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PROJECT BUILDING

KEYWORDS
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Building Information Modeling (BIM) in Brazil's ARCHITECTURE, ENGINEERING AND CONSTRUCTION (AEC) INDUSTRY

A Review and a Bibliometric Study.

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• ABSTRACT •

Building Information Modeling (BIM) is transforming how buildings are designed, constructed, operated, maintained and demolished and has attracted significant attention as a process that can positively impact the performance of architecture, engineering and construction (AEC) projects. The research and use of BIM processes and software in Brazil are incipient. This paper aims to provide a review of the scope of the Brazilian BIM literature and outlines the most important directions for future research. The work is developed based on an extensive and critical bibliographic study on journals, papers, conferences and Brazilian-authored master's and doctoral dissertations. The results show little significant Brazilian contributions in the international field and scarce BIM implementation in the Brazilian AEC industry, especially in interoperability issues, post-construction phases, and life cycle analysis.The reasons for this finding are the lack of professionals involved in the entire life cycle of buildings who have expertise in BIM tools and processes as well as the fact that teaching and research on BIM in universities and Brazilian research centers are weak compared to other countries, which shows the need for these institutions to adopt the BIM model as an essential tool for teaching engineering and architecture.

INTRODUCTION

The architecture, engineering, construction, facilities management and demolition communities are currently motivated to manage construction resources more efficiently (Volk, Stengel, & Schultmann, 2014) due to their scarcity, the importance of building sustainability (Akbarnezhad, Ong, & Chandra, 2014) and more stringent laws for the recycling and reuse of construction materials and the safety and health of construction workers and building users (EU Parliament and the Council, 2011).

To achieve these goals, reduce the cost and delivery time and increase the productivity and quality of a given enterprise (Azhar, 2011), innovation in Building Information Modeling (BIM) technology, defined as a set of interrelated policies, technologies and processes that constitute an approach to digital project information and data management throughout a building's life cycle (Akbarnezhad et al., 2014; Penttilä, 2006), provides methods of predicting, managing and monitoring the environmental impact of the project construction and development through a virtual prototyping and visualization technology (Wong & Zhou, 2015). Although it is possible to work in an integrated manner without parametric modeling, BIM facilitates urban and environmental comfort analyses, the extraction of quantitative measurements and the harmonization of designs (Uechi, Paula, & Moura, 2013).

Compared to other countries, the implementation of BIM processes and concepts in Brazil has been difficult due to the scarce standardization in the sector, from construction components to construction products, in addition to the fragmentation of construction processes and the lack of understanding of the potential of BIM by company owners, who consider its implementation to be an expense rather than an investment (Souza, Hisamoto, Santos, & Melhado, 2012).

Although the use of BIM is incipient in the country, since 2007, some Brazilian private companies and civil construction institutions have mobilized for the implementation and the development of research on BIM (Souza, Wyse, & Melhado, 2013). The following six initiatives can be cited: Grupo BIM Interdisciplinar [Interdisciplinary BIM Group], Rede BIM Brasil [Brazil BIM Network], Sinduscon-SP, Comitê de Desenvolvimento de Normas de Modelagem da Informação da Construção [Committee for the Development of Standards for Building Information Modeling], the TICHIS Project by FINEP (Addor & Santos, 2013; Souza et al., 2013) and the Associação Brasileira de BIM [Brazilian BIM Association] (Associação Brasileira de BIM, 2016).

Several articles on BIM have been published in Brazil, showing a gradual increase in the number of publications on the topic (Carneiro, Lins, & Neto, 2012a, 2012b; Checcucci, Pereira, & de Amorim, 2011). According to Andrade and Ruschel (2009b), based on data up to 2009, research on the topic is limited to architecture firms that focus on BIM for the design process, whereas case studies on design and construction, client benefits and the use of the platform by other industries in the sector's production chain are not approached consistently.

Thus, the objectives of this article are to evaluate Brazilian publications on BIM in journals and national and international events; to analyze these publications using bibliometric indicators; and to characterize them to identify the topics that are the most frequently addressed, the potentials and difficulties in the use of the technology and the existing gaps for future studies.

MATERIALS AND METHODS

The development of this investigation began as a critical literature review for the purpose of identifying, evaluating and interpreting the existing scientific production. During the bibliographic review, the following criteria for delimitation of the study were established: only publications related to the topic of BIM authored by Brazilian authors were reviewed; the publications could be national or international, in conferences and indexed journals as well as master's theses and doctoral dissertations; and only the scientific production from 2007 to 2015 was considered. The following search terms were used: "BIM", "Building Information Modeling", "Interoperabilidade [Interoperability]", "3D", "4D", "5D", "6D" and "7D". These terms had to appear in the abstract, title or keyword fields.

A total of 190 academic publications were collected following the adopted criteria. These works were archived, and their data were extracted and processed for content analysis. The categorization of the topics was addressed as well as the identification of gaps, with the goal of improving the Brazilian state of the art and delineating strategies for future investigations.

In addition to this approach, this study analyzed the publications using bibliometric indicators, organizing them into graphs and tables. The following bibliometric indicators were used: distribution by year, distribution by author, distribution by university and publishing regions.

It is important to note that this study reviewed the most relevant conferences and journals as well as theses and dissertations from the collections of the universities of University of São Paulo (USP) and State University of Campinas (UNICAMP), which could be complemented by the bibliometric analysis of Machado, Ruschel, and Scheer (2016), who collected 353 bibliographic sources about the topic at hand.

Works from international authors were also researched and are cited throughout the study to characterize the BIM concepts and processes and to identify the topics that have not yet been discussed in Brazilian articles.

-- Characterization of the Consulted Sources --

The national sources consulted, such as conferences, journals and theses and dissertations, are shown in **Table 1**. In total, 162 works published in Brazil were consulted.

Sources		Number of publications
Conferences	TIC[a] (2007; 2009; 2011, 2015)	70
	ENTAC[b] (2008; 2010; 2012; 2014)	46
	SBQP and TIC (2013)	17
	SBQP[c] and WBGPPCE (2011)	7
	ENEGEP[d] (2015)	3
	WBGPPCE[e] (2007)	1
Journals	Ambiente Construído (2013; 2014; 2015)	8
Theses and dissertations	USP[f] (2007; 2012; 2013; 2014; 2015)	6
	UNICAMP[g] (2012; 2014; 2015)	4
Total number of publications		162

a. Encontro de Tecnologia de Informação Comunicação na Construção Civil [Meeting on Information and Communication Technology in Civil Construction]
b. Encontro Nacional de Tecnologia do Ambiente Construído [National Meeting on Constructed Environment Technology]
c. Simpósio Brasileiro de Qualidade do Projeto no Ambiente Construído [Brazilian Symposium on Constructed Environment Project Quality]
d. Encontro Nacional De Engenharia De Produção [National Meeting on Production Engineering]
e. Workshop Brasileiro de Gestão do Processo de Projeto na Construção de Edifícios [Brazilian Workshop on Design Process Management in Building Construction]
f. Universidade de São Paulo [University of São Paulo]
g. Universidade Estadual de Campinas [State University of Campinas]

TABLE 01. Brazilian Publications in Brazilian Events, Journals and Universities

Sources		Number of publications
Conferences	ICCCBE[a] (2011; 2014; 2015)	5
	IGLC[b] (2011; 2012; 2013)	4
	BIC[c] (2015)	3
	ELECS[d] (2013)	1
	ICCSEE[e] (2009)	1
	CIB[f] W102(2009)	1
	EuroNoise[g] (2012)	1
	BS[h] (2013)	1
Journals	IFIP Advances in Information and Communication Technology (2014; 2015)	5
	Innovations and Advances in Computer Sciences and Engineering (2010)	2
	Simulation Series (2013)	1
	Advanced Techniques in Computing Sciences and Software Engineering (2010)	1
	Green Design, Materials and Manufacturing Processes (2013)	1
	Innovative Developments in Design and Manufacturing–Advanced Research in Virtual and Rapid Prototyping (2010)	1
Total number of publications		28

a. International Conference on Computing in Civil and Building Engineering
b. Conference of the International Group for Lean Construction
c. Bim International Conference
d. Encontro Latinoamericano de Edificações e Comunidades Sustentáveis [Latin American Meeting on Sustainable Buildings and Communities]
e. International Conference on Civil, Structural and Environmental Engineering Computing
f. Conseil International du Bâtiment W102 Conference
g. European Congress and Exposition on Noise Control Engineering
h. Conference of International Building Performance Simulation Association.

TABLE 02. Brazilian Publications in International Events and Journals

Regarding international sources, the search was conducted in the "Engineering Village" indexed research site (Corrêa & Santos, 2015) in the Compendex® database. As shown in **Table 2**, the Brazilian production in the international stage is scarce, with only 28 publications found.

BIBLIOMETRIC ANALYSIS RESULTS

--- Publication Distribution by Year ---

The analysis of the publication distribution by year indicator demonstrates a gradual increase in the Brazilian scientific production on BIM. According to **Figure 1**, in 2007, the first year of the period considered in this study, only four publications are identified, corresponding to 2.1% of the total, whereas in 2015, which is the year with the largest number of works, the number of publications is 61, or 32.1% of the total. It is also important to note that, starting in 2011, there is a significant increase in production, indicating a growing number of Brazilian studies on the topic.

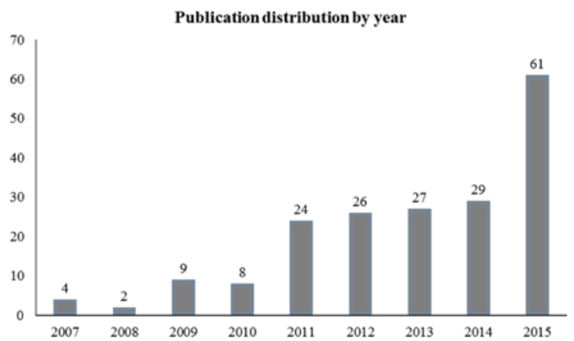

FIGURE 01. Publication distribution by year

One of the probable causes for the increased number of studies on the topic of BIM is the growing use of the platform by the Brazilian civil construction market (Barbosa & Carvalho, 2012). The adoption of BIM, essentially for three-dimensional (3D) modeling, detailing, documentation (Hippert & Araújo, 2010), project visibility and conflict verification (Chagas, Padilha, & Teixeira, 2015), may also be a motivation for the development of research in other areas.

-- Publication Distribution by Universities and Regions --

Analyzing the Brazilian production by universities, 38 different universities are counted, with 34 being Brazilian and four foreign. According to **Table 3**, USP contributes with the most publications (50 studies), representing 21.9% of the total. The second, third and fourth places are occupied by UNICAMP, with 26 publications; UFPR, with 19 publications; and UFBA, with 15 publications, respectively. Together, these four universities represent 51.4% of the national production.

University	Number of publications	Percentage
University of São Paulo (USP)	50	23.4%
State University of Campinas (UNICAMP)	26	12.1%
Federal University of Paraná (UFPR)	19	8.9%
Federal University of Bahia (UFBA)	15	7.0%
Federal University of Ceará (UFC)	12	5.6%
Federal University of Rio Grande do Sul (UFRGS)	10	4.7%
Federal University of Rio de Janeiro (UFRJ)	8	3.7%
Federal University of Pernambuco (UFPE)	8	3.7%
Fluminense Federal University (UFF)	6	2.8%
Others	60	28.0%

TABLE 03. Number of Publications by University

The universities listed as "Others" in **Table 3** have between one and five publications, and they correspond to 28% of the total. This group comprises 29 institutions, with the following four being foreign universities: Technion in Israel, Carleton University in Canada, Tamil Nadu Open University in India and the University of Lisbon in Portugal. Among the publications listed in **Table 3,** 22 are developed as collaborations between universities, with the following international collaborations standing out: USP, Technion and Tamil Nadu Open University (Manzione, Abaurre, Melhado, Berlo, & Sacks, 2011); the Federal University of Campina Grande and Carleton University (Freire, Wang, & Wainer, 2013); and UFPE, UNICAMP and the University of Lisbon (Beirão, Mendes, & Celani, 2015).

This study also investigates the publication distribution by Brazilian state, as shown in **Figure 2**, and finds that the state that produced the most on the topic of BIM is São Paulo, with 86 works. In second place is Paraná, with 27 publications, followed by Bahia, with 15, and Rio Grande do Sul, with 14. The analysis indicates that the southeastern region (composed of the states of São Paulo, Rio de Janeiro, Minas Gerais and Espírito Santo) has contributed the most to the Brazilian scientific production, with 109 works. This finding may be associated with the greater number of higher education institutions in the region, better infrastructure, and even the greater demand for research in the area due to the needs of the civil construction market, which is more developed in that region of Brazil.

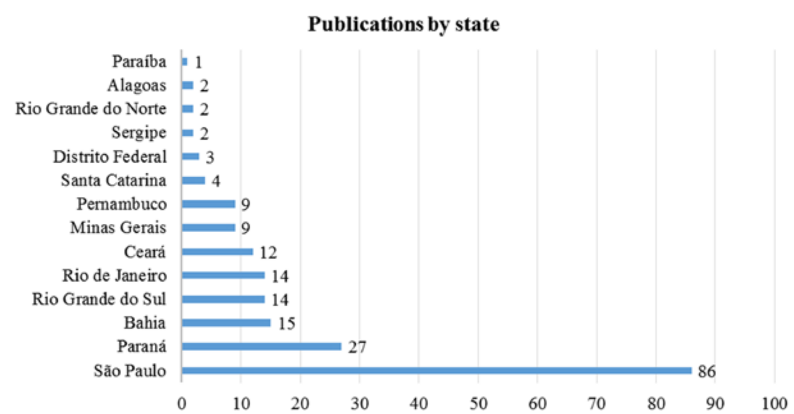

FIGURE 02. Publication by state

--- Publication Distribution by Author ---

The author count reveals that 259 different authors have published on BIM, representing 0.733 articles per author when calculating a simple average for the total number of reviewed articles. Of these authors, 207 authors only authored one publication. **Table 4** lists the 10 authors who have published the most on this topic. The number of publications refers to the works in which the researchers participated as authors or co-authors. The main researcher is E. T. Santos, who is affiliated with the faculty of the Polytechnic School of USP, with 26 publications, corresponding to 14% of the total. This author is followed by R. C. Ruschel, with 20 publications, who is affiliated with UNICAMP, and S. Scheer, with 16 publications, of the Federal University of Paraná (UFPR).

Author	Number of Publications	Percentage %
Santos, E.T. (USP)	26	14%
Ruschel, R. C. (UNICAMP)	20	11%
Scheer, S. (UFPR)	16	8%
Melhado, S. B. (USP)	10	4%
Andrade, M. L. V. X. (UNICAMP)	8	4%
Formoso, C. T. (UFRGS)	7	4%
Isatto, E. L. (UFRGS)	7	4%
Mendes Junior, R. (UFPR)	7	4%
Amorim, A. L. (UFBA)	7	4%
Barros Neto, J. P. (UFC)	7	4%

TABLE 04. Number of Publications by Author

CRITICAL LITERATURE REVIEW

Given its wide approach throughout the building's life cycle, BIM can be characterized by dimensions, known as 3D, 4D, 5D, 6D and 7D (Czmoch & Pękala, 2014; Simões, 2012). After an extensive bibliographic review, it is found that this classification scheme would not be adequate for the classification of the Brazilian literature because several publications do not fit the existing dimensions. Therefore, based on the terms and approaches identified after an extensive study of the subject, this study groups the publications according to the topics shown in **Table 5**, with 26 articles simultaneously classified into two categories, given that they fit into more than one area.

The classification of the publications, described below, demonstrates that most Brazilian articles focus on matters of process implementation, with 63 publications, as well as modeling, design and documentation, with 53 publications. The least researched areas

Publications		Number of publications
BIM Implementation and Processes	(Abaurre, 2014; Addor & Santos, 2014, 2015; Andrade & Amorim, 2011; Andrade & Ruschel, 2009; Baldauf, Formoso, & Miron, 2013; Barbosa & Carvalho, 2012; Barison & Santos, 2011; Bastos, Fonseca, Gomes, & Santos, 2011; Carneiro et al., 2012a, 2012b; Chagas et al., 2015; Checcucci et al., 2011; Coelho, Farssura, & Melhado, 2015; Cornetet & Florio, 2015; Crespo & Ruschel, 2007; Cunha, Santos, & Salgado, 2015; Dantas Filho et al., 2015; de Paula, Uechi, & Melhado, 2013; Delatorre & Santos, 2014; Dias & Arantes, 2015; Durante, Mendes, Scheer, & Garrido, 2015; Farina & Coelho, 2015; Fernandes & González, 2014; Ferreira & Weber, 2015; Florio, 2007; Furukawa & Arantes, 2015; Lima, Albuquerque, Pereira, & Melhado, 2014; Lima, Costa, & Paula, 2011; Maciel, Oliveira, & Santos, 2013; Maciel, Oliveira, & Santos, 2014; Manzione & Melhado, 2014; Menezes, Viana, Pereira, & Palhares, 2013; Mota & Neto, 2012; Nome, Cabizuca, Goulart, Pereira, & Pereira, 2010; Pereira & Amorim, 2013; Permonian & Neto, 2015; Rabelo, Lyrio Filho, & Amorim, 2008; Ribeiro, Silva, & Lima, 2010; Romcy, Cardoso, Bertini, Paes, & Rodrigues, 2012; Romero & Andery, 2010; Romero & Scheer, 2009; Santos, 2009; Santos, Vendrametto, González, & Correia, 2015a; Santos, Vendrametto, González, & Correia, 2015b; Scheer, Ito, Ayres Filho, Azuma, & Beber, 2007; Shigaki, Ozório, & Hirota, 2012; Silva & Amorim, 2011; Silva & Carreiro, 2015; Silva, Coelho, & Morais, 2013; Ruschel, Andrade, Sales, & Morais, 2011; Ruschel & Fabricio, 2008; Santos et al., 2014; Simões, 2012)	63
Interoperability	(Carvalho & Scheer, 2011; Corrêa, Ferreira, Neto, & Santos, 2012; Corrêa & Santos, 2013; Domingues & Oliveira, 2015; Ferrari, Silva, & Lima, 2010; Ayres & Scheer, 2009; Furukawa & Arantes, 2015; Valente et al., 2011)	8
Time Management	(Andrade, Assis, & Brochardt, 2015; Araújo, Nome, Pinto, & Fernandes, 2012; Biotto, Formoso, & Isatto, 2012, 2013, 2015; Boszczowski & Trento, 2015; Brito & Ferreira, 2015; Campos, Júnior, Carvalho, Vasconcelos, & Neto, 2012; Ferreira, Matos, & Garcia, 2012; Fouquet & Serra, 2011; Garrido, Guarda, Mendes, & Campestrini, 2013; Garrido, Mendes, Scheer, & Campestrini, 2015; Garro, Ishihata, & Santos, 2013; Leão, Isatto, & Formos, 2014; Mendes, Cleto, & Garrido, 2014; Mendes, Scheer, Garrido, & Campestrini, 2014; Mendes, Scheer, Santos, Paula, & Gouvêa, 2013; Nascimento, Biz , Freitas, & Scheer, 2011; Scheer, Mendes, Campestrini, & Garrido, 2014; Witicovski & Scheer, 2011)	22
Cost and Viability Management	(Andrade & Matsunanga, 2014; Bassette, Morais, & Ruschel, 2012; Campos et al., 2012; Costa & Serra, 2014; Guerretta & Santos, 2015; Lima, Naveiro, & Duarte, 2012; Lima, Naveiro, & Lima, 2013; Lima, Silva, Morais, & Ruschel, 2012; Mendes, Cleto, et al., 2014; Mendes, Scheer, et al., 2014; Mendes et al., 2013;	16
	Morais, Granja, & Ruschel, 2013; Nascimento et al., 2011; Scheer et al., 2014; Soares & Amorim, 2012; Suzuki & Santos, 2015)	
Facilities Operation, Maintenance and Management	(Araújo, Hippert, & Abdalla, 2011; Bastian, 2015; Carvalho & Scheer, 2015; Junior & Padilha, 2015; Kehl, Siviero, & Isatto, 2011; Sales & Ruschel, 2014; Teles, 2015) Melhado, 2015; Sombra, Correia, & Neto, 2011; Souza et al., 2012, 2013; Souza, Lyrio Filho, & Amorim, 2009; Stehling & Ruschel, 2015; Stehling & Arantes, 2013; Uechi et al., 2013)	7
Modeling, Design and Documentation	(Addor & Santos, 2014; Andrade & Ruschel, 2009a, 2009b, 2011; Baldauf et al., 2013; Brígitte & Ruschel, 2013; Calixto, Morais, & Ruschel, 2015; Campos, 2014; Costa, Staut, & Ilha, 2014; Crespo & Ruschel, 2007; Cunha et al., 2015; Dantas Filho et al., 2015; de Paula et al., 2013; Debs & Ferreira, 2012, 2014; Delatorre & Santos, 2015; Fernandes & González, 2014; Ferreira, 2007; Freire et al., 2013; Gaspar & Manzione, 2015; Groetelaars & Amorim, 2011; Hippert & Araújo, 2010; Junior & Padilha, 2015; Kater & Ruschel, 2014; Kehl & Isatto, 2015; Mendes, 2012; Mendes & Santos, 2011; Menegotto, 2012; Michaud & Neto, 2014; Monteiro, Ferreira, & Santos, 2009; Monteiro & Matias, 2015; Moreira, Silva, & Lima, 2010; Neto, 2014; Neto & Ruschel, 2015; Neto & Santos, 2015; Oliveira, 2009; Paiva, Diógenes, & Cardoso, 2015; Paula, Silva, & Melhado, 2014; Pergher, Freitas, & Scheer, 2013; Rabelo et al., 2008; Romcy, Cardoso, Bertini, & Paes, 2014; Santos, Vendrametto, & González, 2014; Santos, Vendrametto, González, & Neto, 2014; Scheer & Ayres Filho, 2009; Schneck, Kern, Mancio, González, & Hehn, 2012; Silva, Salgado, & Silva, 2015; Tonissi, Goes, & Santos, 2011; Uechi et al., 2013; Valente, Sales, Kater, & Ruschel, 2011; Xavier & Silva, 2013; Ywashima & Ilha, 2010)	53
Teaching	(Araújo, 2011; Barison & Santos, 2011; Barison & Santos, 2014a, 2014b; Beirão et al., 2015; Brito, Kehl, Isatto, & Formoso, 2011; Nascimento, Cardoso, & Borges, 2014; Natumi, 2013; Rêgo & Carreiro, 2015; Romcy, Tinoco, & Cardoso, 2015; Ruschel, Andrade, &	17
Life Cycle Analysis and Energy, Thermal and Acoustic Analyses	(Araújo et al., 2012; Bohrer, Mattana, Silva, & Librelotto, 2015; Brígitte & Ruschel, 2013; Ferrari et al., 2010; Ferreira, 2015; Ferreira, Baracat, & Kurokawa, 2014; Freire & Amorim, 2011; Freire, Tahara, & Amorim, 2012; Graf, Marcos, Tavares, & Scheer, 2012; Marcos, 2015; Marcos & Tavares, 2013; Marcos & Yoshioka, 2015; Mattana, Boher, Librelotto, & Silva, 2015; Oliveira, Scheer, & Tavares, 2015; Paula et al., 2014; Pinha & Moura, 2012; Pires, González, Roos, Brenner, & Kern, 2012; Rodrigues, 2015; Simões, 2012; Tahara, Freire, & Amorim, 2013; Valente et al., 2011)	22
City Information Modeling (CIM)	(Almeida & Andrade, 2015; Amorim, 2015; Bastian, 2015; Beirão et al., 2015; Cavalcanti & Souza, 2015; Corrêa & Santos, 2015; Pereira Filho & Serra, 2015)	7

TABLE 05. Definitions of the BIM Topics and Classification of the Brazilian Articles

are Facilities operation, maintenance and management and City Information Modeling (CIM), with seven publications each.

--- BIM Implementation and Processes ---

The construction process in Brazil is linear and consists of the hiring of an architect and other designers by the owner as well as project coordination by the owner or a specific company to which this task is delegated, sending the designs in two-dimensional (2D) printed documentation to the construction site, which will be the responsibility of a construction company that may be hired at any point during the process (Addor & Santos, 2013). Adopting construction simulation practices in a virtual environment (Azhar, 2011) impacts the entire production process, given that BIM cannot be treated as only a software tool but as a collaborative process (Eadie, Browne, Odeyinka, McKeown, & McNiff, 2013) between the stakeholders, expanding the organizational borders and improving the project's organizational performance during the design and construction phase (Arayici, Coates, Koskela, Kagioglou, Usher, & O'Reilly ,2011), thus allowing work based on the principles of concurrent engineering (Andrade & Amorim, 2011; Pretti, 2013).

Although BIM is a reality in various countries, a large portion of Brazilian civil construction industry professionals are ignorant about or have not had contact with BIM software (Menezes, Viana, Pereira, & Palhares, 2013). In the city of Rio de Janeiro, for example, Rabelo, Lyrio Filho and Amorim (2008) find that only 15% of all architecture firms employ the BIM modeling process. Although there is generally some interest by the design teams to adopt BIM (Lima, Albuquerque, Pereira, & Melhado, 2014), even where the platform was adopted, its use as a process rather than as only a tool is infrequent (Andrade & Amorim, 2011; Maciel, Oliveira & Santos, 2013). The lack of integration between design and production, which could have been facilitated by the use of BIM, contributes to the occurrence of design errors, reworking, delays and time and material waste (Fernandes & González, 2014).

The studies describe that architecture and engineering firms, as well as other Brazilian civil construction companies, adopt BIM due to the following factors: 3D modeling (Barbosa & Carvalho, 2012; Ferreira & Weber, 2015; Hippert & Araújo, 2010; Monteiro & Matias, 2015), project visibility and error reduction, a reduction in the time spent on production and delivery (Chagas et al., 2015; Mota & Neto, 2012; Souza, Lyrio Filho, & Amorim, 2009), harmonization and interferences due to conflicts (Chagas et al., 2015; Dantas Filho, Borges, Soares, Souza, Guerra, & Cardoso, 2015; Ferreira & Weber, 2015; Monteiro & Matias, 2015; Mota & Neto, 2012; Permonian & Neto, 2015; Stehling & Arantes, 2013), detailing and the generation of simultaneous blueprints (Barbosa & Carvalho, 2012; Hippert & Araújo, 2010; Permonian & Neto, 2015), the facilitation of design modification, higher design quality, the improved design presentation to the client (Souza et al., 2009) and a reduction in reworking (Mota & Neto, 2012).

According to Delatorre and Santos (2014), the implementation of BIM follows certain patterns, always beginning with the motivation of the board of directors who sponsors the project and imposes the process, followed by the training of a specific team and the development of a pilot design by that team. The authors emphasize that the ability to use the software is a requirement for the subsequent hires. Souza et al. (2013) discuss the management of the BIM design process, presenting the "Guide for Design Process Coordination in the Modeling Context", whose goal is to establish the project coordinator's responsibilities and to structure the planning, organization and information flow control tasks. Thus, the recommendations for the implementation of BIM found in the researched literature include: hiring a technology specialist (Souza et al., 2012); choosing one or more pilot enterprises that will be developed by a qualified team (Souza et al., 2012); instituting a BIM manager for the implementation project who is knowledgeable and experienced in the processes, construction systems and information technology to be implemented (Souza et al., 2009, 2012); elaborating a needs program (Manzione & Melhado, 2014); organizing the design process and information flow (Manzione et al., 2011; Romero & Scheer, 2009; Souza et al., 2013); and defining a common data language (Nascimento, Biz, Freitas & Scheer, 2011). Shigaki, Ozório and Hirota (2012) describe periodic multidisciplinary meetings and external viewers, such as users and consultants, as process facilitators. Andrade and Ruschel (2011) highlight the collaborative design practices between engineers and architects.

According to Addor and Santos (2013), the communication activities and coordination processes, analysis and design meetings in BIM are different from their traditional counterparts. In other publications, the same authors propose optimized and iterative configurations for the infrastructure of design coordination rooms (Addor & Santos, 2013) and meeting rooms (Addor & Santos, 2014a, 2014b) based on BIM processes, and they present criteria for evaluating the quality of their layouts (Addor & Santos, 2015).

The difficulties in the implementation of BIM that have been encountered in Brazil include the following: the lack of trained professionals; the time investment required for technology implementation; the lack of partners and other designers who use the platform (Chagas et al., 2015; Hippert & Araújo, 2010; Lima et al., 2014; Maciel et al., 2014; Morais, Granja & Ruschel, 2013; Silva, Coelho, & Melhado, 2015); the high cost of software and hardware (Chagas et al., 2015; Garro, Ishihata & Santos, 2013; Maciel et al., 2014; Permonian & Neto, 2015); the absence of incentives and training by the companies; the lack of initiative by the professionals (Permonian & Neto, 2015; Silva & Coelho et al., 2015); the reluctance to change (Delatorre & Santos, 2014; Silva & Coelho et al., 2015); the inexistence of templates with Brazilian standards and nomenclature (Garro et al., 2013; Lima et al., 2014) and guidelines for model preparation (Kater & Ruschel, 2014); legal, contractual and authorship issues (Abaurre, 2014; Souza et al., 2013); the lack of contribution by suppliers to the modeled objects (Sombra, Correia & Neto, 2011; Souza et al., 2013); and the lack of absorption and demand by the market (Maciel et al., 2013, 2014; Souza et al., 2009). Other obstacles found in the Brazilian literature are the lack of interoperability between software packages; the fragmentation of the design process (Maciel et al., 2013; Nascimento et al., 2011; Silva & Coelho et al., 2015), which prevents interaction among those involved in the project; and the absence of result feedback practices (Garro et al., 2013).

The publications analyzed reveal that most authors analyze the implementation of BIM in Brazilian architecture and engineering firms, construction companies and real estate development companies (Barbosa & Carvalho, 2012; Chagas et al., 2015; Coelho, Farssura, & Melhado, 2015; Cornetet & Florio, 2015; Dantas Filho et al., 2015; Dias & Arantes, 2015; Durante et al., 2015; Hippert & Araújo, 2010; Lima et al., 2014; Menezes et al., 2013; Moreira, Silva & Lima, 2010; Mota & Neto, 2012; Permonian & Neto, 2015; Souza et al., 2009), whereas the studies by Romero and Scheer (2009), Nascimento et al. (2011) and Menezes et al. (2013) analyze the use of BIM by public entities for issuing permits, taxation or project development. The study by Stehling and Ruschel (2015), in turn, observes the platform implementation process in a modular furniture factory. It is important to highlight the study by Manzione and Melhado (2014), who propose four references for determining the level of maturity of the design process using BIM, broadening the concept of level of detail (Delatorre & Santos, 2015; Trani, Cassano, Todaro, & Bossi, 2015) currently in effect in the "BIM world".

--- Modeling, Design and Documentation ---

Projects require multidisciplinary teams, with specialists in various areas involved in the enterprises throughout their life cycles, including builders and operators (Souza et al., 2012). Given that, in the Brazilian reality, projects are developed in parallel by the different professionals involved (Michaud & Neto, 2014; Ywashima & Ilha, 2010) and given that the use of BIM processes is incipient, especially in mechanical, plumbing and electrical projects, the multidisciplinary nature and harmonization of the disciplines are hindrances to the process (Addor & Santos, 2013; Michaud & Neto, 2014), and the final design solution may not be the most adequate (Ywashima & Ilha, 2010).

This study finds many works that focus on the topic of modeling, design and documentation, reflecting the Brazilian reality in which BIM is adopted essentially for these purposes. However, most works perform literature reviews (Andrade & Ruschel, 2011; Costa & Serra, 2014; Crespo & Ruschel, 2007; Debs & Ferreira, 2012; Hippert & Araújo, 2010; Lima, Naveiro, & Duarte, 2012; Michaud & Neto, 2014; Silva & Amorim, 2011; Ywashima & Ilha, 2010) on the topic, leading us to describe only publications with significant contributions to the topic at hand. Using the BIM classification model of supermodeling, metamodeling, modeling and micromodeling proposed by Scheer and Ayres Filho (2009), most publications correspond to the level of modeling.

Works on this topic include the simulation by Tonissi et al. (2011), who conduct a case study by elaborating a 3D model containing the disciplines of architecture, structure, plumbing and air-conditioning and by performing a comparative, quantitative and qualitative critique of the conflict analysis methods in the traditional 2D method and the BIM model. The authors conclude that the conflict detection in the BIM model is 78.7% higher than that with the traditional 2D tool.

Some studies tackle questions about customization, improvements or integration in BIM applications. For example, Menegotto (2012) developed an application, programmed for the BIM graphics environment, with the goal of assisting designers during the design of kinetic facades, essentially during the stages of visual simulation of movement patterns, demonstrating that the BIM tool is efficient for obtaining dynamic architecture element simulations. Romcy et al. (2012) create a plug-in that automatically generates layouts of ceramic blocks following pre-established parameters through the concepts of modular coordination. Mendes and Santos (2011) construct a program for residential real estate sales that consists of the presentation of an interactive environment developed in virtual reality based on the BIM model and presented by stereoscopic projection, called Maquete Virtual Interativa (Virtual Interactive Model, MVI). In addition to these studies, it is important to highlight the research by Kater and Ruschel (2014), who implement a proposal for automatic parametric rule verification in a BIM model to verify the compliance with fire safety standards, as well as the research by Pergher et al. (2013), who establish the criteria for a basic checklist for design and modeling in the pre-project stage, based on Lean Thinking (Womack & Jones, 2010).

Kehl and Isatto (2015) and Neto and Santos (2015) simulate the automatic verification of project requirements for a BIM model through the input of rules into the Solibri Model Checker software. Kehl and Isatto (2015) identify problems of harmonization and qualitative rules inquiry, but the software is found to be efficient for the automatic verification of quantitative rules.

Studies based on simulations of the BIM functionalities are also identified, such as the study by Monteiro et al. (2009), who perform experiments to compare the representation of the wall element from block and wall families, comparing the advantages and limitations of each functionality, as well as the work by Debs and Ferreira (2012), based on the study of the characteristics of a pre-fabricated architectural concrete panel, which must be considered and parameterized in BIM models. Campos (2014) also simulates several virtual scenarios in the construction of subsidized housing in light steel frame, validating that BIM aids in design decision making and planning and reduces costs and material quantities. Neto and Ruschel (2015) develop a plywood formwork components library for reinforced concrete in the Autodesk® Revit® Architecture software and through a simulation in the Autodesk® Navisworks® Simulatesoftware (Arayici et al., 2011), they incorporate these components into construction planning. Monteiro and Matias (2015) compare the functionalities of two BIM tools, Autodesk® Revit® and Graphisoft® Archicad (Design Builder, 2016).

Few publications tackle the topic of "building systems", as shown by the literature review by Costa et al. (2014), who indicate the great need for research on this topic. However, it is worth highlighting the study by Guerretta and Santos (2015), who demonstrate building systems modeling for the harmonization and extraction of quantitative information on materials.

--- Teaching ---

The teaching of BIM processes in Brazil is fragmented and comprehends only a specific phase of the building life cycle (Andrade & Ruschel, 2011), considering BIM to be a tool and essentially addressing matters of modeling. The work by Ruschel Andrade, Sales and Morais (2011) rectifies this assertion, comparing the implementation of BIM in three architecture and civil engineering schools in Brazil with two international schools (one from Israel and another from Hong Kong). This study demonstrates that the investigated Brazilian universities implemented and applied BIM at the design and construction level, focusing on 3D modeling, automatic extraction and documentation, conflict detection and planning, whereas in the foreign universities, in addition to during the design and construction phases, BIM is also used in the building operation phase, in thermal and energy efficiency analyses, cost surveying and prototyping.

The difficulty of using BIM software is also observed, even the ignorance of the existence of the platform on the part of students. The study by Rabelo et al. (2008) reveals that only 4.08% of the students at the School of Architecture and Urbanism of the Fluminense Federal University (Universidade Federal Fluminense, UFF) have knowledge of BIM programs. Nascimento et al. (2014) identify that the main difficulties for students in the BIM class in the architecture and urbanism program at the Federal University of Juiz de Fora are the input of information into the programs and finishing a full project using this technology, concluding that such difficulties are consequences of the ignorance of the construction process, management and information technology. It is important to emphasize that many teaching methods instruct on the use of BIM software without discussing how the technology affects the design process (Nome et al., 2010).

A pedagogical experiment performed by Flório (2007) shows that teaching by means of parametric modeling can aid students in understanding the construction components, their associations and their impacts on the development of spaces. Brito et al. (2011) also report an experiment that consisted of elaborating a hypothetical viability study using BIM, exploring the collaborative functionality of the platform, involving Brazilian students and students from universities in three other countries (the United States, Turkey and Israel). The study concludes that, even with the communication challenges and the different techniques and construction standards between the countries, BIM enabled a better understanding of the project for all parties involved. Ruschel and Fabricio (2008) emphasize that the implementation of BIM in the teaching network may stimulate the development of studies, theses and dissertations in the area. Romcy et al. (2015) compare the experiences and repercussions among students after introducing a specific BIM course in the syllabi of two architecture and urbanism programs in Brazilian universities. The main advantages observed by the students are related to the 3D model and the 2D views.

Because BIM has been implemented in a gradual and diverse manner in Brazilian architecture and civil engineering programs (Ruschel et al., 2011), with the intention of aiding professors in the planning of courses with BIM content, Barison and Santos (2014a, 2014b) propose a questionnaire-based online tool for planning courses using BIM. The questionnaires consider the students' knowledge level, the content difficulty and the professor's skills and knowledge. Based on the answers, the tool generates graphs with recommendations for planning the course.

For the implementation of BIM processes to be stimulated in educational institutions, it is necessary for professors to understand the concepts of coordination, integration and collaboration for the practice of the design process and that they review the syllabi (Ruschel et al., 2011).

--- Interoperability ---

Interoperability is based on the exchange of file formats to fulfill the need to transfer data among applications, allowing contributions from various specialties and tasks associated with the design, production and operation of construction projects. To support the interchange of product and object models, data model standards have been developed, with the Industry Foundation Classes (IFC) and CIMsteel Integration Standard Version 2 (CIS/2) being the two main construction data formats (Eastman, Teicholz, Sacks, & Liston, 2014).

Because the use of BIM processes presumes the possibility of managing the different disciplines and intermediaries during the entire building life cycle, the elaboration of an integrated model and the sharing and exchange of information among collaborators imply the need for interoperability between the BIM software packages and the complementary programs (Corrêa et al., 2012; Garrido et al., 2013). Given that interoperability is not restricted to one BIM dimension, it is necessary to treat it as an intrinsic approach to all stages of the process.

This research shows that, although in Brazil the lack of interoperability is a difficulty that is present in projects (Morais et al., 2013), there are few publications that address the issue. Andrade and Ruschel (2009a) compare the interoperability of the main BIM 3D modeling software packages, Autodesk® Revit® and Archicad®, as well as other BIM 3D model viewers (IFC Engine Viewer and Nemetschek IFC Viewer). They conclude that the applications have different classification standards, properties and measurement units for the same objects, that data exchange results in geometric quality loss and that the same model presents different errors in each software package.

Tahara et al. (2013) perform thermal comfort simulations based on a BIM model using the Autodesk® Ecotect® (Araújo et al., 2012) program, comparing the .DXF™ (Araújo, Hippert, & Abdalla, 2011) and .gbXML (Barbosa & Carvalho, 2012) data exchange formats. The authors observe interoperability problems and that both formats recognize the model geometry but not the properties of the construction elements. Carvalho and Scheer (2011) create structural models in the Autodesk® Revit® Architecture and Archicad® software packages. They analyze the import and export processes of the model for the Tekla Structure (Oliveira, 2009), Multiplus Cypecad (Eastman et al., 2014) and Autodesk® Revit® Structures (Araújo, 2011) programs and classify the import/export results as total or partial interoperability.

It is important to also highlight the study by Corrêa et al. (2012), who develop an application that allows for 3D geometric visualization of IFC models and the extraction of quantitative data from these models.

--- Time Management ---

The articles addressing time and planning correspond to the 4D BIM dimension, which promotes the interaction between 3D models and time (Collier & Fischer, 1995; Leinonen & Kähkönen, 2000; Suzuki & Santos, 2015), the course of processes (Tommelein, 2005) and the planning of their elements. The possibility to simulate scenarios, test construction options, analyze incompatibilities and integrate information into a single database provides more options for decision making in production, reduces variability, improves communication between participants (Mendes, Scheer, Garrido, & Campestrini, 2014) and optimizes the sequencing of activities (Eastman et al., 2014).

Ferreira et al. (2012), Biotto et al. (2012), Garrido et al. (2013), Garro et al. (2013) and Biotto et al. (2013) conduct case studies that simulate a building's project phases and the stages and activities of the construction site using BIM. BIM makes it possible to analyze interferences in activities, identify the best attack strategies, establish choices regarding activity flows and transport equipment for possible productivity increases and identify instances of incoherence in the planning performed up to that point. Garrido et al. (2015) also identify the possibility of extracting auxiliary designs, visualizing the model in the building's exact location and inspecting the built environments as BIM benefits. Based on the modeling performed, Biotto et al. (2013) elaborate a production management method that is divided into the following three planning phases: the company preparation stage for implementing BIM and other planning tools; the production management phase, consisting of strategic planning decisions involving production activities and processes, equipment, resources and action plans; and data analysis, decision making and adjustments, which encompass the visualization of the modeled elements.

Mendes, Scheer et al. (2014) and Garrido et al. (2015) present a case study on the interaction between a BIM model and the Last Planner System (Ballard, 2000) for the analysis of planning and production control (PPC) activities. The model aids in the visualization of the process, allowing for the detection of previously unconsidered workloads and the re-planning and review of long-, medium- and short-term plans.

Leão et al. (2014) and Andrade et al. (2015) test the use of BIM at the construction site using tablets. The first study focuses on the analysis of the integrated production control and the quality of the construction project, and the second evaluates and compares the performance and functionality of the programs and equipment.

--- Cost and Viability Management ---

The use of the BIM tool for calculating and managing construction costs does not substitute for the role of a budget officer, but it facilitates the troublesome calculation of quantitative data and the fast visualization, identification and evaluation of the enterprise conditions, providing support for specific budgeting tasks, reducing errors and improving the accuracy and reliability of estimates (Eastman et al., 2014).

The works found in the Brazilian literature include the studies by Soares and Amorim (2012), Lima, Naveiro, & Lima (2013), Mendes et al. (2013) and Andrade and Matsunanga (2014), who address automatic cost estimation calculations based on the geometric characteristics of the building in BIM modeling.

Soares and Amorim (2012) performed simulations at the viability study stage of a commercial enterprise, evaluating the impact of construction typologies on the construction costs using the following two cost calculation methods: cost per square meter of equivalent area and cost per construction element.

Lima et al. (2013) develop a cost calculation method called Geometric Unitary Cost (GUC), which allows for a comparative analysis of the costs of different geometries. These authors develop BIM models from a sample of different projects, and based on a multiple linear regression model, they estimate the costs of these buildings based on their geometries.

Mendes, Cleto, and Garrido (2014) describe a method of extracting information from the BIM model and integrating it into a long-term plan based on the work breakdown and cost compositions data from Sistema Nacional de Pesquisa de Custo e Índices da Construção Civil (National Survey System of Civil Construction Cost and Indices, SINAP). To associate the modeled elements with the planning, two new codes Estrutura Analítica de Projeto (Work Breakdown Structure, WBS) and SINAP are added to the model by means of shared parameters. The method is tested in a real case study.

Andrade and Matsunanga (2014) analyze the desired value for subsidized housing architecture solutions and establish a project method based on the monetization of such requirements. In their study, BIM is described as a suggested auxiliary tool for the extraction of quantitative data and values during the preliminary study. The studies corroborate that the geometric characteristics of the building influence the unit and total costs of execution and that BIM technology has great potential for application in this type of study, mainly by streamlining the comparative process between volumetric variations and construction standards.

Bassette, Morais & Ruschel (2012), Costa and Serra (2014) and Guerretta and Santos (2015) compare the quantitative data surveying process performed using the traditional method with the information extraction product of a BIM model. Although there are differences in the results, the automatic extraction has a considerable degree of reliability (Ballard, 2000; Calixto et al., 2015) and produces cost savings due to the accurate calculation of the amounts of materials required (Guerretta & Santos, 2015).

--- Facilities Operation, Maintenance and Management ---

Given that BIM is founded on an information-rich coordinated model (Eastman et al., 2014), in the civil construction industry, there is interest in the use of BIM in the post-construction phases (Becerik-Gerber, Jazizadeh, Li, & Calis, 2011) of use, operation, maintenance and demolition (Volk et al., 2014) because BIM allows integrated views of the spatial management systems, an overview of the activities (Akcamete, Akinci, & Garrett, 2010), property control, real-time data access and emergency management (Becerik-Gerber et al., 2011). In addition, BIM makes buildings cleaner, safer, more efficient and more economical for the proprietor (Hammond, Nawari, & Walters, 2014).

The Brazilian literature continues to address these subjects in a subtle manner. The study by Sales and Ruschel (2014) portrays the feedback process of a BIM model based on data collected in a post-occupation evaluation. Araújo et al. (2011) analyze the BIM characteristics corresponding to building maintenance tasks, such as the potential for the creation of parameters regarding the maintenance of model elements, which can be used by material suppliers, designers and professionals responsible for maintenance management. In addition to these works, it is important to cite the research by Groetelaars and Amorim (2011), who describe data acquisition techniques and the development of as-built drawings by means of point clouds and analyze case studies that generate BIM models based on those data. Bastian (2015) and Junior and Padilha (2015) experiment with digital ground photogrammetry techniques for the generation of geometric models of an urban section, and they identify some limitations regarding the precision of the digital model.

Carvalho and Scheer (2015) conduct a literature review, indicating authors who discuss the use of BIM in support of waste management activities, and they note the lack of research that quantifies the waste generated in construction activities using BIM technology.

--- Life Cycle Analysis and Energy, Thermal and Acoustic Analysis ---

Simulations and bioclimatic analyses are also products of BIM software or compatible tools (Freire et al., 2012). The Brazilian publications found can be summarized as environmental comfort (lighting, thermal and acoustic) and energy efficiency analyses as well as energy and carbon simulations incorporated into the construction phase.

In BIM digital models, Pinha and Moura (2012) and Pires et al. (2012) simulate lighting and thermal comfort analyses using the Ecotect applications and thermal performance and energy efficiency analyses using the EnergyPlus software (Collier & Fischer, 1995), respectively. They test construction alternatives and evaluate what bioclimatic strategies are the most appropriate for the building in the analysis. Freire et al. (2012) compare six programs – Ecotect , Autodesk® Green Building Studio (Arayici et al., 2011), Energy Plus, Design Builder, Graphisoft EcoDesigner Star (Domingues & Oliveira, 2015) and Autodesk® Project Vasari (Gil, Almeida & Duarte, 2011) – and classify and organize the types of analysis that they enable. Bohrer et al. (2015) analyze the exposure to sunlight of the environments of an institutional building throughout the year using the Archicad® program and identify the spaces and facades with the best lighting performance.

Marcos and Tavares (2013) and Marcos and Yoshioka (2015) perform studies using the Archicad® software, simulating different construction systems based on embodied energy and CO^2 data models, extracting the element loadings and comparing the results. Graf et al. (2012) also use a virtual model created with the Autodesk® Revit® Architecture program, in which embodied energy and carbon information is attributed to the construction elements. It is important to note that neither of these two studies analyzes activities during the post-construction periods. Ferreira (2015) analyzes the EnergyPlus data dictionary and presents a method for the parameter extraction and recognition of low-complexity BIM components, such as windows and doors.

Schneck et al. (2012) study different alterations in a building's volume, seeking the least environmental impact and a reduction in the building's embodied energy; they obtain an architectural approach that reduces the embodied energy by 12.6%. Oliveira et al. (2015) conduct a literature review, surveying studies that analyze the methods of using BIM to evaluate the sustainability of buildings.

CITY INFORMATION MODELING (CIM)

According to Stojanovski (224, p.4), "CIM is an analogy to BIM in urbanism", being the evolution of GIS (Wong & Zhou, 2015) by allowing the 3D representation and establishment of relationships between urban elements. Gil et al. (2011) argue that CIM is equivalent to the BIM concept for urban planning. The articles classified in this category address the use of BIM for the planning, management and monitoring of city development projects.

Amorim (2015) discuss the CIM concept by analyzing other authors' concepts, addressing the view and focus of software manufacturers (Autodesk, Bentley and Esri) and presenting available tools, such as GIS and CityGML. The author highlights that CIM is a digital urban system aimed at planners, designers, builders, operators and city managers. Almeida and Andrade (2015) present a theoretical discussion on the possibilities of integration between the physical and functional data of the building allowed by BIM and urban data through GIS. Pereira Filho and Serra (2015), Corrêa and Santos (2015) and Cavalcanti and Souza (2015) conduct a literature review and indicate references and current efforts for the use of BIM in the urban context.

DISCUSSION AND CONCLUSIONS

This work reviews 190 Brazilian scientific publications that address the topic of BIM in several research areas and contributes to the understanding of the Brazilian state of the art on the topic.

Although BIM has great potential for application in civil construction, the review provided evidence that a great part of the publications are oriented toward literature reviews and case studies that recount implementations in architectural firms and construction companies. The publications report that the Brazilian industry is deficient in the understanding of the concept itself and that BIM has been implemented as a tool, generally in the initial phases of the enterprise's life cycle.

Simultaneously, the analysis identifies that the number of publications on BIM has increased over time. It is also observed that the scientific production is concentrated in the southeastern region, mainly guided by the state of São Paulo. It is important to highlight that the three most published authors are affiliated with the three universities with the largest number of works. It is also important to note that cooperation with foreign universities is scarce and that the increase in international collaboration is one of the challenges for the Brazilian scientific production.

Although the topic has been studied in the context of project coordination and concurrent engineering practices, a lack of discussion on the implementation of the BIM concept throughout the enterprise process and a lack of discussion on the project directives with the use of BIM are observed. The inexistence of research oriented toward legal and contractual matters, such as the development of contract models, model authorship norms, digital certifications, licensing and other public processes, is also highlighted.

Few publications that address the areas of creation and customization of software and libraries are found, demonstrating the need for future studies to encompass the creation of applications and plug-ins, standards and details as well as parameterized libraries for the Brazilian market. The modeling and dimensioning of mechanical, electrical and plumbing (MEP) systems and the multidisciplinary and collaborative process between teams are seldom-studied areas in Brazil.

In the area of teaching, some isolated initiatives for the adoption of BIM are observed, such as the adoption of the platform in some courses or in experiments for a specific class, always linked to the professor's initiative. The need to restructure the syllabi for architecture and engineering courses, so that the design and construction processes are based on BIM technology, is evidenced.

The interaction of the 3D model with the construction stages, with studies oriented toward construction site planning, the reduction of improvisation, waste and re-working and quality control in the construction process, as well as the study of the workflow, are potential topics to be studied.

The interoperability between BIM platforms is seldom discussed, and it requires studies in the areas of data exchange between modeling software packages and planning platforms, the budget, commissioning, maintenance and operation as well as the tools for thermal, energy and acoustic analysis and life cycle analysis databases.

On the topic of facilities operation, maintenance and management with BIM, which is still scarcely researched, the gaps encompass the construction of as-built BIM, space and asset management, maintenance management (preemptive, predictive and corrective), pathological manifestations, systems control and monitoring, retrofitting and demolition management. The Brazilian research deficit in this area has been corroborated by the German literature review by Volk et al. (2014), who investigate the international state of the art on BIM for existing buildings based on 180 international references.

Other challenges are in the area of life cycle analysis and energy, thermal and acoustic analysis, given that dedicated analyses for the Brazilian reality, especially those encompassing carbon emissions, carbon equivalents and energy indices incorporated in the pre- and post-construction phases, the verification of recyclable material indices, the development of new materials, sustainable strategies, environmental certifications and waste management and generation, have yet to be explored.

CIM is one of the least explored topics by Brazilian articles. Studies that address data acquisition, urban infrastructure systems and related services and activities, as well as the interoperability between BIM and GIS, stand out as gaps.

It is important to emphasize that the initiative by public agencies, especially the federal government, as well as the involvement of the institutions representing the intervening parties in the sector's production chain, can contribute to the insertion of BIM on the national stage.

Encouraging the integration between all intervening parties in an enterprise, BIM is a new paradigm for the Brazilian civil construction industry. Improvements in design processes and the quality of their execution and use will be promoted not only with pragmatic and short–term solutions with the use of technology but also through organizational maturity and the evolution of procedures and workflows that unite the platform throughout the entire process. ◆

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