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EVOLUTION OF BIM: EPISTEMOLOGY, GENESIS AND DIVISION INTO PERIODS

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SUMMARY: *There is no consensus among BIM practitioners and theorists as to whether BIM is an evolution from CAD systems or a total revolution in construction. In the history of BIM, there have been a number of important, epoch-making events that have changed the direction of BIM. From the concept of BIM, to the technology used in construction, to the methodology, to the process, to the holistic idea of BIM, one can see the evolution of user approaches to its use. BIM has two dimensions: an information system and a philosophy. Thus, BIM is both a tool and a philosophy that brings about a revolution. Several decades of BIM development prompts reflection and the delineation of perhaps some stages of maturation. This paper presents a theory of cognition (epistemology), essential for understanding the history of BIM. The genesis of the separation of BIM from CAD makes it clear that specific factors influenced further developments. Thus, the aim of the study was to periodise BIM in view of various factors that may be relevant to researchers interested in BIM and companies using or implementing BIM. The literature survey maintained inclusivity to reflect both positive and critical aspects of BIM. The periodisation of the history of BIM was done due to 3 factors: idea, approach and organisational culture. The development of the BIM idea established the direction in which systems and software development was heading, the user approach forced interoperability and the organisational culture emphasised increasing efficiency. Working according to the openBIM approach or within an IPD framework is probably not the end of the anticipated level of BIM maturity. The division into periods will probably be the subject of much discussion, but will perhaps set the directions for the future.*

KEYWORDS: *periodisation, BIM, CAD, epistemology, genesis, periods, idea, approach, organisational culture, future.*

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1. INTRODUCTION

Enthused by the possibilities of BIM (Building Information Modelling), we try to explore its secrets, yet the more we learn about BIM, the more uncomfortable we feel about our lack of knowledge or experience. Those experienced in BIM are well aware that BIM is a complex subject that is difficult to define clearly. Particularly as BIM has virtually extracted itself from CAD (Computer Aided Design). Currently BIM affects basically every stakeholder in the construction process. Thus, the range of people who should be aware of what BIM is (and what it is not) is extremely wide. And it is not just about the investor, designer, contractor or manager. BIM is penetrating ever deeper, involving manufacturers of construction materials, service providers, health and safety inspectors, site engineers, subcontractors, public administration staff or even the neighbours of the planned project (Khan et. al., 2021). In a mature approach, each of them should be able to familiarise themselves with the BIM model, should be able to find information that is important from their point of view and perhaps provide comments that are relevant from their point of view. A BIM model is colloquially understood as a semantic database of a building object. Therefore, semantics (geometry, topology, meaning) is what gives BIM the additional power and strength to be able facilitate thing that CAD cannot (Kumar, 2015). BIM undoubtedly opens up entirely new possibilities. Understanding and facilitating the adoption of BIM in different markets is of increasing interest to policy makers, researchers and other stakeholders in the construction industry. While models can promote the science of BIM, there is still a need in many countries to promote BIM, develop templates, roadmaps or implementation policies (Kassem, Succar, 2017). At the same time, there are many flaws (Lu et. al., 2017) and lacks (Sun et. al., 2017) of the implemented BIM technology in the tools available on the market. The development of BIM software has not kept pace with the development of BIM theory and practice presented in the academic field. New methods and concepts are emerging that are too slowly being adapted to IT solutions.

BIM behaves like a socio-technical system - it changes public institutions, companies, business models, education, workplaces and careers, and is changed by the environment in which it operates. It is not just a tool for automation or integration, but a tool for further specialisation. Specialisation is the key to a division of labour that results in more knowledge, higher quality projects and more creative people (Turk, 2016). It is widely regarded as a mature technology, yet it is developing and evolving all the time. Which way it will go largely depends on national implementations and its results. The example of the UK shows that a multi-year and even very ambitious plan can be successful. The UK government's early and strong commitment to BIM makes the UK a world leader in BIM adoption (Cheng, Lu, 2015). Many countries are taking their lead from the UK implementation. Other countries, in turn, are going their own way. The use of BIM in construction projects is effective, but still the use of BIM is still slow in many countries, including for example China (Luo et al., 2022). Regardless of the level of adoption, the theory of knowing BIM is extremely important. At least four decades of BIM's development invite reflection related to its history and perhaps the division of this period into a specific framework. In the past, many developments have been epochal. The division into epochs is not a matter of course and, depending on one's perspective, may yield different results. The aim of the study was therefore to periodise BIM in the light of various factors. Periodisation is essential to keep the BIM story in order, reduce uncertainty and increase understanding when using BIM.

To achieve the aim, it was decided to make an in-depth literature study. The review primarily covered scientific publications related to the history of CAD and BIM. In addition, most of the known BIM handbooks were studied, which contain many references to the distinguish of BIM from CAD. Historical research has made it possible to draw up a description of the genesis of BIM. The epistemology of BIM arose from the clash of many different authors positions on model building. The periodisation that forms the core of the study is the result of all these considerations.

2. EPISTEMOLOGY OF BIM

The main objective of engineering is properly executed change (technical, economic, organisational, social, etc.). A definition for engineers is made by Billington: Engineering or technology is the making of things that did not previously exist, whereas science is the discovering of things that have long existed. Technological results are forms that exist only because people want to make them, whereas scientific results are formulations of what exists, independently of human intentions. Technology deals with the artificial, science with the natural (Billington, 1983). A prerequisite for the smooth implementation of the intended technological changes is proper preparation, above all conceptual preparation, which is the essence of all design (Słyk et al., 2015). It is 'design' that is indicated as the main methodological distinction of practical sciences (Kotarbinski, 2003). The design process that the designer is familiar with from practice is the process of generating ideas for solutions to improve and enhance existing solutions. In order to do this, the designer uses tools, resources and other available means that result in a specific action. In teaching engineering we also need a graphical representation of buildings and impart knowledge about their condition and behaviour. When teaching engineering, we refer to the same real world objects that have an explicit conceptualisation in BIM. BIM is causing a profound change in the way engineers are taught, which is oriented towards integrated design (Turk, Starčič 2020). In the case of the wider construction industry, the task of design is to shape a high-quality space in which people live. BIM is another tool after the drawing board and CAD systems that improves the design process itself. However, CAD files contain detailed geometric information that is not suitable for use in downstream applications such as process planning (Nasr, Kamrani, 2006). In turn, the lack of non-geometric parameters in CAD systems has reinforced the need to look for other IT solutions.

In the process of designing with BIM, the designer uses knowledge. This knowledge, in turn, should be certain, scientific, and relate to the essence of the issue at hand. BIM theory generally derives from empiricism, or experience, which is then transferred to practice. The practitioner, in turn, can demonstrate its weakness, leading to further development of the theory. Without BIM theory, a novice practitioner can easily make mistakes (out of ignorance, omission or carelessness). This is important because we now consider a designer to be an eligible specialist. Thus, others, who are not specialists, without being able to judge the conduct of the specialist designer, place their trust in him or her, which must not be disappointed. In conclusion, the designer is responsible for posing a problem and solving it in accordance with the art of engineering. BIM theory determines how tools should be used, but is also constrained by, and rooted in, existing application practices. Similarly, new tools (software, procedures, conventions, etc.) are dictated by both theory and these existing practices. This reciprocity can be useful in the implementation of BIM, but at the same time it remains a source of unnecessary limitations. There is still room to improve productivity at every level, if not to reject some of the assumptions of BIM (Koutamanis et.al, 2021).

Regardless of the industry, designers build so-called models in their daily work. Building a model is usually understood as an attempt to reflect reality (in other words, an image of reality), and with digital developments, the models being built are becoming more sophisticated and their capabilities are increasing. And it is not at all about the third dimension, which our perception perceives better. The more important aspect here is the degree of 'saturation' with information. BIM models, in a simplified sense, are a relational database that stores information about a building object (volume or infrastructure) or collection(s) of these objects throughout their life cycle. The more information there is, the greater the knowledge of the development in question, and therefore the more informed the decisions made.

In the 1950s the first project management methods and techniques appeared in the industry, but there was a lack of tools for verification and validation tools, which led to further improvements in project management methodologies in the construction industry, among others (Koskela et. al., 2017). Over time, further project management methodologies emerged, from PMI to Prince, to Lean-Agile, which are still used today in smaller and larger construction projects (McArthur, Bortoluzzi, 2018). In most cases, however, regardless of the methodology used, traditional means of communication were used in the 20th century, e.g. handwritten drawings, mock-ups or technical descriptions. The dynamic development of computers confronted the traditional means with new technology (CAD and later BIM), which were either improved, replaced or became irrelevant. BIM has made it possible to represent the architecture of a building in a completely new way, but it has also necessitated the invention of new processes that have changed the way architecture is created. The manufacturing industry continues to evolve and is beginning to use three-dimensional (3D) models as the central knowledge artefact for product data and definition (Ruemler et.al. 2016). In the early stages of BIM development, models were created based on 2D documentation. With the advent of more and more parametric libraries, designers created increasingly sophisticated BIM models, often using a variety of sources (scanning data, archive data, photographs etc.). The integrated data provides more and more modelling possibilities. However, the object libraries, for example, are already large enough that there is a need to download BIM components quickly and efficiently (Li et.al., 2020). Contemporary discourse recognises that digital technology does not displace traditional ways of knowing, but rather stands alongside them, offering its own unique contribution to the epistemology of architecture (Christenson, 2008). In strands of theory, ontology precedes epistemology, and in BIM it underpins the functioning of whole systems, through defined naming of objects and relationships between them. Epistemology is followed by an exploration of the human nature of how things work, from which good practice is drawn, forming the basis of the methodology. Methodology in BIM focuses on generating value for the project - improves the product/service.

Over time, it has become apparent that the problem is not the use of BIM software, which can be mastered, but collaboration between designers or trades. Researchers and computer scientists have developed virtual and physical collaboration platforms for AEC (Architecture, Engineering, Construction). Improving communication through the use of wireless and cloud technologies has been identified as an important factor in maintaining the quality of this collaboration. Interoperability and online storage of models is already widely used in BIM (Park, Nagakura, 2014). Interoperability in BIM is defined as the ability to exchange data between applications to facilitate automation and avoid data re-entry. First, however, despite promotional and standardization efforts by national and international agencies, multiple solutions will continue to evolve as integration and differentiation processes occur simultaneously (Miettinen, Paavola, 2014). Second, perfectly interoperable integrated systems will thus never be achieved (Turk, 2020). At the same time, providing IFC, BCF or according to mvdXML rules is not at all that simple (Zhang, Beetz, Weise, 2015). In turn, filtering out desirable elements, such as collision with detection report, is one of the issues that needs to be urgently addressed in the construction industry (Lin, Huang, 2019). Holzer, in his 2014 reflections, notes that practitioners are well aware that the quality of BIM itself depends on a deeper understanding of the building construction process. There is a danger associated with the use of BIM by inexperienced designers, which can imply inefficiencies in the design process as well as in the delivery of the project (Holzer, 2014). In addition to the knowledge of BIM technology, it is crucial to educate oneself to think critically, to be open and attentive to innovations, to be able to adapt to rapidly changing environmental conditions, and to communicate and manage information efficiently in a multidisciplinary team. BIM, along with the development of the software, has become a symbol of collaboration, but the adversarial nature of corporate branding and market dominance has led to a number of mutually incompatible BIM offerings (Wierzbicki, de Silva, Krug, 2011).

Let the multitude of problems (integration into GIS (Geograpfic Information System) (Borkowski, Kochański, Wyszomirski, 2023), macro to micro object modelling (Pratama et. al., 2020), insufficient BIM-BEM interoperability (Afzal et. al., 2023), insufficient filtration options despite the use of MVD (Baumgärtel et. al., 2016) etc.) faced by researchers, computer scientists and practitioners (Song et al. 2017) show how complex it is. Designers are using various workarounds to solve the problems, because BIM is evolving all the time and the development of technology has not kept pace with the development of the methodology (Holzer, 2016). At this point, it should be made clear what BIM is and what it is not. BIM is not software. BIM is not Revit, as some say. The BIM process is not about building stunning 3D models that will ultimately culminate in photorealistic exciting visualisations. BIM is a 'process' that completely changes the status quo in the construction industry. A new paradigm is emerging: BIM is a new way of organising work throughout the construction project process. A BIM model is a body of knowledge and information about a construction object that forms the basis for decision-making throughout the life cycle of that object. Eastman and his group define it as follows: Building Information Modelling (BIM) is a collaborative way for multidisciplinary information storing, sharing, exchanging, and managing throughout the entire building project lifecycle including planning, design, construction, operation, maintenance, and demolition phase (Eastman et al., 2011). Eastman has repeatedly stressed that BIM is about activity undertaken by humans, not a model built by humans. BIM is defined and understood differently by both well-known organisations and many researchers. BIM can be considered from two perspectives - a broader and a narrower one. BIM *sensu largo* is a process based on the collaboration of people, information systems, databases and software. In a much broad sense, it can also include hardware, tangible and intangible resources or knowledge. BIM *sensu stricto* is a semantic database of the construction object accompanying it throughout its life cycle.

3. GENESIS OF BIM

It is not possible to state unequivocally what caused the distinguished of BIM from the CAD solutions used to date. Aetiological factors can be identified in at least a dozen or more. Among the most important of these are:

- The need to automatically solve design problems that do not require a designer's decision, which Christopher Alexander was the first to write about. The entering of successive iterations each time involves specific work to be done by the designer. Some of these problems have been successfully solved, others are being worked on;

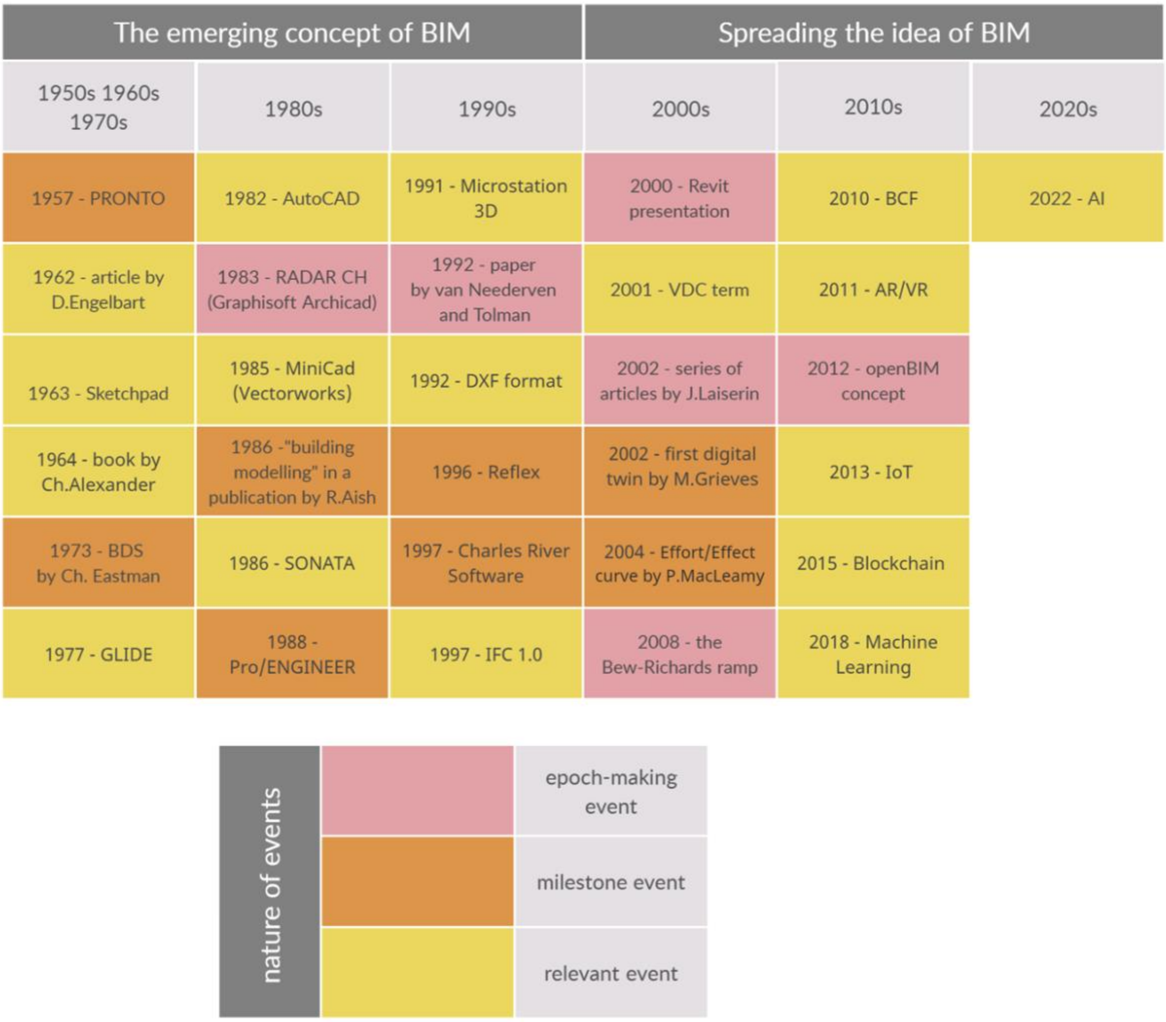
- The ever-increasing complexity of the designs being produced, and the consequent increase in the number of drawings, lists and reports in the technical documentation. Editing at a late stage of design involved tedious manual modification of CAD objects and their features separately on all the documentation elements that required it. In BIM this problem also exists, but to a lesser extent;
- As designs became more complex, an increasing number of design collisions began to be recognised. Geometric collisions on 2D documentation are more difficult to catch than in 3D space. The lack of tools to detect collisions resulted in their occurrence in projects, and their resolution was usually associated with specific costs incurred during project execution. However, it should be remembered that geometric collisions can be detected automatically, unlike utility, functional or standards collisions;
- The capacity of the 2D space on a specific sheet, e.g. A3, is limited, so there was sometimes not enough space for additional information on technological solutions or comments on specific details. The problem is still present despite the use of semantic and capacious databases. Paper drawings are irreplaceable on construction sites for the time being.

The aforementioned factors led to the emergence of technology that initially changed the way projects were drawn up and then changed the way work was organised throughout the investment process. In a way, each of these factors led to the development of IT applications that solved the problems of a specific set of users. What did not catch on in industry was adapted successfully in the AEC industry. In the 1990s and early 2000s, researchers signalled that BIM (although not well defined or widespread at the time) was one of the most promising advances in the construction industry. Various groups of BIM enthusiasts informed members of their associations, societies, chambers, clusters, etc. in various ways about the adoption of BIM. However, the disruptive nature of the extensive network of actors (stakeholders) that make up construction projects has posed the greatest challenge to maintaining and replicating the BIM network in subsequent projects (Linderoth, 2010). In a way, this problem has been solved, with successive implementations and national obligations to use BIM. However, at the core of all this BIM evolution was and still is education (Sharag-Eldin et al., 2010).

In 2014, Miettinen and Paavola predicted that BIM would evolve rapidly through conscious experimentation and learning from practitioners. This view suggested that in parallel with the integration of systems, through standardisation and national guidelines and differentiation through the development of competing software platforms, the use and development of BIM would progress (Miettinen, Paavola, 2014). Today, after nearly a decade, this prediction can be confirmed. Over the past decade, interest in BIM has been growing exponentially. BIM shows potential not only in the design and construction of buildings, but also has great potential for integration into Building Condition Assessment (BCA) practice. BIM provides a 'bridge' between virtual modelling and the physical building that provides accurate data for facility maintenance activities. BIM models are used to manage facilities for day-to-day duties, preventive maintenance, repairs or retrofit work (Che-Ani et.al, 2016).

In a 2015 study, researchers performed an abstract analysis of 975 articles to empirically identify key research areas and topics in BIM. Among those listed were design practices, implementation and adoption methods, safety management or urban plans and analysis (Yalcinkaya, Singh, 2015). If a similar analysis were done today, the results would perhaps be similar, but there would be far more key areas. BIM is beginning to penetrate many industries related to the wider space. Other researchers analysing the content of 317 journal articles published between 2008 and 2017, indicate that 90% of articles on BIM were written in the last 5 years of the period mentioned. This demonstrates that the BIM literature now has greater synergy and maturity. BIM is very often accompanied by terms such as: "sustainability", "energy efficiency", "green building" and "safety" (Santos et al., 2019). This, in turn, demonstrates the positive use of BIM in the design and construction process in accordance with the doctrine of sustainable development. Smart City has been a popular concept in recent years. It is a vision of integrating multiple Information and Communication Technology (ICT) and Internet of Things (IoT) solutions to securely support the management of city resources. With the rapid development of sensory technologies and cloud computing, there is growing interest in IoT solutions that leverage BIM platforms to provide a unified view of rich contextual building information. However, enriching BIM models with real-time IoT data streams is a difficult task due to the lack of sufficient interoperability (Shahinmoghadam, Natephra, Motamedi, 2021). Smart City applications need massive data, both static and dynamic, current and historical, geometric and semantic, microscopic and macroscopic, etc. Once collected, the management and application of this data often uses BIM and GIS technologies (Ma, Ren, 2017). Arguably, it is the proliferation of Smart City ideas that will amplify and accelerate the development of BIM. BIM enables the construction of specific digital twins, e.g. bridges (BrIM - Bridge Information Modelling) and the integrating such systems with BSM (Bride Management System) systems streamlines various processes (Mohammadi et. al., 2023). Digital twin is a key enabler of ICT revolution to address these challenges towards automated and intelligent construction (Jiang et al., 2022). In BIM, the creation of digital twins for prefabrication is a growing market, not only for products but also for housing or buildings (Li et. al., 2019). The construction of digital twins for various objects located in space will be an everyday occurrence for professionals in many industries.

All of the above-mentioned events have had an impact on the formation and evolution of BIM. In the course of an in-depth literature study, the most important ones were collected and listed (fig. 1). The listed events were categorised according to their significance into: epoch-making, milestones and relevant. These formed the basis for the development of the BIM periodisation. Due to the different nature of the events, they affected different groups of stakeholders in the construction processes. Hence, the periodisation also had to be developed from different angles.



The emerging concept of BIM			Spreading the idea of BIM		
1950s 1960s 1970s	1980s	1990s	2000s	2010s	2020s
1957 - PRONTO	1982 - AutoCAD	1991 - Microstation 3D	2000 - Revit presentation	2010 - BCF	2022 - AI
1962 - article by D.Engelbart	1983 - RADAR CH (Graphisoft Archicad)	1992 - paper by van Neederven and Tolman	2001 - VDC term	2011 - AR/VR	
1963 - Sketchpad	1985 - MiniCad (Vectorworks)	1992 - DXF format	2002 - series of articles by J.Laiserin	2012 - openBIM concept	
1964 - book by Ch.Alexander	1986 -"building modelling" in a publication by R.Aish	1996 - Reflex	2002 - first digital twin by M.Grieves	2013 - IoT	
1973 - BDS by Ch. Eastman	1986 - SONATA	1997 - Charles River Software	2004 - Effort/Effect curve by P.MacLeamy	2015 - Blockchain	
1977 - GLIDE	1988 - Pro/ENGINEER	1997 - IFC 1.0	2008 - the Bew-Richards ramp	2018 - Machine Learning	

nature of events		
	🟥	epoch-making event
	🟧	milestone event
	🟨	relevant event

FIG. 1: Significant events in the development of BIM Significant events in the development of BIM.

Extracted events in the history of BIM are related to both the needs suggested by Engelbart, Eastman or Alexander, among others, and the developing software that responded to these needs. Important formats (DXF, IFC etc.) or concepts (BDS, BM, openBIM) that influenced the development of CAD or BIM were also highlighted. The different developments were discussed during the periodisation due to various factors.

4. PERIODISATION OF BIM

4.1 Periodisation factors

There is no consensus among theorists whether BIM is a revolution or an evolution of CAD systems. By revolution we usually mean a significant change that usually occurs over a relatively short period of time. As BIM has been popularised as an idea for quite a long time, it is probably difficult to talk about a revolution. The evolution of BIM has been going on for several decades and is still going on. It is also difficult to identify the beginning of the development of the BIM idea. The 1960s and 1970s saw the first publications and experiences that guided the development of design software. One noteworthy example is Douglas C.Engelbart, who in his 1962 publication recognised the increasing complexity of the designs being created and envisaged the development of relational databases to be used and exchanged by different people throughout the investment process (Engelbart, 1962). Shortly thereafter, in 1964, the British-American architect Christopher Alexander published a book in which he indicates that some of the design problems can be solved by automating processes. In his publication, he provides the basis for the development of object-oriented programming, the construction of parameters for the objects used and the possibility of performing analyses and simulations on a 'digital equivalent'. He showed in depth the repetition of design solutions in detailed problems and how they can be reused as blue prints. Such templates are the basic components for automatic design processes. However, the knowledge (inference) problems are not solved by Alexander, namely to automatically find and suggest templates and suggest the necessary adaption to the specific design problem at hand. Alexander may have suggested a semi-automatic process. His key contribution was the introduction of templates, the definition of the template structure and the manual working with these templates (Alexander, 1964). The subsequent development of applications such as CSG (Constructive Solid Geometry) or BREP (Boundary REPresentation) led Charles Eastman to build the concept of BDS (Building Description Systems), in which he uses libraries of parametric objects that are necessary to build holistic models of building structures (Eastman, 1974). The BDS paid attention to the features that distinguish general-purpose building description systems from special purpose buildings, the data structures, the access scheme and how the database and analysis programmes interact. BDS reduced design costs, through the efficiency of drafting the design itself and subsequent analysis. However, BDS did not gain widespread popularity because few architects had the opportunity to use it (Latiffi, Brahim, & Fathi, 2014). Based on this and many other experiences, applications were built in various parts of the world in an attempt to improve the daily work of designers.

Undoubtedly, the first important development was the appearance of Radar CH software (later Archicad) in 1983, which differed significantly from existing CAD programmes. The Hungarian company Grapfisoft developed, as it later turned out, a revolutionary tool that changed the course of events. Shortly afterwards, with the appearance of Revit (which was developed on the basis of the experience with Pro/ENGINEER and Reflex), discussion began about the term that would replace CAD. Thus, the appearance of the first application, clearly distinguishable from the others, can be considered the start of the first BIM era, where applications began to be distinguished that enabled advanced parametric design, characterised by relational databases and the ability to categorise objects.

More than 40 years of development of BIM technology prompts consideration of a possible periodisation of this period. The division into eras seems to be a good solution that not only puts the achievements to date in order, but perhaps sets the course for further developments. Over the course of four decades, there have been a number of landmark events that have changed the course of further developments in the BIM theoretical and practical community. Suffice it to mention the publication of the drawing of the so-called Bew-Richards ramp (definition of maturity levels) or the presentation of the openBIM concept (the idea allows different stakeholders to participate in the BIM process regardless of the software used). For this reason, the periodisation cannot be considered from only one perspective. In the course of many years of deliberation and literature studies, it was decided to divide into epochs (periods) due to:

- idea,
- approach,
- organisational culture.

4.2 Periodisation of BIM by idea

The first documented definitions (from 1986 onwards) dealt with digital building modelling, BM (building modelling), but the idea did not receive much publicity (Januszkiewicz, Kowalski, 2020). Before the acronym BIM was used, among others: Product Model, Building Product Model or Building Model (Aish, 1986) due to the ISO10303 STEP term "Product Model" from 1986-1998 and continuing until about 2002 in parallel to BIM (model). It was not until 1991 that the first attempt to spread the concept of BIM appeared. In an article by Giles A. (Sander) van Nederveen and Frits P. Tolman, BIM was referred to as a technique for the multi-faceted representation of a building using views of its model (van Nederveen, Tolman, 1992). This date can be considered a landmark, as it was from this moment that the discussion on a term that could replace CAD began. Until then, it was often said to be merely an evolution from 2D to 3D and defined as 3D CAD. Although the concept did not initially gain popularity it forced the scientific community to consider it further. However, it was not until a series of articles by Jerry Laiserin (from 2002) that the idea of BIM became widespread. At the same time, software vendors are trying to come to a consensus on what to call the technology that will revolutionise the construction industry. With the appearance of the BIM White Paper published by Autodesk (2002), BIM becomes a popular phrase and an oft-repeated acronym. The year 2002 can thus be considered a breakthrough. Since then, the idea of BIM has spread at an exponential rate, permeating many industries related to space design in the broadest sense (Fig. 2). Even despite the development of other ideas e.g. VDC (Virtual Desing and Construction), DT (Digital Twin) or VB (Virtual Building), it is BIM that has gained popularity worldwide. And although some people treat these terms as synonyms, a distinction must be made between the process (VDC) and the model (VB). There is still disagreement in many circles whether BIM is a technology, a methodology or a process. Research shows that there is also still a problem with a clear understanding of BIM and the adoption of a uniform definition (Doan et. al., 2018). However, there is a consensus that BIM is the future of modern digital construction. Consequently, the main research trends at the turn of the century focused on improving pre-planning and design, clash detection, visualisation, quantification, costing and data management. This was followed by industry-specific tools such as energy analysis, structural analysis, scheduling, progress tracking and job safety in BIM software. The more industries BIM permeated, the more the issue of organizing processes was raised. The basis for working in BIM is the multi-part standard ISO19650, which deals strictly with BIM. However, the ISO16739 data exchange or ISO21597 multimodel method standards are also important. Only in the last decade has the emphasis from software development shifted from earlier life cycle (LC) stages to maintenance, renovation, deconstruction and end-of-life considerations, especially for complex and sophisticated structures (Pezeshki, Ivari, 2018). It is estimated that the operation and maintenance stage accounts for approximately 60% of the total life-cycle cost of a facility or building (Guillen et al. 2016). Thus, the potential benefits in these stages may be greater than in the design or construction phase of a project.

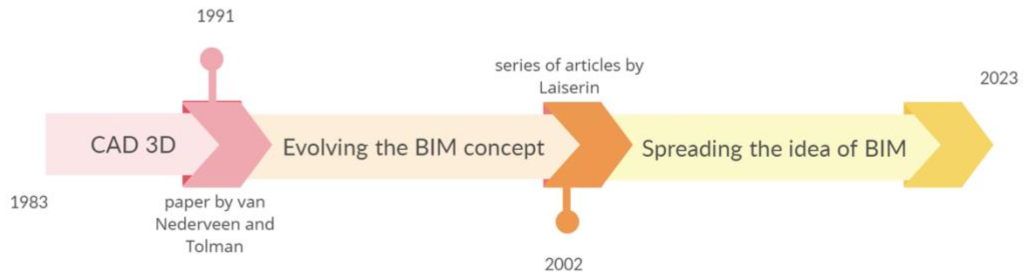


FIG. 2: Periodisation of BIM by idea.

4.3 Periodisation of BIM by approach

In the 1980s and 1990s, design in Archicad, MiniCAD etc. applications was based on models for single buildings. Often the technological limitations of these applications resulted in the inability to design a larger number of buildings, let alone infrastructure facilities stretching for kilometres. Developed by Charles M. Eastman, the BDS concept (Eastman, 1974), developed over almost two decades and used by numerous software manufacturers, has accompanied numerous projects, facilitating the day-to-day work of designers. The object libraries popularised by

Eastman found their way into many popular software packages (Ingram, 2020). The resulting models used blocks (AutoCAD), objects (Archicad), families (Revit) or components. Regardless of the semantics used, design work was greatly accelerated, but this does not change the fact that they were still models, to some extent limited. These limitations were due, among other things, to the strictly defined working area (e.g. a maximum of 2 miles from the centre point - currently it is 10 miles), the lack of certain functionalities (e.g. the inability to break down wall structures into layers) or the weaknesses of the computers of the time (e.g. single-task processors, little RAM). Around the turn of the century, computer and software developments made it possible to work with larger relational databases. Models became more and more detailed and programmes became more and more comprehensive. At one time, Autodesk Revit software was advertised and sold under three forms dedicated to specific industries (Revit Architecture, Revit Structure, Revit MEP). Although some of the problems have been solved, e.g. the aforementioned breaking down of wall structures into layers, there are still other problems, e.g. the inability to return to the original form of a wall after it has been broken down. Thus, without data compatibility, i.e. compatibility of objects and model structure (interoperability), the benefits of BIM will be lost due to information errors and masses of manual work.

The beginning of the 21st century has seen the continuous development of BIM technology. However, most models are created using the tools of a single manufacturer, e.g. Archicad-DDScad collaboration. The exchange of native models between designers from different industries is either impossible or requires the use of plug-ins or middleware applications. Spatial coordination of models is hampered by the use of different spatial references. Different approaches (ways of interacting and behaving) are used, but communication is still not effective. Open standards are rarely used and the idea of openBIM is yet to emerge. This era can be called 'closed BIM'.

A milestone in the development of BIM came in 2012 and the announcement of the idea of openBIM (Building SMART, 2012). This is a universal approach to the collaborative design, implementation and operation of buildings based on open standards and workflows. The initiators of this approach were Graphisoft and Tekla. In the following years, more companies joined the movement, mainly from the Nemetschek Group. Subsequently, the buildingSMART organisation, to which all of the aforementioned belong, took on the role of promoting the openBIM idea to software developers, designers, investors and everyone else involved in the construction process. The implementation of the openBIM idea allows project team members to participate in the BIM process regardless of the software tools they use. The idea promotes a transparent and collaborative open workflow, while creating a common language for commonly used processes and providing relevant design data for use throughout the lifecycle of a construction project. OpenBIM enables a focus on workflow compatibility rather than data compatibility, meaning that project team members can be selected based on their competence rather than their ability to operate a particular manufacturer's tools. As a result, team members can use the software that best suits their needs and are better able to maintain control over their own project data, while being able to collaborate with others. The proliferation of openBIM has meant that smaller software vendors are better able to compete with larger providers.

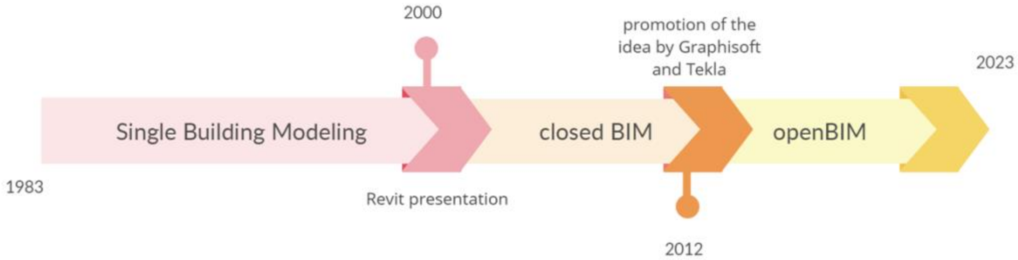


FIG. 3: Periodisation of BIM by approach.

Enthusiastically embraced, the idea of openBIM has fuelled software development, increased the quality of models and therefore projects. The last decade has seen an exponential increase in interest in openBIM and an increasingly small number of sceptics. However, this does not mean there are no challenges or risks arising from its use. Guidelines for BIM model structure are still lacking, with the result that exchange models, even those modeled in IFC and exchanged in an SPF file in IFC format, are incompatible in terms of model structure. Working from a databases based on APIs or cloud solutions is still problematic and requires high digital competence (Afsari, Eastman, Shelden, 2017).The evolution of BIM is ongoing, but it seems that the years 2012-2022 belonged to the idea of openBIM (Fig. 3).

4.4 Periodisation of BIM by organisational culture

The first era of BIM in this case will be related to the lack of so-called inter-industry coordination of BIM models. The models built in the 20th century are single-discipline models and their innovation was usually limited to, for example, generating flat 2D documentation from a 3D model. Sometimes the reverse was done, e.g. for existing building structures (reverse engineering of structures). Having the technical documentation of an existing project, its digital equivalent in 3D space was built. Regardless, we could call the level of development of BIM technology 'lone' BIM. For several years, we have been familiar with the term, which just covers single-industry models, where it is difficult to talk about any industry collaboration or inter-industry coordination. It was not until the development of tools in design software (e.g. Teamwork in Archicad), the emergence of new applications for collision detection or, finally, the development of EDMS (Electronic Document Management System), CDE (Common Data Environment), etc., that the spatial coordination of BIM models became possible and communication in the design process improved. The many benefits and advantages of federating (combining) models from different industries have begun to be recognised. Designers are beginning to use increasingly sophisticated communication methods and techniques throughout the development process, which in turn is contributing to the productivity of the industry as a whole. The closer the collaboration, the better the results. However, it is important to note that in collaborative BIM environments implemented in CDE, there can be risks associated with fully digital data sharing. Sharing data with third parties such as subcontractors, suppliers, consultants and other project partners through central data networks, as well as relying on cloud services, significantly increases the risk of external and internal cyber attacks. Hence the GAIA-X initiative, which aims to develop a federated secure data infrastructure for Europe and ensure European digital sovereignty. With regard to CDE, the idea is to ensure the safety and security of data deposited in shared environments. As these attacks can lead to financial losses, business disruption and reputational damage (Turk, Sonkor, Klinc, 2022). Cloud repositories and services have another key concern from an implementation point of view - there is a certain cost associated with subscribing to servers and services, which can marginalise smaller and medium-sized businesses looking to adopt BIM (Adamu, Emmitt, Soetanto, 2015).

Since the publication of the so-called Bew-Richards ramp (or wedge), companies have been able to explore their 'maturity' in BIM. Up to this point (2008), the main emphasis in BIM development had been firmly on technology. This was necessary because standardised data exchange is a mandatory prerequisite for effective BIM-based workflows between the various participants - integrated BIM (iBIM) - and the development and implementation of such a standard has proved much more complex than thought. The aim of BIM in this sense is not to integrate construction processes and reduce industry fragmentation. The real goal, with practical benefits, is to enable even greater specialisation and division of labour (Turk, 2016). However, despite the technical problems and limitations in data exchange that still exist, the main obstacle to iBIM implementation in recent years has not been technology, but old work processes, old business models and conservative attitudes in the industry. Finally, in the last few years, the development focus has started to shift towards necessary changes in processes and business models (Kiviniemi, 2011). But in many cases, it has become apparent that there is much to work on and that the anticipated Level 3 is unattainable for many. Even at Level 2, there are problems with federating models, where you often have to use add-ons or write your own solutions (Beach et. al., 2017). Anticipated Level 3 is difficult to define, but assumes that all stakeholders in the investment process are working together using BIM technology. Ultimately, level 3 of the so-called iBIM refers to a fully integrated, comprehensive digital model of building site information, covering all trades, developed and updated at all stages of the investment process, to which all stakeholders have digital access. Given the known technological, organisational and often human limitations, the consensus is that this has not yet been achieved. Recent studies suggest that improving information exchange with the help of open standards is Level 3A. Level 3B is additionally referred to as direct connection to the sensors of devices and machines (IoT - Internet of Things). Real-time sensor data transfer (telemetry) is Level 3C. Monitoring the status of devices and their potential failures thus brings us closer to the idea of a digital twin. The highest level is 3D, where additionally the framework and structure of the ontology, i.e. the codification of everything in BIM, are defined. Thus, there should be no problems in communication, and its degree of efficiency is at the highest possible level (Esser, Vilgertshofer, Borrmann, 2023). Thus, there is a lack of guidelines for standardized work and standardized structure / morphology of the model. An object-centered ontology such as IFC, ifcOWL or BOT-OWL is not sufficient (Seeaed, Hamdan, 2019). What is missing is a model structure ontology. This serious one makes BIM not really work as expected. The models listed are incompatible and error-prone, and a lot of extra manual work makes it difficult to achieve most of the expected benefits. This poses a serious barrier to BIM.. (Fig. 4).

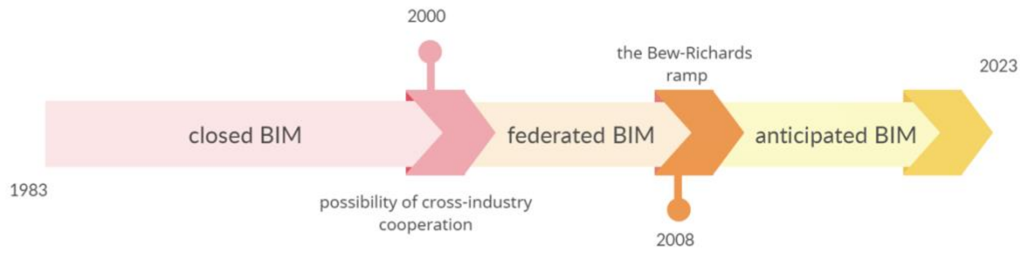


FIG. 4: Periodisation of BIM by organisational culture.

Which direction will BIM go now? Research no longer focuses its attention on presenting the benefits and advantages of using BIM. Predictions from researchers are that users will look for more efficient implementation of BIM (BIM projects vs. better BIM projects) in the form of high-performance tools, users, interactions and processes (Abdirad, Pishdad-Bozorgi, 2014). Other studies show that the BIM ontology is still not properly defined throughout the project lifecycle. There are various existing interpretations of the acronym BIM and other IM (i.e. PIM, PLIM, CIM, DIM, LIM, HBIM, BrIM and AIM), but these interpretations only describe BIM from a specific perspective, without regard to the overall relationships. This can cause problems and misunderstandings during communication, coordination and contracting. The industry needs to learn to exploit the full potential of IPD (Integrated Project Delivery) and BIM, and as numerous studies have shown, this will depend on raising the level of competence of staff in the AEC industry (Karasu, Aaltonen, Haapasalo, 2022). There is no need for a sophisticated BIM, but on the other hand, BIM as a whole has matured and, as with other disciplines, proper harmonisation and a clear ontology is necessary for its further development (Matějka, Tomek, 2017). Another literature review mainly points to three types of future directions for BIM methodology: i) BIM tends to develop towards a knowledge orientation, ii) social science methodologies can be implemented using BIM as another type of expert methodology, iii) the ability to continuously change and the ability to learn is the driving force of BIM methodology and will be the key to future smart applications (Pezeshki, Ivari, 2016).

New concepts are emerging e.g. EBIM (Enterprise BIM), which is an emerging, unexplored, holistic organisational concept that aims to support and optimise business management throughout the lifecycle of buildings and infrastructure. EBIM assumes a consistent transition from the BIM model to asset management (AM) and facility management (FM) (Godager, Onstein, Huang, 2021). This arguably marks the beginning of the next era in BIM history - the era of mature knowledge-based BIM. What follows is a time of sustained BIM adoption in individual countries and companies. The solutions being adopted have a solid factual and technical basis. Drawing on the good practices and experiences of others, societies should become convinced of BIM - the time has come to take full advantage of it. Recently, extended reality (XR) technologies, which simulate a construction project in a multi-dimensional digital model and present many aspects of the project, have become popular and can add value at all stages of the project (Alizadehsalehia, Hadavib, Huangc, 2020). A recent broad survey of the literature suggests that the adoption of new technologies such as Artificial Intelligence (AI) and Machine Learning (ML) can help address existing limitations of BIM applications. Similarly, an integrated Blockchain architecture can help to securely track and immutable data interactions between BIM project participants (Celik, Petri, Barati, 2023). Within the prevailing IT prosperity, it is usually observed that some IT technologies are better adopted than others, with some organisations successfully adopting a particular technology while similar others do not (Xu, Lu, 2022). However, it was found that one type of technology cannot completely solve individual problems. Currently, these technologies are often used independently of each other and do not form a coherent system. Thus, a suitable fusion of the mentioned technologies to support the development of BIM is advisable (Khudhair et.al. 2021). Perhaps there will also be a fusion of BIM with 3D printing technologies for entire buildings. So far, it is difficult to imagine that 3D printing can replace traditional construction in the next few years. It is more possible that both technologies will be present in the industry (Sakin, Kiroglu, 2017).

5. CONCLUSION

The three perspectives presented in the article (idea, approach, organisational culture) in the periodisation of BIM is only a proposal given for discussion. The ambition of the scientific community should be to unify both the ontology of concepts and the history, which is important for further development. Dividing the history of BIM into periods is a good opportunity to discuss what has been achieved in the field so far. During the course of the research, some limitations were encountered due to various positions of well-known BIM figures related to their achievements and contributions (e.g. Gábor Bojár's letter to Jonathan Ingram). Numerous publications highlight various events as milestones. Notwithstanding BIM is the future of modern construction and, along with Smart City and the assumptions of Industry 4.0, is likely to be part of something bigger that will change the status quo in the AEC industry to date. The future of BIM is unknown and the direction will be set by practitioners implementing BIM at a high level of maturity. Software is providing an increasing degree of interoperability, new techniques and tools are being developed in the BIM process and people are becoming bolder in challenging themselves in the BIM world. On the other hand, BIM tools often provide only basic techniques for exchanging models. As a result, incompatible data sets are exchanged, leading to error-prone and corrupt BIM models and requiring a lot of manual work to clean up the exchanged models from errors.

In conclusion, several questions need to be raised. Is a periodisation of BIM needed? In the author's opinion, definitely yes. If only for the cognitive aspect. Anyone working in BIM should learn the history of its separation from CAD and its subsequent evolution. Can designated periods be standardised without regard to perspective? It seems that the division into the eras of (i) single building modelling, (ii) closed BIM, (iii) openBIM is the simplest and most easily communicated division of BIM history. This division could be more widely disseminated if only in the BIM handbooks that reach a wide range of BIM users. What will be the future directions of development of anticipated BIM? It is hard to guess, but one can predict that we will be moving towards iBIM - a fully interactive process, based on interoperable technologies, using AI but also the ephemeral side of human nature. The consequence will undoubtedly be progress, but also challenges for researchers - the results provided by AI must be verified or validated in some way. What about meta-cognition (thinking about one's own thinking), which only characterises humans? Is it possible to replace it? The epistemology of BIM, in which AI is making an increasing contribution (e.g. Plans2BIM software), does not provide an answer to this question.

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