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BIM implementation in building maintenance management

Authors:



¹Prof. **Anita Cerić**
anita@grad.hr



¹Prof. **Ivica Završki**
zavrski@grad.hr



¹Assoc.Prof. **Mladen Vukomanović**
mvukoman@grad.hr



¹**Ivona Ivić**, MCE
iivic@grad.hr



²Assist.Prof. **Maja-Marija Nahod**
majan@grad.hr

¹University of Zagreb
Faculty of Civil Engineering
Department of Construction Management

²Ministry of Construction and Physical Planning

Subject review

Anita Cerić, Ivica Završki, Mladen Vukomanović, Ivona Ivić, Maja-Marija Nahod

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Building Information Modelling (BIM) implies a multi dimensional information model of building, based on fundamental 3D model, which enables information sharing among project participants during the whole life cycle of a building. Integration of building maintenance and BIM is proposed for the purpose of a more efficient management of building maintenance activities. This paper analyses the benefits of BIM implementation in building maintenance, as well as its limitations. The integration of BIM and automation is proposed to enhance traditional building maintenance methods. Finally, a comprehensive BIM implementation strategy for the building maintenance phase is defined.

Key words:

BIM, building maintenance, implementation strategy, construction industry

Pregledni rad

Anita Cerić, Ivica Završki, Mladen Vukomanović, Ivona Ivić, Maja-Marija Nahod

Implementacija BIM-a u održavanju građevina

Building Information Modelling (BIM) podrazumijeva izradu višedimenzionalnog informacijskog modela građevine, koji se temelji na osnovnom 3D modelu i omogućava dijeljenje informacija među sudionicima u projektu tijekom cijelog životnog vijeka građevine. Za učinkovitije upravljanje održavanjem građevina predlaže se integracija održavanja građevina i BIM-a. U radu se analiziraju prednosti i ograničenja implementacije BIM-a u održavanju građevina te se daje prijedlog integracije BIM-a i automatizacije za unaprijeđenje dosadašnjih tradicionalnih metoda. Na kraju je definirana sveobuhvatna strategija implementacije BIM-a u fazi održavanja građevina.

Ključne riječi:

BIM, održavanje građevina, strategija implementacije, građevinska industrija

Übersichtsarbeit

Anita Cerić, Ivica Završki, Mladen Vukomanović, Ivona Ivić, Maja-Marija Nahod

Implementierung von BIM in der Gebäudeinstandhaltung

Das Building Information Modeling (BIM) umfasst die Erstellung eines mehrdimensionalen Gebäudeinformationsmodells, das auf einem grundlegenden 3D-Modell basiert und den Austausch von Informationen zwischen den Projektteilnehmern über die gesamte Lebensdauer des Gebäudes hinweg ermöglicht. Für ein effizienteres Management der Gebäudeinstandhaltung wird die Integration von Gebäudeinstandhaltung und BIM vorgeschlagen. In dieser Arbeit werden die Vorteile und Einschränkungen der Implementierung von BIM bei der Instandhaltung von Gebäuden analysiert und die Integration von BIM und der Automatisierung vorgeschlagen, um die bisherigen traditionellen Methoden zu verbessern. Schließlich wird eine umfassende BIM-Implementierungsstrategie für die Gebäudeinstandhaltungsphase definiert.

Schlüsselwörter:

BIM, Gebäudeinstandhaltung, Implementierungsstrategie, Bauindustrie

1. Introduction

Construction ranks among the largest of industries in the worldwide economy, with approximately 10 billion US dollars spent on construction services and products [1]. However, over the last two decades of industrial development, growth in the construction industry has amounted to no more than 1 per cent, which is much less than the growth of the overall economy (2.8 per cent) or the 3.6 per cent growth in the manufacturing industry [1]. Thus, the construction industry lags behind the global economy by 1.6 trillion US dollars. Some of the recommendations for closing this gap include a digitisation strategy, automation, the implementation of modular manufacturing, and the introduction of robotics in the design, construction, and maintenance of buildings [1,2]. These trends reach their full affirmation in the development of Industry 4.0, which implies the use of cybernetic-physical systems, the Internet of things, computer clouds, artificial intelligence, and similar technologies [3,4]. This is reflected in the technological and business processes in the construction industry, as well as in the building operation and maintenance phase. Building maintenance costs most often exceed the costs incurred in other phases over the lifecycle of buildings. Depending on the type of building, such costs amount to approximately 60 per cent of the total lifecycle cost of a building [5-7]. In addition, one of the consequences of the development of modern technologies is the integration of various phases in the construction process and the search for optimum solutions within the overall lifecycle of a building [8].

To enable successful maintenance management, it is necessary to provide proper cooperation of all participants in the project, from building maintenance experts to experts involved in the design process, and subsequently, in the construction of a building. A new trend in the construction industry, namely, Building Information Modelling (BIM), has enabled easier interoperability and cooperation of all participants. BIM implies the development of a multidimensional building information model, which, in addition to offering a 3D geometry, gathers significant information about the building elements and involves all participants in the construction process. The establishment of a 3D building model, with relevant information needed for a proper maintenance of the buildings, leads to a reduction in the cost and time needed for such maintenance and building administration [9]. BIM and automation can also be used together in the advancement of traditional construction methods [10] and, hence, in the operation and maintenance of buildings.

Relevant studies are reviewed in this paper to explore the possibilities of implementing BIM in the maintenance of buildings and to define the advantages and limitations of BIM in this field. Because of its specific features, the use of BIM technology for building maintenance (part of the facility management) must also be explored for existing buildings (mostly built without the use of BIM) and for those yet to be built. In addition, when referring to the maintenance of existing buildings, a particular emphasis should be placed on historic buildings with their peculiarities and specific legislation related to their protection and preservation.

An exploratory survey of the practical use of BIM is also described. Eighteen selected experts from companies that presumably

have experience in BIM implementation took part in the study. The survey revealed the degree of use of BIM in the surveyed companies and the opinion of respondents on BIM implementation in the maintenance of buildings. Based on a literature review and exploratory survey, a BIM implementation strategy is proposed in the final part of the paper. The strategy includes all lifecycle phases of a building, and hence the operation and maintenance stage, through three implementation stages. Finally, the current situation regarding BIM implementation in the maintenance management in the Republic of Croatia is presented, and conclusions regarding the steps to be taken in the future are provided.

2. Literature review

Azhar et al. [11] point to two main advantages of using BIM in the maintenance of buildings:

- a) all significant information is presented in a single electronic file
- b) persons in charge of maintenance no longer need to search through large amounts of data to obtain the information they require.

However, although the use of BIM in maintenance activities seems to be very useful, the implementation lags behind the BIM implementation in the phases of design and construction [7]. One of limiting factors is the unavoidable high level of BIM model development that is needed in the maintenance of buildings [12,13], as explained in more detail below.

2.1. Level of Development of BIM

In 2008, the American Institute of Architects (AIA) developed the Level of Development (LOD) [14]. The LOD consists of the level of detail and level of information. The former indicates a level that is used to ensure a common understanding of information demands in various stages of a project, whereas the latter indicates the level of required non-graphical information throughout the project. It is important to note that the new standards published in late 2018, ISO 19650, Part 1 [15] and Part 2 [16], have introduced a new nomenclature for BIM. Therefore, the level of information required is used instead of the level of information and detail. However, the aim is for ISO 19650 Part 3 [17], which defines the BIM implementation in the operation and maintenance phase, to be published no earlier than 2020.

There are five main LODs-100, 200, 300, 400, and 500-with a wide range of definitions (Figure 1). The LOD Specification Guide [18] covers the entire range of construction sets, systems, and components, and has become a reference enabling individual professions in the construction industry to specify and clearly express the content and reliability of BIM implementation in the various phases of the lifecycle of a building.

The LOD concept starts from the fact that elements in construction models develop gradually from less detailed information during the initial project phases to greater levels of detail in the advanced

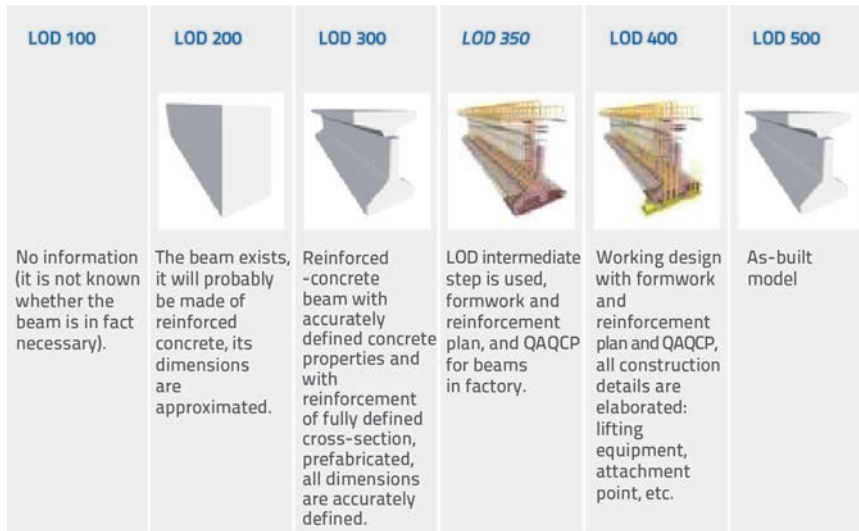


Figure 1. Basic Levels of Development of a BIM [19]

phases of the lifecycle of a building [13]. In its document regarding BIM, Natspec [13] also defines the BIM element classification aspects for each LOD. Thus, the LOD 100 (conceptual) elements are BIM elements that are only conceptually marked at their position (as a symbol or other generic representation). Furthermore, the element represented as a generic system or object with associated approximate information regarding the quantity, size, shape, location, and orientation, and with some non-graphical information, can be classified as LOD 200 (approximate geometry). If an element is specified as an accurate generic system or object with accurate information regarding the quantity, size, shape, location, and orientation, it is classified as LOD 300 (precise geometry). If the detailing, fabrication, assembly, and installation information is added to an element described as LOD 300, this element is then classified as LOD 400 (fabrication element). The highest model development level, LOD 500 represents the as-built state of an element with all information available regarding the element.

When LOD 500 is reached, the next difficulty in the BIM implementation in the maintenance phase is the lack of information

that has to be included in the BIM such that efficient building maintenance activities can be conducted. In the National BIM Report issued in 2015 [20], an example of a typical masonry wall is presented, with an indication of some required information (Table 1). The PAS 11923:2014 [21] is currently still applicable as the specifications for BIM in the operation and maintenance phase of a building. According to this standard, steps must be taken to ensure that LOD 500 contains all information from the previous phases that will be submitted to the client after the project delivery phase. The format recommended for an information exchange is the Construction Operations Building Information Exchange (COBie) [22]. COBie represents a standardised format in the form of calculation tables (.xls) that

contain all information about a particular building. This information is submitted to the client through the information model for operational purposes, similar to the way in which a physical building is submitted to a client [23].

The manner in which significant data are obtained when integrating the BIM and maintenance depends on whether we are dealing with construction projects at the initial stage or with existing buildings [9]. However, the advantages of BIM implementation are unquestionable in both cases. The integration of BIM and maintenance in the initial stages of a project is described below, and the use of BIM on existing buildings is considered as well.

2.2. Integration of BIM and building maintenance management during the initial stages of a project

The main characteristic of BIM implementation in a construction project at the initial stage is the integration of the maintenance and initial investment phases of the project, i.e. the cooperation between

Table 1. Typical masonry details: graphical and non-graphical information [20]

Graphical information	Non-graphical information	
	<p>Properties:</p> <ul style="list-style-type: none"> • Accuracy tolerances (for structural performance) • Design requirements (applicable where there is a contractor-designer component) • Working life • Fire performance • Structural performance - impact, M&E services vehicular • Heat loss (U value) 	<p>Execution:</p> <ul style="list-style-type: none"> • Workmanship during adverse weather • Cleanliness • Reference and sample panel requirements (to mortar workmanship, materials quality) • Specific product installation requirements (e.g. installing cavity wall insulation, installing lintels, block bonding new walls to existing, laying frogged bricks in mortar)
	<p>Product properties</p> <ul style="list-style-type: none"> • Thermal conductivity • Freez/thaw resistance • Recycled content • Dimensional tolerances for masonry units • Compressive strength 	

maintenance managers and designers during the design stage of the project. Maintenance experts are confronted with a significant quantity of information they need to find, analyse, and update with the realisation of each activity, and BIM offers a simple means of storing all such data in a single electronic file [24]. In addition, according to published research, 50 per cent of the problems related to maintenance can be avoided if their main causes are already eliminated at the design stage [25, 26]. Furthermore, it has been emphasised [6, 24, 27-29] that maintenance must be considered during the design stage; thus, all relevant maintenance information can be taken into account when deciding on the structure and materials to be incorporated in a building. In a number of countries worldwide, the building maintenance plan is already an integral part of the design documents. However, the designers and contractors participating in the initial stages of the project rarely know what data are significant for the efficient functioning of the building maintenance management system, and the experience-based data gathered during actual maintenance do not reach them [29]. In this context, an often cited problem is the impossibility of engaging with a maintenance expert team during the design because, in most cases, this team is not even formed during the design stage [30]. The problems in communication, thus, prevent the optimisation of all systems in the lifecycle of a building. BIM may be a solution to these problems because a considerable amount of data and knowledge from building maintenance experts can be found in digital libraries (databases); thus, the need for the continuous presence of experts during the design stage becomes less pronounced. The BIM library model for maintenance management, presented in Figure 2, provides for the presence of maintenance activities in all the previous phases of the lifecycle of the building [30]. The central part of the model is the BIM library (database), containing all information

regarding the concerns and warnings in the maintenance of similar buildings. This information is available to designers during the design phase and to contractors during the construction phase. After the building is handed over to the client and the final beneficiary, i.e., at the onset of the operation phase of the building, all activities are noted in the project database. Consequently, they are available to all participants in the project and as a benchmark document that can be used on all future projects.

2.3. Integration of BIM and maintenance management of existing buildings

Some additional activities are needed for BIM implementation during the maintenance of existing buildings. To create a BIM for an existing building, the data on the geometry and topology of the building not provided in the design documents must be obtained. This is achieved using special data registration techniques and surveys, the best known methods being photogrammetry and laser scanning. Photogrammetry is a procedure involving photographing and linearly mapping the contours of the building from a stereomodel, whereas laser scanning involves scanning with a terrestrial laser scanner and point cloud analysis [31]. Both methods are rapid, and the data obtained can be introduced in the BIM [32]. Figure 3 shows a comparison between the point cloud created through laser scanning and a BIM model derived from the same point cloud.

Existing buildings that are particularly demanding for maintenance include historic buildings. From a technical standpoint, some specifics of these buildings are the irregular form of structural elements, ornaments, and sculptural and artistic details. All of these elements are a challenge for BIM with regard to the digitisation and selection

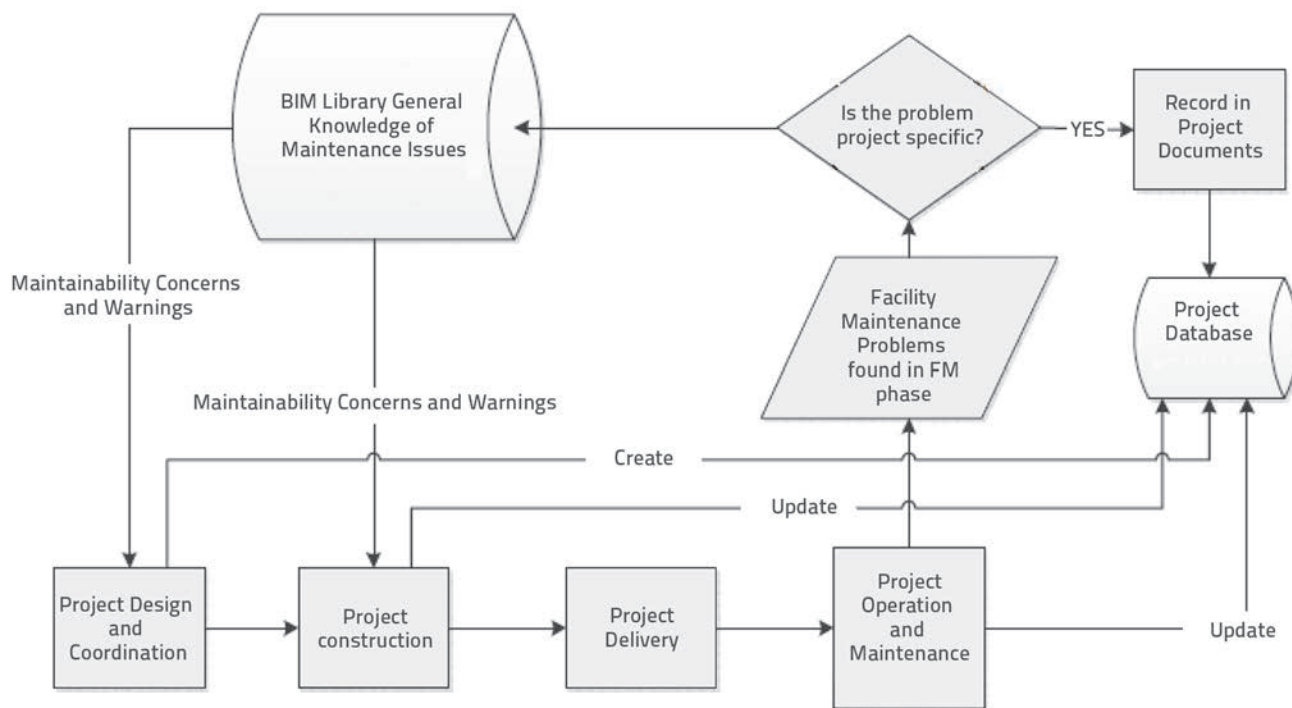


Figure 2. Functioning of BIM library for maintenance [30]



Figure 3. Comparison of the scanned building's point cloud and the BIM model [32]

in the way the point clouds should be registered and accurately transferred to the BIM. This problem can be solved through the automatic or semi-automatic recognition of the elements in BIM software during the transfer of point clouds from laser scans [33].



Figure 4. HBIM of an irregular wall in Valentino Castle [33]

Because of the specific features of historic buildings, the term Historic Building Information Modelling (HBIM) has been coined for the BIM modelling of such buildings [33-36]. HBIM was developed by researchers [37, 38] as a link between modern technology and BIM in the field of historic buildings. HBIM functions as an addition to BIM and is a prototype of a database of parametric elements created from information on historic buildings [34].

The possibilities offered by BIM with regard to historic buildings include the faster and simpler recognition of the condition of the building, recognition of the ageing and deterioration of its elements, planning of remedial and renovation activities, and, in general, the overall building use planning. In addition, BIM enables the 3D presentation of historic buildings as well as the creation of virtual reality for buildings, which can also be used for educational and tourism purposes [33]. An example of the successful implementation of HBIM at Valentino Castle in Italy can be seen in Figure 4.

2.4. Advantages and limitations of BIM implementation in building maintenance management

The main advantages and limitations of BIM implementation in building maintenance management are shown in Table 2. They are defined based on currently available studies and an analysis of a number of case studies [24, 39-45].

To realise all the advantages of BIM, it is first necessary to overcome some basic limitations. The greatest obstacles hindering the

Table 2. Advantages and limitations of BIM implementation in building maintenance management

Advantages	Limitations
<ul style="list-style-type: none"> Accurate geometrical representation of the parts of the building. 	<ul style="list-style-type: none"> Unclear and invalidated benefits of BIM in ongoing maintenance practices.
<ul style="list-style-type: none"> Faster and more effective information sharing. 	<ul style="list-style-type: none"> Lack of demand for BIM deliverables by the owner community due to the uncertainty about what BIM might be used for.
<ul style="list-style-type: none"> An accurate equipment inventory can reduce operation and maintenance contracting costs from 3% to 6% by identifying and tracking facility equipment and facility square footage. 	<ul style="list-style-type: none"> Amount of work that needs to be done to define the specific maintenance needs for which a model is necessary and how that model may need to be prepared to meet the needs.
<ul style="list-style-type: none"> Enhanced efficiency of activities in a typical work order process. 	<ul style="list-style-type: none"> Details on what information is to be provided in BIM model, when and by whom, are not defined.
<ul style="list-style-type: none"> Barcode system could also be incorporated into BIM for the ease of accessibility of relevant documents. 	<ul style="list-style-type: none"> Maintenance management personnel's limited experience with BIM technology.
<ul style="list-style-type: none"> Reduced time by eliminating additional trips to the same location to carry out unscheduled work orders by providing accurate field conditions and maintenance information before leaving the office. 	<ul style="list-style-type: none"> Lack of clarity about responsibility in insurance and contracts.
<ul style="list-style-type: none"> The simulations of scenarios of refurbishment projects are possible in 3D environment. 	<ul style="list-style-type: none"> Lack of standardized maintenance tools and processes.
<ul style="list-style-type: none"> For refurbishment projects, BIM and associated technologies such as laser scanning are expected to reduce the cost of producing as built information. 	<ul style="list-style-type: none"> Lack of interoperability among BIM solutions and between BIM solutions and maintenance systems.
<ul style="list-style-type: none"> More predictable environmental performance and life cycle costing. 	<ul style="list-style-type: none"> The rigid approach to adopting new processes and technologies in the construction industry.

implementation of BIM in different companies can be identified by questioning BIM users. One such exploratory survey was conducted for an interest group in Malaysia [46]. The results have shown that the main obstacle to the introduction of BIM are not financial reasons, but rather insufficient competence/technical support, inadequate education, subjective and cultural issues, and the opinion that BIM is not better than other procedures that are currently in use [31]. These strategies mentioned in this paper that can contribute to a more efficient implementation of BIM include the need to ensure proper education, which involves increasing the awareness regarding the need to introduce BIM, preparing instructions for BIM implementation, and introducing relevant improvements in institutions of higher learning [46].

In addition, a similar exploratory survey was conducted in Croatia by the authors of this paper. The objective of the survey was to identify the level of BIM implementation in the surveyed companies, and to determine their opinion on BIM implementation in the sphere of building maintenance. Eighteen experts selected from companies that are likely to have experience in the use of BIM took part in the survey. The respondents were directors (5), designers (4), BIM managers (2), associate designers (2), a planning engineer (1), architect (1), section manager (1), sales department manager (1), and one respondent who identified himself simply as an employee. Most respondents (39 per cent) have between 6 and 10 years of experience in their profession. Their companies are mostly involved in design (94 per cent), and 78 per cent of the respondents have had some experience with BIM. A considerable percentage of companies (79 per cent) have used BIM on more than six projects, mostly involving residential buildings (29 per cent), industrial plants (21 per cent), and infrastructure projects (18 per cent).

When asked about the need to apply BIM during the operation and maintenance of buildings, 56 per cent of the respondents answered positively, and no one gave a negative answer; significantly, 39 per cent did not even answer the question. This high percentage of non-answers can be explained by the lack of knowledge regarding the possibilities of BIM in the area of maintenance management.

The greatest risks identified by respondents regarding the implementation of BIM in their companies and projects include inadequate education of the personnel, the price of BIM software, insufficient client requests for BIM implementation, unsatisfactory interoperability of computer programs, considerable investments in computer equipment, and the extended time required to finish a job owing to the complexity of the software. An analysis of the answers provided by the respondents revealed that the main risks that must be acted upon prior to BIM implementation involve better education in this area, as well as an increased general awareness regarding the significance and benefits of BIM implementation, which can greatly exceed the initial investments in the education of employees and in the computer infrastructure required.

Based on all the information gained from a literature review and according to an exploratory survey of the current situation, it is recommended that a clearer BIM implementation strategy must be defined as a precondition for the successful implementation of BIM in building maintenance and for the reduction of all of the above-mentioned risks.

3. Strategy of BIM implementation in building maintenance management

The strategy of BIM implementation in all lifecycle stages of a building, including the longest one, namely, the operation and maintenance stage, is proposed based on examples from countries that have made the greatest advances in the implementation of BIM in their civil engineering practice.

The US General Services Administration started introducing BIM in public projects when it formed the national 3D-4D-BIM program in 2003. It also formulated BIM guidelines and standards that have gained international recognition [47].

In 2011, the UK started implementing its five-year strategy (UK Government Construction Strategy) for the implementation of BIM in all public projects by the year 2016. In addition, the BIM Task Group was formed, which assists both public and private industry companies in reengineering their business processes to become compliant with the BIM processes [48].

In Finland and Denmark, the governments provide monetary incentives to support research and development in the field of BIM. The Finnish government passed general BIM guidelines that have been greatly supported in the construction industry; as such, public industry in this country is the main initiator of BIM projects [47]. In addition, Denmark is leading the development of a new BIM standard classification that may become applied across the entire European Union [47]. Germany has developed its own BIM guidelines in which BIM is described as both a process and a technology. BIM benefits are emphasised, and general guidelines for its implementation are given [49]. Germany also has a strategic plan for introducing BIM in all public projects, which can also be applied to other construction project financing modalities. The proposed strategic plan includes a gradual implementation of BIM within the scope of three stages: the preparation, a pilot project, and implementation. The strategic plan is to be realised within five years [49, 50]. The Czech Republic has its own organisation called the Czech BIM Council (czBIM) with several working groups dealing with the standardisation, methodology, education, and terminology, as well as the benefits and risks in BIM implementation. BIM is being promoted with the support of the national government through professional conferences and is being introduced in high schools and universities [49].

These national examples show that the public bodies that define the regulatory guidelines for BIM implementation have a significant role in the implementation of BIM. Some of the main determinants of BIM implementation cited in the literature [47] include the following:

- a) guidelines issued by the governments of individual countries and industries,
- b) the creation of a competitive edge in a particular profession,
- c) national and global standards,
- d) national and global BIM libraries (databases),
- e) legal regulation of the BIM processes,
- f) integrated procurement delivery,
- g) the regulation of required information, i.e. model quality,

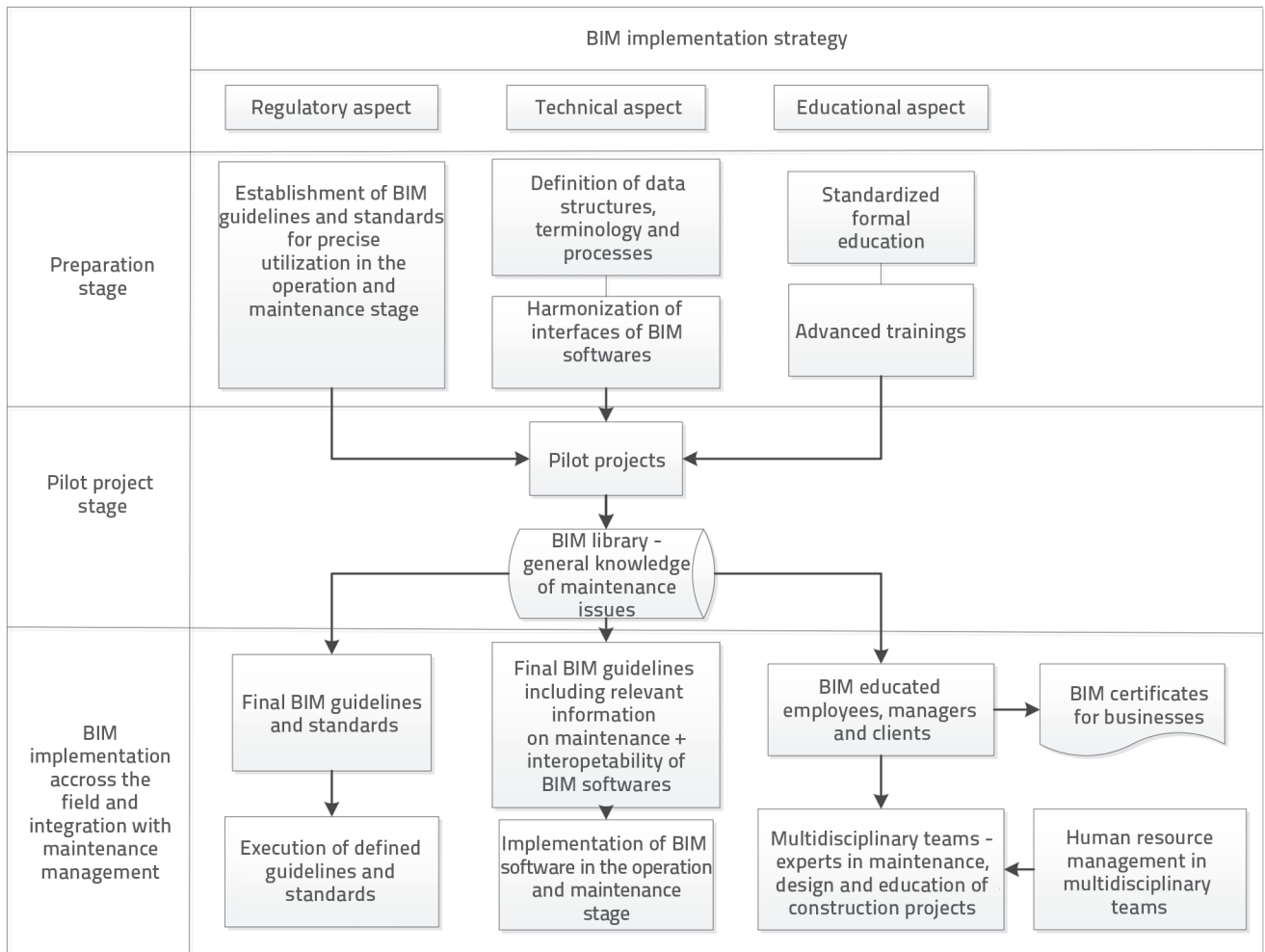


Figure 5. Strategy of BIM implementation in building maintenance

- h) the ranking of BIM competencies (maturity models),
- i) education and research in BIM, and
- j) changes in the business processes.

Based on an overview of the state-of-the-art methods and practices in various countries worldwide, an overview of a general model, i.e., the BIM implementation strategy, including the building maintenance stage, is shown in Figure 5. The proposed strategy includes three main aspects: regulatory, technical, and educational. These three aspects must pass through various levels of development and act simultaneously to eventually enable the successful implementation of BIM in the construction industry, which is oriented toward the entire lifecycle of the building. The described strategy involves three stages, namely, preparation, a pilot project, and implementation, each of which also contributes to the successful implementation of BIM during building maintenance management. The specific features of each of these stages are described below.

3.1. Preparation stage

From a regulatory aspect, the preparation stage includes a study of BIM implementation examples in other countries and the establishment of the initial BIM guidelines and standards based on

the current level of development of digitisation and the possibilities of absorbing the innovation in a particular country. BIM projects can involve both new buildings and the renovation or maintenance of existing buildings. The optimum alternative selection criterion must be defined for each project to minimise the costs and/or impact on the environment throughout the lifecycle of the project. In this respect, it is necessary to include analyses and predictions of future maintenance, involving both regular maintenance and operational maintenance. BIM implementation is certainly possible even before the enactment of a regulatory framework specific for such modelling. Current practice shows that, owing to the advantages of BIM, the private sector is at the forefront of the BIM demand. As shown in relevant studies, public bodies, i.e., competent ministries and various professional associations, play a key role in the implementation of BIM on public projects.

From a technical standpoint, the first step involves the standardisation of terminology, processes, and interfaces of BIM software. Here, the general objective is the standardisation of BIM at the national level. In addition, software solutions that do not support BIM are currently most often used during the building maintenance stage. For this reason, an indispensable step is also the development of BIM software for maintenance management. It is important to insist on the standardisation of a BIM interface and compatibility between

various providers of software solutions to enable the undisturbed exchange of relevant information between the various life stages of the project. The full interoperability in the use of various systems is currently a significant challenge with regard to BIM implementation [51]. Furthermore, professional associations dealing with the maintenance of buildings should specify sets of relevant data that must be contained in each model of a realised building to enable its proper application during the building operation stage.

Another significant aspect during the preparation stage is education, i.e., the conduct of comprehensive educational activities by educational institutions and the establishment of an environment involving knowledge on BIM and its integration with the maintenance phase. It is necessary to organise education sessions regarding the use of BIM, its benefits, and its specific features. Educational institutions should introduce BIM education in their regular study programs, which must also be complemented by professional education seminars for business users. It is only through education that the awareness of the BIM benefits can be increased, including a reduction in the limitations (a loss of time and resistance by individuals) that occur owing to the lack of knowledge regarding BIM processes and technology among employees. To link all BIM processes within a particular company, it is advisable to employ a BIM manager who will be responsible for the coordination of all employees working with BIM and for monitoring the BIM processes.

3.2. Pilot project stage

After defining the initial national BIM guidelines and standards, competent companies are engaged in the pilot project stage, and the initially set frameworks are tested. Pilot projects provide a database of information that must be implemented in BIM models for a more successful transfer to further stages and, finally, to the building operation stage.

Automation in the integration with BIM is recommended to enable an additional increase in productivity and more advanced building maintenance. In fact, the minimum lifecycle cost of a building is becoming an increasingly significant category, and the workforce shortage in the labour market is becoming more pronounced. For this reason, it is necessary at the design stage to anticipate technical solutions that reduce the need for maintenance and enable the replacement of human labour with machine work at the building operation and maintenance stage, i.e., the application of Industry 4.0. Some of these include quick response codes (QR), virtual and augmented reality, and the use of robots in building maintenance.

The QR code implies a two-dimensional graphic representation that, when read, directs the user to a particular web page containing an unlimited quantity of alphanumeric and graphic data. During the process of creation and implementation of QR codes, the important stages are coding, during which the code is formed, and reading, with an establishment of links to web addresses. Smartphones are most often used as QR code readers and as a means for connecting to the Internet. QR technology was created in Japan near the end of the last century and is today used in manufacturing and sales, and in the broadest environments. During the building maintenance process, QR code technology is used in the visualisation of parts, assembly,

devices, and technical details of a building, and for the presentation and interpretation of their maintenance and servicing procedures. This technology significantly simplifies the approach to maintenance, increases worker safety, reduces the error-making possibility, and increases productivity. In addition to BIM and QR codes, virtual reality and augmented reality can also be used to better visualise buildings. Virtual reality (VR) is a technology that had already started to gain recognition in the second half of the last century in the form of simulators used in medicine, the automotive industry, and in the aviation and military industries. At the present-day level of development, virtual reality achieves an extremely faithful 3D model of an existing space or a location that is in the design stage, in which the user has an impression of movement. In this respect, VR has been used to present design solutions to designers during the preparation of technical documents and to buyers of real estate at the selling stage.

Technical properties of virtual reality systems enable their implementation at the stage of operation and maintenance of buildings. The faithful representation of movement through a space defined by BIM enables the remote participation of various teams of experts who, through interaction with their colleagues situated at a distant location, can gain insight into a particular space of an activity related to the operation and maintenance of a building. Participants can ask each other questions, discuss the visualisations, and make rapid decisions [52]. This approach saves time for experts, eliminates travel costs, speeds up activities, and enables the remote cooperation among team members selected based on their expertise.

Augmented reality (AR) is a technology by which the user sees objects in a real environment, augmented with computer-generated images or sounds. This technology is presently used in many highly varied fields of human activity.

There are numerous examples of the implementation of augmented reality in the maintenance of buildings, one of which is an intelligent helmet by which the user sees a three-dimensional model of an object, as well as instructions for its use, servicing, or repair. Infrared thermography is an additional example. It enables technicians to see the conditions of electrical and other systems, based on their heating levels. A special category of AR enables the real-time delivery to workers of working instructions, checklists, and other technological and organisational information required for proper performance of a particular task [53].

It is expected that AR will prove highly significant for practical work in the maintenance of buildings, and this field will be fully determined using this exciting technology. AR will enable greater work quality and productivity, and a higher level of worker safety, while also offering some additional completely novel achievements and applications. Yet another technology that can be used in integration with BIM involves the use of robots in the maintenance of buildings. The term robot dates back to 1920 and has evolved since that time to refer to a computer-operated machine that can automatically conduct a number of complex activities [54]. The usual effects that are expected from the implementation of robotisation are lower costs in the use of robots compared with other technical solutions, better efficiency in operational processes, a development more

responsive to the needs of the users, and avoidance of injuries at work, and a higher productivity of resources [55]. The use of robots in the construction industry, as related to complex production management systems, has been increasing for many decades, both in practice and theory, and concerns the construction of new buildings and the maintenance of existing buildings [56]. In current practice, robots are being widely used to maintain floor surfaces; wash windows; maintain green areas, roads, motorways, and railways; ensure access to and maintain buildings in nuclear zones; conduct urgent interventions; and perform many other tasks. The development of the 5G wireless network will encourage the further development of all of the above-mentioned applications, including many new implementations of automation and robotics in the construction industry, particularly in building maintenance.

During this phase, it is important for building maintenance to define, based on pilot projects, a common BIM library containing all the information regarding the problems and experience associated with the maintenance of buildings. This also implies a definition of maintenance information that must be included in BIM.

3.3. Stage of BIM implementation and its integration with maintenance management

After the pilot project stage, the final BIM guidelines and standards, and possibly the legal framework needed for introducing BIM in public projects, can be defined, as has been done thus far in a number of countries. BIM guidelines are generally defined for all construction projects, and they have to be further elaborated to fit all stages of the construction investment cycle, which also includes the operation and maintenance stage of the buildings.

Work on BIM projects implies the work conducted by multidisciplinary teams. The maintenance experts should already have been included during the design stage in the case of a new project, whereas designers should be included during the maintenance stage in the case of existing buildings. All stages within the lifecycle of a project must be integrated to enable a successful implementation of a BIM project. At the very beginning of the project, it is important to define the data that must be implemented in the BIM model. When defining these items, BIM libraries can be useful, and the data can be extended depending on the specific features of the project. Experts in the areas of maintenance, design, and construction should cooperate in the design and construction stages through multidisciplinary teams. To provide for such cooperation, devising a human resource management plan at the team level is indispensable. Companies should pay particular attention to this segment to prevent a loss of information from errors in communication or understanding.

After construction, the BIM should be updated by adding as-built information and additional data as needed for a successful operation and maintenance of the building. A model prepared in this way is retrieved by maintenance experts who transfer it to the maintenance software, which is defined in advance and is compatible with the previously used software. It is also necessary to provide for continuous education of the maintenance personnel and improve the technical conditions to ensure continuous benefits

from the BIM implementation in the maintenance of buildings. Standardised certificates will enable a very simple classification of companies qualified to work on a particular BIM project. Thus, the interests of the client will be protected, and the competitive edge of some companies present on the market will be emphasised. It is important to note that certification in this field is proposed as a comparative advantage, rather than as an obligation.

3.4. Implementation of BIM in the maintenance of buildings in the Republic of Croatia

In Croatia, just as in other countries worldwide, activities related to the maintenance management of buildings have been increasingly developed in recent years. In general, the size of an existing building stock is considerable when compared to newly constructed buildings, and thus there is a need for adequate maintenance. With the high cost of operational maintenance, it can be questioned how much the companies dealing with maintenance management are willing to invest in education and development of worker competence. Based on example countries that are more advanced in BIM implementation [47], it can be expected that an obligatory BIM implementation for all public projects will be introduced over time in Croatia. This brings up the question regarding who will maintain these buildings and how to best profit from BIM such that its implementation does not stop at the building construction stage. In fact, a typical feature of construction as a branch of industry is that it is slow to accept changes in the given processes and technologies. However, companies will have to adjust over time to new conditions and client requirements in the sense that they will have to invest in new software packages and the education of their personnel. If clear national requirements for building maintenance are already set during the initial BIM implementation stage, the companies will have sufficient time to adjust to new market conditions.

Highly developed technologies and considerable investments required for BIM introduction have, thus far, been a considerable obstacle for Croatian companies.

In addition, problems include insufficient education regarding BIM and inadequate possibilities for additional training. Although professional BIM training sessions are being organised in Croatia, they are mostly oriented toward commercial programs, and are organised by the distributors of such software [49]. However, a broader and unbiased education is needed for a good quality training of personnel, allowing them to become capable of selecting the tools and processes that are best suited for a particular project or company. An example of positive changes can be seen in the initiation of new projects in the Croatian education industry, such as the organisation of BIM summer schools at the Faculty of civil engineering in Zagreb and Faculty of civil engineering, architecture and geodesy in Split, and the use of QR codes in educational projects. Figure 6 shows an example of a QR code that links the user with the characteristics of a column as a structural element of a building. This feature was used in the Erasmus + project, ElBigMac, the objective of which was to stimulate interest of high school students more interested in the field of civil engineering.



Figure 6. Example of QR code. Source: ElBigMac e-book [57]

Croatia is currently making preparations for the introduction of BIM in the construction industry. The Croatian Institute for Standardisation, the Croatian Chamber of Civil Engineers, and the Croatian Chamber of Architects, have been actively working toward the formalisation of Croatian BIM guidelines [49]. General guidelines for devising a proper BIM approach in civil engineering have been issued by the Croatian Chamber of Civil Engineers [19], and the BIM open guide for architects has been prepared by the Croatian Chamber of Architects [58]. However, some parts of these documents have not been fully harmonised, and there is still a need for the development of comprehensive BIM guidelines at the national level. The Croatian Ministry of Construction and Physical Planning (MGIPU) has initiated the BIM Working Group, whose members are representatives of professional engineering chambers, the aim being to encourage a networking of chambers and a more intensive evaluation of BIM. In addition, the Working Group is regularly monitoring the activities of the EU BIM Task Group at the EU level (EU BIM Task Group activities are funded and supported by the EU Commission) to allow the market to rapidly prepare for the next stage of evaluations regarding the introduction of BIM in construction projects. The e-development of MGIPU activities is currently at an advanced level of development and includes an information system for physical planning, e.g., an e-permit modulus. Work is underway to introduce a standardised BIM model format as a part of the input data for the delivery of construction permits. Of course, the entire process will go through a pilot stage, i.e., an optional no-obligation stage. Finally, the considerable simplification of documents for the planning, monitoring, and control of the construction investments, and for the control of maintenance, may be expected in a few years, which is to be implemented precisely through BIM.

4. Conclusion

The main advantages and limitations of the BIM implementation in the maintenance of buildings are set out based on an analysis of the relevant literature and case studies. These advantages and limitations must be properly recognised to enable the successful implementation of BIM during the building maintenance stage. An analysis of existing studies was presented in this paper. On this basis, and based on an exploratory survey involving experts from selected companies, a strategy for BIM implementation

in building maintenance management was proposed. It should be noted that the main risks that must be considered prior to the final implementation of BIM include insufficient education in this field and an inadequate level of awareness regarding the significance and benefits of BIM. These benefits can exceed by far the initial investment in employee education and computer infrastructure.

In fact, efficient maintenance management implies the integration of information management through the long-term management of buildings and short-term construction activity. Benefits can be seen in real savings through the reduced cost of an automatic transfer of accurate, full, and unambiguous information at handover; a better understanding of the operational and building maintenance needs; better decisions regarding the building functionality and maintenance costs; dynamic measurement and registration of energy efficiency levels, deficiencies and failure events; better organisational and strategic planning aimed at obtaining more complete and accurate information regarding the building; and, finally, better quality information.

To improve traditional building maintenance methods and primarily increase the work productivity and enable an easier visualisation, the authors propose BIM integration and automation, i.e., modern technology involving Industry 4.0, such as QR codes, virtual and augmented reality, and robots. In fact, the minimum lifecycle cost of buildings is becoming an increasingly important category, as additionally emphasised by the workforce shortage in the labour market, which is why modern technical solutions must be anticipated.

Example countries that have made the highest achievements in the implementation of BIM in the construction industry clearly show that the main role in implementation is assumed by states and professional associations promoting higher awareness and better education. Not only do these countries participate in the preparation of national guidelines and standards for the implementation of BIM, they also provide financial support for the research and development in this area. Based on current knowledge regarding BIM implementation during the entire lifecycle of a project, it can be concluded that the use of BIM has changed the way in which we view the construction industry as a whole. However, to take full advantage of this area, BIM must also be implemented during the operation and maintenance stage of a building. Proper education and human resource management contribute significantly to the quality of BIM implementation in all processes conducted on construction projects, which also include the stage of building maintenance. The Republic of Croatia is currently at the initial stage with regard to the implementation of BIM in its construction industry. Nevertheless, with proper preparation and deployment of strategic activities, the nation can become a role model to other countries in the region regarding the advancement of its construction industry.

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