ESCUELA DE CONSTRUCCIÓN CIVIL
FACULTAD DE INGENIERÍA

Revista de la Construcción
Journal of Construction

Research Article

Requirements for BIM implementation in AEC companies: a Brazilian case study

Ayanna Karina de Assis Santos Wanderley[1], Alberto Casado Lordsleem Júnior[2], Joaquin Humberto Aquino Rocha[3], *

[1] Civil Engineering Program, University of Pernambuco, Recife (Brazil); ayannakarina@hotmail.com
[2] Civil Engineering Program, University of Pernambuco, Recife (Brazil); acasado@poli.br
[3] Civil Engineering Program, Federal University of Rio de Janeiro, Rio de Janeiro (Brazil); joaquin.rocha@coc.ufrj.br
*Correspondence: joaquin.rocha@coc.ufrj.br

Received: 12.09.2022; **Accepted:** 10.06.2023; **Published:** 31.08.2023

Citation: Wanderley, A., Lordsleem Júnior, A. and Rocha, J. (2023). Requirements for BIM implementation in AEC companies: a Brazilian case study. Revista de la Construcción. Journal of Construction, 22(2), 455-481. https://doi.org/10.7764/RDLC.22.2.455.

Abstract: Building Information Modeling (BIM) is widespread in many countries; however, its implementation still encounters some barriers in Brazil. In addition, during the BIM implementation process, some companies give up because they do not achieve the expected result. In the Metropolitan Region of Recife, adherence to the BIM methodology is less than 5% of the research universe, which is 445 among companies and professionals. This study evaluates the fulfillment of the necessary requirements for BIM implementation at Brazilian architecture, engineering, and construction (AEC) companies. The methodology was carried out using case studies and its strategy was based on the following steps: identification of the state-of-the-art and of requirements for BIM implementation, which allowed the determination of the criteria for evaluating the companies studied; the criteria determined were use to elaborate an online form for identification of AEC companies in Recife (Brazil) and a questionnaire for conducting interviews with the selected companies; subsequently, case studies were developed, and data analysis. The case studies were carried out at five AEC companies which had a median fulfilment of requirements of 65%. Many of the companies presented BIM 1.0 characteristics. It has been verified that the BIM implementation is more effective at companies where a greater number of BIM requirements are applied. The companies with the fewest requirements applied, or those that did not meet the requirements in practice, did not present significant advances in BIM implementation. The main research contributions were the compilation of the requirements for BIM implementation. Therefore, this study produces knowledge that can assist companies in the AEC industry experiencing similar difficulties in BIM implementation as those described in this paper.

Keywords: Building information modeling, implementation requirements, AEC companies, Brazil, case studies.

1. Introduction

Building Information Modeling (BIM) (Succar, 2009) is one of the major innovations in the architecture, engineering, and construction (AEC) industry (Okakpu et al., 2019; Raouf & Al-Ghamdi, 2018) and its adoption has increased exponentially (Fitz & Saleeb, 2019; Ahankoob et al., 2018). BIM has the potential to reduce the costs of each building lifecycle phase, improve delivery time, and facilitate product quality assurance (USACE, 2011). In the study by Rodgers et al. (2016), top managers of large AEC companies admitted that small and medium businesses could have a greater advantage from turning the old CAD system into a new BIM system because of their agility. In addition, Carmo et al. (2019) point out that BIM implementation provides improvements in collaboration between architects, engineers, and builders.

In a survey by McGraw-Hill Construction (2014), with builders on all continents, it was possible to verify that 75% of these companies reported a positive return on investment in BIM. According to the survey, the percentage of Brazilian companies that implemented BIM and obtained a return on investment was above the world average. From the forty construction companies interviewed, 85% stated that the return on investment in BIM was positive (McGraw-Hill Construction, 2014).

In North America, according to McGraw-Hill Construction (2012), it is estimated that BIM use in the AEC industry grew from 28% in 2007 to 71% in 2012. In a recent study by the American Institute of Architects (2020), it is stated that 100% of large architecture firms use BIM in the USA. However, even where BIM is established, there are gaps with regard to its use in the design and construction phases that need to be filled in order to optimize the use of this methodology (Andersen & Findsen, 2018). Furthermore, in some countries, BIM implementation is restricted, as demonstrated by Juszczyk et al. (2015), whose reports and analysis of McGraw-Hill Construction (2012) showed evidence of a BIM implementation rate of 58% in South Korea. Similarly, according to the RICS School of Build Environment (2014) at Amity University, the BIM implementation rate is 22% in India and 25% in the Middle East. Huber (2012) states that the rates for New Zealand and Australia are 34% and 19% respectively.

Likewise, the study carried out for the Western European AEC industry by McGraw-Hill Construction (2010) revealed that the level of BIM implementation was 36%. However, recent studies have shown that there is considerable growth in BIM adoption between 2010 and 2023, mainly in Asia, Europe, and North America (Adeniyi et al., 2022).

In Brazil, in 2018, the Federal Government made the National Strategy for BIM Dissemination official through the publication of Law No. 9377, which set deadlines for BIM implementation. The deadlines will begin to count from 2021, 2024, and 2028 and will cover the entire building lifecycle (Brazil, 2018). However, in Brazil, BIM use is incipient, and its advantages are not fully disseminated. Louzas (2013) conducted a field survey of 588 Brazilian engineers and architects, and concluded that 90% of interviewees intended to use BIM within a maximum of five years. However, 62% of interviewees did not yet use the methodology.

The same can be observed in other developing countries, such as Vietnam, where a government mandate for BIM use was created in 2016, but for which there are still no official guidelines, national standards, or encouragement to implement projects focused on BIM (Nguyen, 2017).

To change this scenario, some countries, such as Australia and the United States of America (USA), have developed federal guidelines to assist in the deployment and dissemination of BIM. In these guidelines, implementation requirements are presented, with some of them being considered essential for successful implementation (NATSPEC, 2014; USACE, 2006).

To Menezes (2011), the initial difficulties reported by companies regarding BIM implementation are generally associated with high costs, which involve software, machines, and training for users, as well as the incompatibility of BIM applications and the lack of collaboration between the companies involved. AEC companies and professionals therefore need to be assured that the time and money invested in implementing BIM will deliver valuable returns (Jin et al., 2017).

The elaboration of studies that prove positive results from BIM implementation can therefore contribute to BIM diffusion, improving elaboration, construction, and management processes in the AEC industry (Le et al., 2018). Also, a full assessment of the current state of research in the BIM field will facilitate the efforts of AEC professionals and researchers to identify where efforts should be focused (Hosseini et al., 2018).

Due to the low level of BIM methodology implementation in many countries and the introduction of national policies for BIM implementation in several countries, this study aims to evaluate the fulfilment of the requirements for BIM implementation in Brazilian AEC companies and its relation to adequate BIM development.

2. Building information modeling

For Tobin (2008), there are three generations of BIM (Figure 1), called BIM 1.0, BIM 2.0, and BIM 3.0. Succar (2009) adds to these generations pre-BIM, before BIM 1.0, and Integrated Project Delivery, after BIM 3.0.

It is important to emphasize that pre-BIM systems are often dependent on two-dimensional documentation and detailing, even when 3D visualizations are generated. Quantities, cost estimates, and specifications are typically not derived automatically from the display template nor are they linked to the documentation. In addition, collaborative practices between stakeholders are not prioritized and the workflow is linear and asynchronous (Succar, 2009).

2.1. *Implementation in the world*

BIM implementation is accelerating worldwide, driven by government mandates, clients, and contractors as they realize the possible benefits of BIM in both the short and long term (Smith, 2014; Loyola & López, 2018).

For Kiviniemi et al. (2008) and Wong et al. (2011), the USA is the best example of the emerging use of BIM. Since 2007, the General Services Administration has determined that project approval be conditional on BIM software file presentations for architectural and structural elements (Kiviniemi et al., 2008).

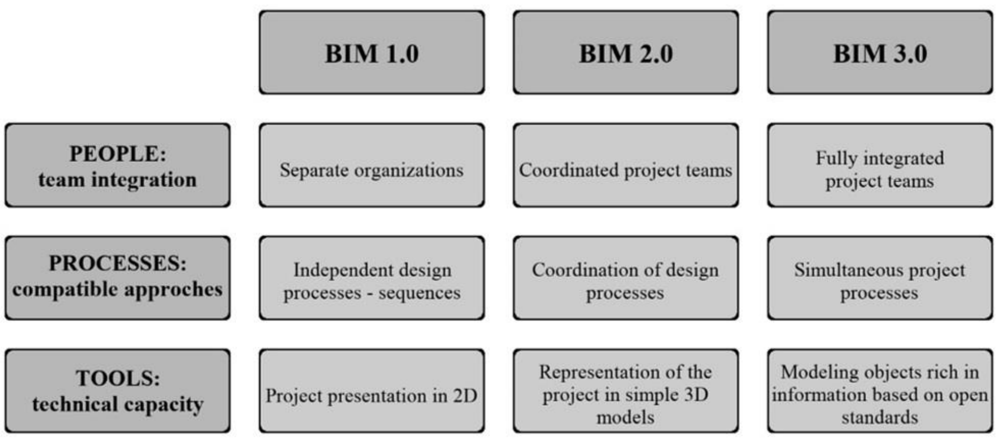


Figure 1. Evolution of BIM implementation. Adapted from Andrade (2012).

Finland was one of the pioneers in the implementation process. In 2001, Senate Properties, a government organization responsible for estate management for the Finnish state, started a project in 2006 that achieved a positive result with an integrated model. Since October 2007, it has been mandated that all designs be delivered in BIM software that has achieved Industry Foundation Class certification (Kiviniemi et al., 2008; Kiviniemi, 2015; Kassem & Amorim, 2015).

In 2014, the European Parliament voted to modernize public construction projects in the European Union and encourage BIM use, recommending that public construction contracts or projects drafted for public constructions in the Member States should require BIM software use. It was defined that the Member States have two years to implement this in their national legislation.

Starting in 2011, China's national BIM policy was announced by the State Ministry of Housing and Urban-Rural Construction (SMHURC, 2011), in order to establish relevant standards over the following years. A more detailed strategic plan was released from the State Ministry of Housing and Urban-Rural Construction (SMHURC, 2013) in another BIM application proposal, stating that, by 2016, government-invested projects over 20,000 square meters and green buildings at the provincial level should adopt BIM in both design and construction. It was also found that BIM implementation faced challenges in China, such as a lack of well-developed standards and legislation, insufficient interoperability and collaboration among different design disciplines, and difficulties in implementing BIM during the entire building lifecycle (He et al., 2012; Ding et al., 2015; Liu et al., 2017).

In Brazil, with the National Strategy for the Dissemination of BIM, it is expected that, by 2028, BIM implementation will cover the entire building lifecycle (Brazil, 2018). In addition to governmental initiatives, the Brazilian Architecture Offices Association (AsBEA), with the purpose of offering information and tools related to BIM implementation, developed the first edition of the BIM Good Practices Guide in 2013 through the BIM Technical Group, targeting the AEC industry and entrepreneurs.

2.2. *Implementation requirements*

In order to deploy BIM, there must be changes in technologies, processes, and policies. According to Succar and Kassem (2015), these areas can evolve independently or collectively, according to the implementation stages. The key to success in implementing BIM is not simply to automate existing processes, but rather to create a new business process. For this, a change in company culture is required, aiming at virtual construction (USACE, 2006).

For Autodesk (2014), to be successful at implementing BIM, organizations need a strategy that addresses their specific needs and business values. Eastman et al. (2010) suggest that a change is needed in almost every aspect of a company's business. This requires some practices, presented in Figure 2, that go beyond the simple acquisition of software and hardware.

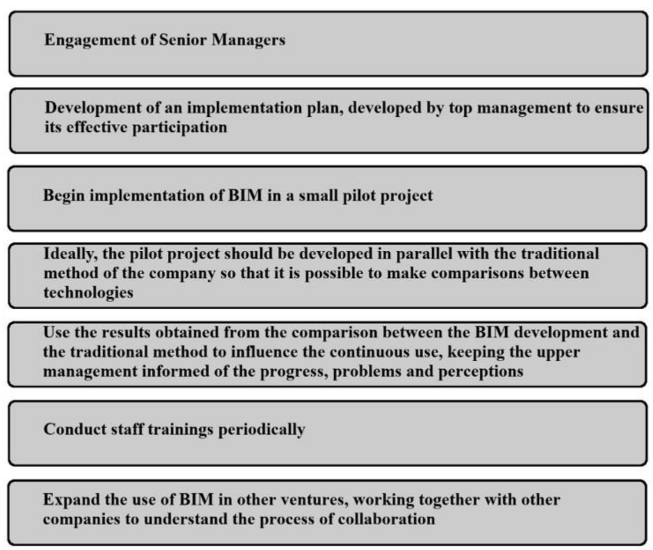


Figure 2. Changes needed to implement BIM. Adapted from Eastman et al. (2010).

Some countries, because of government incentive or on the initiative of nongovernmental associations, have developed guidelines for the introduction of BIM. Figure 3 shows the main documents used in different countries. It should be noted, however, that there is no general approach to implementation in the documents listed in Figure 3.

The guidelines presented in Figure 3 deal with multiple subjects, with those presenting information specifically on BIM implementation being highlighted in the implementation content column of Figure 3, using Roman numerals I, II, III, IV, V, VI, VII, and VIII that correspond to the following stages of implementation: Getting Started with BIM; Building Information Modeling (BIM) Roadmap; Building Information Modeling (BIM) Roadmap – Supplement; BIM Implementation: An Owner's Guide to Getting Started; Building Information Modeling Execution Planning Guide 2.0; AEC UK BIM Technology

Protocol; AsBEA Guide: Good Practices in BIM (Fascicle I and II); and Collection BIM implementation in builders and developers.

By analyzing the guidelines (Figure 3) and their implementation approaches, it was possible to select 12 (twelve) recurring requirements, which are presented in Figure 4. It was also possible to observe that the most recent and more detailed guides, such as the AsBEA, developed in Brazil in 2013, the National Australia Guide (NATSPEC, 2014), and the Collection of BIM Implementation in construction companies and developers (CBIC, 2016) focus their content on implementation and address practically all the requirements necessary for BIM implementation.

Country	Organization	Document	Implementation content	Year	Number
Australia	National Building Specification (NATSPEC)	Getting Started with BIM	✓	2014	I
USA	US Army Corp of Engineering (USACE) and Engineer Research and Development Center (ERDC)	Building Information Modeling (BIM) Roadmap	✓	2006	II
USA	US Army Corp of Engineering (USACE) and Engineer Research and Development Center (ERDC)	Building Information Modeling (BIM) Roadmap - Supplement.	✓	2011	III
USA	The Construction Users Roundtable (CURT)	BIM Implementation: An Owner's Guide to Getting Started	✓	2010	IV
USA	National Institute of Building Sciences General Services Administration (GSA)	National Building Information Modeling Standard	✗	–	–
USA	General Services Administration (GSA)	GSA Building Information Modeling Guide 01 - 08	✗	–	–
USA	Computer Integrated Construction Research Program (CICRP)	Building Information Modeling Execution Planning Guide 2.0	✓	2010	V
USA	U.S. Department of Veterans Affairs	The VA BIM Guide	✗	–	–
Germany	Federal Office for Building and Regional Planning	BIM Guide for Germany	✗	–	–
Hong Kong	Hong Kong Housing Authority	BIM Standards, user guides, and library components for contractors.	✗	–	–
Japan	Ministry of Land, Infrastructure, Transport and Tourism.	2013 Guidelines for architecture BIM Models	✗	–	–
Malaysia	Public Works Department	BIM Guideline Standard (2016)	✗	–	–
New Zealand	Ministry of Business, Innovation and Employment	New Zealand BIM Handbook (2014)	✗	–	–
Normay	Statsbygg	Statsbygg Building Information Modeling Manual Version 1.2.1	✗	–	–
Denmark	Agency for Enterprise and Construction	3D Working Method	✗	–	–
Singapore	Building and Construction	Singapore BIM Guide version 2	✗	–	–
UK	AEC UK CAD & BIM Standards	AEC UK BIM Technology Protocol	✓	2015	VI
Brazil	Brazilian Association of Architecture Offices	AsBEA Guide: Good Practices in BIM (Fascicle I and II)	✓	2013	VII
Brazil	Brazilian Chamber of Construction Industry	Collection BIM implementation in builders and developers	✓	2016	VIII

Figure 3. Guides related to BIM practices.

Requirements	Function	Guides I	II	III	IV	V	VI	VII	VIII
Define metrics	Establish measure unit, which will be used both in the project developed in BIM and in the project done in a traditional way to evaluate the implementation processes and delineate improvement of these processes.	✓	✗	✓	✗	✓	✓	✓	✗
Define goals	Determine the level of proficiency desired for each improvement and the time frame for its implementation. Emphasizing the main improvements that can be obtained with the BIM uses chosen to be deployed in the company.	✓	✓	✓	✓	✓	✓	✗	✓
Develop an implementation plan	The deployment plan should identify the company's current landscape with respect to existing resources, technologies and processes; Identify the needs for these items; establish methodology and deadlines to improve these items, and to meet deployment objectives such as increasing productivity, reducing documentation costs, improving coordination and project accuracy, among others.	✓	✓	✓	✗	✓	✓	✓	✓
Define the uses of BIM in the company	Define the BIM uses that are compatible with the action area and the company objectives, giving priority to the uses that provide the greatest return on effort and are less damaging to existing workflows, in order to motivate the team.	✓	✓	✗	✓	✗	✓	✓	✓
Define a team to BIM implementation	Determine a priority team composed by BIM, technical leader and designers, defining the roles and responsibilities of each member of the team, so that no one is overwhelmed.	✓	✓	✓	✓	✓	✓	✓	✓
Restructure Information Technology (IT) resources	Restructure software, hardware, server and internet. You must select the software according to the BIM uses defined and note that the other items such as hardware, server and internet have their settings determined from the chosen software.	✓	✓	✓	✗	✓	✓	✓	✓
Training	Essential for forming new BIM teams, but in addition it is necessary, continuously assess and recycle the skills of those who have been trained. For training, consideration should be given to content items, lesson organization, documentation and recycling.	✓	✗	✓	✓	✓	✓	✓	✗
Define implementation support	Define a managerial support, necessary support for the implementation processes, through an experienced internal professional, or an external consultant. And also, define the technical support can still be divided between software support and infrastructure support, including hardware, server and internet.	✓	✗	✓	✗	✓	✗	✓	✗
Define a BIM workflow	It should be defined according to its peculiarities and the BIM uses of each company, so it may be different for each type of company.	✗	✓	✗	✓	✗	✓	✓	✓
Define the internal standards	Define or update company standards to meet BIM's needs. Among the standards to be defined specifically for BIM are templates, libraries, naming, and structuring of folders.	✓	✓	✓	✗	✗	✓	✓	✓
Start a pilot project	Considered the practical application for all definitions of the deployment process and especially the deployment plan, it is imperative for the deployment process.	✓	✗	✓	✓	✗	✗	✗	✓
Check implementation and review the plan	Deployment processes should be periodically reprogrammed based on the progress, problems, and perceptions gained during deployment; The references created during the project metrics and goals definition should be analyzed.	✓	✓	✗	✗	✓	✓	✗	✓

Figure 4. Topics covered in the implementation guides.

3. Methodology

Given that the main guidelines for BIM implementation have similar requirements with regard to how to carry out the implementation process (Figure 4) and because of the scarcity of studies analyzing the potential application of these requirements for successful BIM implementation, this study seeks to identify synergies between BIM implementation and the fulfillment of BIM requirements. For this purpose, the following hypotheses were considered:

- Research hypotheses 1: The fulfilment of requirements by a company influences BIM implementation.
- Research hypotheses 2: The higher the number of requirements targeted by a company, the greater the chances for success in BIM implementation in the company.

As the requirements presented by the guidelines seek to prepare AEC companies for BIM implementation and ensure that it is not begun prematurely, the validation of the above hypotheses makes it possible to understand not only how requirements affect BIM implementation, but also whether BIM implementation requires compulsory adoption of requirements.

To verify the validity of the above hypotheses, this study was carried out using case studies (Gil, 2010) on BIM implementation at five AEC companies, generating knowledge that can be applied in practice (Rodrigues, 2007). The research strategy was based on the following premises:

1) Preliminary bibliographic survey: identification of the state-of-the-art on BIM use at AEC companies and requirements for BIM implementation;
2) Data collection methodology definition: elaboration of an online form for identification of AEC companies that use BIM and elaboration of a questionnaire for conducting interviews with the selected companies;
3) Case studies development: application of questionnaire at AEC companies to characterize BIM implementation;
4) Data analysis: critical and comparative case studies data analysis.
5) Based on the strategy defined, the study contemplated the steps described in Figure 5.

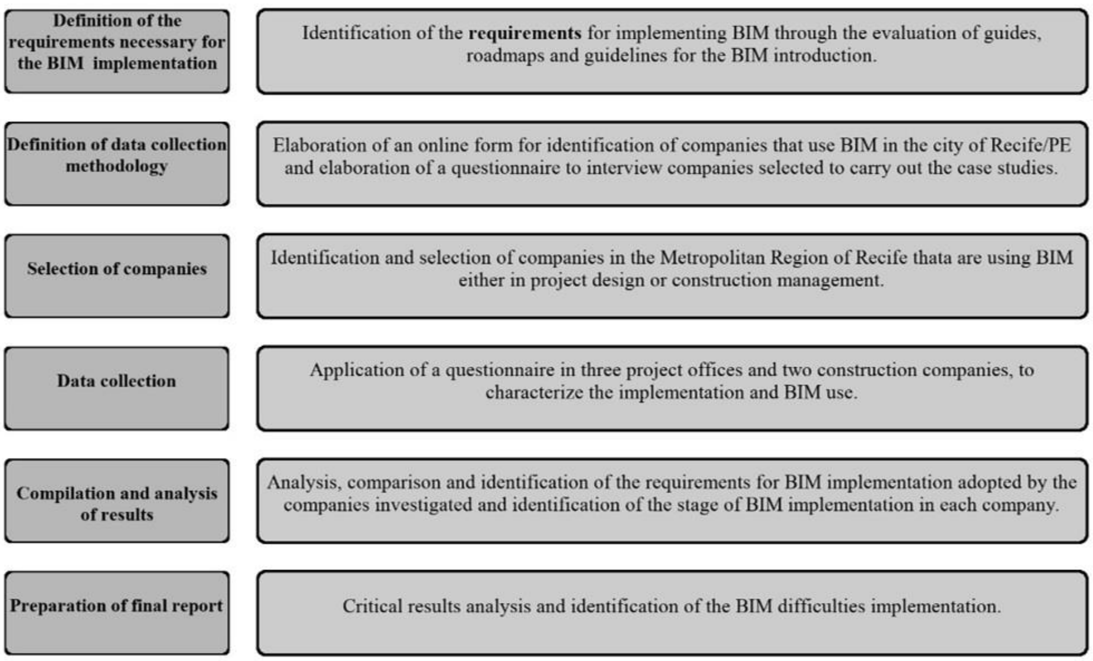


Figure 5. Research development steps flowchart.

The case studies were carried out in Recife, a city located in Brazil and capital of the state of Pernambuco, where BIM initiatives were investigated at the Syndicate of Architecture and Engineering Consulting Companies of Pernambuco (SINAENCO/PE), the Civil Construction Industry Syndicate of Pernambuco (SINDUSCON/PE), the Real Estate Market Company Association of Pernambuco (ADEMI/PE), and in the group called BIM Community -PE that aims to disseminate and exchange experiences about BIM. Due to the continental dimensions of Brazil, the city of Recife has characteristics similar to many other large Brazilian cities, and the implementation of BIM is at a similar stage (Wanderley, 2017). For this reason, this city was chosen for the development of this study.

The investigation was initially done through an online application form that aimed to identify companies that had some BIM initiative, to develop case studies. Companies that had experiences with BIM were selected for carrying out the case study, selecting AEC companies that demonstrated greater progress with BIM implementation.

Case studies were then carried out, with data collection performed through interviews with professionals responsible for implementing BIM at each company. The interviewee answered a questionnaire with both closed questions and open questions that would allow for answers containing information not foreseen by the researcher. The questionnaire aimed to characterize the company and the interviewee, as well as the project under evaluation. BIM use at the companies was analyzed to find out who made the decision to implement BIM at the company, whether the board participates in the implementation, and, finally, to verify the fulfillment of the implementation of BIM requirements. The questionnaire was divided into 8 parts:

1) Data of the company and of the person in charge: identification data of the company. Name, position, and professional training of the person in charge.
2) Characterization of the company: area of activity, time of existence, number of works, among others.
3) Characterization of entrepreneurship for the implementation of BIM.
4) Use of BIM: BIM concept, demand for BIM projects, willingness to use BIM, among others.
5) Decision to implement BIM: initiatives and participation of the board of directors in the implementation of BIM.
6) Organization and structuring: definition of metrics and BIM implementation goals. Development of a BIM implementation plan. Definition of the use of BIM. Definition of a team with a matrix of responsibilities. Restructuring of the Information technology (IT) sector of the company. Team training in BIM. Provide support for BIM implementation.
7) Processes: definition of the workflow in BIM and internal company standards.
8) Observations.

When analyzing the BIM implementation process, there are actions that must be performed and actions that, although not mandatory, are interesting for implementation. These actions were assumed in this work as requirements. Therefore, after carrying out these initial analyzes, the questionnaire also provides for the analysis of the assumptions for BIM implementation, for this purpose, direct questions were prepared about the assumptions for implementation, with the purpose of verifying compliance with requirements and open questions to examine the procedure for the implementation of the requirement. The closed questions make it possible to simplify the understanding of the questions and the organization of the answers, in addition to making the questionnaire practical, on the other hand, the open questions favor freedom of expression from the respondent's point of view and the respondent's opportunity to address unforeseen topics by in the questionnaire.

In this study, interviews were conducted in five companies, two construction companies, two facilities design offices and an architecture design office. Five companies were selected from the Metropolitan Region of Recife that have already used BIM and are in the process of implementation. Due to the incipient development of BIM in Pernambuco, with no case studies in stage 3.0, for analysis and calibration of results, the companies were compared in relation to the company that presented a greater amount of attendance to the requirements for implementation.

The fulfillment of the 12 requirements was measured by determining the percentage of total sub-steps evaluated in each requirement. The sub-steps to be evaluated to verify compliance for each requirement were collected from the eight BIM implementation guides selected for use in this study (Figure 4). It should be noted that not all guidelines studied presented the same sub-steps for verifying compliance with each requirement. This study therefore sought to gather sub-steps from all selected guides in order to explore as much information as possible. The company with the best implementation result was used as an evaluation parameter for the other companies, which were compared with the company. For comparison purposes, the fulfillment of each premise and the continuity given to each premise within the company were used. It was also verified the stage in which each company is found according to the stages established by Tobin (2008).

Each of the 12 requirements was given equal weight, making them equivalent to 8.33% out of a potential total of 100%. However, the 8.33% for each requirement was divided by the number of sub-steps in that requirement and then multiplying it by the number of sub-steps that were implemented.

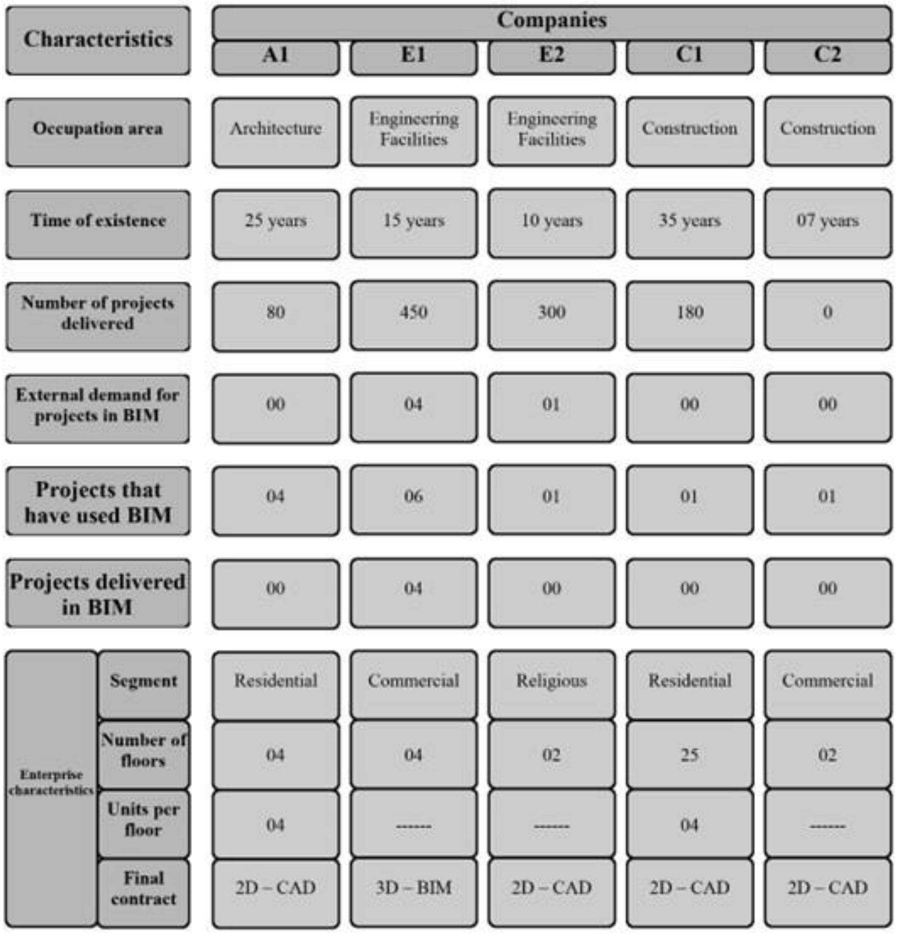
4. Results and discussion

Figure 6 presents a summary of the results obtained from the research carried out by the SINAENCO, SINDUSCON, and ADEMI organizations, as well as by the BIM Community, indicating that, of the 31 respondents to the online form, only 19 companies use BIM in their projects. However, a closer look at each individual response made it clear that, despite the fact that they use BIM; the software used by the companies does not characterize this use. It was also observed that, for the majority, BIM applications are used for conception, collaboration, and design visualization. Through analysis of the answers provided through the online forms, it was verified that BIM use in Recife is still moving towards BIM stage 1.0.

Among the companies responding to the online form, those with greater experience in the implementation of BIM were selected to be interviewed, due to the number of projects that used BIM and the software used. The selected sample consisted of one architecture design company, two engineering facility design companies, and two construction companies. The companies selected for the questionnaire application and data collection were designated by a letter corresponding to their area, such as 'A' for architecture, 'E' for engineering, and 'C' for construction. Numbers were used to differentiate two companies from the same area, such as Company 'C1' and Company 'C2'. Figure 7 presents the main characteristics of the companies and also shows the projects characteristics evaluated at each of the companies studied, including the segment, number of floors, and units per floor. It should be noted that only company E1 uses BIM designs for the final contract; the remaining companies use 2D designs.

Entity	Number of representative companies	Number of companies that sent responses to the online form	Number of respondent companies that have design in BIM
SINAENCO	35	0	0
SINDUSCON	185	0	0
ADEMI	105	11	4
BIM Community	120	20	15

Figure 6. Responses from the organizations to the online form.



Characteristics		A1	E1	E2	C1	C2
Occupation area		Architecture	Engineering Facilities	Engineering Facilities	Construction	Construction
Time of existence		25 years	15 years	10 years	35 years	07 years
Number of projects delivered		80	450	300	180	0
External demand for projects in BIM		00	04	01	00	00
Projects that have used BIM		04	06	01	01	01
Projects delivered in BIM		00	04	00	00	00
Enterprise characteristics	Segment	Residential	Commercial	Religious	Residential	Commercial
	Number of floors	04	04	02	25	02
	Units per floor	04	------	------	04	------
	Final contract	2D – CAD	3D – BIM	2D – CAD	2D – CAD	2D – CAD

Figure 7. Companies' characterization.

4.1. *BIM use companies' characterization*

4.1.1. Company A1

Company A1 adopted the use of BIM in 2010. When it began, the company decided to use the methodology first in the elaboration of the architecture design and has not yet expanded its use into other design areas. The A1 project analyzed in this study is a housing complex with six towers, each tower having four floors and four units per floor. The elaboration of this project in BIM allowed for faster development and adjustment to the design, mainly because it is a project with very similar characteristics on all levels, meaning that a single design can be reused several times.

The company decided to begin implementing BIM in order to reduce the delivery time specifically for the project analyzed in this study. However, this decision was taken internally only to meet the deadline requested by the client, although this was not required for design elaboration. Company A1 succeeded in reducing the desired deadline, but the BIM implementation process has since become stagnant. The company uses BIM only in the elaboration of architecture designs and after this stage, it continues the facility design elaboration using 2D software.

4.1.2. Company E1

Company E1 adopted BIM when it began using Revit Architecture and Revit MEP software, as well as Autodesk software that later merged with Revit Structure, which is the software used by the company today.

The E1 project analyzed in this study is a commercial building with four floors having a different architectural plan on each floor. Although company E1 had already developed other buildings using BIM, this project was considered the first BIM experience because of the client's demands for elaboration and collaboration. Initially, even without demand for BIM designs, company E1, which had been hired to reconcile designs already executed in 2D CAD, chose to model all designs in Revit to perform collaboration and present the modeling result to the client aiming to arouse interest in the use of BIM. This strategy was successful, convincing the client to ask for BIM designs.

4.1.3. Company E2

Company E2 uses Revit software, with its Architecture, Structures and Facilities systems (mechanical, electrical, and hydraulic). The company does the sizing and project analysis, while subcontracting services for the draft designs. For company E2, however, BIM implementation has not yet modified its work procedures, in other words, the designs continue to be elaborated by the company while the draft designs are subcontracted.

The company E2 project analyzed in this study is a two-story building, without standardization between the floor layouts. In this project, the use of BIM software began with the purpose of modeling, dimensioning, and collaboration of design areas. However, due to the high investment required for BIM use, which would lead to an increased price and longer time to complete the final project, the client changed their mind and the BIM projects were suspended, leaving the final contract establishing that the designs be developed in the traditional 2D CAD model. However, company E2 has not yet given up on BIM implementation. Although the pace has slowed due to lack of demand and the facility design development files already being organized for building information modeling. In this sense, the company has gradually developed its own files as libraries and templates, besides performing periodic training.

4.1.4. Company C1

Company C1 began implementing BIM for a residential project for which it contracted for all the designs to be executed in BIM. There was no external demand to implement this methodology. The decision was internal with the purpose of rationalizing the construction processes.

The C1 company project analyzed in this study is a residential building with two towers having 25 floors each. As it is a construction company, it contracted the executive designs from other parties for the planning objective, collaboration, and supply control. For its initial BIM implementation, company C1 contracted all designs for the execution of the project with the help of local companies. Even though the companies were carefully selected, company C1 was unable to continue implementing BIM for its first BIM project due to the quality of the designs, which were not considered adequate for execution and were used in some cases for quantitative survey only. This made it necessary to execute the contracting designs in 2D software, the usual constructor practice.

4.1.5. Company C2

Company C2 is part of a group formed by several constructors, who construct both commercial and residential buildings. Although some companies in the group have more than 30 years of experience, company C2 has only about seven years of existence and has already chosen to implement BIM in its first venture.

The C2 company project investigated in this study is a commercial building with two floors having a different architectural plan for each floor. BIM is used within the company itself, which contracts the designs in 2D - CAD and then models them for the purpose of collaboration. Initially, company C2 performed the building information modeling after receiving the designs in 2D and before their release for construction. However, most of the designs were not used directly for building execution due to the resistance of those responsible for the execution. This, along with a reduction in team size and the fast pace of the building execution, made it impossible for the modeling to be released before execution. Only a logging model was used, showing the history of modifications made in the initial designs.

4.2. *BIM requirements implementation stage*

Table 1 presents a compilation of the companies' answers regarding the fulfillment of requirements for BIM implementation for the projects investigated. In this table, it is evident that E1 has a total requirements percentage higher than that of the other companies, though the percentages reached by companies A1, E2, C1, and C2: 60%, 54%, 65%, and 65%, respectively, are considered high for companies that have not been able to advance the process.

4.2.1. Company A1

Company A1 fulfilled 60% of BIM requirements (Table 1). It was noted that company A1 did not define any metrics and had no targets for implementation. Although they defined all the items anticipated for the implementation plan, they did not keep all decisions in practice, since the human resources planning elaborated during the implementation process did not match the company resources at interview time. The same applies for the deadlines: three months were defined for implementation, while the same plan is still in use after seven years. The team was defined adequately for the implementation but was then disbanded. The information technology restructuring requirement was maintained in company A1, but it was not initially planned for the server to be used for design development, an important item to ensure collaboration. The item that guarantees the maintenance of team training is recycling, but this item was not foreseen in company A1, so the requirement is not considered as continuous at the company. The defined workflow did not focus on BIM use, so it was not accounted for in the requirement fulfillment percentage.

The implementation of the first BIM experience continues, however, to be partially implemented, because company A1 continues to develop projects in BIM. Its implementation has not evolved because it has not inserted new uses in new designs, which have the same characteristics as the project investigated in this study. Following the architectural modeling, the company continues the project elaboration in 2D. Based on the above considerations, company A1 presents the design development in BIM in an unidisciplinary way: the designs are used to automate the generation of documents and quantitative registers. Thus, company A1 can be characterized to be in BIM stage 1.0.

4.2.2. Company E1

Company E1 fulfilled 90% of BIM requirements (Table 1). Company E1defined six of the seven metrics, with some of them already having been defined in the traditional design process and used in the BIM implementation. Although 86% of the metrics were defined, only the quality goal was defined.

Table 1. Fulfilment to the requirements for BIM implementation.

Requirements	Parameters for punctuation	Company results				
		A1	E1	E2	C1	C2
1 Metrics	8.33%	0%	7.14%	0%	1.19%	0%
1.1 Performance	1.19%	0%	1.19%	0%	0%	0%
1.2 Quality	1.19%	0%	1.19%	0%	1.19%	0%
1.3 Customer relationship	1.19%	0%	1.19%	0%	0%	0%
1.4 Scope	1.19%	0%	0%	0%	0%	0%
1.5 Costs	1.19%	0%	1.19%	0%	0%	0%
1.6 Contracts	1.19%	0%	1.19%	0%	0%	0%
1.7 Deadlines	1.19%	0%	1.19%	0%	0%	0%
2 Goals	8.33%	0%	1.19%	0%	1.19%	0%
2.1 Performance	1.19%	0%	0%	0%	0%	0%
2.2 Quality	1.19%	0%	1.19%	0%	1.19%	0%
2.3 Customer relationship	1.19%	0%	0%	0%	0%	0%
2.4 Scope	1.19%	0%	0%	0%	0%	0%
2.5 Costs	1.19%	0%	0%	0%	0%	0%
2.6 Contracts	1.19%	0%	0%	0%	0%	0%
2.7 Time limits	1.19%	0%	0%	0%	0%	0%

3 Implementation plan	8.33%	8.33%	8.33%	8.33%	8.33%	6.68%
3.1 Objectives	1.67%	1.67%	1.67%	1.67%	1.67%	1.67%
3.2 Methodology of implementation	1.67%	1.67%	1.67%	1.67%	1.67%	1.67%
3.3 Infrastructure planning	1.67%	1.67%	1.67%	1.67%	1.67%	1.67%
3.4 Human resource planning	1.67%	1.67%	1.67%	1.67%	1.67%	1.67%
3.5 Deadlines	1.67%	1.67%	1.67%	1.67%	1.67%	0%
4 Uses of BIM projects	8.33%	8.33%	8.33%	8.33%	8.33%	8.33%
Yes	8.33%	8.33%	8.33%	8.33%	8.33%	8.33%
Not	0%	-	-	-	-	-
5 Definition of the team	8.33%	8.33%	8.33%	8.33%	8.33%	8.33%
Yes	8.33%	8.33%	8.33%	8.33%	8.33%	8.33%
Not	0%	-	-	-	-	-
6 Restructuring	8.33%	4.16%	6.24%	6.24%	6.24%	6.24%
6.1 Software	2.08%	2.08%	2.08%	2.08%	2.08%	2.08%
6.2 Hardware	2.08%	2.08%	2.08%	2.08%	2.08%	2.08%
6.3 Internal Network / Server	2.08%	0%	2.08%	2.08%	2.08%	2.08%
6.4 External network (Internet)	2.08%	0%	0%	0%	0%	0%
7 Training	8.33%	6.24%	8.33%	8.33%	6.24%	6.24%
7.1 Training content	2.08%	2.08%	2.08%	2.08%	2.08%	2.08%
7.2 Classroom organization	2.08%	2.08%	2.08%	2.08%	2.08%	2.08%
7.3 Documentation	2.08%	2.08%	2.08%	2.08%	2.08%	2.08%
7.4 Recycling of knowledge	2.08%	0%	2.08%	2.08%	0%	0%
8 Support	8.33%	8.33%	8.33%	8.33%	8.33%	8.33%
Yes	8.33%	8.33%	8.33%	8.33%	8.33%	8.33%
Not	0%	-	-	-	-	-
9 Workflow	8.33%	0%	8.33%	0%	8.33%	8.33%
Yes	8.33%	-	8.33%	-	8.33%	8.33%
Not	0%	0%	-	0%	-	-
10 Internal Standards	8.33%	8.33%	8.33%	6.24%	0%	4.16%
10.1 Libraries	2.08%	2.08%	2.08%	2.08%	0%	2.08%
10.2 Templates	2.08%	2.08%	2.08%	0%	0%	2.08%
10.3 Nomenclature	2.08%	2.08%	2.08%	2.08%	0%	0%
10.4 Structuring Folders	2.08%	2.08%	2.08%	2.08%	0%	0%
11 Implement a first BIM project	8.33%	8.33%	8.33%	0%	8.33%	8.33%
Yes	8.33%	8.33%	8.33%	-	8.33%	8.33%
Not	0%	-	-	0%	-	-
12 Check / Review the plan	8.33%	0%	8.33%	0%	0%	0%
Yes	8.33%	-	8.33%	-	-	-
Not	0%	0%	-	0%	0%	0%
Total score	100%	60.38%	89.54%	54.13%	64.84%	64.97%

The objective of the implementation plan was observed to be to increase the design, adding more information and facilitating the understanding of the design by the construction team. Some standards previously defined in the traditional model have been used in the internal standards definition. In addition, standards such as libraries, templates, and manuals have also been defined. In company E1, it is possible to verify that all requirements were handled in the implementation, configuring the process as adequate. Because the requirements provided evolution, the success of the implementation was justified. Company E1 presents design development and collaboration with other companies in BIM, such as architecture design companies. Although the communications between the design companies do not happen simultaneously, company E1 has the characteristics of a BIM implementation in stage 2.0.

4.2.3. Company E2

Company E2 fulfilled 54% of BIM requirements (Table 1). In company E2, there was an absence of metrics and goals definition. The company established an implementation plan but has not put it into practice. In addition, it presented training focused only on the BIM software. Company E2 partially maintains the internal standards development, as it is gradually developing its libraries with specific elements for the development of its designs. Since it has not implemented its first BIM experience, company E2 has also not monitored or controlled the implementation. By not developing designs in BIM, making use of the chosen software only to occasionally generate 3D visualizations, and without presenting automatic generation of quantitative, specification, or cost estimates, company E2 presents characteristics of the pre-BIM stage.

4.2.4. Company C1

Company C1 fulfilled 65% of BIM requirements (Table 1). Company C1 fulfilled the same percentage goals and metrics for BIM implementation as company E1. However, the metrics and goals considered by company C1 do not allow for BIM implementation evaluation in the company, so this percentage was not considered as a requirement in practice in the implementation. Although the implementation plan was defined, it was not put into practice due to a lack of design approval. According to the interviewee's reports up to the time of data collection, no other implementation attempts were made. As a result, the plan did not continue.

To ensure training continuity, recycling is necessary, but this item was not implemented at company C1, therefore training is a requirement that is no longer being implemented at the company. The workflow was not fully implemented, so implementation is considered partial for this item. The company did not define any internal standards for BIM implementation and, with regard to the first BIM experience, the company could not finalize the project that was begun, nor did it have the initiative to execute a new project to continue implementation. Implementation cannot therefore be monitored nor controlled. As the BIM designs contracted by company C1 were not approved, it was not possible to use the quantitative, specification, or cost estimates that were generated automatically from the BIM designs. These activities had to be carried out again after contracting the designs in 2D software, so the BIM designs were used only for 3D visualizations, characterizing company C1 as being in the pre-BIM stage.

4.2.5. Company C2

Company C2 fulfilled 65% of BIM requirements (Table 1). Company C2 has not defined metrics or goals for BIM implementation. The team defined did not remain for the implementation. Today, company C2 only has one technician and two trainees as members of the BIM team. The implementation does not reflect retraining, which ensures the maintenance of team training, including the team engineer responsible for support, who is not part of the team and has not been replaced. Initially, the internal standards were not fully defined and at the moment, no process to define these standards is performed at the company. Company C2 also does not check and re-plan the model. BIM project development at company C2 is done by a technician, who does the modeling in BIM software for designs received in 2D. Since these designs are used only for 3D construction visualization, company C2 can be characterized as being in the pre-BIM stage.

4.3. *BIM requirements implementation discussion*

Given the information presented and by means of a qualitative analysis of the results, it was possible to understand that not only the implementation, but the longevity of the implemented requirements, is important for BIM development. Table 2 presents information about the requirements implemented at the beginning and, according to the interviewee's reports, the requirements that continue to be practiced at the companies (Table 2).

Table 2. Requirements that are still under development in companies.

Requirement	Company results									
	A1		E1		E2		C1		C2	
Metrics	0%	● red	7.14%	● green	0%	● red	1.19%	● orange	0%	● red
Goals	0%	● red	1.19%	● green	0%	● red	1.19%	● orange	0%	● red
Implementation plan	8.33%	● yellow	8.33%	● green	8.33%	● orange	8.33%	● orange	6.68%	● green
BIM projects uses	8.33%	● green	8.33%	● green	8.33%	● green	8.33%	● green	8.33%	● green
Team Definition	8.33%	● orange	8.33%	● green	8.33%	● green	8.33%	● green	8.33%	● orange
Restructuring	4.16%	● green	6.24%	● green	6.24%	● green	6.24%	● green	6.24%	● green
Training	6.24%	● orange	8.33%	● green	8.33%	● green	6.24%	● orange	6.24%	● orange
Support	8.33%	● green	8.33%	● green	8.33%	● green	8.33%	● green	8.33%	● orange
Workflow	0%	● red	8.33%	● green	0%	● red	8.33%	● yellow	8.33%	● green
Internal Standards	8.33%	● green	8.33%	● green	6.24%	● orange	0%	● red	4.16%	● orange
Implement a first BIM project	8.33%	● yellow	8.33%	● green	0%	● red	8.33%	● orange	8.33%	● green
Check / Review the plan	0%	● red	8.33%	● green	0%	● red	0%	● red	0%	● red
Total score	60%		90%		54%		64%		65%	

Legend

● red	Requirement not met	● orange	Requirement not continued	● yellow	Requirement partially continued	● green	Requirement continued

Company E1 meets all requirements, even though the fulfilment percentage is not 100%, while the other companies all present some unmet requirements. In addition to implementing all requirements, BIM application at company E1 is perennial, because it has maintained all implemented requirements since the beginning of the implementation, unlike the other companies that, in addition to not implementing all requirements, did not maintain all of those that were implemented BIM.

5. Conclusions

The present study evaluated BIM implementation in AEC companies operating in Recife/PE, Brazil, through the analysis of requirements for implementation in order to establish a possible relationship between meeting requirements and stages of BIM.

The results from the online forms showed that adherence to BIM is scarce in the city of Recife, because, among the four sectorial entities presented, which represent a total of 445 companies and professionals, only 19 affirmed that they are using BIM, less than 5% of the sample searched.

Regarding the results obtained by the questionnaire, it was possible to note a relationship between the requirements met by the companies and the evolution of BIM, as company E1, which obtained the highest requirement fulfillment percentage, 90%, is implementing the methodology in policies, processes, and technologies, in addition to presenting BIM stage 2.0 characteristics. The results show not only that meeting requirements positively influence the implementation of BIM, but also that, when requirements are not met, implementation faces difficulties, as the other four companies that obtained requirement fulfillment percentages below 65%, are not adequately evolving to implement BIM, presenting characteristics of BIM stage 1.0 at company A1, and of the pre-BIM stage at the other companies.

It is also noted that, for the BIM implementation to evolve, in addition to meeting the requirements, it is also necessary to maintain them at the companies. While companies A1, E2, C1, and C2 have met some requirements, when compared to company E1, they show no consistency in meeting them. It can also be observed that each company presented totally different ways of approaching BIM implementation. It is worth noting that, although the quantitative analyses corroborate with the qualitative analyses, the latter are more effective in understanding the evolution of the BIM implementation process at companies.

Given the results presented, it is understood that the hypotheses established for this research were elucidated through the case studies developed and that they are not too obvious to be tautology. This is because companies with higher levels of requirements fulfilled were more successful in implementing BIM and BIM implementation also boosted the fulfillment of requirements, as they are guiding instruments in planning and implementing the use of BIM.

This expectation of this paper is to contribute to the understanding of BIM implementation at companies, enabling more assertive implementation. Additional study contributions were the requirement identification and compilation for BIM implementation, based on the BIM Guides established in Brazil and throughout the world, and the identification of difficulties in implementing requirements, through the development of case studies. This research therefore produces knowledge that allows companies in the AEC industry that experiencing the same difficulties described in this paper to successfully implement BIM. On the other hand, the limitations of the study are recognized, since the results are mostly specific and qualitative, where the companies studied present different particularities. Subsequent studies may consider a larger sample size, not only companies from the Recife Metropolitan Region, but also from other cities in order to generalize the findings. However, as it was presented, the contribution is based on providing guidelines for future BIM implementations, especially in the region, where companies have similar characteristics and BIM adoption is constantly growing.

As for proposing suggestions to overcome the barriers identified, it is understood that the actions of sectorial entities, such as CBIC and AsBEA, through course development and provision of guides for BIM implementation, along with actions by the Federal Government of Brazil, through the development of legislation to stimulated BIM implementation, has widely promoted BIM use and helped companies to overcome the current barriers to implementation. Continuous software cost reductions have also contributed to facilitating the implementation of BIM at Brazilian companies.

The compilation and practical application description of the essential requirements for a successful BIM implementation are suggestions for future study. In addition, it is suggested to increase the number of BIM guides to be investigated in order to expand the number of BIM requirements.

Author contributions: A.K.A.S. Wanderley: Conceptualization, methodology, data collection, results' analysis, document writing, review and supervision, and enhancement of manuscript. A.C. Lordsleem Júnior: Conceptualization, methodology, document writing, review, supervision, and enhancement of manuscript. J.H.A. Rocha: Methodology, document writing, review, and results' analysis.

Funding: Not applicable.

Acknowledgments: To CAPES (Coordenação de Aperfeiçoamento de Pessoal de Nível Superior) for the financial support.

Conflicts of interest: The authors declare no conflict of interest.

References

Adeniyi, O., Thurairajah, N., & Leo-Olagbaye, F. (2022). Rethinking digital construction: A study of BIM uptake capability in BIM infant construction industries. Construction Innovation, (ahead-of-print).

Ahankoob, A., Manley, K., Hon, C., & Drogemuller, R. (2018). The impact of building information modelling (BIM) maturity and experience on contractor absorptive capacity. Architectural Engineering and Design Management, 14(5), 363–380.

American Institute of Architects (2020). Firm Survey Report 2020. AIA, Washington. Available at: https://content.aia.org/sites/default/files/2020-11/2020_Firm_Survey_Report.pdf

Andersen, M. T., & Findsen, A. L. (2018). Exploring the benefits of structured information with the use of virtual design and construction principles in a BIM life-cycle approach. Architectural Engineering and Design Management, 1–18.

Andrade, M. L. V. (2012). Performative Design in the Recent Architectural Practice Conceptual Framework. College of Civil Engineering, Architecture and Urbanism of the State University of Campinas, Campinas.

Autodesk (2014). BIM pilot, getting started for construction professionals. Available at: http://staticdc.autodesk.net/content/dam/autodesk/www/campaigns/test-drive-bim-q3/bds/getting-startedguide-v3.pdf

Brazil (2018). Decree No 9377, May 17, 2018. National Strategy for Dissemination of Building Information Modeling. Official Journal of the Union, Brasília.

Carmo, C. S. T.; Almeida, G. Z., & Souza, L. L. (2019). Gestão de projetos da construção civil com a metodologia BIM aplicada: Estudo de caso [Project management in civil construction applying the BIM methodology: case study]. Brazilian Journal of Production Engineering, 5(2), 107-119 (in Portuguese).

CBIC - Brazilian Chamber of Construction Industry. (2016, September 15). Collection of BIM Implementation for Builders and Developers. Available at: http://cbic.org.br/bim/.

Ding, Z., Zuo, J., Wu, J., & Wang, J. Y. (2015). Key factors for the BIM adoption by architects: A China study. Engineering, Construction and Architectural Management, 22(6), 732–748.

Eastman, C., Teicholz, P., Sacks, R., & Liston, K. (2010). BIM Handbook: a guide to Building Information Modeling for owners, managers, designers, engineers and contractors. New Jersey.

Fitz, D. V., & Saleeb, N. (2019). Examining the quality and management of non-geometric building information modelling data at project handover. Architectural Engineering and Design Management, 1–14.

Gil, A. C. (2010). Como elaborar projetos de pesquisa [How to design research projects]. São Paulo: Atlas (in Portuguese).

He, Q., Qian, L., Duan, Y., & Li, Y. (2012). Current situation and barriers of BIM implementation. Journal of Management in Engineering, 26(1), 12–16.

Hosseini, M. R., Maghrebi, M., Akbarnezhad, A., Martek, I., & Arashpour, M. (2018). Analysis of Citation Networks in Building Information Modeling Research. Journal of Construction Engineering and Management, 144(8).

Huber, R. (2012). New Zealand national BIM survey 2012. Masterspec-Construction Information Ltd.

Jin, R., Hancock, C. M., Tang, L., & Wanatowski, D. (2017). BIM Investment, Returns, and Risks in China's AEC Industries. Journal of Construction Engineering and Management, 143(12).

Juszczyk, M., Výskala, M., & Zima, K. (2015). Prospects for the use of BIM in Poland and the Czech Republic – Preliminary research results. Procedia Engineering, 123, 250 – 259.

Kassem, M., Amorim, S. (2015). BIM Building Information Modeling no Brasil e na União Europeia. Brasília. (in Portuguese).

Kiviniemi, A. (2015). Experiences from the BIM-Adoption in Finland and UK – Clients as the drivers of innovation. Liverpool: School of Architecture at University of Liverpool.

Kiviniemi, A., Tarandi, V., Karlshøj, J., Bell, H., & Karud, O. J. (2008). Review of the development and implementation of IFC compatible BIM: final report of the Erabuild Project. Erabuild.

Le, N. O., Er, M., & Sankaran, S. (2018). The implementation of Building Information Modelling (BIM) in construction industry: Case studies in Vietnam. International Journal of Engineering and Technology, 10(4).

Liu, Y., Nederveen, S. V., & Hertogh, M. (2017). Understanding effects of BIM on collaborative design and construction: An empirical study in China. International Journal of Project Management, 35(4), 686–698.

Louzas, R. (2013). Research shows that over 90% of architects and engineers intend to use BIM in up to five years. Available at: http://piniweb.pini.com.br/construcao/carreira-exercicioprofissionalentidades/artigo291885-1.aspx

Loyola, M., & López, F. (2018). An evaluation of the macro-scale adoption of Building Information Modeling in Chile: 2013-2016. Revista de la Construccion, 17(1), 158-171.

McGraw-Hill Construction. (2010). The business value of BIM in Europe: Getting building information modelling to the bottom line the United Kingdom, France and Germany (Smart Market Report). New York: McGraw-Hill.

McGraw-Hill Construction. (2012). The business value of BIM in north America: multi-year trend analysis and user ratings (2007-12) (Smart Market Report). Bedford: McGraw Hill.

McGraw-Hill Construction. (2014). The Business Value of BIM for Construction in Major Global Markets: How Contractors Around the World Are Driving Innovation With Building Information Modeling (Smart Market Report). Bedford: McGraw Hill.

Menezes, G. L. B. B. (2011). Breve histórico de implementação da plataforma BIM [A briefhistory of the implementation of the BIM platform]. Cadernos de Arquitetura e Urbanismo, 18(22), 152-171. (in Portuguese).

NATSPEC - National Building Specification. (2014). NATSPEC BIM Paper NBP 002: Getting Started with BIM. Available at: http://bim.natspec.org/images/NATSPECDocuments/NATSPECBIMPaperGettingstartedwith_BIM140529.pdf.

Nguyen, K. T. L. (2017). Adoption building information modelling (BIM) in general contractor. Asian Institute of Technology, Thailand.

Okakpu, A., GhaffarianHoseini, A., Tookey, J., Haar, J., & Ghaffarianhoseini, A. (2019). Exploring the environmental influence on BIM adoption for refurbishment project using structural equation modelling. Architectural Engineering and Design Management, 1–17.

Raouf, A. M. I., & Al-Ghamdi, S. G. (2018). Building information modelling and green buildings: challenges and opportunities. Architectural Engineering and Design Management, 1–28.

RICS School of Build Environment (2014). State of BIM Adoption and Outlook in India. Noida: Amity University.

Rodgers, C, Hosseini, M. R., Chileshe, N., & Rameezdeen, R. (2016). Building information modelling (BIM) within the Australian construction related small and medium sized enterprises: Awareness, Practices and Drivers. Construction Law Journal, 32(3), 257–268.

Rodrigues, R. M. (2007). Pesquisa Acadêmica: Como facilitar o processo de preparação de suas etapas [Academic Research: How to facilitate the process of preparing your steps], São Paulo: Atlas. (in Portuguese).

SMHURC - State Ministry of Housing and Urban-Rural Construction. (2011). The 2011–2015 development guideline for the construction industry digitalization. Beijing.

SMHURC - State Ministry of Housing and Urban-Rural Construction. (2013). Request for proposal on BIM application in the construction industry. Beijing.

Smith, P. (2014). BIM implementation - Global strategies. Procedia Engineering, 85, 482–492.

Succar, B. (2009). Building information modeling framework: a research and delivery foundation for industry stakeholders. Automation in Construction, 18(3), 357-375.

Succar, B., & Kassem, M. (2015). Macro-BIM adoption: Conceptual structures, Automation in Construction, 57, 64-79.

Tobin, J. (2008). Proto-building: to BIM is to build. AECbytes. Available at: http://www.aecbytes.com/buildingthefuture/2008/ProtoBuilding.html.

USACE - United States Army Corps of Engineers. (2006). Building Information Modeling (BIM): A Road Map for Implementation to Support MILCON Transformation and Civil Works Projects within the U.S. Washington.

USACE - United States Army Corps of Engineers. (2011). Building information modeling (BIM) roadmap: supplement 2 - BIM implementation plan for military construction projects. Bentley Platform. Washington.

Wanderley, A. K. A. S. (2017). Premisses for Building Information Modeling implantation in design and construction companies: case studies. Polytechnic School of Pernambuco University, Recife.

Wong, A. K., Wong, F. K., & Nadeem, A. (2011). Government roles in implementing building information modelling systems: Comparison between Hong Kong and the United States. Construction innovation, 11(1), 61-76.