Checklist proposal to assess the implementation of Building Information Modeling (BIM) technology applied to reinforced concrete structures

Proposta de *checklist* para avaliação de implantação da tecnologia Building Information Modeling (BIM) aplicado à estruturas de concreto armado

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ABSTRACT
The implementation of Building Information Modeling Technology (BIM) in Brazil is a matter of relevance in the civil construction scenario. The BIM BR Strategy, promoted by the Federal Government, seeks to encourage the development of the civil construction sector, establishing the use of technology in the execution of works and engineering services. The Federal Government's intention is to guarantee the development of the civil construction sector in order to bring economys to public budgets and transparency in bidding processes, in addition to contributing to the optimization of maintenance and asset management processes. Given the importance of Reinforced Concrete Structures for the Civil Construction sector, and considering concrete as the second most consumed material in the world, questions about the environmental damage caused by its production chain are indispensable. Technological innovation then becomes one of the main alternatives to minimize CO_2 emissions associated with the cement industry, aiming at more durable and sustainable structures. In order to contribute to this process, this article presents the proposal for a BIM Technology Implementation Checklist applied to Reinforced Concrete Structures with suggestive guidelines for each of the 10 BIM Dimensions. Thus, conducting an assessment of the levels of BIM implementation brings several advantages within a market in which it is mandatory to adopt the Technology for the procurement of public works, which makes the evaluation process, a fundamental tool for the dissemination of the Technology BIM in the country.

Keywords: Building Information Modeling, Construction Industry, Reinforced Concrete, Sustainability.

RESUMO
A implantação da Tecnologia Building Information Modeling (BIM) no Brasil é um assunto de relevância no cenário da construção civil. A Estratégia BIM BR, promovida pelo Governo Federal, busca incentivar o desenvolvimento do setor da construção civil, estabelecendo a utilização da tecnologia na execução de obras e serviços de engenharia. O intuito do Governo Federal é garantir o desenvolvimento do setor de construção civil de forma a trazer economicidade para os orçamentos públicos e transparência aos processos licitatórios, além de contribuir para a otimização de processos de manutenção e gerenciamento de ativos. Visto a importância das Estruturas de Concreto Armado para o setor da Construção Civil, e considerando o concreto como segundo material mais consumido no mundo, questionamentos sobre os danos ambientais causados pela sua cadeia produtiva são indispensáveis. A inovação tecnológica se torna então uma das principais alternativas para minimizar as emissões de CO_2 associadas à indústria

cimenteira, visando estruturas mais duráveis e sustentáveis. De maneira a contribuir com este processo, o presente artigo apresenta a proposta de um *Checklist* de Implantação da Tecnologia BIM aplicado à Estruturas de Concreto Armado com diretrizes sugestivas para cada uma das 10 Dimensões BIM. Dessa forma, realizar uma avaliação dos níveis de implementação BIM traz diversas vantagens dentro de um mercado em que é obrigatório a adoção da Tecnologia para a contratação de obras públicas, o que se faz do processo de avaliação, uma ferramenta fundamental para a disseminação da Tecnologia BIM no país.

Palavras-chave: Building Information Modeling, Construção Civil, Concreto Armado, Sustentabilidade.

1 INTRODUCTION

The Architecture, Engineering, Construction and Operation (AECO) sector is undergoing changes, which are sustained due to the adoption of Building Information Modeling (BIM). According to Eastman *et al.* (2014), BIM is a technology that allows the development of an entire enterprise in a completely digital way, which presents accurate data regarding the entire construction, from inputs, geometry and even information that contributes to the progress of the construction, being able to assist until the end of the project's useful life.

BIM comes to offer professionals working in the area a whole process of organizing information in a standardized format, which contains all the information necessary for the design and subsequent maintenance of the structure. Through BIM, each element of the structure has its own library that characterizes this element and its properties, according to Ferreira *et al.* (2012).

Taking into account the impact generated to meet the demand of Brazilian civil production processes, the sustainable analysis of Reinforced Concrete Structures is essential. Responsible teams with experience in the development of sustainable buildings, reveal that the efficiency of the entire process is the secret to the success of its conclusion (LAPINSKI *et al.*, 2006). Therefore, the use of BIM Technology is essential, since it guarantees a better planning and integrability of all work stages, achieving satisfactory final results for the whole process and reducing the use of resources that degrade the environment.

2 THEORETICAL REFERENCE

2.1 BUILDING INFORMATION MODELING

The BIM definition would have been used primarily by Charles Eastman, defining this technology as “a digital model that represents a product, which, in turn, would be the result of the information flow in the development of your project”. When properly implemented, BIM enables a more integrated design and construction process, resulting in better quality constructions with reduced cost and execution time (CBIC, 2016). As stated by Covas (2016), BIM can be defined as a technology which the aim is to handle the information involved in the entire construction process of the building, being structured information, hierarchical, organized, with the objects defined parametrically, and mainly accessible countless stakeholders in the process.

According to CBIC (2016), technology has the potential to change the culture of agents in the entire production chain in the sector, as its use requires new relationships between architects, designers, consultants and contractors. The challenge for implementing this technological platform is to promote conditions of feasibility to gather a set of multidisciplinary information about the enterprise, being present in the entire life-cycle of the enterprise, from the production of each component in the industry, even in the project phases, execution, use, operation, maintenance and demolition of the construction being still, a construction simulation, accessible to all involved.

According to ABDI (2017), it's common to associate BIM Technology only with software and computers, but it’s a cultural change. Therefore, for an effective implementation of BIM Technology three factors are essential: Technology, people, and processes connected to each other by procedures, standards and good practices. BIM is based on structured and coordinated information, and on the existence of a harmonious workflow that leads all of that information from the base program to the operation and maintenance phase of a project.

According to CBIC (2016), interoperability is the ability to manage and communicate electronic products and project data between collaborating organizations and individuals who, together, make up a team for the development of projects, contracts, constructions, maintenance and business process systems. Interoperability must be achieved, since it seeks to facilitate coordination between professionals and work tools. Therefore, constituting a major acquisition for this sector, which deals daily with several problems arising from the incompatibility of information and finds in interoperability a way to interconnect the various software that are essential to design, build and manage a building (RODAS, 2015).

2.1.1 BIM dimensions

One of the concepts that permeate the implementation of the present work technology around the world is the 10 BIM Dimensions Theory, proposed by Arnal (2018). The objective of this approach is to align all agents by classifying the main stages of construction projects throughout the construction life-cycle, with the main purpose of industrializing construction processes.

2.1.1.1 Protocols for implementation (1D)

Initially, the first dimension deals with the Protocols for the Implementation of BIM Technology, such as Technical Standards, Documents and Project Standardization, for example. The BIM Standardization in Brazil is still in the process of development, the main ones available until that moment are NBR 15965-1:2011 and NBR ISO 12006-2: 2018. These are responsible for the standardization, coding and classification of project data for a more assertive communication between developers and computer systems, essential to establish workflows.

2.1.1.2 Collaborative workflows (2D)

In the second dimension, the concepts of collaborative workflows are introduced, including innovative ways of contracting and project management solutions, according to Arnal (2018). Meanwhile, as maintained by Martini *et al.* (2019), the incorporation of BIM Technology in a workflow has a fundamental argument for advancing processes in view of the projects quality, in addition to a more effective and economical execution of the work, resulting in a clear and objective representation of the model or infrastructure system to be built. With BIM technology, this process is centered on the virtual work methods of construction, where the Optimization Cycles are carried out simultaneously in all design centers involved in the project (ABDI, 2017).

2.1.1.3 Modeling (3D)

According to Covas (2016), BIM is not just software or a means for viewing information in three-dimensions. BIM is a technology in the treatment of information that directly affects the quality, cost and time of construction. Primarily, the big difference between 3D modeling software and BIM software is its ability to generate parametric objects. For Rosso (2011), parameterization guarantees the generation of editable objects that can be changed automatically, providing support for BIM technology. Without this capability, the software is just another 3D object modeler.

2.1.1.4 Strategic Planning (4D)

Strategic planning is essential, especially when referring to constructive ventures. The fourth and fifth BIM dimensions deal with this topic, linking to each of the modeled elements the costs and time of installation and execution, information that is extremely important mainly for the owner of the project (BRITO, 2015). BIM 4D incorporates all time planning, precisely linked to each of the elements modeled in the 3D dimension.

2.1.1.5 Budget (5D)

According to Campestrini *et al.* (2015), the fifth BIM dimension is the complete construction budget, including costs for materials, labor and equipment. With the parameterization of the elements involved in the project of the enterprise, it is possible to associate the time and cost of the installation and execution of the processes, improving the forecasting. According to ABDI (2017), one of the main advantages, especially in public projects, is the possibility of extracting quantitative, descriptions and schedules directly from the virtual model, resulting in a greater suitability of the project, minimizing budget errors and service additives. However, the fifth dimension is only executable if the previous dimensions are executed assiduously.

2.1.1.6 Sustainability (6D)

Concerns regarding the sustainability of projects and constructions, especially the emission of CO_2, are one of the main challenges currently. The civil construction industry, nationally and internationally, is driven by the use of more sustainable methodologies to minimize the critical waste scenario and establish environmental protection goals. The use of BIM technology as a potential to contribute to national sustainability is still scarce, even with the incentive for environmental certifications to adapt projects (GOSLING et al., 2020), as for example, the North American Leadership in Energy and Environmental Design (LEED) method and the Brazilian seal (AQUA), High Environmental Quality (ALVES, 2019).

2.1.1.7 Operation and Maintenance (7D)

The seventh dimension of BIM Technology, also known by the term Facilities Management, is related to the entire process of managing the facilities, according to Ferreira (2005) Facilities Management addresses the strategic management of people, spaces, work processes and investment within a organizational environment, highlighting the operation and maintenance of its building systems and subsystems. The 7D model helps to improve the quality of service provision throughout the lifecycle of a project, and in addition, which increases the information aimed at its management and maintenance. It is also worth mentioning that this dimension ensures that everything in a project remains in its best form from the first day until the demolition of the structure itself.

2.1.1.8 Safety and Health (8D)

The eighth dimension is focused on safety and health during all phases that involve the constructive enterprise (design, execution and maintenance). According to Arnal (2018), this dimension aims to achieve the concept of Zero Accident. This topic is only feasible when the dimensions previously presented are well defined. Since the project meets all parameterization requirements and all work tests are computerized before the start of the execution, the possible accidents can be predicted and avoided, ensuring the safety of all workers involved in the execution process of the enterprise.

2.1.1.9 Lean Construction (9D)

The ninth dimension of BIM Technology is about the introduction of the lean construction management philosophy, according to Arnal (2018). When this concept is applied to the design process, it implies a significant reduction of waste, such as savings in construction costs, reduction of execution time and design cycles, promoting an increasingly faster and industrialized construction. According to Eastman *et al.* (2014), the lean construction foundation tends to evolve simultaneously with BIM.

2.1.1.10 Industrialization (10D)

The implementation of BIM technology purpose is to incorporate the construction industry seeking to improve the processes that structure civil construction today. According to Arnal (2018), all BIM dimensions aim to reach the industrial level. This step allows a more productive and assertive execution of the enterprise, therefore, more sustainable. According to CBIC (2016), one of the main reasons for the low rate of industrialization and use of prefabricated products in Brazil is the lack of well-defined projects. In BIM technology, when all dimensions are clear for everyone involved, unforeseen events related to industrial processes are mitigated.

Therefore, the dissemination of BIM Technology, according to ABDI (2017), goes beyond an innovation for the market, and it's necessary to build a strategy for implementation, together with the government, so that the civil construction industry is boosted. The BIM implementation must be based on productivity, sustainability, control, clarity and optimization of the allocation by public expenditures and costs in private enterprises.

2.1.2 BIM maturity levels

Depending on the degree of collaboration in a construction project, it's possible to determine at what level of maturity the adoption of BIM is in the company. These levels are divided into 4, the first level being Pre-BIM, which refers to traditional 2D practices, and still with inefficiency and significant barriers; the second level, BIM Level 1, which refers to the transition from 2D to 3D, where the model starts to be built with real architectural elements; the BIM Level 2 where there is progress from 3D modeling to collaboration and interoperability; and at the last level, BIM Level 3, those involved in the project interact in real time allowing complex analyzes in the initial phases of the project (SUCCAR, 2009).

2.1.3 level of development (LOD)

According to AIA (2013), there are 5 LOD levels, starting at LOD 100 with a preliminary volumetric representation, without worrying about the precise shape, size or location. The LOD 200 is a generic graphic representation, with approximate quantities, size, shape, location and orientation. The LOD 300 is a precise and coordinated graphics, suitable for costing, quantity, size, shape and location are more accurate. Coordination and compatibility between disciplines is carried out at this stage.

In the LOD 400, the project is represented with sufficient details and precision for the manufacture, assembly, installation, budget and planning of the model. LOD 500 is the design representation of how it was built ("As Built"), the models and associated data are suitable for the maintenance and operations of the installation.

In view of the progress in the studies of BIM technology and its practical use, it was necessary to organize the stages of development and detailing a construction project. Therefore, in 2013, through the publication of the "Project Building Information Modeling Protocol", the American Institute of Architects (AIA) specified Level of Development (LOD) as a reference that allows industry professionals from AECO to specify and articulate with a high level of clarity the content and reliability of BIM models at various stages of the design and construction process. This clear articulation allows later users to clearly understand the usability and limitations of these models.

2.2 BIM TECHNOLOGY APPLIED TO REINFORCED CONCRETE STRUCTURES

The adoption of BIM for the design of Reinforced Concrete Structures generates exponential growth in the AECO sectors, but for this to happen, it's necessary to establish a process of continuous improvement in defined workflows. One of the main impacts that the implantation of BIM technology can generate is greater quality control in the end of the design, reduction in the time spent during the design and greater productivity within the construction site, resulting in more sustainable works with less waste generation (GONÇALVES, 2019).

According to Rodrigues *et al.* (2017), environmental issues have increasingly alarmed countries, and the amount of waste generated by buildings has become one of the centers of discussions on sustainability. In view of the environmental context in which the modern world finds itself, the useful life of Reinforced Concrete Structures is a matter of great relevance. Among the factors that lead to compromise of the Reinforced Concrete Structures, carbonation is one of the main causes of the deterioration of the reinforcement. Caused by the high concentration of CO_2 in the atmosphere in urban centers, it makes essential to adopt more sustainable methods throughout the industrial chain (COUTO, 2017).

According to Felix (2018), although the cement industry is considered one of the most polluting in the sector, concrete has the potential to absorb this gas, through the carbonation process, partially offsetting the emissions generated in its production, but directly affecting durability and service life. It's known that a sustainable building requires the development of new evaluation parameters, review of adopted procedures, use of alternative inputs, qualification of the workforce, in addition to other aspects. In parallel, with Industry 4.0 it's more feasible to use prefabricated structures and modular structures.

The adoption of sustainable solutions for Reinforced Concrete Structures is a topic to be discussed. Ensuring quality and meeting the necessary strength by reducing the amount of cement in the composition of the concrete becomes a paradigm to be discussed. The use of nanotechnology in Reinforced Concrete Structures, for example, according to Cruz (2014), guarantees a significant increase in strength, making it an effective solution for optimizing the mix and reducing the consumption of clinker and cement, contributing to sustainability in the production chain of Reinforced Concrete.

3 METHODS AND TECHNIQUES

The methodology adopted was divided into three phases, Bibliographic Research, contextualization of the BIM application in Brazil and development of guidelines through a Checklist for the BIM implementation Technology, applied to Reinforced Concrete Structures. In the first phase, an exploratory bibliographic research was carried out, characterizing the main concepts that permeate BIM Technology (Dimensions, Development Levels and Maturity Levels), to direct how they will be applied in practice through the Checklist.

Taking into account the importance of Reinforced Concrete Structures for the Brazilian civil construction scenario and in contrast to the damage caused to the environment, this phase also includes the description of more sustainable practices in the execution of these structures. Challenges in implementing sustainable guidelines for the execution of civil works are frequent. Despite the profusion of the pillars of sustainability, and the importance of socio-environmental responsibility, several companies in the civil construction sector still find it difficult to seek sustainable solutions to the problems generated by their activities.

The second phase refers to the contextualization of the BIM application in Brazil, and consists of finding viable ways and methods that help both companies related to civil construction, as well as the clients responsible for the project. This step mainly aims to interpret the data obtained in the research phase, interweaving the concepts related to BIM Technology and sustainable practices in the execution of Reinforced Concrete Structures. For this, interviews were carried out between professionals experienced in BIM Technology. In the form of a questionnaire, the interview sought to collect predominantly descriptive data and situations related to the implementation of BIM Technology in companies directly related to civil construction.

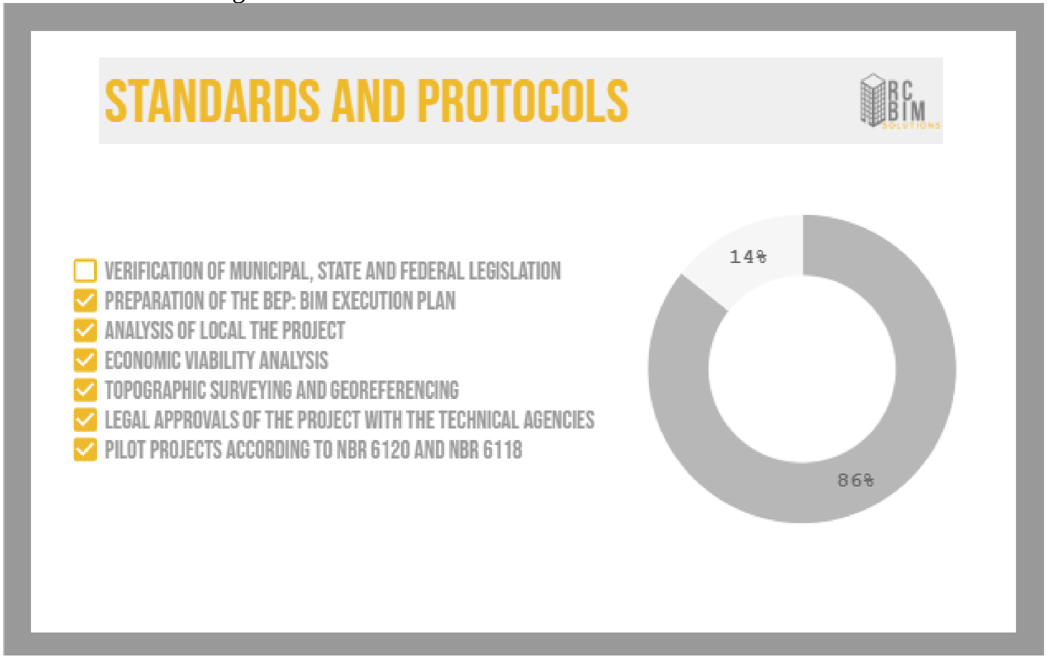
The third phase is characterized by the elaboration of a “BIM Technology Implementation Checklist, applied to Reinforced Concrete Structures", in order to provide information and concepts regarding the implementation of BIM Technology in companies or construction projects, aiming at design of sustainable reinforced concrete structures. With addition, in order to classify a BIM project, targeting the users to steps that may be implemented in the execution of the project, it’s intended to generally represent the level of implementation for each BIM Dimension, and the LOD in which the project is find, through the data entered in the Checklist.

4 CHECKLIST FOR BIM TECHNOLOGY IMPLEMENTATION ASSESSMENT

Based on bibliographic research and an interview with professionals in the area of civil construction, who are immersed in a market that requires future developments to adapt to BIM Technology, a Checklist was devised, in order to assess the percentage in which companies or enterprise accede the great BIM practices in relation to each of dimensions. The main concepts that guided the proposal were: Theory of 10 Dimensions BIM, by Arnal (2018), and the concepts of LOD determined by AIA (2013).

With regard to the first BIM dimension, the proposed Checklist presents guidelines related to standards and protocols such as the verification of municipal, state and federal laws, preparation of BIM Execution Plan (BEP), carrying out an entire analysis of the project site, an economic feasibility analysis, conducting topographic survey and georeferencing, legal approvals of projects with technical bodies and in the development of pilot projects see NBR 6120:2020 and NBR 6118:2014 for Reinforced Concrete Structures.

Figure 1 - First Dimension Checklist - Rules and Protocols



Source: Authors (2021)

With regard to the second BIM dimension, guidelines on the corporate workflow are presented in the Checklist, such as the development of an interoperable dictionary based on the NBR 115965:2011 and NBR ISO 12006-2:2018 standards, the consolidation of the workflows in open formats for collaboration, hiring a project leader (BIM Manager), obtaining software licenses, qualifying the team responsible for the projects and creating a BIM service that would function as a collaborative platform between designers, work and owners.

The third BIM dimension, guidelines are presented in the Checklist regarding the modeling of the project itself, such as, basic definitions for the design of the architectural model, the realization of a modeling according to the best execution practices, the definitions of the finishing materials and renderings, validation of the descriptive memorial, analysis and compatibility of projects (clash detection), indication of fillings, ducts and plumbs of the installations.

In the fourth BIM dimension, guidelines are presented in the Checklist in which they refer to the strategic planning of the enterprise, the definitions of the construction methods, plans for monitoring works, plans for monitoring tests and technological control, elaboration of planned vs. accomplished, elaboration a Project Analytical of Structure and the physical monitoring of the work with measurements and inspections.

In the fifth dimension, it’s presented in the Checklist, guidelines about the budgeting process of the enterprise, which would be the preparation of a memorial according to NBR 12271, preparation of the equivalence according to the preliminary project, linking the budget with the execution of the work, linking the work schedule supplies, quantitative extraction from the executive model and quantitative extraction for the entire useful life of the project.

With regard to the sixth BIM dimension, the Checklist guidelines emphasize Green BIM, such as controlling the water and energy consumption of the enterprise, conducting an energy efficiency analysis, conducting the control of the Waste Transport Manifesto, carrying out a Civil Construction Solid Waste Management Program, analysis of the carbon lifecycle and sustainable certification programs.

In the seventh BIM dimension, guidelines are presented in the Checklist, which refer to the operation and maintenance step of the enterprise, being the use and operation manual see NBR 14037, the storage of guarantees and invoices, project execution as built, analysis of the lifecycle see NBR 15575, facilities management and preventive maintenance plans see NBR 15575 and NBR 5674.

The eighth BIM dimension refers to health and safety, and the Checklist presents guidelines that focus on this step, being the training of employees for the work carried out within the construction site, control of rocker, scaffolding and shoring projects, simulation the execution of the project to detect possible accidents, prevention through design (safety through design), planning excavations to avoid periods of rain and technological control of the concrete during the use of the building.

In the ninth BIM dimension, guidelines referring to Lean Construction are presented in the Checklist, being the use of prefabricated structures, actions and or projects that avoid waste of materials within the construction site, logistic analysis of the inputs at the construction site, the use of projected mortar, use of robots in civil construction and use of cut, folded and assembled frames.

In the tenth BIM dimension, the Checklist presents guidelines with a focus on the industrialization part of civil construction, being the use of precast structures, use of machined mortar, use of machined concrete, use of mixed structure, use of high performance concrete with the addition of carbon nanotubes and bioconcrete.

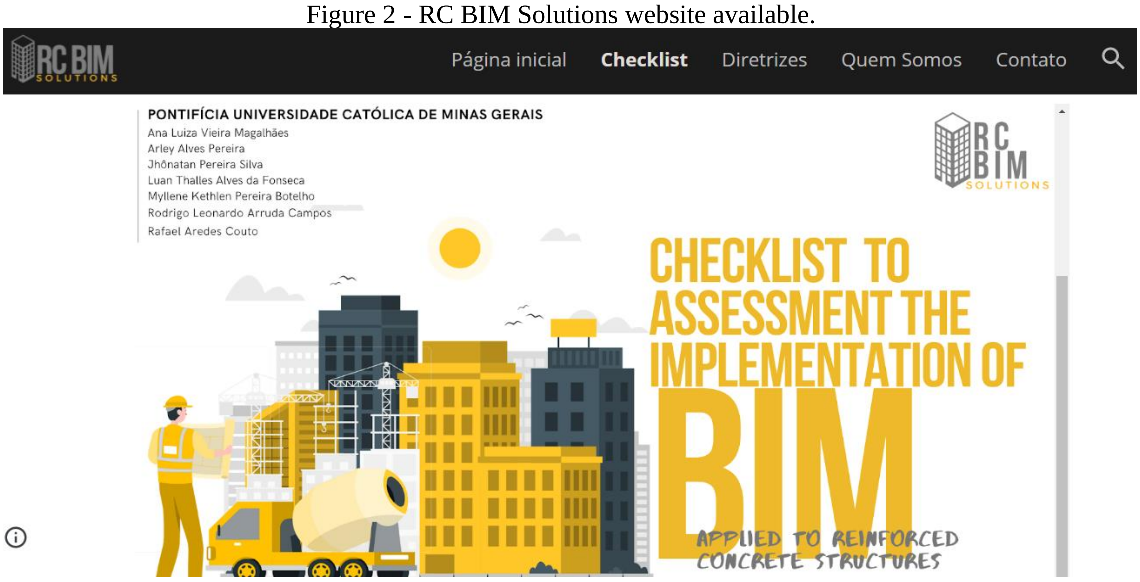
5 RESULTS AND DISCUSSIONS

The Checklist proposed in this article aims to facilitate the Implementation of BIM Technology, in companies and enterprises that are looking for economy and transparency in all processes. In addition to contributing to the optimization of implantation processes, the material provided tends to answer questions and guide, through the proposed steps, to a promising and effective implantation process of BIM Technology throughout the building's lifecycle, from conception up to the maintenance, operation and demolition phase.

With the goal of a more dynamic and clear process, the Checklist was developed in an Excel spreadsheet, where checkboxes and donut charts were used to visualize the percentage implemented in each dimension. As the company performs a given guideline proposed in the Checklist, it's selected, which results in a percentage increase in the graph of that respective dimension. It's worth mentioning that all the guidelines proposed in the Checklist had their weight distributed equally, within their respective dimensions. Through the percentages accumulated within each of the dimensions, a graph in the form of columns is shown the percentage of implementation in each dimension that the company achieved according to the guidelines that were proposed in the Checklist. At the end, the level of detail implemented in the project is presented, which can vary from LOD 100 to LOD 500.

In addition to the elaboration of the proposed Checklist, a website (www.rcbimsolutions.com) was developed in order to provide the information proposed in the Checklist (Figure 2). Above all, it aims to contribute to the implementation of BIM Technology, collaborating indirectly with the implementation of the Strategy Proposed by the Federal Government, BIM BR. When analyzing the main difficulties in implementing the new concepts surrounding BIM Technology, the website also provides a brief summary of each of the guidelines presented in the Checklist.

Figure 2 - RC BIM Solutions website available.



Source: Authors (2021)

6 CONCLUSIONS

BIM Technology is a subject that is on the agenda in the Architecture, Engineering, Construction and Operation (AECO) sector, due to the considerable increase in the use of Technology in the world, together with Decree number 10.306, of April 2, 2020, that established its use in the execution, directly or indirectly, of public works as of January 1, 2021 (BRASIL, 2020).

In addition to decree Number 9.983, of August 22, 2019, whose objective is the dissemination of BIM, stimulating the training of professionals and students, as well as the development of an entire platform and a national library aimed at BIM (BRAZIL, 2019), making it mandatory for companies to adopt BIM Technology.

This fact promotes an exponential demand for processes of diffusion and assessment of the level of BIM implementation by companies, designers and freelance professionals. Therefore, facts like this make this article relevant in order to assist the process of implementing BIM Technology.

The performance of the BIM implementation levels assessment has several advantages, since it can be verified in which guidelines or dimensions, the company lacks or in which it stands out the most. Allowing, through the information provided, a clear and coherent decision making, in addition to punctuating more sustainable strategies for undertaking reinforced concrete structures, raising the quality of the services provided by the company.

The elaboration of a virtual platform for making available the developed guidelines and the Checklist unified the points worked during the article, fulfilling the objectives initially considered. Finally, with the mandatory use of BIM for public works contracts, an implementation level assessment tool is essential, since this process is fundamental and contributes to the dissemination of technology in the country.

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