailed consideration of the extent and level of development of BIM in construction projects in Germany, a data sources were collected, which includes: national standards, legislative acts, scientific articles, publications.

In this work, exclusively theoretical research methods were used, such as a preliminary search for literary sources, data analysis, classification of the data obtained.

Data analysis was carried out according to the algorithm presented in Figure 4.

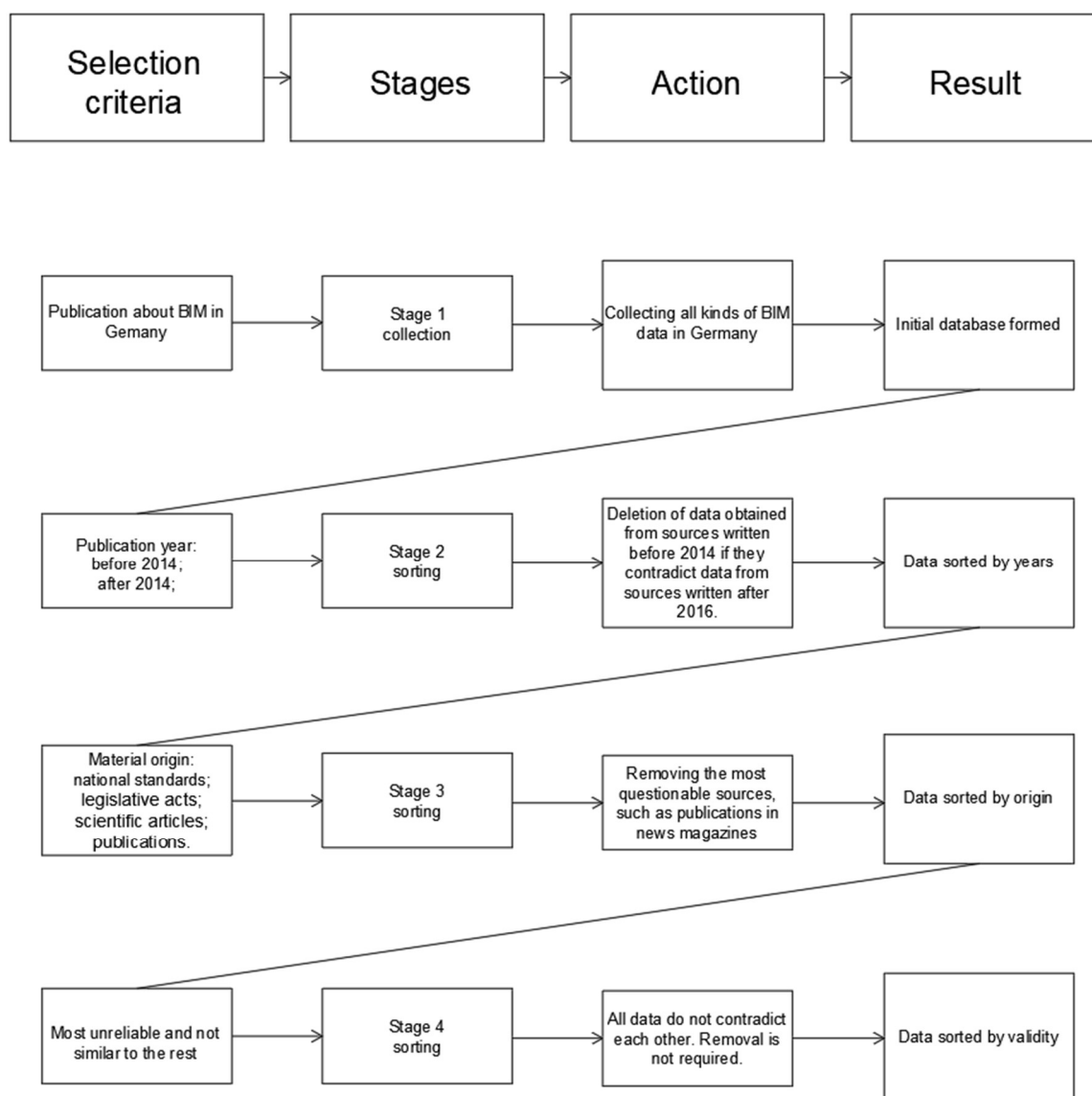


Figure 4. Data selection methodology.

5 German BIM policy

To introduce BIM into the construction industry, many countries around the world are creating government initiatives, and Germany is no exception. These initiatives provide an accurate list of required standards, contract forms and guidelines. When creating the initiative, the German government took an example from the initiatives taken by:

- In the UK, where the BIM initiative was adopted in 2010.
- In Finland, where the Senate Properties was adopted in 2007.
- In Sweden, where the Statsbygg was adopted in 2013.
- In Denmark, where the BIPS was adopted in 2013.
- In the Netherlands, where the Rgd was adopted in 2013.

The experience of these countries has shown that government initiatives have a large positive impact on the use of BIM and the compliance of new projects with the ISO 19650 international standard. (Borrmann et al. 2020, 452–465.)

5.1 Initiative projects of the government

The use of BIM in Germany is achieved through the creation of initiative projects. Projects are created by the German authorities with the participation of existing specialists from various companies. The reasons for creating projects were:

- Weak level of BIM usage in Germany.
- The presence of errors and inaccuracies in the construction of public facilities.
- Small detailing of costs during construction.
- High level of production costs. (Borrmann et al. 2020, 452–465.)

5.1.1 Road Map for Digital Design and Construction

The German government encourages the use of BIM for work processes in the AEC area, as do the governments of most industrialized countries. The National Commission in 2014 analyzed a large number of large-scale construction projects and concluded that it is necessary to reduce project risks. To do this, the government proposes to use BIM for a wide range of technological processes. After that, a strategic plan was developed for the consistent implementation of BIM methods in the construction of infrastructure and public

places. The developer was the German Ministry of Transport and Digital Infrastructure, which published a BIM roadmap (“BIM-Stufenplan”) in December 2015. (Borrmann et al. 2020, 452–465.)

It defines the following general goals:

- Reducing cash costs, eliminating cost overruns, increasing accuracy in the design and planning of the facility
- reducing the number of errors in the design of the object, by finding conflicts and increasing cooperation between the performers and customers of the project
- improving the accuracy of construction processes by simulating the entire construction cycle
- detailed consideration of the increase in costs caused by the adoption of new solutions by the customer
- visualization of all possible options for planning an object
- Improved communication with the public
- visualization of projects for maximum validity of the project and transparency of its implementation
- Optimization of life-cycle costs
- transfer of the digital model to the customer of the project for further use as the basis for managing the facility
- implementation of data on monetary or resource costs for repairs, maintenance and operation in order to model costs throughout the life cycle.

The BIM roadmap provides a rough definition of “Niveau 1” for BIM-based project delivery encompassing the following key features:

- verification of information models made using BIM technology for compliance with EIR requirements
- use only open formats for data exchange between interested parties (the most common IFC, less common GAEB and OKSTRA)
- use of the common data environment established in ISO 19650
- implementation of the principle of federated management of BIM models according to ISO 19650

- determination in each project of the information requirements that the employer puts forward (EIR) with an exact indication of the catalogs of attributes and objects, options for using the model, its volume and elaboration.
- the introduction of a mandatory requirement for the supplier to create a detailed BIM execution plan, which is inextricably linked with the ways of performing EIR.
- introduction of mandatory procurement and procurement requirements described in ISO 19650

The implementation of construction projects should not contradict previously adopted legislative acts, while the project must also comply with the above characteristics. (Borrmann et al. 2020, 452–465.)

In order to make the transition to BIM simple and easy to implement in the execution of construction projects, the remuneration clause (Honorarordnung für Architekten und Ingenieure – HOAI) is not canceled or changed. However, this may be required when introducing Niveau 2. It is assumed that when performing work in federal infrastructure facilities, Niveau 1 will be fully implemented from December 2020. (Borrmann et al. 2020, 452–465.)

This goal will be achieved in stages:

- Phase 1: 2015 –2017: Preparation Phase
- Phase 2: 2017 –2020: Extended Pilot Phase
- Phase 3: from 2020: BIM Niveau 1 for new projects

In order to establish the exact conditions for the application of BIM in order to achieve performance level 1, the number of transport infrastructure objects designed using BIM will be regularly increased starting from the summer period of 2017. All facilities are included in the pilot phase of the project and are used to analyze the applied solutions. (Borrmann et al. 2020, 452–465.)

5.1.2 TheBIM4INFRA2020 Project Implementing the BIM Roadmap

Following Phase 1, a global project tender was published to facilitate the implementation of Phase 2 of the BIM Roadmap. This tender was announced by the German Ministry of Transport, the winner was the BIM4INFRA2020 consortium. The consortium included construction and law companies, design and architectural bureaus, consulting and management companies. (Borrmann et al. 2020, 452–465.)

The main members of the consortium are:

- Technical University of Munich
- Ruhr University Bochum
- Planen Bauen 4.0
- HOCHTIEF ViCon
- Obermeyer Planen
- Obermeyer Beraten
- AEC Deutschland
- WTM Engineers
- Max Bogl
- Kapellmann & Partne
- BIM454 A. Borrmann

The BIM4INFRA2020 project included a work plan, which consisted of the most important main points:

- creation of a strategy and structure of information components and databases
- development of recommendations for the implementation of BIM in construction projects and the industry as a whole
- compliance with legislative and legal acts when performing construction projects using BIM
- control and management of pilot projects
- create an accurate BIM 2020 project scenario (Borrmann et al. 2020, 452–465.)

After analyzing the implementation of the pilot projects, it was decided to document the results obtained and make them available to all interested parties. 10 different guidance documents have been created that accurately characterize the main aspects of the implementation of construction projects using BIM. (Borrmann et al. 2020, 452–465.)

BIM4INFRA2020 dwelled in the most detail in its publications on such points as:

- use of the IFC format when exchanging data between performers and the customer
- basic concepts and description of the general process

- monetary specifications related to fees and contracts
- contract templates
- vendor-independent data exchange
- requirements for the information provided and databases for employers
- options for using BIM technologies in construction
- description of BIM technologies
- BIM project execution plan with examples and templates
- BIM development levels (Borrmann et al. 2020, 452–465.)

The BIM4INFRA2020 project has been of great benefit to the introduction of BIM into the German construction industry, as the following results have been achieved:

- BIM guides have been published, providing comprehensive information about the technology, its application in objects and examples
- created the basic concept of databases on construction sites
- a BIM 2020 scenario is accurately formulated based on an assessment of use cases

These results provided critical milestones for the implementation of the German BIM Roadmap. In addition to use in the construction industry, the German government proposes to use BIM for infrastructure and housing construction. In connection with this, the German Building Industry Digitization Center was launched. (Borrmann et al. 2020, 452–465.)

5.2 BIM standards and guidelines

National standards and guidelines began to cover much more issues after the initiative projects BIM4INFRA and Road Map for Digital Design and Construction. There was an accurate distribution of responsibilities of project participants, control over the compliance of projects with the international standard ISO 19650, and the use of OpenBIM technology expanded. There was a strategy of work with databases. There are examples of successful use of BIM, with a complete list of required sections. Below is a figure 5 with a list of standards and guidelines, a strategy, national BIM groups, and a description of the platform that promotes the development of BIM in Germany. (European Construction Sector Observatory, 2021.)

Type of BIM support measures			
Countries	BIM/Digital Construction Strategy	BIM Standards and/or guidance	National working group on BIM
Germany	<ul style="list-style-type: none"> The roadmap for digital design and construction (Stufenplan Digitales Planen und Bauen 4.0) 	<ul style="list-style-type: none"> Deutsches Institut für Normung e.V. (DIN) (en) DIN SPEC 91400 (en) Guidance: BIM-Leitfaden für Deutschland 	<ul style="list-style-type: none"> The Federal Ministry of Transport and Digital Infrastructure (BMVI) (en) planen-bauen 4.0: official-BIM steering group established by the BMVI (de)
Countries	Digital Construction Platform	Type of platform	
Germany	Yes	<ul style="list-style-type: none"> "Deutschland baut!" Description: a common platform for all companies in the construction sector and a network to facilitate cooperation among industry stakeholders. Description: the national centre for the digitisation of the building industry. It is the federal government's central public contact point for information and activities relating to Building Information Modelling (BIM). The products, open standards and concepts are made available to both public construction and the entire construction value chain. 	

Figure 5. Type of BIM support measure (European Construction Sector Observatory, 2021).

Currently, Germany have put in place mandatory BIM requirements applicable either to all projects or at least for projects of a determined minimum budget.

6 Current BIM condition in Germany

By now, approximately 70% of German design and construction organizations use BIM technologies in projects at various levels. At the same time, the vast majority are architectural and design organizations. Whereas, for all projects worth over 100 million euros, BIM is mandatory from 2017. And for all government contracts related to the construction of federal infrastructure, BIM became mandatory from December 31, 2020. These government decisions prompted major players in the construction market to actively implement BIM in projects at all stages of production. (O'Malley 2021.)

The highly developed construction market in Germany testifies to the advanced and widespread adoption of BIM. The German government has a significant influence on the implementation of BIM by investing in standardization, supporting BIM projects, training specialists in the field of BIM. All assistance is provided within the framework of the vision of digitalization of the German construction industry everywhere. (O'Malley 2021.)

For comparison, Figure 6 below shows the level of BIM applied, the date BIM became mandatory, and the percentage of companies using BIM in different countries.











State of BIM Adoption in 2021: 7 Top Countries Compared			
	 The most common BIM level(s)	 When did BIM become mandatory?	 Percentage of construction companies that use BIM
 UK	2, with development towards 3	2016 for government projects	73%
 Germany	1, some cases of 2 and 3	2017 for projects worth over €100 million	70%
 Poland	1, growing rates of 2	2030 for capital construction projects with a state budget	43%
 France	2	1 st January 2022	35% – real estate 50 – 60% of construction companies
 Croatia	0, some cases of level 1	Not currently mandatory	25% of designers 4% of contractors
 Austria	1, with local standards pushing for 3	2018 – 20 for cost control in public buildings	20%
 Russia	1, growing rates of 2 and 3	1 st March 2022 for all government-funded projects	12%

Figure 6. State of BIM Adoption (O'Malley 2021).

6.1 Interest in BIM technologies

BIM is the most promising and used digital technology in the construction sector; however, its market penetration in the EU is still moderate. In fact, in Europe, 29% of construction companies use BIM 3D (which includes the exchange of information and the creation of

graphic and non-graphic information); and 61% have never used it. The numbers are down significantly for BIM 4D, with only 6% of companies implementing it. (European Construction Sector Observatory, 2021.)

Figure 7 shows the average level of BIM maturity in EU countries based on survey responses. With the exception of a few countries that did not receive responses from the survey conducted as part of this study, there is a relatively high average level of BIM adoption. Germany is below the EU average. The implementation of BIM in EU Member States is also linked to the current legal framework. (European Construction Sector Observatory, 2021.)

The European BIM market was valued at €1.8 billion in 2016 and was forecast to grow by 13% to reach €2.1 billion in 2023. Globally, the BIM market is expected to grow at 18% annually from 2019. (European Construction Sector Observatory, 2021.)

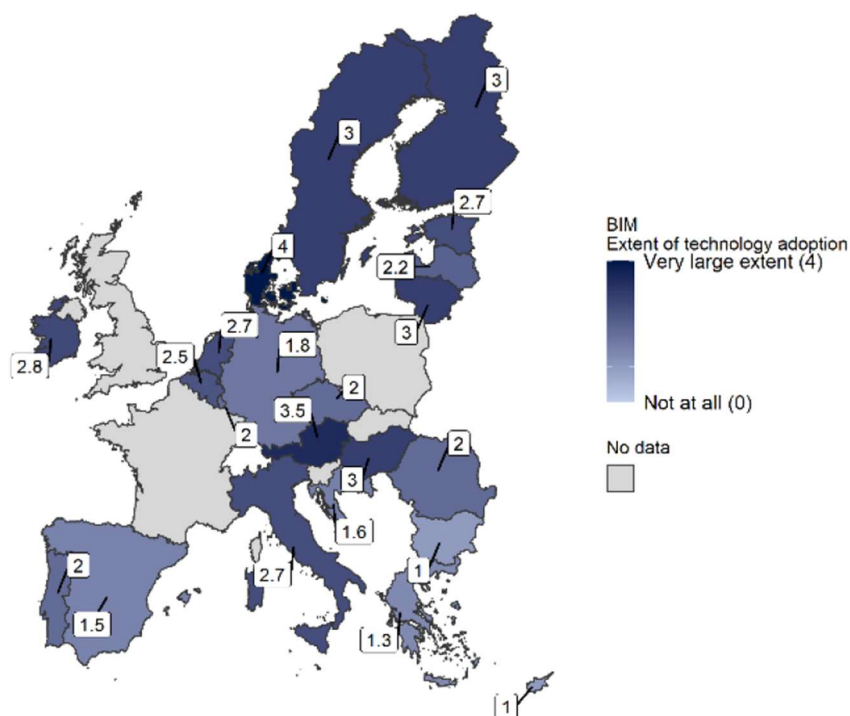


Figure 7. Extent of BIM adoption (European Construction Sector Observatory, 2021).

To assess the interest of specialists in BIM, it was decided to use the data of the average monthly search volume of BIM 2016-2020 in Google per 100,000 population, this is shown in Figure 8. At the same time, Germany has a high level of interest, which is at the level of 60%. Germany is in the list of leading countries in terms of interest in the topic.

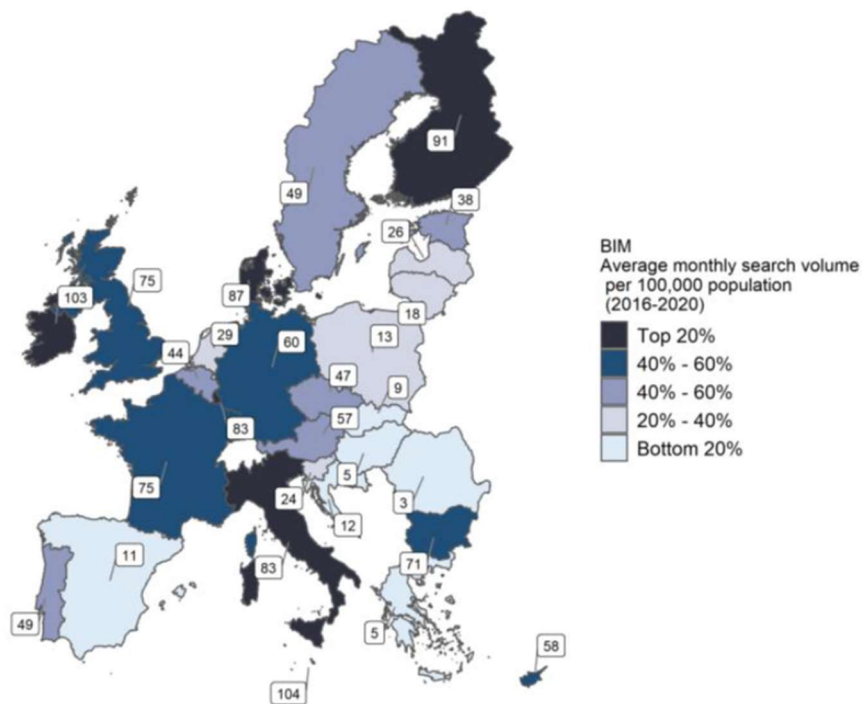


Figure 8. Average monthly BIM search volume 2016-2020 (European Construction Sector Observatory, 2021).

To assess the dynamics of the interest of BIM users, it was decided to use the increase in the number of search queries related to BIM. In this case, Germany has a 27% increase in interest, which is the average for European countries.

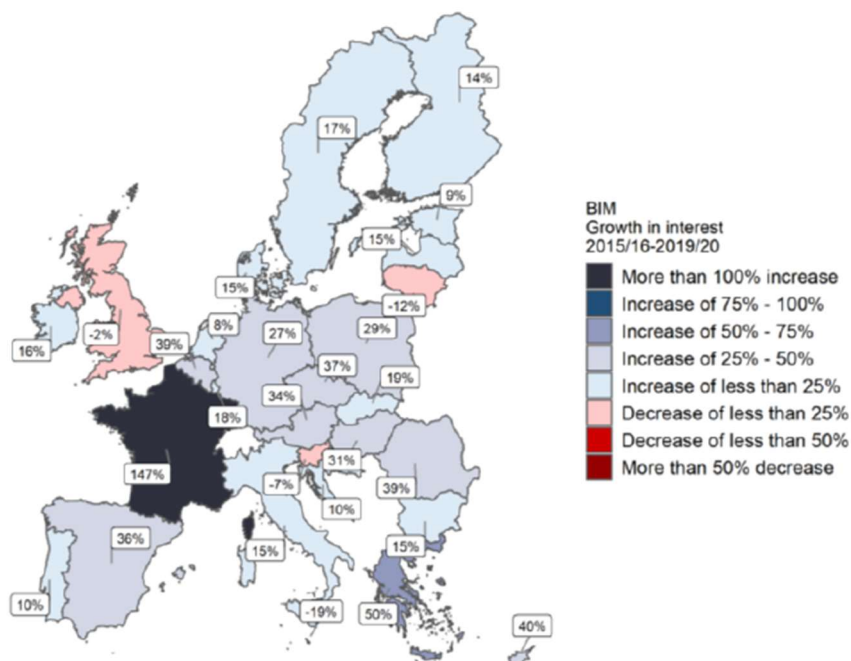


Figure 9. BIM’s growth in interest 2015-2020 (European Construction Sector Observatory, 2021).

6.2 Organizations associated with BIM

This section will look at the most influential BIM-related companies that have made significant contributions to the development and application of the technology.

HOCHTIEF ViCon is one of the largest German companies engaged in BIM consulting, BIM management, training of specialists, collection of necessary data. The company participated in the development of the Road Map for Digital Design and Construction, in which it developed guidelines, requirements for model database structures, recommendations on legal issues, and monitoring pilot projects. (HOCHTIEF ViCon 2021.)

WTM Engineers is a significant company in the field of BIM and construction in general. The company is engaged in consulting, design of aboveground and underground structures, construction supervision, BIM solutions. They took an active part in the development of the Road Map for Digital Design and Construction, are members of the buildingSMART and BIM HUB Hamburg associations, the most significant projects are: Hamburg Municipal Authorities Administrative Head Office, Huntebrücke A29 interstate, Reyher company grounds. During the development of these projects, BIM technologies were used, digital twins were created, after which work was carried out on the construction of structures. (WTM Engineers 2022.)

DEUBIM is an important player in the BIM-related services market. The main area of work is consulting based on the digitalization of construction sites and real estate using BIM. In addition, the company provides training services for BIM specialists. DEUBIM is a member of the buildingSMART association and is a co-shareholder of the planen-bauen 4.0 initiative. (DEUBIM 2018.)

GSP Network is a significant company involved in the implementation of BIM technologies in German construction companies. The main direction is activity in the field of consulting. The company offers its services for the implementation of BIM in the company, consulting on BIM issues in existing projects and training of specialists. GSP Network is a member of the buildingSMART association. (GSP Network.)

In addition to companies, there are non-profit associations that take a huge part in the development of BIM, the development of textbooks and related literature.

BuildingSMART Deutschland - the main goal of the association is to develop and standardize open, i.e., manufacturer-neutral information exchange in projects using BIM, as well as to standardize and define all possible related workflows. For this, the multi-level structure of work according to the buildingSMART International model has proven itself well. To

spread the idea of Open BIM exchange of experience, the association regularly organizes seminars, webinars and conferences, as well as a wide range of proposals for networking and professional exchange at the national, international and regional levels. (BuildingSMART Germany 2021.)

BIM HUB Hamburg is a non-profit association whose main goal is to create a common database on BIM technologies and promote technology in construction companies. (BIM HUB Hamburg.)

6.3 BIM education

One of the most important factors contributing to the development of BIM in the country and an increase in the level of use is the training of existing specialists in the field of construction and students of construction specialties. Many companies, including those mentioned earlier, are engaged in the retraining of existing specialists, and there are various courses for students in educational institutions. These can be both higher education institutions and certified centers of excellence. A short list of institutions and courses that will help you learn BIM:

University of Applied Sciences, Dresden. Dresden University of Applied Sciences was founded in 1992 and has a broad engineering profile in teaching and research complemented by artistic skills. It is a regional and international university with a large number of practical courses in engineering combined with a diverse background in applied research. BIM related courses: 3D modeling, BIM for Building Systems Engineering, Geodesy and BIM. (Hochschule für Technik und Wirtschaft Dresden.)

The Institute of Digital and Autonomous Construction, Hamburg. The Institute for Digital and Autonomous Building (IDAC) offers courses in a wide variety of fields. In addition to teaching the fundamentals of civil and environmental design, the IDAC team continuously integrates current trends and the latest developments in research and engineering practice into courses. As a result, not only are courses offered in an attractive and balanced way, but the needs of students wishing to become familiar with the latest, innovative areas of information technology and civil engineering computing are met. BIM related courses: BIM applications, BIM data management, BIM data exchange. (Institute of Digital and Autonomous Construction 2022.)

Technical university of Dortmund. The main direction of the university is mechanical engineering. The research achievements of this university in the field of engineering are well

known nationally and internationally. For students of builders, the university may be of interest in the areas of Structural engineering and MEP engineering. The main emphasis is on physics, computer science, statistics and logistics. (Technische Universität Dortmund.)

Technical university of Munich. One of the best technical universities in Europe. The main goal of the university is the pursuit of excellence in teaching and research methods, education in various disciplines and the active promotion of scientists who begin their journey within the walls of this educational institution. The university has a large number of connections with educational institutions and companies, both in Germany and around the world. In international rankings, TUM is consistently among the best European universities. BIM related courses: 3D/4D building information modeling and processing, modeling of structural infrastructure, construction process, simulation and optimization, computerized lifetime management, crowd simulation, collaborative computational steering. (Dean McClements 2019.)

Technical University of Darmstadt. The university is synonymous with excellent modern science and sets itself huge challenges in the development of artificial intelligence and energy extraction methods. The university has a significant impact on modern scientific discovery through visionary learning opportunities and outstanding discoveries. BIM-related courses: knowledge-based BIM/CAD (BIM/CAD), computer science in civil and environmental engineering, informatics in civil and environmental engineering, databases for engineering applications. (Dean McClements 2019.)

6.4 Industries that use BIM

The range of application of BIM technologies is growing every day. Due to the convenience and automation, it is beginning to be used in all areas related to real estate, this applies to both cities and infrastructure facilities.

6.4.1 House modeling

House modeling has its own characteristics, such as interior modeling, zoning in the architectural section, a large number of details, such as fittings. Modeling of buildings and structures has its own characteristics, such as interior modeling, zoning in the architectural section, a large number of details, such as fittings. For this type of design, Autodesk Revit is the most preferred program. This program allows you to work in a 3D model, with the output of 2D drawings and documentation. Figure 10 shows the Autocad Revit user interface.

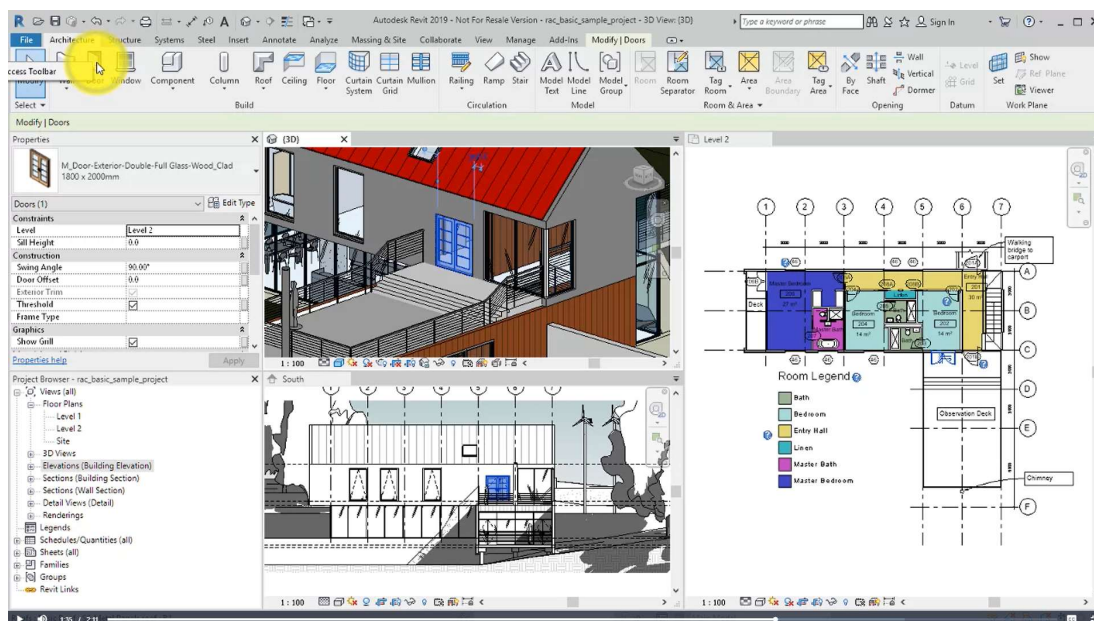


Figure 10. Autodesk Revit interface (Autodesk Help 2021).

In addition, Revit provides the ability to create 3D visualizations and models for a virtual situation.

In second place in terms of applicability is Archicad, the main purpose of the application is to create architecture, visualization and documentation. (Jan Paul Schop 2021.)

In third place is the solution from Vectorworks, it allows you to create architectural solutions for the project, industrial and landscape design, create 3D models and issue documentation. (Jan Paul Schop 2021.)

Figure 11 shows the ranking of the use of software for BIM and CAD projects by architects.

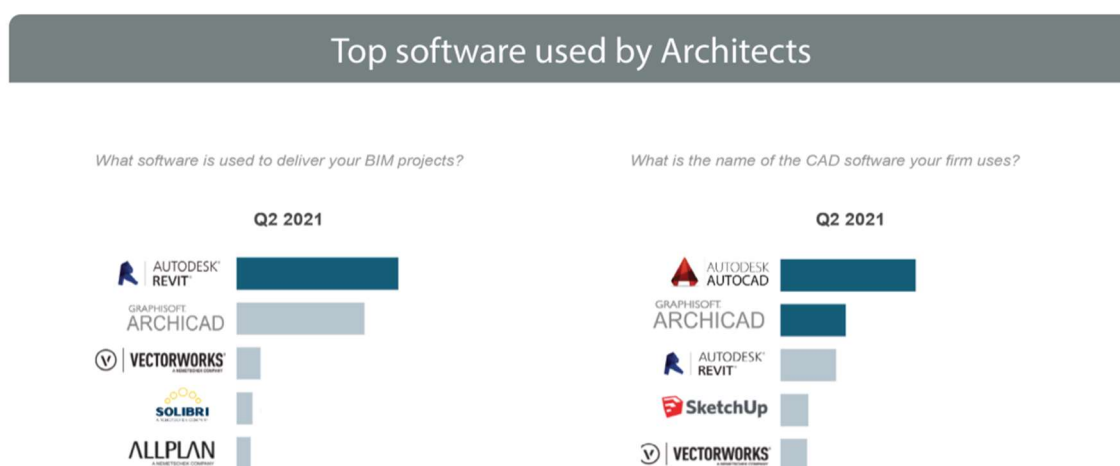


Figure 11. Top software used by Architects in Germany (Jan Paul Schop 2021).

6.4.2 City modeling

To adopt the right urban development strategies, it is necessary to use the latest technologies, including BIM technologies. Modern cities are branched systems that consist of a large number of demographic, environmental and economic conditions. When using BIM, we can create a digital twin of a city with a description of environmental, infrastructural, and geographical parameters. We will be able to simulate various situations that may arise in the future. It becomes possible to assess the extent of pollution and simulate the consequences for the city, as well as to accurately assess the possibility of a traffic collapse when the number of cars in the city increases, or during major events such as sports championships. One of the city's digital twins was created in Urban Digital Twins for Smart Cities and Citizens: The Case Study of Herrenberg, Germany. As a result, a 3D twin of the building was obtained with the characteristics of the streets in terms of pollution, a mathematical model of the road network, which makes it possible to estimate the throughput of the streets. To create a 3D model, 3D scanning technology was used, after which a model was created in Paraview using Hawk and special software COVISE and OpenCOVER. This made it possible to automate the processing of two-dimensional images. Georeferenced spatial syntax data for their 3D representation in virtual reality. DepthmapX, a multi-platform open source software, was used to create the mathematical model. (Dembski et al. 2020.)

6.4.3 Infra modeling

As part of the BIM4INFRA2020 project, pilot infrastructure projects were implemented to address the exact consequences and shortcomings of the decisions made. Consider the example of one of them using BIM in infrastructure design. BIM pilot project of the Federal Ministry of Transport (BMVI) Eight-lane extension of the A99 autobahn near Munich Replacement of structure 27/1 on railway line 5556. The model was created in Revit, and imported into the GIS system via IFC. (Schaller et al. 2017.)

Due to the lack of a large amount of data, we will consider programs that are widely used in many countries. Figure 12 shows the scheme for exporting BIM models from REVIT to IFC format.

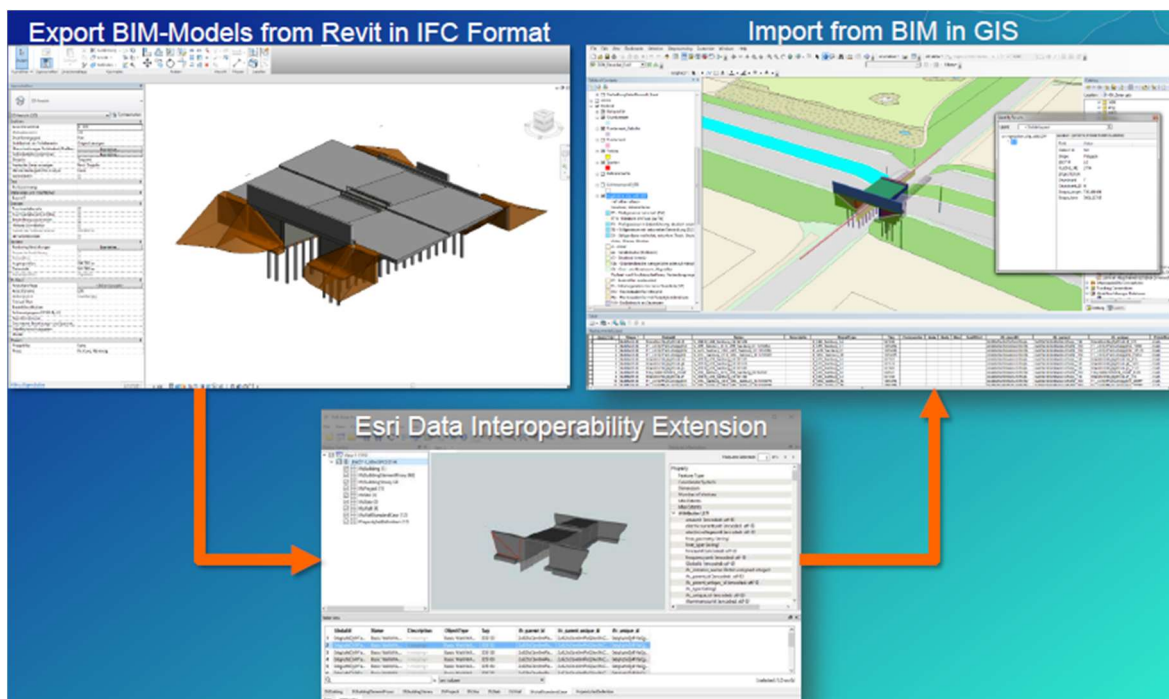


Figure 12. Export BIM-Models from Revit in IFC Format (Schaller et al. 2017).

Autodesk Civil 3D is software that enables design engineers to create landscape forms, infrastructure objects. This software package allows you to work with objects in 3D and 2D, display topographic survey, accurate data for each mark of the landscape.

Autodesk InfraWorks is a software that allows you to perform the concepts of objects in the natural and built environment. The main purpose of use is to visualize the decisions made, to evaluate the solution at any stage.

Trimble Novapoint is a set of design tools in Trimble's advanced BIM solution for infrastructure projects that enables civil engineers to efficiently design all aspects of today's highways and railroads, traffic and industrial tunnels, bridges of various configurations, water and sewer systems. For infrastructure facilities, a large number of solutions from Trimble are used: Novapoint Go, Novapoint Landscape, Novapoint Railway and other.

6.4.4 Structural modeling

For structural design, the most applicable in Germany is Autodesk Revit. This software allows you to create models of reinforced concrete structures with the exact location of reinforcing bars, embedded parts, and assign a large number of properties for accurate calculation, such as the weight of the structure, its cost, exact dimensions. When designing metal structures, it is possible to develop junctions in detail, accurately position the necessary holes and fasteners, such as bolts, nuts and studs. (Auxalia 2022.)

A lesser used BIM software for structural design is Tekla Structures. This is a handy tool for designing load-bearing and enclosing structures made of steel or reinforced concrete. In the development of reinforced concrete structures, there are special tools for automatic reinforcement of elements; in the development of steel structures, there are a large number of preinstalled plugins for creating structural fasteners. Tekla Structures provides a variable work environment that allows you to enter the required number of parameters, including: resource costs, durability of elements, fire resistance, corrosion resistance. An example of using Tekla Structures is the Wolkenhain lookout. Figure 13 shows a view of the observation deck in Tekla Structures. The Wolkenhain observation deck is located at an altitude of 120 meters above sea level in the center of Berlin's Kienberg district. (Trimble Solutions Corporation 2018.)

With model-based planning and execution, the company was able to realize a complex steel structure concept. With Tekla Structures, the builder has a huge advantage of being able to discuss the project, always having an up-to-date model. In addition, some of the structures began to be made before the drawings were drawn, since the task for the CNC was formed on the basis of the model. This decision allowed to significantly save the time of the project implementation. (Trimble Solutions Corporation 2018.)

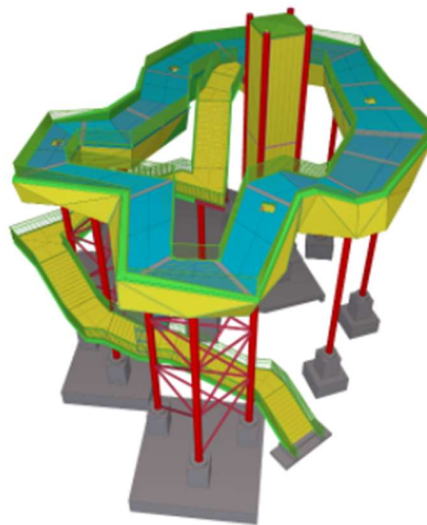


Figure 13. View of the observation deck model in Tekla Structures (Trimble Solutions Corporation 2018).

7 Summary

According to the given data, BIM specialists have an average level of interest in BIM technology in the European Union.

Germany now has a solid foundation for the worldwide implementation of BIM at maturity level 1 in accordance with ISO 19650. Initiative projects by the German government have standardized, streamlined and refined the processes associated with the implementation and use of BIM. BIM design guides and contract templates have been developed. There are good examples of BIM implementation that have been used as innovative tools in the BIM4INFRA project. Also, the mandatory use of BIM level 1 according to ISO 19650 in the construction of public facilities should significantly stimulate design organizations.

In addition to government measures, there are associations that promote technology development, these are BuildingSMART Deutschland and BIM HUB Hamburg, which compile textbooks and manuals on BIM, and also carry out a continuous exchange of information between members of the associations. BuildingSMART is an international organization and has experience in BIM development in many European countries, which allows it to be well ahead of Germany in this matter. There are a large number of consulting companies in Germany that are able to implement and maintain BIM in the company at levels above maturity level 1 in accordance with ISO 19650.

BIM education is at a high level, there is a large selection of universities with a wide range of courses on this technology. Classes are taught by active specialists who participate, among other things, in government initiative projects. With all this, BIM technology is mainly used by large companies, as they can afford large one-time costs for consulting companies, in order to save money in the future. While medium and small companies use BIM at best during the architectural design stage.

The most popular BIM design software is Autodesk Revit as it can be used for infrastructure models as well as house models. The newest and most promising direction of City-modeling is carried out only by the largest scientific institutions with the support of the Government.

Germany has everything it takes to implement BIM at maturity level 1 according to ISO 19650.

To increase the level of BIM in the future, it is necessary to increase the requirements for the construction of public facilities and add preferences for innovators in this area.

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