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THE CRITICAL SUCCESS FACTORS FOR THE IMPLEMENTATION OF BUILDING INFORMATION MODELLING METHODOLOGY ON SMALL AND MEDIUM-SIZED PRIVATE COMPANIES IN BRAZIL

OS FATORES CRÍTICOS DE SUCESSO PARA A IMPLEMENTAÇÃO DA METODOLOGIA DE MODELAGEM DE INFORMAÇÕES PREDIAL EM PEQUENAS E MÉDIAS EMPRESAS PRIVADAS NO BRASIL

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ABSTRACT

The Building Information Modelling methodology (BIM) represents the most advanced method for an integrated design, planning, construction, optimization, and maintenance of construction projects. Although recognized as a promising, useful, and effective methodology, its implementation in Brazil has been slow and limited. Many difficulties and obstacles need to be overcome by companies implementing it. These challenges are especially difficult for small and medium-sized enterprises (SME's), as they have limited budget and resources. This work aims to identify, evaluate and correlate the main difficulties encountered by companies that plan to implement the BIM methodology, as well as the critical success factors (CSF's) that will lead to a successful BIM implementation. A literature review was performed to identify these difficulties and CSF's in four areas: (1) implementation; (2) design phase; (2) construction phase; (3) facilities management. As a result, 13 difficulties and 13 CFS's were identified and assessed by 15 professionals of the Architecture, Engineering, Construction and Operations (AECO) industry. The 6 most significant difficulties identified by both authors and professionals are a) implementation costs; b) team's lack of technical qualification and experience; c) lack of standardization in project data and documents; d) resistance and reluctance to change; e) lack of time; and f) writing and adapting new contracts to the BIM requirements. The 6 most significant critical success factors are a) redesigning and adapting internal processes; b) improving designer's knowledge on construction and management; c) evaluating initial investment and costs; d) promoting an organizational and cultural change; e) providing training and qualification for all team members; and f) developing an effective implementation planning. These are elements that cannot be neglected by companies that seek to properly implement BIM.

KEYWORDS: Building Information Modeling. Construction Management. Project Management

RESUMO

A metodologia de Modelagem de Informações prediais (BIM) representa o método mais avançado para um projeto integrado, planejamento, construção, otimização e manutenção de projetos de construção. Embora reconhecida como uma metodologia promissora, útil e eficaz, sua implementação no Brasil tem sido lenta e limitada. Muitas dificuldades e obstáculos precisam ser superados pelas empresas que a implementam. Esses desafios são especialmente difíceis para as pequenas e médias empresas (PME's), pois têm orçamento e recursos limitados. Este trabalho tem como objetivo identificar, avaliar e correlacionar as principais dificuldades encontradas pelas empresas que pretendem implementar a metodologia BIM, bem como os fatores críticos de sucesso (CSF's) que levarão a uma implementação bem-sucedida do BIM. Foi realizada uma revisão biblio literatura para identificar essas dificuldades e as CSF's em quatro áreas: (1) implementação; (2) fase de projeto; (2) fase de construção; (3) gestão de instalações. Como resultado, 13 dificuldades e 13 CFS foram identificadas e avaliadas por 15

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profissionais da indústria de Arquitetura, Engenharia, Construção e Operações (AECO). As 6 dificuldades mais significativas identificadas por autores e profissionais são: a) custos de implementação; b) falta de qualificação técnica e experiência da equipe; c) falta de padronização nos dados e documentos do projeto; d) resistência e relutância em mudar; e) falta de tempo; e f) redação e adaptação de novos contratos às exigências do BIM. Os 6 fatores de sucesso crítico mais significativos são: a) redesenhar e adaptar processos internos; b) melhorar o conhecimento do designer sobre construção e gestão; c) avaliação do investimento inicial e dos custos; d) promover uma mudança organizacional e cultural; e) fornecer treinamento e qualificação para todos os membros da equipe; e f) desenvolver um planejamento de implementação eficaz. São elementos que não podem ser negligenciados por empresas que buscam implementar adequadamente o BIM.

PALAVRAS-CHAVE: Modelagem de informações de construção. Gestão da Construção Civil. Gerência de projetos

1. INTRODUCTION

During the last decades important changes occurred in society. New technologies, processes, and materials have been developed. The Internet promoted a revolution in the way people interact and communicate. Further developments can be envisioned as the “4th Industrial Revolution” becomes more present including the Internet of Things (IoT), artificial intelligence (AI), big data, business intelligence (BI), and virtual reality (VR). Even the way people behave and relate to each other has changed.

Several industries have achieved important gains in productivity by implementing innovative and disruptive solutions. (CHRISTENSEN; RAYNOR; MCDONALD, 2015). However, construction industry has implemented innovations at a slower pace than others. (GREE, 2016; ARMSTRONG; GILGE, 2016).

The traditional paper-based bidimensional design method was used for many decades, where different designers worked independently and information exchange was slowly transferred among them, based on the physical transfer of plans and construction documents published on paper.

Then a significant improvement was achieved with the development of computers. The Computer-Aided Design (CAD) methodology eventually replaced the plans originally drawn in paper by plans designed in computer software. Faster and more precise, these plans were easily modified and eventually printed. The Internet also contributed to another improvement with designers exchanging electronic drawings by email and other file transfer methods. A faster collaborative approach was in its initial stages. (EASTMAN, et al., 2008).

Following the CAD-based era, the construction industry promoted the most significant improvement in recent years: Building Information Modelling (BIM). It is an evolution from previous traditional methods of design and construction management, and it is recognized as the key to enhance construction productivity, performance, and project management.

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Building Information Modelling

According to the Câmara Brasileira da Indústria da Construção (CBIC), BIM is a set of policies, processes and technologies that, combined, generate a methodology to manage the process of designing a building, testing performance, managing its information and data, using digital platforms (based on virtual objects), throughout its lifecycle. It is a progressive process that enables modeling, storage, exchange, consolidation, and easy access to the various groups of information about a building or installation to be build, used, and maintained. (CBIC, 2016).

BIM is the most up-to-date methodology to promote integrated and collaborative construction project management, from design to facilities management, including all project phases such as design, optimization, compatibilization, procurement, construction, turn-over, and operations. Drawings are now not only computer-based, but tridimensional models including parametric information such as materials and their physical characteristics, cost, time, and other parameters that will eventually be extracted and used in planning, budgeting/cost estimate, scheduling, and management activities.

Besides, the collaborative approach is maximized as a single repository of data is used to provide designers with simultaneous and real-time access to construction documents, drawings, and plans. In its most advanced stage, if properly implemented and fully functional, BIM represents a set of virtually integrated design, construction and operation (viDCO) tools and concepts. (SUCCAR, SHER; WILLIAMS, 2012).

1.1 OBJECTIVE

This research aims to identify, evaluate, and correlate the difficulties and the critical success factors (CSF's) for the proper implementation of the BIM methodology in private small and medium-sized enterprises (SME's) in Brazil.

To properly meet the overall aim of this research, the following specific objectives were defined:

1. Identify difficulties and critical success factors indicated by authors in previous academic research;
2. Evaluate Brazilian companies that implemented BIM methodology, assessing the difficulties and critical success factors previously identified;
3. Develop a consolidated, prioritized, and correlated list of difficulties and critical success factors based on the literature review and the assessment by professionals.

1.2 METHODOLOGY

This research is classified as qualitative research, which is commonly used to evaluate subjective data in nature. Qualitative research is focused on aspects of reality that cannot be quantified, focusing on understanding and explaining the dynamics of social relationships. Researchers using qualitative methods seek to explain why things are, but they neither quantify values nor subject them to fact-proof because the analyzed data are non-metric. (GERHARDT; SILVEIRA, 2009).

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The collected information is classified as exploratory research, where the subject is better understood, alternatives are formulated, and new ideas are found. This type of research aims at providing greater familiarity with the problem, making it more explicit or helping to build hypotheses. (NAOUM, 2009; GERHARDT; SILVEIRA, 2009).

To fulfill the proposed objectives indicated in section 1, two research efforts were performed:

1. Literature review;

2. Data collection through semi-structured interviews and questionnaires.

The literature review was performed to identify and list the difficulties and critical success factors indicated by authors in their recent studies. This initial research resulted on non-prioritized lists of difficulties and critical success factors.

The research phase included semi-structured interviews and questionnaires with selected companies that implemented, or are currently implementing, the BIM methodology. During this phase a qualitative evaluation of the non-prioritized list of difficulties and critical success factors was performed. Interviewed professionals were also asked to share their impressions about the difficulties and the overall complexity of the implementation process.

Finally, findings from the literature review and the research were consolidated, correlated and prioritized.

2. LITERATURE REVIEW

Any implementation has at different levels, challenges and difficulties. Several authors have listed difficulties that prevent BIM from being implemented. Based on the selected sample, the following difficulties were identified:

2.1 Difficulties

Team's lack of technical qualification and experience

BIM methodology requires new methodologies and new tools to be learnt. Due to the limited diffusion of the methodology, the lack of technical skills and experience of the workforce was pointed out by Checcucci (2013), Eadie (2013), and Cornetet (2015) as a significant difficulty. Training and professional qualifications, which require time and resources, are required and impact the cost incurred by companies. (BRANDÃO, 2016; GU, 2010; SANTOS, 2016; SANTOS, 2017). Due to the complexity of the tools and the limited amount of available training material, learning BIM is difficult and takes a significant amount of time and energy. (CHECCUCCI, 2013; MOZZATO, 2013; SANTOS, 2016).

Resistance and reluctance to change

Several authors researched teams that participated in the implementation of BIM, including some that gave up the process. Authors indicated that the teams faced difficulties in adapting to the new methodologies, which are sometimes opposed to the current operational pattern. (SANTOS, 2016). Members of the surveyed teams demonstrated fear of change and insecurity. (GU, 2010; CHECCUCCI,

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2013; MOZZATO, 2013; BRANDÃO, 2016; SANTOS, 2017; ALMEIDA, 2018). In some cases, there has been even some disinterest, since the dissemination of the methodology is limited. (ALMEIDA, 2018).

Implementation costs

BIM methodology requires the installation of new systems and computers. In the early stages it is necessary to purchase the software and, in some cases, invest in computers that have the necessary processing capacity. In an advanced stage, BIM requires data hosting in a cloud repository, allowing shared and simultaneous accesses. Good practices in Information and Communication Technologies (ICT) require safety measures to be implemented, including redundancy, and high availability. All this technological apparatus has costs and requires important investments. (SOUZA, 2009; EADIE, 2013; BRANDÃO, 2016; CORNETET, 2015; SANTOS, 2016; SANTOS, 2017; ALMEIDA, 2018).

In addition to the cost of equipment, there are other associated costs such as training, consulting services, and process adaptation. (CHECCUCCI, 2013; MOZZATO, 2013; BARISON, 2015; SILVA; CRIPPA; SCHEER, 2019).

Lack of communication and collaboration between players (internal and external)

Authors (GU, 2010; CHECCUCCI, 2013; EADIE, 2013; MOZZATO, 2013; CORNETET, 2015; SANTOS, 2016) indicate that the lack of proper communication and collaboration is an issue that makes BIM implementation more difficult. There are two aspects on this problem: a) lack of internal collaboration, within a company, amongst team members; and b) lack of external collaboration amongst different companies and players. This is especially true because AECO industry is normally too fragmented and an organic integration is not easily obtained.

Methodology complexity

BIM is complex in nature and requires effort to be understood and applied. The challenge before those willing to implement it may represent a significant barrier to be overcame. For example, software used are rigid, not intuitive, and require specific training; updating the parametric model, and integrating it to the construction schedule, is challenging. (CORNETET, 2015; SANTOS, 2016; SANTOS, 2017; SILVA; CRIPPA; SCHEER, 2019).

Lack of interoperability

One of the major challenges of BIM implementation is compatibility and interoperability with the tools used. In the last stage BIM requires intercommunication and exchange of information between different systems and designers. However, this does not always occur, which causes frustration and even the withdrawal of the model. (SOUZA, 2009; CHECCUCCI, 2013; SANTOS, 2016; SILVA; CRIPPA; SCHEER, 2019).

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Other difficulties

Other difficulties identified by authors include: difficulty in writing and adapting new contracts to the BIM requirements (EADIE, 2013; SANTOS, 2016); lack of standardization in project data and documents (SILVA; CRIPPA; SCHEER, 2019); lack of time (SOUZA, 2009; CHECCUCCI, 2013; BRANDÃO, 2016; SANTOS, 2016; ALMEIDA, 2018); poor strategic and operational planning (SOUZA, 2015); difficulty in measuring the sales values of parametric modeling services (DIAS, 2015); and problems with the Electronic Document Management System (EDMS). (DIAS, 2015).

As demonstrated, authors listed several difficulties and challenges that affect BIM methodology implementation. To be able to overcome them and to implement BIM, companies must pay attention to the CSF's and take actions to ensure they are properly addressed.

The main 13 difficulties are listed as follows:

1. Team's lack of technical qualification and experience;
2. Resistance and reluctance to change;
3. Implementation costs;
4. Lack of communication and collaboration between internal players;
5. Lack of communication and collaboration between external players;
6. Methodology complexity;
7. Lack of interoperability;
8. Difficulty in writing and adapting new contracts to the BIM requirements;
9. Lack of standardization in project data and documents;
10. Lack of time;
11. Poor strategic and operational planning;
12. Difficulty in measuring the sales values of parametric modeling services;
13. Problems with the Electronic Document Management System (EDMS).

2.2 Critical Success Factors

The selected sample includes 30 papers dealing with the implementation of BIM methodology, all including potential CSF's for implementation. Several themes and ideas were identified. The main ideas related to an overall implementation are:

Cultural change

Several authors indicate that organizational and cultural changes are amongst the most significant challenges for the BIM implementation. For example, Souza (2015) says that companies are struggling when trying to implement BIM. Its implementation means change and change sometimes is difficult.

Companies that avoided implementing BIM are indicating that their main challenge is the lack of flexibility/adaptability of their employees, and team's resistance to change the work method. What is needed to implement BIM are a firm decision from top management, strong technical qualification, and

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a successful cultural transition. Also needed are promoting a cultural change and a focus on a collaborative team. It is a key element and should include all team members. (CHECCUCCI, 2013; MENDES JR., 2014; MOZZATO, 2013; CORNETET, 2015; SOUZA, 2015; BRANDÃO, 2016; FERRARI, 2016; LOPES, 2017; ALMEIDA, 2018; SANTOS, 2018; BRITO, 2019)

Coelho (2017) indicates that the BIM Manager may be considered as an essential player to facilitate the cultural change needed during the implementation.

Cost analysis

Decision makers must be prepared to properly evaluate the initial implementation cost. Solid strategic thinking is needed in order to evaluate BIM's cost benefit. Those implementing BIM must have a clear vision of the return on investment associated with its implementation. Initial investment is high, which may prevent small companies from implementing it. (COELHO, 2017; BRITO, 2018)

Workforce training and qualification

Workforce qualification is needed, and companies must constantly qualify teams on new technologies. BIM brings new tasks, tools, and methods that should be learned by the workforce. Barison (2015) warns that students haven't been qualified on BIM methodology, thus jeopardizing its implementation. Particularly, academic programs in Brazil don't adequately include BIM teaching. There is not a common method to teach BIM, thus companies invest in training and frequently focus on BIM software only, not on the BIM methodology. It is essential that academia adequately implement the teaching of BIM in a uniform way. This will enhance BIM implementation amongst companies as more qualified personnel is available on the market. For example, traditional project managers, well trained and qualified on classic methods, now need to receive adequate training on BIM methodology and its new methodology, processes and tools. The lack of understanding and training of BIM reflects on a lower satisfaction level with it. (MOZZATO, 2013; CORNETET, 2015; BARISON; 2015; COELHO, 2017; SANTOS, 2017; WANDERLEY, 2017; SANTOS, 2018).

Olegario (2019) says that the role of construction project managers is changing in order to accommodate BIM requirements. The traditional project managers' position is currently in a transition phase. Companies implementing BIM are converting the project manager to being a BIM Manager. This role transition requires new capabilities and training, so the BIM manager can eventually facilitate the cultural change as mentioned by Coelho (2017).

Process adaptation and improvements

Companies usually have well defined processes and face difficulties when trying to adapt them to the BIM methodology. New, reorganized, and improved internal processes are needed to potentialize BIM functionalities. The implementation should take place in small steps, thru pilot projects, with constant evaluation of the results achieved. Some changes on organizational models are needed, as well as in the way all players interact each other. (SOUZA, 2015; CORNETET, 2015; COELHO, 2017;

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WANDERLEY, 2017). Hartmann (2012), however, indicates that it is still possible to implement BIM on companies with well stablished working processes. The "technology pull" approach may be used, where well stablished working processes guide technology implementation.

Implementation planning

Planning the implementation of BIM was mentioned by Cornetet (2015) and Wanderley (2017). Authors indicate that some companies face difficulties to implement BIM due to lack of understanding and wrong expectation about BIM. A clear deployment plan, including team's roles and definition, workflow and approval processes, performance goals, adequate metrics, and a defined timeline are required for a successful implementation.

Contract terms and conditions

Santos (2017) explains that BIM may be implemented by two different methods: outsourcing or internalization. Both methods have pros and cons. Companies are different and face distinct challenges. The choice of the preferred method must be aligned with their conditions. When outsourcing is chosen, a procurement process is put in place which will eventually end-up on contracting a vendor. New processes and methodologies make it necessary to adjust classical contract terms and conditions between client-vendors. Current contracts are not adapted to BIM methodology; they must be adapted to properly allow the BIM implementation. (MANENTI, 2018).

Technology solutions

Construction developments have become increasingly complex and difficult to manage. The use of Information and Communication Technologies (ICT) in the construction industry is still considered low and the low productivity of the sector can also be attributed to this factor. It is in this scenario that a new paradigm of project development has been introduced through BIM. (DURANTE, 2016).

Although BIM implementation is not just replacing old methods of design by a new software, it does include the selection and implementation of new software and collaborative tools. This is an important decision due to the learning curve and costs associated. (MOZZATO, 2013; COELHO, 2017).

Construction companies are seeking to innovate and improve the quality, productivity and sustainability of their projects. At the same time, they are also seeking to reduce costs, lead-times, and rework. Cornetet (2015) adds that the sector is getting more competitive, thus requiring new technologies that allow AECO companies to develop plans and projects on a more collaborative, efficient and controlled way. ICT plays an important role in the process of increasing competitiveness amongst construction companies, by helping these objectives, sometimes divergent, to be met. (SILVA JR., 2013; MENDES JR., 2013; BAIA, 2015; DURANTE, 2016; LOPES, 2017; WANDERLEY, 2017). BIM represents a competitive advantage, an innovative and technological solution for construction companies to maintain their market position. (LIMA, 2019).

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In a recent dissertation, Brito (2019) indicates that the interoperability, which is the ability to exchange relevant data and information amongst different systems, is a CSF for the BIM implementation on the public sector. The same may be also considered for the private sector since collaborative work requires an adequate information flow.

Integrated and collaborative approach

A construction project includes several players and stakeholders, such as clients, designers, architects, engineers, surveyors, consultants, and public officials. The implementation of BIM promotes a better information flow and communication amongst these players. However, it requires an environment adequate for collaborative work, partnership, and cooperation. The segregation between these disciplines can represent a significant barrier to the diffusion of the practices related to BIM. (ADDOR, 2015; FERRARI, 2016; DURANTE, 2016; BRITO, 2019).

Santos (2016) investigated 4 architecture practices that implemented BIM in order to evaluate its progress. All companies are still in the pre-BIM stage, according to Succar (2008) classification, which is an initial implementation phase. The conclusion was that these companies still need to invest in the development of partnerships between players to be able to provide clients with a complete solution.

Shen (2010) states that the key for BIM implementation and dissemination is the collaborative work between academia, AECO players, and government**.**

Improve designer's knowledge on construction and management

Ferrari (2016) says that designers, mainly architects, lack knowledge about construction processes. Since BIM design process requires the anticipation of decisions related to construction, this barrier must be overcome for the full achievement of BIM benefits. Information and parameters set during the design phase must consider the construction method and sequence. (UCHOA, 2017). Similarly, Coelho (2017) indicates that design companies are leading the implementation of BIM in Brazil, however at the same time these companies are struggling as they try to implement it. Training in management skills are needed for design companies to succeed.

Apply adequate Level of Development (LOD)

Santos (2018) analyzed the use of BIM in the licensing process of new construction by the municipality. The conclusion is that BIM can be useful for this specific purpose, however, correct and adequate information must be included in the model so BIM can properly work. His conclusion is as obvious as it is critical to avoid the rubbish in, rubbish out (RIRO) effect.

Brazil has severe problems during the construction phase that are frequently related to poor plans and design issues. Plans, drawings and specifications must have an adequate LOD to allow the bidding process, price analyses, constructability assessment, and all other subsequent processes in order to succeed. BIM is a response for the planning and design problems. (LI WANG, 2012; BAIA, 2015; GUERRETA, 2017)

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Improved visual interpretation of final product

Brito (2015) explains that end-users, normally clients, have difficulties to understand and interpret planning documents due to the large number of information contained in them. The visualization of 4D models is neither easy, nor intuitive, and sometimes even not friendly. A color-based methodology is proposed to help user to better interpret 4D models.

Efficient interoperability for design

Dias (2015) studied the possibility of using industry-based solutions to improve construction industry. The conclusion is that advanced computational systems can bring contributions to the AECO sector, not only by technological diversity, but also by the possibilities of interoperability associated with the range of systems used by industry.

Plans developed on BIM include information from different sources and disciplines. It may become a complicated process. It is critical that additional tools be implemented to promote an efficient interoperability, to properly extract, analyze, manage and use data from plans developed in BIM. Different authors explored this gap and proposed solutions. Zhang (2010) and Kim (2013) proposed a framework to allow the proper use of these data and system to integrate different plans, drawings and specifications. Wu (2012) proposed a system to promote an integrated planning is presented, allowing for BIM to be used on construction jobsites. Benefits extrapolate the design phase and may improve the construction phase too.

Efficient interoperability for construction

Like the design phase, BIM, to be effective during the construction phase, needs efficient interoperability capabilities. The use of integrated tools for construction planning makes it possible to better integrate different players, in different places, working on distinct processes. Planners and project managers need automated tools to better integrate information from different sources, plans, drawings, and specifications, thus being able to: define better construction schedules (CHEN, 2013; LIU, 2015), reduce accidents (HU, 2012), better coordinate off-site production and on-site assembly (LIU, 2014), improve construction monitoring and control (SAINI, 2013; LUKE, 2014), enhance cost predictability, quality and timeliness (PITAKE, 2013; WANG, 2013), optimize construction processes (TSERNG, 2013; MENDES JR., 2014; SOUZA, 2017), better manage demolitions (YUN, 2017). Most of these authors also proposed frameworks and systems to support their conclusions, thus helping to propagate BIM methodology and facilitate its implementation.

In summary, the main 13 CSF's are listed as follows:

1. Promoting an organizational and cultural change: all players within a company must understand the benefits of BIM, the difficulties to implement it, and gain the correct vision of the future. Minds and hearts must be converted to a new methodology, so old processes and tools are left behind.

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2. Evaluating initial investment and costs: as in any implementation there are associated costs that should be well evaluated. Mid-sized companies have a limited budget, so an adequate cost x benefits analysis is critical.

3. Providing training and qualification for all team members: implementing BIM means new processes, new tools, and new roles. All players, besides being converted to it, must learn how to properly function within this new methodology.

4. Redesigning and adapting internal processes: BIM methodology may impose changes in the way a company operates. It may be necessary to adjust and adapt current processes to a new model.

5. Developing an effective implementation planning: a plan with goals, metrics, clear definition of roles, milestones, and performance targets is needed so management may track implementation and proceed with corrections during the process when needed.

6. Amending contract terms and conditions: new working relationships require current contract terms to be adjusted. This is needed to reduce litigation and other legal issues.

7. Identifying technology solutions: tools are an important part of the BIM methodology. A company must adequately evaluate which technological solutions make sense and meet their needs.

8. Promoting an integrated and collaborative environment: BIM methodology implies on collaborative work amongst different players, working remotely but jointly, accessing real-time (on an advanced stage of implementation) the same database of plans.

9. Improving designer's knowledge on construction and management: because BIM-based design may anticipate and solve construction/management problems during the design phase, it is important that designers improve their knowledge on construction techniques and management.

10. Applying an adequate level of development: the effective use of BIM is closely related to the level of details. After design, subsequent phases (construction and facilities management) will benefit if models are created with relevant and needed information.

11. Improving visual presentation of 4D models: 4D models may be complex and hard to be understood, especially for clients.

12. Ensuring efficient interoperability for design: it is necessary that systems used during the design phase are fully integrated, promoting the adequate and correct exchange of information amongst different designers.

13. Ensuring efficient interoperability for construction: similarly, systems used for construction must provide project managers with information that is useful on the day-to-day jobsite activities.

3. RESEARCH

The research was performed amongst private small and medium-sized enterprises in Brazil. A total of 20 professionals, from 16 companies, were invited to participate. In total, 3 professionals from 3 different companies were invited to participate in interviews, and 17 questionnaires were sent to professionals from 13 companies. All 3 interviews were held and 12 professionals from 9 companies

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responded the questionnaires. The final sample resulted in 15 respondents from 12 companies as indicated in Table 1.

Table 1 - Research sample

Research	Invited / Issued		Responded	
	Professionals	Companies	Professional	Companies
Interviews	3 (15%)	3 (16%)	3 (20%)	3 (25%)
Questionnaires	17 (85%)	13 (82%)	12 (80%)	9 (75%)
Total	20	16	15	12

Research was performed during the month of February 2020. Responses from the interviews and from returned questionnaires were collected and are summarized as follows:

Sample and respondents' analysis

The research sample included 15 AECO industry professionals. Out of these 15 professionals, 86% (N=13) are engineers and architects. They occupy different organizational positions amongst the 12 companies they work for. Results show that 60% (N=9) occupy operational positions such as buyers, project managers, and designers, while 40% (N=6) occupy executive levels including director or company owner.

Their professional experience is extensive and significant. Amongst the respondents, 60% (N=9) of them have more than 10 years of experience. However, when the specific experience with the BIM methodology is considered, the result is the opposite. Only 1 respondent (7%) has more than 10 years of BIM-specific experience. The remaining 93% (N=14) have less than 10 years, and 10 respondents (66%) have less than 5 years of BIM-specific experience.

The sample stratification shows that project managers have more BIM-related experience than other groups (average of 4.7 years which represents 52% of their overall experience), followed by designer (4.4 years; 33%), directors/owners (3.3 years; 16%), and buyers (1 year; 13%).

Table 2 indicates that respondents have, on average, 14.93 years of overall professional experience and only 3.80 years of experience with BIM. It means that only 25% of their professional experience has included the BIM methodology.

Table 2 - Statistical analysis of respondents' professional experience

Statistical analysis	Overall Professional Experience	BIM specific Experience
Average	14.93	3.80
Sample Standard Deviation	11.30	2.31
Sample Variance	127.78	5.31

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Based on these analyses, it is possible to conclude that the research sample includes professionals with varied professional experience, from a few years to some decades of service. Respondents are also heterogeneous in their professional positions, with respondents working in operational up to executive levels. It adds both maturity and experience as well as a contemporaneity for the research. Different generations, exposed to diverse professional experiences and technologies, can provide enriched insights and meaningful responses.

However, the sample is significantly more homogeneous when BIM specific experience is considered. Regardless of their overall experience, all respondents have only recently interacted with BIM in their careers.

It indicates that the BIM methodology is relatively new for the respondents and, consequently, it is possible to assert that it is also new for the Brazilian AECO industry. This is consistent with the conclusions from the literature review where several authors indicated that BIM is still in early stages in Brazil.

The 12 companies where respondents work are all classified as small and medium-sized enterprises (SME's). Their sizes vary from 10 to 90 employees, with services being provided from 3 to 49 years. Table 3 indicates that these companies concentrate their activities on 5 major areas. "Design – Architecture" and "Design – MEP" (Mechanical, electrical and plumbing engineering) represent most of the sample (59%; N=7). "Construction" represents 25% of the sample (N=3) with "Consulting and training" and "Design – Structure" representing together 16% of the sample (N=2).

Table 3 - Quantity of companies by core business.

Core Business	Quantity	%
Design - Architecture	4	34%
Design - MEP	3	25%
Construction	3	25%
Consulting and training	1	8%
Design - Structure	1	8%

Although BIM methodology is applied in all 12 companies, respondents indicated that in 3 companies it is still under implementation. Research shows that companies where BIM is already implemented have an average of 22.56 years of services and an average of only 4.89 years applying the BIM methodology (which represents 22% of their time of service). For the companies where BIM is still under implementation the average of year of service is 29.67 and they have an average of only 3.00 years applying BIM (which represents 10% of their time of service).

Combined, all companies have on average 24.33 years of service, but are applying the BIM methodology for only 4.42 years (which represents 18% of their time of service) as shown on Table 4.

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Table 4 - Statistical analysis of companies' years of service.

Statistical analysis	Average years of service	Average BIM specific years of service
Average	24.33	4.42
Sample Standard Deviation	14.38	2.50
Sample Variance	206.79	6.27

Like the respondents, the standard deviation and variance of the years of service of the researched companies, as well as their use of BIM, indicate that companies are more homogeneous in the years of BIM utilization when compared to their overall years of service. The analysis also demonstrates that companies have only recently been applying BIM on their activities.

Figure 1 shows, for each company (identified by their core business), that the BIM specific years of service remains relatively constant even when the overall years of service reaches higher levels.

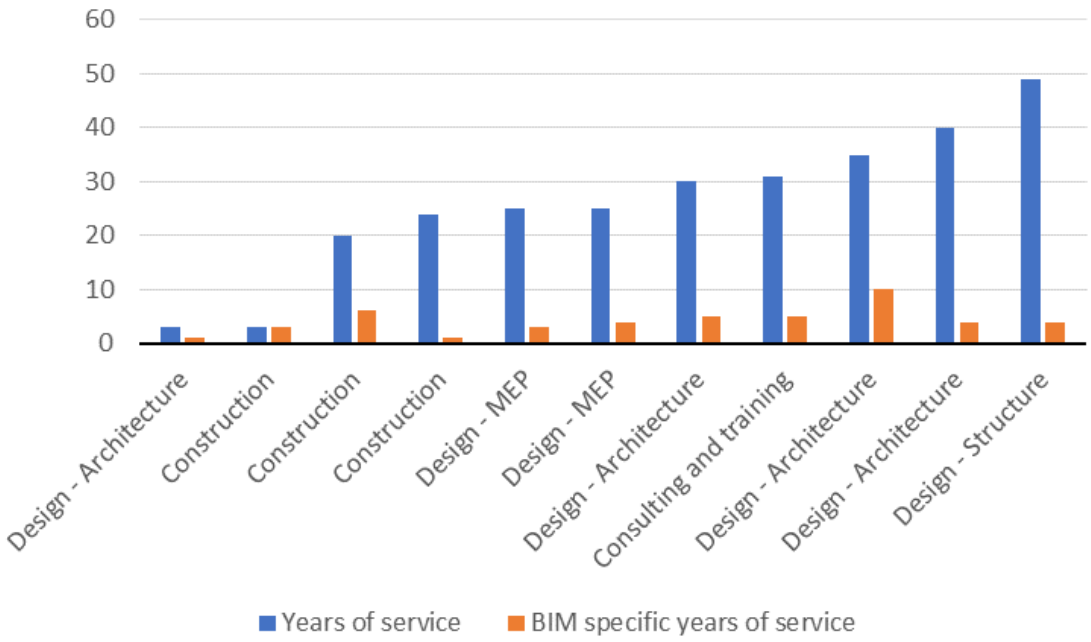


Figure 1 - Companies' overall and BIM specific years of service.

Based on these analyses, it is possible to conclude that the researched companies operate on several sectors within the AECO industry, including design, construction, consulting and training, with some companies rendering services for many years (+40 years; N=2), while some have been just recently established (3 years; N=2). This mix of older companies with start-ups adds value to the research since different perspectives can be captured in the responses.

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As noted on the analysis of the respondents' profile, companies are also significantly more homogeneous when BIM specific years of service are considered. Regardless of their overall years of service, all companies have only recently implemented BIM in their activities.

It corroborates that the BIM methodology is relatively new for the Brazilian AECO industry, which is consistent with the conclusions from the literature review

Research indicates a predominant use of BIM on design and planning activities (92%) amongst researched companies. It matches with the literature review as authors (DELATORRE, 2014; ADDOR, 2015) also indicated a major concentration of the BIM utilization on these same phases, then followed by construction management and facilities management.

Facilities management received no positive response from any respondent, thus representing 0% of the utilization amongst researched companies. It also matches with the literature review as authors indicated a limited use of BIM on this specialty.

Respondents indicated the BIM systems they use for the several specialties. 14 systems were mentioned by respondents. A total of 53 mentions were given by the respondents when asked to indicate, by specialty, the BIM system used. The most mentioned systems were Autodesk – Revit that alone represented 42% (N=22) of the responses, followed by Graphisoft – ArchiCAD (13%; N=7), then Multiplus – Arquimedes (8%; N=4). These 3 systems (Autodesk – Revit, Graphisoft – ArchiCAD, and Multiplus – Arquimedes) represent combined 62% of the responses amongst the 14 systems indicated. Other 11 systems represented together 32% of the responses. The Figure 2 shows the treemap of the BIM systems indicated by respondents.

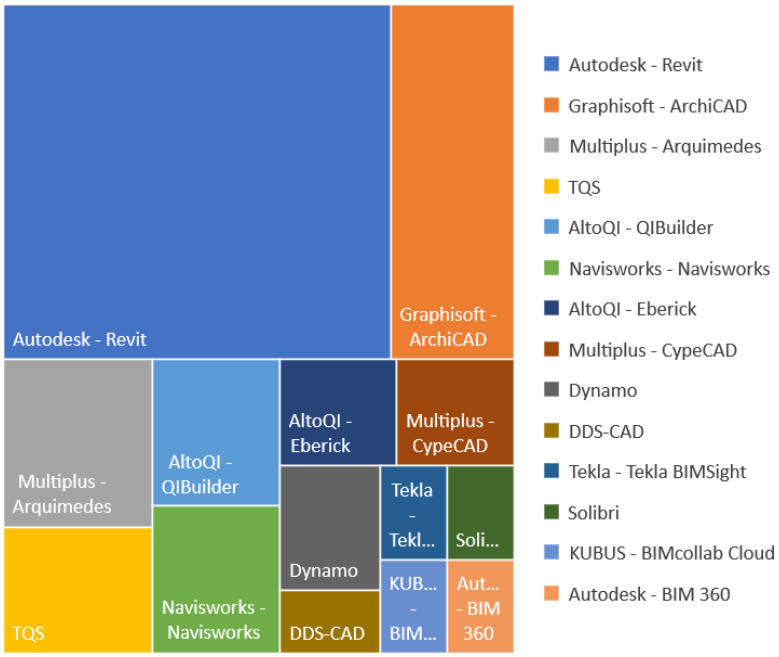


Figure 2 - Most common BIM systems utilized.

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The analysis of the results indicated that all 15 respondents (from the 12 companies) indicated that systems used are integrated and connected to each other; 11 respondents (from 9 companies) responded affirmatively that designers remotely and simultaneously access the same database; and 12 respondents (from 10 companies) indicated that plans are edited and maintained in a single data repository.

The Figure 3 shows the number of positive answers from respondents (and consequently from companies) by the main characteristic of each implementation stage.

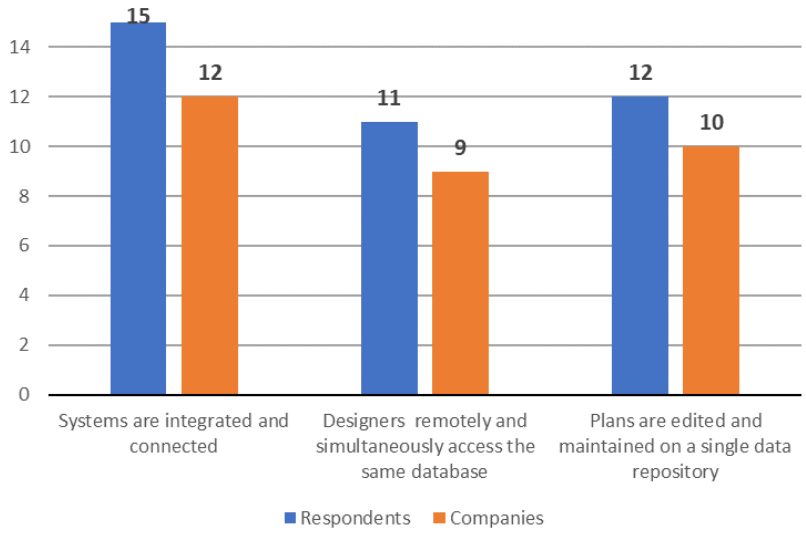


Figure 3 - Number of respondents and companies by implementation characteristics.

Although all researched companies are currently using BIM on their activities, they are at different stages of its implementation. Data shows that respondents indicated no company either in “Pre-BIM stage” or in “Post-BIM stage”. Respondents also indicated that companies are currently in BIM Stage 1 (25%; N=3), in BIM Stage 2 (33%; N=4), and in BIM Stage 3 (42%; N=5) as shown in Figure 4.

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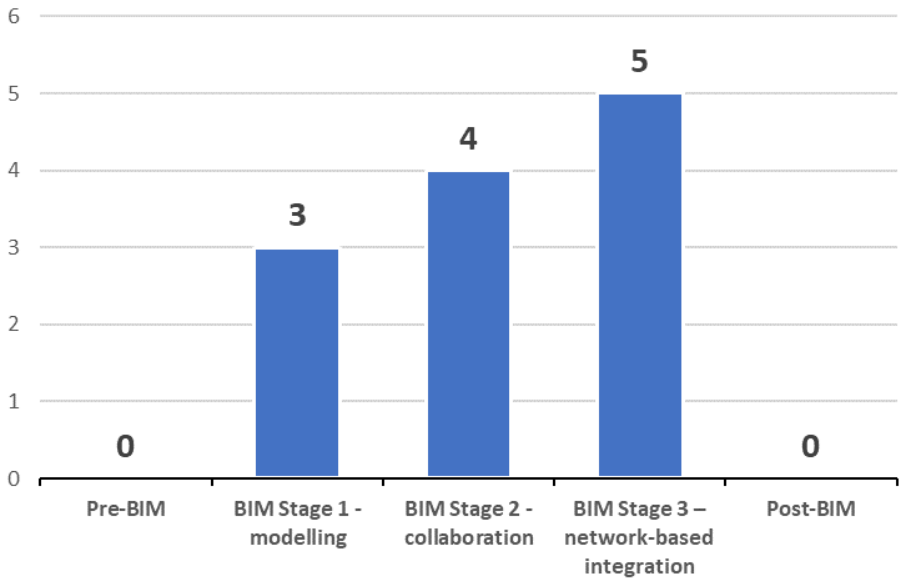


Figure 4 - Companies by implementation stage.

It is possible to conclude that the researched companies represent a sample with a broad range of years of experience, including both traditional/consolidated companies and young start-ups as well. Companies are, however, more homogeneous when BIM specific utilization is considered. Regardless of their overall existence, all companies have only recently implemented BIM in their operations.

Researched companies have different focus and core businesses, including design, construction, consulting and training. These companies use BIM in various specialties and, consequently, use several systems to meet their needs. This diversity of core business, specialties and systems used adds value for the research since different views and experiences are provided by respondents.

All companies have been using BIM methodology, although in different stages of implementation. They are concentrated in intermediary stages.

No respondent indicated the utilization of BIM in facilities management by any company, and consequently no BIM system was mentioned for this specialty.

3.1 Analysis of the "Difficulties"

Respondents indicated their level of agreement in each difficulty listed in the questionnaire using the statements of the Likert Scale as follows: 1 - Strongly disagree; 2 - Disagree; 3 - Neither agree nor disagree; 4 - Agree; and 5 - Strongly agree.

The Table 5 shows the percentage of the quantity of responses for each difficulty.

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Table 5 - Percentage of the quantity of responses for each difficulty

Difficulties x Statement	Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree
Difficulty 1	33.33%	60.00%	0.00%	6.67%	0.00%
Difficulty 2	26.67%	53.33%	13.33%	6.67%	0.00%
Difficulty 3	46.67%	46.67%	6.67%	0.00%	0.00%
Difficulty 4	6.67%	20.00%	20.00%	46.67%	6.67%
Difficulty 5	13.33%	20.00%	26.67%	33.33%	6.67%
Difficulty 6	20.00%	33.33%	26.67%	20.00%	0.00%
Difficulty 7	13.33%	20.00%	40.00%	26.67%	0.00%
Difficulty 8	20.00%	40.00%	26.67%	13.33%	0.00%
Difficulty 9	33.33%	53.33%	6.67%	6.67%	0.00%
Difficulty 10	6.67%	60.00%	20.00%	0.00%	13.33%
Difficulty 11	13.33%	40.00%	20.00%	20.00%	6.67%
Difficulty 12	13.33%	33.33%	33.33%	20.00%	0.00%
Difficulty 13	6.67%	26.67%	40.00%	26.67%	0.00%

Based on the consolidated responses by difficulty, it was calculated the percentage of representativeness of affirmative responses over all possible responses. This percentage was calculated as the sum of “strongly agree” and “agree” responses divided by the total number of responses (15) times 100. The percentage of other possible responses was calculated as the sum of “neither agree nor disagree”, “disagree”, and “strongly disagree” divided by the total number of responses (15) times 100. Results are shown in Table 6.

The prioritization of the difficulties was based on the percentage of affirmative responses over possible responses. The percentage of responses “agree” was used to tiebreak difficulties with the same percentage of affirmative responses. The equivalent concept was followed when other responses were tied.

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Table 6 - Percentage of affirmative responses by difficulties

Difficulties	% of affirmative responses	% of other responses	Ranking
Difficulty 1	93.33%	6.67%	2
Difficulty 2	80.00%	20.00%	4
Difficulty 3	93.33%	6.67%	1
Difficulty 4	26.67%	73.33%	13
Difficulty 5	33.33%	66.67%	10
Difficulty 6	53.33%	46.67%	7
Difficulty 7	33.33%	66.67%	11
Difficulty 8	60.00%	40.00%	6
Difficulty 9	86.67%	13.33%	3
Difficulty 10	66.67%	33.33%	5
Difficulty 11	53.33%	46.67%	8
Difficulty 12	46.67%	53.33%	9
Difficulty 13	33.33%	66.67%	12

The Figure 5 shows the consolidates number of responses by difficulty, but now following the prioritized ranking.

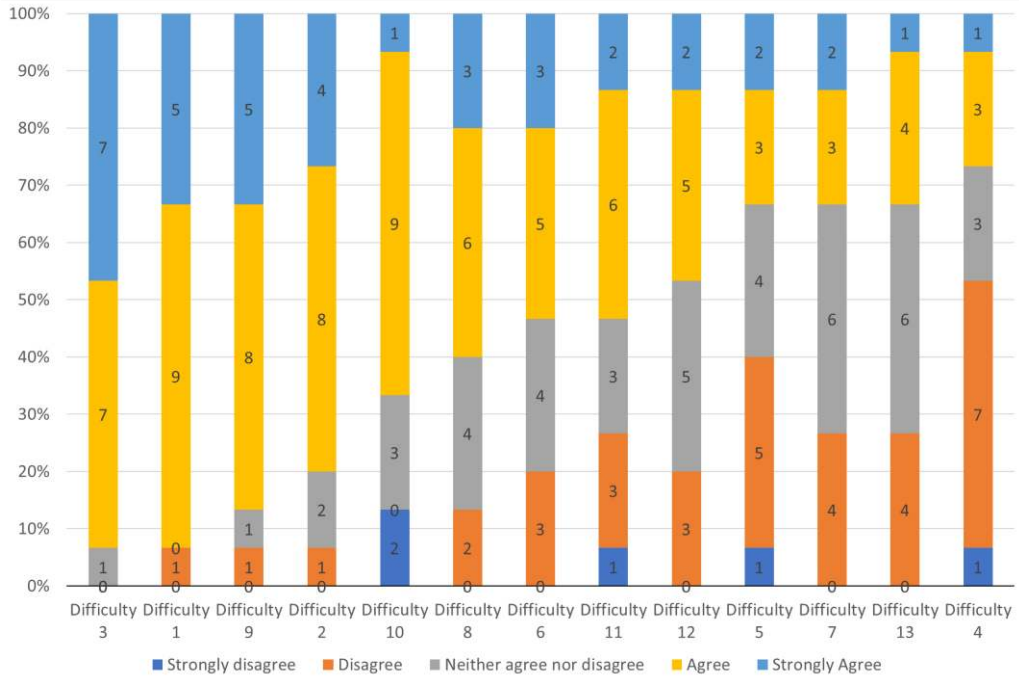


Figure 5 - Consolidated responses by prioritized difficulties.

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3.2 Analysis of the "Critical Success Factors"

Respondents indicated their level of agreement on each CSF listed in the questionnaire using the statements of the Likert Scale as follows: 1 - Strongly disagree; 2 - Disagree; 3 - Neither agree nor disagree; 4 - Agree; and 5 - Strongly agree. Table 7 shows the percentage of the quantity of responses for each CSF.

Table 7 - Percentage of the quantity of responses for each CSF

CSF x Statement	Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree
CSF 1	60.00%	33.33%	6.67%	0.00%	0.00%
CSF 2	26.67%	73.33%	0.00%	0.00%	0.00%
CSF 3	46.67%	46.67%	6.67%	0.00%	0.00%
CSF 4	53.33%	46.67%	0.00%	0.00%	0.00%
CSF 5	46.67%	46.67%	6.67%	0.00%	0.00%
CSF 6	20.00%	66.67%	6.67%	6.67%	0.00%
CSF 7	20.00%	53.33%	20.00%	6.67%	0.00%
CSF 8	26.67%	66.67%	0.00%	6.67%	0.00%
CSF 9	40.00%	60.00%	0.00%	0.00%	0.00%
CSF 10	13.33%	66.67%	20.00%	0.00%	0.00%
CSF 11	6.67%	53.33%	33.33%	6.67%	0.00%
CSF 12	6.67%	73.33%	20.00%	0.00%	0.00%
CSF 13	13.33%	73.33%	13.33%	0.00%	0.00%

Based on the consolidated responses by CSF, it was calculated the percentage of representativeness of affirmative responses over all possible responses. This percentage was calculated as the sum of "strongly agree" and "agree" responses divided by the total number of responses (15) times 100. The percentage of other possible responses was calculated as the sum of "neither agree nor disagree", "disagree", and "strongly disagree" divided by the total number of responses (15) times 100. Results are shown in Table 8.

The prioritization of the difficulties was based on the percentage of affirmative responses over the other possible responses. The percentage of responses "agree" was used to tiebreak difficulties with the same percentage of affirmative responses. The equivalent concept was followed when other responses were tied.

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Table 8 - Percentage of affirmative responses by CSF.

CSF	% of affirmative responses	% of other responses	Ranking
CSF 1	93.33%	6.67%	4
CSF 2	100.00%	0.00%	3
CSF 3	93.33%	6.67%	5
CSF 4	100.00%	0.00%	1
CSF 5	93.33%	6.67%	6
CSF 6	86.67%	13.33%	8
CSF 7	73.33%	26.67%	12
CSF 8	93.33%	6.67%	7
CSF 9	100.00%	0.00%	2
CSF 10	80.00%	20.00%	10
CSF 11	60.00%	40.00%	13
CSF 12	80.00%	20.00%	11
CSF 13	86.67%	13.33%	9

Figure 6 shows the consolidated number of responses by difficulty, but now following the prioritized raking ranking.

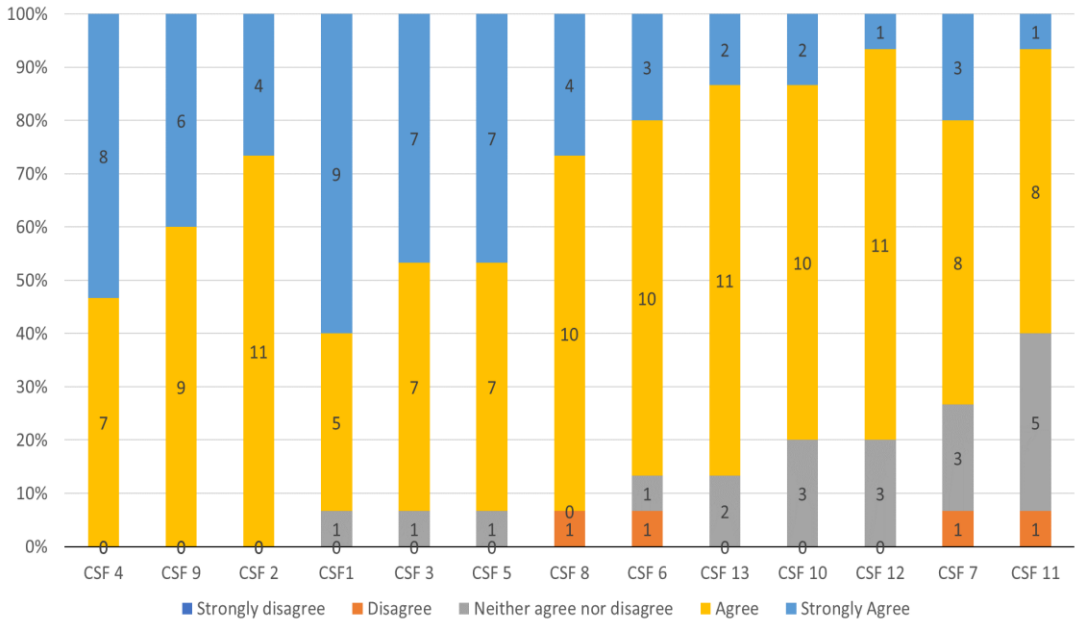


Figure 6 - Consolidated responses by prioritized CSF.

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3.3 Critical Success Factors prioritization

The respondents were asked to identify and prioritize the 5 most important CSF using a rating scale from 1 (less important) to 5 (most important). Answers from only 8 respondents were included in this analysis due to the lack of consistency amongst respondents. This was a free choice evaluation, solely based on their experience.

The total score of each CSF was calculated as the sum of the responses from each respondent, the highest score thus representing the highest priority. Data was consolidated to create a prioritized list of the 5 top CSF's. The Table 8 shows this list according to the results.

Table 8 - Total score and ranking of top 5 CSF

CSF	Total Score	Ranking
CSF 1	26	1
CSF 2	15	4
CSF 3	25	2
CSF 4	11	5
CSF 5	22	3
CSF 6	7	7
CSF 7	8	6
CSF 8	4	8
CSF 9	1	9
CSF 10	0	11
CSF 11	1	9
CSF 12	0	11
CSF 13	0	11

Based on the free choice of respondents, the list of the top 5 prioritized CSF is shown in Table 9.

Table 9 - Prioritized list of top 5 CSF

CSF	Ranking
CSF 1 - Promoting an organizational and cultural change	1
CSF 3 - Providing training and qualification for all team members	2
CSF 5 - Developing an effective implementation planning	3
CSF 2 - Evaluating initial investment and costs	4
CSF 4 - Redesigning and adapt internal processes	5

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Critical Success Factors and Difficulties correlation

Because most of the difficulties and all CSF's don't assume a normal distribution, and data is ordinal, the non-parametric Spearman's Rank Correlation Coefficient was selected as the proper method to analyze such samples. (Spencer and Pharm, 2015).

The results of each correlation coefficient between CSF's and difficulties are indicated in Table 10.

Table 10 - Spearman's Rank Correlation Coefficient (rs)

CSF x Difficulties	Difficulty 1	Difficulty 2	Difficulty 3	Difficulty 4	Difficulty 5	Difficulty 6	Difficulty 7	Difficulty 8	Difficulty 9	Difficulty 10	Difficulty 11	Difficulty 12	Difficulty 13
CSF 1	0.20	-0.09	-0.02	0.28	0.07	-0.44	0.19	0.05	-0.20	-0.03	-0.09	0.07	0.25
CSF 2	0.24	0.15	0.08	0.33	0.41	0.14	0.33	0.55	0.27	-0.06	0.00	0.36	0.20
CSF 3	0.81	0.39	0.27	0.26	-0.02	-0.60	0.24	-0.10	0.17	-0.24	-0.21	-0.15	0.36
CSF 4	0.25	-0.12	0.14	0.00	0.02	-0.03	-0.32	0.05	-0.09	-0.46	-0.06	-0.05	-0.21
CSF 5	0.71	0.25	0.15	0.33	0.16	-0.66	0.24	0.07	-0.12	-0.40	-0.38	0.05	0.13
CSF 6	0.15	0.11	0.11	0.40	0.69	-0.17	0.11	0.66	-0.05	0.15	0.15	0.06	-0.29
CSF 7	0.24	0.16	-0.30	-0.01	0.20	-0.12	0.60	-0.21	0.10	-0.28	-0.52	0.03	0.41
CSF 8	0.26	-0.07	-0.27	0.37	0.64	-0.05	0.52	0.10	-0.08	-0.11	0.00	0.07	0.35
CSF 9	0.33	0.10	0.35	0.30	0.13	0.24	0.35	0.26	0.59	0.00	0.48	0.33	0.65
CSF 10	0.26	0.19	-0.33	-0.08	-0.05	0.15	0.26	-0.45	0.02	-0.41	-0.44	0.00	0.21
CSF 11	0.28	0.17	-0.40	0.26	-0.09	0.11	0.24	-0.18	0.00	-0.01	-0.16	0.55	0.22
CSF 12	0.38	0.01	-0.53	0.33	0.11	-0.01	0.26	-0.09	0.08	0.09	-0.19	0.39	0.25
CSF 13	0.24	0.39	-0.23	0.32	-0.22	0.12	0.22	-0.14	0.07	0.08	0.03	0.55	0.24

To evaluate each correlation coefficient the following thresholds were adopted: 0.00 - 0.19: "very weak"; 0.20 - 0.39: "weak"; 0.40 - 0.59: "moderate"; 0.60 - 0.79: "strong"; and 0.80 - 1.00: "very strong". Similar thresholds were used to evaluate negative correlation.

Most correlations reside between "Weak" and "Weak (-)". The following correlations between CSF and difficulties, listed in Table 11, have a stronger relationship (positive or negative).

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Table 11 - Correlated variables by correlation strength

Correlation strength	Correlated Variables	Correlation strength	Correlated Variables
Very Strong	CSF-3 - DIF-1	**Moderate (-)**	CSF-1 - DIF-6
Strong	CSF-5 - DIF-1		CSF-10 - DIF-10
	CSF-6 - DIF-5		CSF-10 - DIF-11
	CSF-6 - DIF-8		CSF-10 - DIF-8
	CSF-7 - DIF-7		CSF-11 - DIF-3
	CSF-8 - DIF-5		CSF-12 - DIF-3
	CSF-9 - DIF-13		CSF-4 - DIF-10
Moderate	CSF-11 - DIF-12		CSF-5 - DIF-10
	CSF-13 - DIF-12		CSF-7 - DIF-11
	CSF-2 - DIF-5	**Strong (-)**	CSF-3 - DIF-6
	CSF-2 - DIF-8		
	CSF-6 - DIF-4		
	CSF-7 - DIF-13		
	CSF-8 - DIF-7		CSF-5 - DIF-6
	CSF-9 - DIF-11		
	CSF-9 - DIF-9		

4. CONCLUSIONS AND RECOMMENDATIONS

The implementation of BIM in Brazil is still on preliminary stages. Overall, it is estimated that AECO companies in Brazil that apply the BIM methodology represent only 5% of the Brazilian construction gross domestic product (GDP). (MDIC Brasil, 2018; Toledo, 2018). To enhance its broader utilization, the Brazilian federal government launched in December 2018 the Brazilian BIM Strategy, inspired and developed based on the UK BIM model. It includes nine objectives and four specific goals to be achieved by 2028. Therefore, this research aimed to identify, evaluate, and correlate the difficulties and the critical success factors (CSF's) for the proper implementation of the BIM methodology in private small and medium-sized enterprises (SME's) in Brazil.

In order to meet objective 1, a rigorous literature review focused on BIM implementation was performed. A total of 189 papers were selected and 62 reviewed. It was possible to conclude that the scientific production about BIM is balanced between pure academic production (thesis and dissertations) and scientific events and publications (journals and conferences), which is important for the process of transferring knowledge from academia to industry. Papers were classified under 4 different categories based on their main theme: a) implementation; b) design phase; c) construction phase; and d) facilities management. Reviewed papers predominantly covered the implementation of BIM; papers related to design phase and construction phase represented the second largest group. Very few papers addressed the facilities management subject. The conclusion is that academic production is aligned with actual situation of BIM implementation in Brazil, once efforts are concentrated

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on implementation and design, with some efforts on construction and very little presence in facilities management.

This collaboration and alignment between academia and industry is needed because BIM has a significant level of complexity. For a successful BIM implementation, it is needed to understand its difficulties and critical success factors. Therefore, the first output of the literature review was the identification of the difficulties for implementing BIM, which are listed as follows:

1. Team's lack of technical qualification and experience;
2. Resistance and reluctance to change;
3. Implementation costs;
4. Lack of communication and collaboration between internal players;
5. Lack of communication and collaboration between external players;
6. Methodology complexity;
7. Lack of interoperability;
8. Difficulty in writing and adapting new contracts to the BIM requirements;
9. Lack of standardization in project data and documents;
10. Lack of time;
11. Poor strategic and operational planning;
12. Difficulty in measuring the sales values of parametric modeling services;
13. Problems with the Electronic Document Management System (EDMS).

Similarly, the second output of the literature review was the identification of the CSF's for implementing BIM, which are listed as follows:

1. Promoting an organizational and cultural change;
2. Evaluating initial investment and costs;
3. Providing training and qualification for all team members;
4. Redesigning and adapting internal processes;
5. Developing an effective implementation planning;
6. Amending contract terms and conditions;
7. Identifying technology solutions;
8. Promoting an integrated and collaborative environment;
9. Improving designer's knowledge on construction and management;
10. Applying an adequate level of development;
11. Improving visual presentation of 4D models;
12. Ensuring efficient interoperability for design;
13. Ensuring efficient interoperability for construction.

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In order to meet objective 2, a qualitative research was performed among Brazilian AECO SME's. The research included semi-structured interviews, held in person, and questionnaires sent electronically using Adobe Forms functionality. The sample included 15 respondents employed in 12 companies. Detailed results and analysis of the research sample are indicated in Section 4.1 and in Section 5.1. It was possible to conclude that the sample was heterogeneous and diverse, which enriches the study by bringing different perspectives both generational (diverse years of experience) and organizational (diverse professional position). However, the sample is very homogeneous when analyzed by their BIM-specific experience which is natural due to the current status of the BIM implementation in Brazil. All respondents are just recently using BIM in their work. BIM was found to be used in several specialties; however, no use was indicated for facilities management.

Overall, respondents heterogeneously agreed with proposed difficulties with concordance level varying from 26.67% to 93.33%.

It is possible to conclude that most of the difficulties identified are aligned with the perception of the professionals surveyed. However, some difficulties have a lower level of agreement, which may indicate that authors are not fully connected with actual market conditions.

About the CSF's respondents were more homogeneous at the concordance level, which varied from 60% to 100%. Additionally, to the 13 CSF's identified in the literature review, one respondent also mentioned 2 other CSF's. Respondents also freely ranked the top 5 CSF's. It is possible to conclude that there is a significant alignment and concordance about the CSF's indicated by authors and researched professionals. This alignment is important because academic research developed about BIM implementation is crossing the academy borders and reaching the AECO industry via conferences, seminar and technical articles in periodicals. By maintaining this alignment, the AECO industry may benefit from academy results, while academy my benefit from the actual field experience from industry players.

In order to meet objective 3, the evaluated list of difficulties and the evaluated list of CSF's were both prioritized based on the percentage of affirmative responses. This percentage was calculated as the sum of "strongly agree" and "agree" responses divided by the total number of responses (15) times 100. The percentage of other possible responses was calculated as the sum of "neither agree nor disagree", "disagree", and "strongly disagree" divided by the total number of responses (15) times 100. The percentage of responses "agree" was used to tiebreak difficulties with the same percentage of affirmative responses. The equivalent concept was followed when other responses were tied.

The CSF's were correlated with difficulties using the Spearman's Rank Correlation Coefficient. Because most of the difficulties and all CSF's don't assume a normal distribution, and data is ordinal, the non-parametric Spearman's Rank Correlation Coefficient was selected as the proper method to analyze such samples.

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Therefore, Table 12 represents the final consolidated, prioritized and correlated list of critical success factors and difficulties needed to be properly managed for successful implementation of BIM methodology in SME's in Brazil.

This list properly met objective 3 as proposed and represents the main output of this research.

Table 12 - Prioritized and correlated list of CSF and difficulties

Rank	Prioritized list of CSF's	Correlation[2]		Prioritized list of difficulties
		+	-	
1	CSF 4 - Redesigning and adapting internal processes[1]		10	Diff. 3 - Implementation costs
2	CSF 9 - Improving designer's knowledge on construction and management	9 ,11, 13		Diff. 1 - Team's lack of technical qualification and experience
3	CSF 2 - Evaluating initial investment and costs[1]	5, 8		Diff. 9 - Lack of standardization in project data and documents
4	CSF 1 - Promoting an organizational and cultural change[1]		6	Diff. 2 - Resistance and reluctance to change
5	CSF 3 - Providing training and qualification for all team members[1]	1	6	Diff. 10 - Lack of time
6	CSF 5 - Developing an effective implementation planning[1]	1	6, 10	Diff. 8 - Writing and adapting new contracts to the BIM requirements
7	CSF 8 - Promoting an integrated and collaborative environment	5, 7		Diff. 6 - Methodology complexity
8	CSF 6 - Amending contract terms and conditions	4, 5, 8		Diff. 11 - Poor strategic and operational planning
9	CSF 13 - Ensuring efficient interoperability for construction	12		Diff. 12 - Difficulty in measuring the sales values of parametric modeling services
10	CSF 10 - Applying an adequate level of development		8, 10, 11	Diff. 5 - Lack of communication and collaboration between external players
11	CSF 12 - Ensuring efficient interoperability for design		3	Diff. 7 - Lack of interoperability
12	CSF 7 - Identifying technology solutions	7, 13	11	Diff. 13 - Problems with the Electronic Document Management System
13	CSF 11 - Improving visual presentation of 4D models	12	3	Diff. 4 - Lack of communication and collaboration between internal players

[1] Represents CSF's listed as "top 5" by respondents;
[2] Indicates the number of the difficult that correlates with CSF.

In summary, the top 6 difficulties that prevent Brazilian companies from implementing BIM are: *a) implementation costs; b) team's lack of technical qualification and experience; c) lack of standardization in project data and documents; d) resistance and reluctance to change; e) lack of time; and f) writing and adapting new contracts to the BIM requirements. The top 6 critical success factors for a successful BIM implementation are: a) redesigning and adapting internal processes; b) improving designer's knowledge on construction and management; c) evaluating initial investment and costs; d)*

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promoting an organizational and cultural change; e) providing training and qualification for all team members; and f) developing an effective implementation planning.

These are important elements that cannot be neglected by companies that seek to properly implement BIM.

4.1 LIMITATIONS

This research focused on small and medium-sized private companies in Brazil. Because Brazil has continental dimensions, the findings and results may not be generally applicable in, or representative of, each Brazilian region. It is also limited to SME's that, by definition, have limited revenue level and, therefore, a relatively lower investment capacity. These SME's have particularities and differ from the public sector or large corporations. Therefore, findings and results may not be applicable to the public sector or large corporations.

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