BIM APPLIED TO THE TEACHING OF ARCHITECTURE AND URBANISM DESIGN: AN OVERVIEW OF PEDAGOGICAL PRACTICES

BIM APLICADO AO ENSINO DE PROJETO DE ARQUITETURA E URBANISMO: UM PANORAMA DE PRÁTICAS PEDAGÓGICAS

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Abstract

This article deals with Building Information Modeling (BIM) in the context of teaching architectural and urban design. The main objective is to examine BIM-aided architectural design teaching methods that researchers and professors have published. Through a systematic literature review (SLR), we sought to discuss which changes have been observed in research on design teaching in architecture schools when BIM is explicitly incorporated into the design process. Through the premise that there is a methodology or set of specific methodological practices for teaching design aided by BIM, it is intended to extract the teaching practices and experiments gathered in the CuminCad platform, in which a significant number of academic works are published. This way, a list of didactic approaches to BIM applied in project teaching was extracted to subsidize field research and the experimental practice of project teachers. In the end, five categories of BIM approaches in architectural design were found, which point to some possible paths for teaching architecture and urban design from the perspective of incorporating the BIM paradigm.

Keywords: BIM, teaching, design, process, methodologies.

Resumo

Este artigo versa sobre o *Building Information Modeling* (BIM) no contexto de ensino de projeto de arquitetura e urbanismo. O principal objetivo é examinar os métodos de ensino de projeto de arquitetura auxiliados pelo BIM, que foram publicados por pesquisadores e professores. Através de uma revisão sistemática de literatura (RSL), buscou-se discutir quais mudanças têm sido observadas nas pesquisas a respeito do ensino de projeto nas escolas de arquitetura, quando se incorpora, explicitamente, o BIM no processo projetual. Através da premissa de que existe uma metodologia ou conjunto de práticas metodológicas específicas para o ensino de projeto auxiliado pelo BIM, pretende-se extrair as práticas e experimentos de ensino reunidas no repositório CuminCad, no qual está publicado um conjunto significativo de trabalhos acadêmicos. Dessa forma, foi extraído um rol de abordagens didáticas sobre BIM aplicado no ensino de projeto, de forma a subsidiar pesquisas do campo e a própria prática experimental de professores de projeto. Ao final, foram encontradas cinco categorias de abordagens do BIM no projeto de arquitetura, as quais apontam alguns caminhos possíveis para o ensino de projeto de arquitetura e urbanismo sob uma perspectiva da incorporação do paradigma BIM.

Palavras-chave: *BIM, ensino, projeto, processo, metodologias.*
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Introduction

Building information modeling (BIM) is linked to two main significant changes, with implications for teaching and architectural practice, as stated by Russel and Elger (2008). The first concerns structuring information by software in computer-aided architectural

design (CAAD). The second concerns the professional architect's protagonism in controlling the building's information model. Thus, the discussion of a teaching reform, which, according to Oxman (2006), had already been called for at least two decades, is resumed with the new generation of BIM software. Architecture curricula that still do not understand BIM as the "core of the digital planning process", requiring protagonism of skills and competencies on digital tools for architects and urban planners, will be considered outdated (RUSSEL; ELGER, 2008).

The notion of paradigm has been widely applied to BIM, given that some technological and procedural changes are already consolidating, both in the market and from the point of view of legal requirements (CHECCHUCCI, 2014). That's why, when people talk about incorporating BIM into design processes, there has been a lot of talk about a new paradigm. It should be mentioned that a paradigm can be understood as "the scientific achievements, universally recognized that, for some time, provide modular problems and solutions for a community of practitioners of a science" (KUHN, 2005). The BIM paradigm involves concepts, processes and technologies (EASTMAN *et al.*, 2014). However, the extent and complexity of teaching BIM are still being discussed and researched, as explored by Mizumoto and Oliveira (2020, p. 179), when they proposed that "knowing the organization of the themes found from the keywords opens a way for a pedagogical structuring of BIM".

This article results from research investigating didactic strategies specifically focused on teaching BIM in architectural design. Understanding that the insertion of digital technologies in undergraduate architecture and urbanism courses has been widely carried out since the 1990s and that, according to Mizumoto and Oliveira (2020, p. 180), it is possible to see a polarization of knowledge in this subject, it is also greater "investment in the area of BIM Education, in addition to greater collaboration between institutions". For this study, it was defined as reducing the data collection sample to a single repository, CuminCad. Although the search in other databases could enrich the scope of analysis, the definition is justified in the search for standardization of methodological rigour and the analyzed data. It is also observed that this repository is wide enough to include articles that report research carried out on different continents but preserves homogeneity since it publishes articles published by sister societies that discuss the insertion of digital technologies predominantly in the fields of Architecture, Urbanism and Design.

That is why, given this preamble, it should be mentioned that this article starts from the following question: "What are the pedagogical practices when it comes to teaching architecture and urban design aided by BIM?" The aim is, therefore, to highlight the connections and applications that researchers and professors have seen and tested for BIM in the context of architecture and urban design.

Theoretical foundation

Building Information Modeling (BIM)

The acronym BIM has a set of definitions associated with both tools and processes. According to Eastman *et al.* (2014), the current tooling based on BIM technology results from a prediction estimated two decades ago. However, the authors, who use the term BIM to describe an activity and not an object, point out that BIM will continue to develop and depend on a renewal of workflows and practices in civil construction.

For architects and engineers, BIM is considered revolutionary, as it transforms the way of thinking by replacing a 2D representation with 3D digital models (EASTMAN *et al.*,

2014). For the elaboration of projects, Eastman *et al.* (2014) consider three main points of view on the transformation and impact of BIM specifically on the project:

1) Conceptual project: in which a basic plan of the building is developed, with volumetric data, implementation and basic program in software or BIM platform;

2) Analysis of building systems: measurement operations of physical parameters to be expected from the real object performed in software or BIM platform;

3) Information development: automation of the composition and generation of 2D documentation, which in the future will become obsolete with the complete use of the 3D model of the building as faithful documentation of the building

As a disruptive innovation, there are many challenges in incorporating this "profound change of technical and organizational solutions" that is BIM (LIMA; CATAI; SCHEER, 2021, p. 133). One of the significant differences between BIM and the "current predominant CAD system" is the fact that BIM includes elements never considered before, as the geometry parameters together with a single 3D model that brings together all the information of the built object and the interoperability between software, in addition to a robust parallel discussion on lean construction, sustainability and efficiency in the civil construction sector (ALMEIDA; PICCHI, 2018; SEPASGOZAR *et al.,* 2021; OLAWUMI *et al.,* 2018).

The didactics of the design process aided by BIM

As explored by Ruschel and Cuperschmid (2018), several Brazilian studies focused on possible BIM implementations within the classroom of courses in the areas of Architecture, Engineering and Civil Construction. In their teaching action-research processes, the authors explored the BIM implementation process in specific disciplines through didactic action planning cycles according to the paths suggested by the bibliography, but mainly through carrying out actions with monitoring and reflective activity. Three cycles were systematized: "BIM mediating the collaborative project", "BIM helping project coordination" and "BIM Modeling". Thus, three BIM approaches were compiled and brought together multiple pedagogical strategies.

The first cycle formulated by Ruschel and Cupershmid (2018, p.12184-12195) was developed within the "Integrated and Collaborative Design" discipline and brought the perception of obtaining a dependency between design teams. Consequently, a highly complex design exercise is required for the more significant potential for collaboration. In addition, the composition of teams with external members was experimented with, being able to compose postgraduate students, as well as from other disciplines or courses. The second cycle, consisting of the discipline "Integration of CAD Project", proposed the use of 3D coordination and 4D simulation in which the proposed exercises allowed the integration with several undergraduate disciplines and an experience of integration between two different courses. The third cycle, through the disciplines "Applied Computing: introduction to CAD" and "Computer-aided Project and Design", focused on modeling and the "integrating character of the model with the information and of the model with the documentation". In addition, the didactic proposal was to recreate recognized projects in BIM with great precision and integration with disciplines of the same semester, such as models, developing the dialogue with the 2D CAD documentation suitable for prototyping machines. The transfer of tool learning to the extra-class environment was also experimented with.

When looking specifically at the Brazilian scenario, what is observed is an effort on the part of teachers to change the curriculum, with new alternatives for course programs and curricula; an effort to diversify the design proposal, both in the formation of teams

of students with external members and in the greater specificity of learning objectives; and an effort to reach a more advanced level of design, either with extracurricular learning or with a more qualified and focused teaching team. Thus, several teaching strategies are still to be explored and mapped for greater dissemination of the implementation of BIM in the teaching of architecture and urban design.

According to Vasconcelos and Sperling (2016), there is an inertial movement towards greater computability in the general scenario of civil construction. However, when seeking an overview of design teaching based on the classes of interactions proposed by Oxman (2006 apud VASCONCELOS; SPERLING, 2016) and later worked on by Kotnik (2010) – representational, parametric and algorithmic –, the authors investigated the practices of application of computational technologies in contrast to the old representative methods still seen as predominant in literature and practice. Through a search in Latin American journals, between the years 2000 and 2010, in the CuminCad repository, the authors proceeded to classify experiments in teaching architecture and urbanism that were close to digital technologies. Among the didactic strategies explained are:

> *- Didactic strategy with **Independent Interactions**: articles presented a didactic proposal exploring two interactions in the same discipline but as independent activities.*
>
> *- Didactic strategy with **Mixed Interactions**: articles that present interdependent activities in which the model composition process was established at each moment with a type of interaction*
>
> *- Didactic strategy with **Elective Interactions**: articles that present activities with interactions to be chosen by each participant during their design process (VASCONCELOS; SPERLING, 2016, p. 97, emphasis added).*

Thus, the authors revealed an increase in the dissemination of digital technologies in teaching practices in Latin America. However, such methods are still concentrated in representational disciplines and applications rather than in design studios. However, an expanded search is necessary, given that most of the works analyzed were experimental and the technological advancement of other continents is relevant for understanding the practices of teaching architectural design.

Still in the investigation of research on the universe of teaching BIM for architecture and engineering, Mizumoto and Oliveira (2020, p. 176), using a quantitative method, used to analyze data from the bibliography, carried out a systematic review of the literature with the following concatenation of term: (BIM or Building Information Modeling or Building Information Modelling, Building Information Model) and (Educational or-Education or Teaching or Learning or Course or Curriculum or Training or Construction education or Architectural education). A search on the Web of Science platform in 2019 found 670 publications. Then, through a co-occurrence analysis of keywords, they identified 1833 keywords in common and gathered them into eight subtopics: 1-Building Information Modeling, 2-BIM, 3-Design, 4- Implementation, 5-Technology, 6-Information, 7-Construction, 8-Methodology. The first three themes, with the highest occurrence, became a reference for this research to be guided in a more in-depth selection of publications aimed at a specific reading of design teaching aided by BIM, that is, with a focus on the disciplines of project and not exclusively for graphic representation.

Objective

Based on the above, the objective of this article is to highlight the teaching strategies of BIM applied to the teaching of architecture and urban design, whose results have

been published by sister societies from Europe [eCAADe], North America [ACADIA], Asia /Oceania [CAADRIA] and West Asia/North Africa [ASCAAD]) that discuss the insertion of digital technologies predominantly in the fields of architecture, urbanism and design.

Methodology

Through a systematic literature review with a qualitative and exploratory approach, the teaching strategies of the architecture and urban design process aided (or transformed) by BIM were analyzed. The definition of the research problem was consolidated along with the design of the six aspects described by the taxonomy of Cooper's (1989) literature review. The research focused on practices, applications and research results, and field theories. The objective was to criticize and identify central issues. The researcher's perspective remained neutral. The coverage was sought to be representative. The organization of evidence was conceptual and methodological. The chosen audience was researchers in the field and academics.

The starting point was the search for evidence, which consisted of selecting the database and testing possible keywords and studying the repository's search dynamics. In searching for evidence that responded to the research problem, search terms were determined by selecting articles published in peer-reviewed journals and conferences in the CuminCAD repository. The choice of the repository was based on the methodological approach of the study by Vasconcelos and Sperling (2016) and because it consists of a cumulative index that allows "access, through a searchable index, to conference documents (...) with special attention to the publications on computer-aided design in architecture", which includes records from conference journals such as ACADIA, ASCAAD, CAADRIA, eCAADe, SiGraDi, future CAAD, DDSS and others, with publications dating back to 1970 (MARTENS; TURK, 1999, p. 327); such conferences are of great relevance in recent discussions on design teaching and BIM.

When testing the search terms, the following were listed as the primary keywords: "BIM", "project", "teaching", "architectural", and "design". Given that the platform has English as its base language, all searches were carried out in that language and through the advanced search feature for PDF papers. The choice of terms was based on the repertoire acquired through the narrative review developed in the study to justify the research gap. The terminology "teaching" instead of "education" was chosen due to the more practical scope of the verb "to teach" and its proximity to the notion of methodological practice. This search is described in Chart 1.

Chart 1 – Formatting the search in the CumInCAD repository

Search no.	Search	Applied on records satisfying the word list: (in the title) (containing)					Result
test 1	BIM	"project"	AND	"teaching"			1
test 2	BIM	"teaching"					17
test 3	PROJECT	"teaching"	AND	"BIM"	OR	"building information modeling"	4
test 4	PROJECT	"BIM"	OR	"building information modeling"			89
test 5	TEACHING	"BIM"	OR	"building information modeling"			36
test 6	TEACHING	"project"	AND	"BIM"	OR	"building information modeling"	4
test 7	BIM	"architectural"	AND	"design"			24

Source: the authors.

When searching for the term "Building Information Modeling" alone, the result of 7,201 articles was obtained, demonstrating the need for more than one search term for the feasibility of the research. When placed together directly in the "BIM and Project and Teaching" search engine, 15,375 results were obtained. This did not contribute to an effective filtering and joint appearance of terms in searches, given that the platform

searches for terms anywhere in the article. The exact process was carried out with the terms "BIM", "project", teaching" only separated by commas and between quotation marks, and the result was 1,707 articles, which reaffirmed that the search for words anywhere in the text would still not make this study possible.

Six-step filtering was applied to the advanced search. First, we searched for the word BIM in articles that contained the words "project" and "teaching" in their titles, which resulted in an article as a result. Still, with the search for "BIM" but with titles that contained the word "teaching", 17 articles were found. By changing the search word to "project" and entering titles that include "teaching" and "BIM" or "Building Information Modeling", the result was four articles and, for titles that included at least "BIM" or "Building Information Modeling", 89 articles. With the search word "teaching", 36 articles had "BIM" or "Building Information Modeling" in their title, and only four had both "project" and "BIM" or "Building Information Modeling" in their title. Finally, with the search word "BIM" applied to titles that contain "architectural" and "design", a total of 24 articles were found. In all, 175 articles were framed as part of the results of the first selection. However, filtering again by title was necessary to check the most relevant approaches for this study, as shown in Table 1. For the selections by title, abstract and content, papers that met all or 60% of the requirements were considered, following these inclusion criteria:

1) List the capabilities and skills for developing architectural design in BIM;

2) Consider design teaching methodologies that understand the existence of digital technological innovations;

3) Analyze design processes in BIM;

4) Analyze pedagogical practices for Teaching Architectural Design;

5) Analyze the application of BIM in architectural projects.

Table 1 - Results of the systematic literature review

Search no.	Results	Selection by title	Duplicates removal	Selection by abstract	Selection by content
1	1	1	1	1	-
2	17	16	15	15	10
3	4	4	-	-	-
4	89	48	44	21	10
5	36	32	16	15	9
6	4	4	-	-	-
7	24	18	4	-	-
total	175	123	80	52	29

Source: the authors.

For a better design in the filtering of the articles, the articles that fit the following exclusion criteria were removed

1) Explore design practices not applicable by architects and urban planners;

2) Discuss education and the context of BIM implementation in a secondary way;

3) Report, as a case study, a specific project, not deepening BIM capabilities and skills in a learning context;

4) Discuss BIM implementation barriers in the market alone.

Therefore, 105 articles were selected, through titles, with a reduction to 76, excluding duplicates. Articles appearing in previous searches were considered duplicates, following the order of variation of tests from 1 to 7, shown in Table 1. In the selection by abstract, studies that focused on the labor market or concentrated on teaching

project representation did not fit the above criteria. Thus, the sample was reduced to 52 articles and, with the content analysis, to 29.

After reading all selected articles, the predominant approaches were extracted, grouped into categories, and subdivided into focuses. In this way, we sought to frame the main consensuses among researchers in the area and point out the scenarios of pedagogical experimentation in teaching architecture and urbanism to consolidate the perception of BIM as the new paradigm for the teaching-learning processes of the project of architecture and urbanism. The categorical approach is essential for content analysis (SOUZA; SANTOS, 2020). Therefore, groups of articles with very similar practices indicated some common trends in using BIM within the classroom were gathered using a categorical nomenclature. The classification of articles by focus became necessary for a more generalized subdivision, which would unify the categories more comprehensively and facilitate understanding of the whole.

Results

The theoretical-methodological approaches that guided the BIM implementation experiments in undergraduate and graduate courses were extracted from the selected sample to proceed with the qualitative analysis. The nomenclatures given to the approaches were generated by deeply reading the studies and subsequent extraction of a name that summarized the approach or set of approaches applied in the studies or the authors themselves called the BIM approach. Such approaches were first classified into focuses or main objectives (Chart 2): (i) curriculum, (ii) performance and (iii) project quality; then, they were classified. The curricular objective concentrates on the pedagogical approaches of implantation and implementation of BIM in curricular matrices, either in a broad or specific way. The performance objective concerns pedagogical approaches aimed at the best learning curve or levels of a social and emotional relationship and better coverage of BIM competence levels. Finally, the design quality objective combines the approaches intended to achieve more outstanding design quality from volumetric studies and design analysis (structural, mechanical or technical system performance). It should be noted that all selected articles address BIM as paradigmatic and challenging to implement. For each article, only one predominant focus was considered, defined from the perception of the research authors. However, it should be noted that, sometimes, other focuses can be attributed, in a secondary way, to the same article.

Chart 2 – Summary of common aspects of approaches

Focus	Common Aspects
Curriculum	The objectives of these studies consisted of evaluating the interactions between disciplines that address BIM content within a curriculum, or BIM within a single discipline, either with case studies or with reports of authorial experiments. They analyze "how" and "when" to implement BIM in the curriculum. The "how" related to the format of a discipline, course or experience and the "when" related to the moment of insertion.
Performance	These studies focused on analyzing methodologies and theories of pedagogy aimed at the best learning curve or at levels of social and emotional relationship, as well as better coverage of BIM competence levels that are intertwined with communication, collaboration, and information management skills. It can be said that these works analyze the design process from the perspective of collaborative work.
Project Quality	All studies that focused on evaluating the increase in design quality at levels of greater formal manipulation or on analyzes of the performance of structural, mechanical, or technical systems performing a critical analysis of the design process. These works innovated with specific BIM or BIM-parametric modeling strategies

Source: the authors.

Chart 3 shows six articles framed in the Project Quality focus, 17 in Curriculum and 6 in Performance. This result demonstrates a common trend of BIM investigation in the implementation scenario in curriculum matrices, which is consistent with the initial transition period of many architecture schools to include BIM. However, it was

considered necessary to discriminate, through a categorical nomenclature, the groups of articles with very similar approaches and more clearly indicated the tendencies of visualization and understanding of BIM within the classroom.
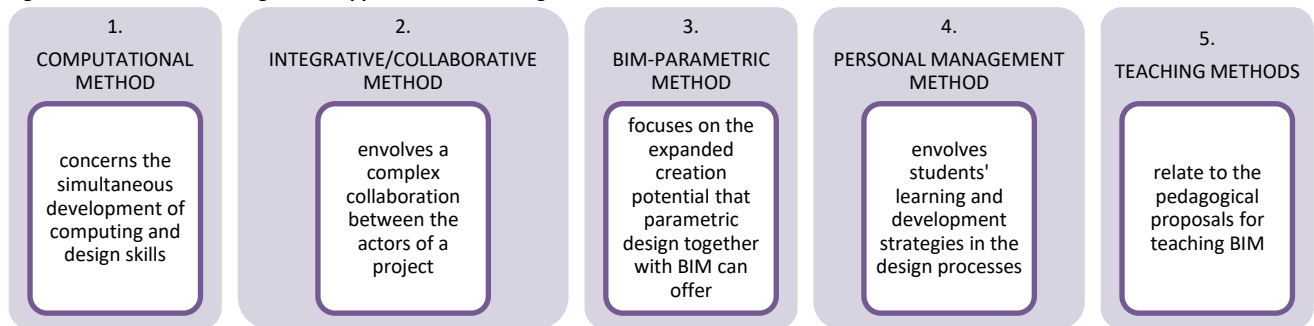
Chart 3 – Theoretical/Methodological approaches found and categorization assigned

Reference	BIM Approaches	Focus	Category/Methodology
Guidera (2006)	Task Specific Computing: Object Modeling Studio	Project quality	Computational
Techel and Nassar (2007)	Segregated-integrative approach	Project quality	Integrative/Collaborative
Vasquez de Velasco and Ângulo (2007)	Multidisciplinary integration	Curriculum	Integrative/Collaborative
Sanguinetti (2009)	An integrated practice	Curriculum	Integrative/Collaborative
Yan (2010)	Parametric design methods	Curriculum	BIM-parametrical
Kang (2010)	BIM class project	Performance	Teaching
Haliburton et al. (2011)	STUDIO 21	Performance	Teaching
Menezes e Pontes (2012)	Modeling made possible by BIM - digital teaching material	Performance	Teaching
Ambrose (2012)	New BIM studio	Project quality	Integrative/Collaborative
Gu and Vries (2012)	Intra and interdisciplinary	Curriculum	Integrative/Collaborative
Zarzycki (2012)	Component-based design	Project quality	BIM-parametrical
Checcucci, Pereira and Amorim (2014)	Integrated approach	Curriculum	Integrative/Collaborative
Boeykens et al. (2013)	BIM as a design methodology	Curriculum	Integrative/Collaborative
Delatorre and Pereira (2014)	BIM by skill level	Curriculum	Integrative/Collaborative
Alwan, Holgate and Jones (2014)	Immersive project-based experience	Curriculum	BIM-parametrical
Delatorre, Pereira and Miotto (2015)	Gradual and integrated insertion	Curriculum	Integrative/Collaborative
Nakapan (2015)	BIM in the first year	Curriculum	Integrative/Collaborative
Vinšová, Achten and Matějovská (2015)	Three levels of curriculum integration	Curriculum	Integrative/Collaborative
Gless, Hailin and Hanser (2018)	Agile methods + BIM-agile coach	Performance	Personal Management
Granero and Calquin (2016)	The project based on personal social skills SEL (Social and Emotional Learning)	Performance	Personal Management
Matejovska et al. (2017)	Individual design studios	Curriculum	Personal Management
Ofluoğlu (2017)	"Design Together" Competition	Curriculum	Personal Management
Cuperschmid and Castriotto (2018)	Blended Learning, B-Learning or Hybrid Learning	Curriculum	Teaching
Isanovic and Çolakoğlu (2018)	Hybrid Learning	Curriculum	Teaching
Modzelewska (2018)	inverted design	Curriculum	BIM-parametrical
Holzer (2019)	Flipped and semi-inverted classroom,	Curriculum	Teaching
Baldessin et al. (2020)	Parametric component system	Project quality	BIM-parametrical
Ponzio et al. (2020)	Parametric design thinking + analog design thinking + BIM strategy = Parametric Morphology Matrix Strategy	Project quality	BIM-parametrical
Vasconcellos, Frison and Cunha (2020)	Self-regulation of learning	Performance	Personal Management

Source: the authors.

We can classify the approaches into five categories, as shown in Figure 1. The above categories are supported by the experiences of Ruschel and Cuperschmid (2018), with the composition of three cycles of systematization of didactic actions in the implementation of BIM in the classroom: "BIM mediating the collaborative project", "BIM helping project coordination" and "BIM Modeling". Categories 1 and 3 communicate directly with the cycle "Modeling in BIM"; categories 2 and 5, with the cycle "BIM mediating the collaborative project"; and category 4, with the cycle "BIM helping project coordination". The "Computing Methods" category refers to a specific approach, that of Guidera.

Figure 1 – Classification categories of approaches to teaching BIM

1. COMPUTATIONAL METHOD	2. INTEGRATIVE/COLLABORATIVE METHOD	3. BIM-PARAMETRIC METHOD	4. PERSONAL MANAGEMENT METHOD	5. TEACHING METHODS
concerns the simultaneous development of computing and design skills	envolves a complex collaboration between the actors of a project	focuses on the expanded creation potential that parametric design together with BIM can offer	envolves students' learning and development strategies in the design processes	relate to the pedagogical proposals for teaching BIM

Source: the authors.

All selected articles meet at least one established inclusion criterion. The articles listed the capabilities and skills for developing an architectural design in BIM, working on design teaching methodologies that understand the existence of digital technology innovations to implement BIM in the classroom, and analysing design processes in BIM or pedagogical practices for Teaching Architecture and Urbanism Design. In this way, it was possible to collect research specifically focused on discussions and experiments around teaching architecture and urban design aided by BIM.

According to Figure 2, it is possible to observe the occurrence of categories by the approach's focus. It should be noted that the category "BIM-parametric method" focused only on curricular and project quality approaches. The "Computational Method" category was worked exclusively under the focus on project quality. The categories of "Teaching Methods" and "Personal Management" both had a curricular and performance focus, and the Integrative/Collaborative Method category had the highest occurrence, with nine studies focusing on the curriculum and two studies focusing on the quality of educational projects.

Figure 2– Categories and their occurrences by focus

Source: the authors.

The Computing Methods Category refers to a specific approach, that of Guidera (2006). In the study by Guidera (2006), article nº1, task-specific computing aims to employ modeling concepts in a design studio's environment but requires the simultaneous development of computing and project (design) skills. For the author, in this way, the BIM skills worked are more focused, and complete knowledge of software is not necessary to complete an exercise. In addition, it has as a learning objective the definition of a relationship between the task and the designed product,

an exciting way of understanding the relationship between the tool in the classroom context.

The "Integrative/Collaborative Methods" encompass the approaches that prioritize the interdisciplinary relationship required by BIM, which involves the development of a complex collaboration between the actors involved. The works included were those by Techel and Nassar (2007), Vasquez de Velasco and Ângulo (2007), Sanguinetti (2009), Ambrose (2012), Gu and Vries (2012), Checcucci, Pereira and Amorim (2014), Boeykens *et al.* (2013), Delatorre and Pereira (2014), Delatorre *et al.* (2015) Nakapan (2015) and Vinšová, Achten and Matějovská (2015). When not called by the authors themselves as an integrated approach in the text, it was possible to understand the nature of the proposal. A highlight should be given to Techel and Nassar (2007, for proposing a segregated-integrative approach to keep the study of topics in separate courses but with cooperation among themselves). The other articles work on BIM as a support tool for design disciplines or "multidisciplinary studios", as worked by Vasquez de Velasco and Ângulo (2007). Ambrose (2012) addresses an exciting inversion, in which the design study begins with a complete and complex building model on which students must work collaboratively beyond a vision centred on the design or the initial phase of a project. Collaboration is reinforced by Boeykens *et al.* (2013), in which they describe two different types of collaboration, the internal one of each team and the team with an external consultant. Part of the didactic content was also explored in a hybrid way, but not as the main objective of the study of the article. Integration occurred not only between knowledge disciplines within the design process but between parts of a curriculum, as worked by Vinšová; Achten and Matějovská (2015), where three levels of integration were proposed throughout graduation.

The main issue addressed in the so-called "BIM-parametric Methods" was the expanded creation potential that parametric design and BIM could provide. The works included were those by Yan (2010), Zarzycki (2012), Alwan; Holgate and Jones (2014), Modzelewska (2018), Baldessin *et al.* (2020) and Ponzio *et al.* (2020). A particular highlight can be given to the article by Ponzio *et al.* (2020), in which the basis for a Parametric Morphological Matrix Strategy is developed. Yan (2010) introduced programming concepts and basic application programming interface (API) scripts, as they are understood as useful in the modeling structure of a BIM object. For Zarzycki (2012) and Baldessin *et al.* (2020), component-based design is defended as innovative, in contrast to the concept-centred design process. Alwan, Holgate and Jones (2014) stand out for focusing on learning through a BIM model developed to "design and acquire sustainable and energy efficient projects" and aligned the contents of climate analysis and mass and solar radiation studies. Modzelewska (2018) works with an "inverted project". However, not how the other articles understood the term. For the author, the "inverted design procedure" is a design process that starts with the 3D spatial form and not with the traditional two-dimensional logic. In this way, there is an introduction to the design in a playful way, aided by BIM software.

For works with a specific and clear emphasis on learning strategies and the student's cognitive/social development in the project processes, the terminology "Personal Management Methods" was created. The articles framed were those by Gless, Hailin and Hanser (2018), Granero and Calquin (2016), Matejovska *et al.* (2017), Ofluoğlu (2017) and Vasconcellos, Frison and Cunha (2020). Gless *et al.* (2018) innovate by exploring management methodologies called "Agile Methods" with the design process; the experiment demonstrated compatibility between the two to inaugurate

an area of multidisciplinary connection with high potential. Granero and Calquin (2016) explore, to the fullest, the personal skills needed in the cooperative architecture environment and experiment with BIM platforms for building integrated skills in the creative, social and technical areas. Matejovska *et al.* (2017) explore individual design, contrary to all other works, to facilitate the learning curve. Ofluoğlu (2017) inaugurated a competition called "Design Together" and reaps results ranging from an experience similar to "real life" to a high acceptance rate of students who considered the collective helpful work to understand the roles of the stakeholders and potential problems of the project. Finally, Vasconcellos, Frison and Cunha (2020) specifically focus on the so-called "self-regulation of learning" as a multidimensional process that directly connects with students' success in the BIM learning curve. BIM modeling was seen as a regulator of learning, increasing, according to the authors, the "mastery of the academic ability to design".

A range of studies turned to pedagogical approaches to teaching BIM and was called "Teaching Methods". The articles framed were those by Kang (2010), Haliburton *et al.* (2011), Menezes and Pontes (2012), Checcucci, Pereira and Amorim (2014), Isanovic and Çolakoğlu (2018), Cuperschmid and Castriotto (2018) and Holzer (2019). Kang (2010) uses BIM in explaining and presenting a project, including a wide range of tools; its primary objectives revolve around the engagement of students in the classroom and the appreciation of an experience close to the reality of real projects. Haliburton *et al.* (2011) brought a design studio dynamic at graduation called Studio 21, which can also be suitable for a postgraduate environment in which the integration and performance analysis of the project is worked on. Menezes and Pontes (2012) worked on assembling digital didactic material to support the classroom. The articles by Cuperschmid and Castriotto (2018), Isanovic and Çolakoğlu (2018) and Holzer (2019) worked on the inverted or semi-inverted classroom, which means content distributed to be studied outside of class time, whether it be the assembly of a playlist of existing online tutorials or courses on third-party e-learning platforms.

A broad spectrum of countries was found in the sample. The surveys were based at important universities and technological institutes for teaching architecture and urbanism, as shown in Figure 3. It should be noted that Brazil and the USA hosted 16 out of the 29 studies. In Figure 4, the sample included articles published mainly through Education and Research in Computer-Aided Architectural Design in Europe (eCAADe), with 37.9%, followed by the Sociedade Ibero-Americana de Gráfica Digital (SIGraDi), with 34.5%.

The sample found through this systematic literature review in the CuminCAD repository brought to this study a broad spectrum of theoretical-didactic approaches published, mainly in academic events. All articles worked on the paradigmatic view of BIM in teaching architecture and urban design. There is still a strong trend of research regarding BIM implementations in curriculum matrices. Still, some works have pointed to innovative strategies using BIM in project teaching, directly interfering in the reasoning and achievement of a collaborative, interdisciplinary and in-depth process in sustainability, efficiency and effectiveness.

Figure 3 – Countries of the analyzed studies

Source: the authors.

Figure 4 – Distribution of studies through publication
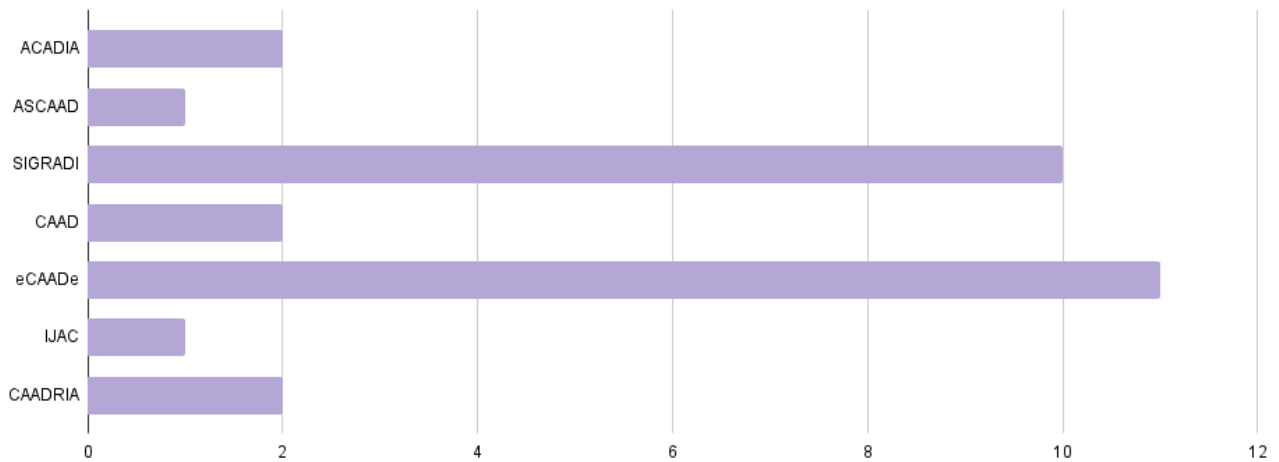
Source: the authors.

However, the five theoretical/methodological approaches to teaching BIM and/or teaching architectural design aided by BIM demonstrate proper ways to be replicated in different contexts.

Assimilating computer and design skills can be crucial in training architecture and urbanism professionals, as explored in Category 1. Working on integration and collaboration in the classroom through BIM as a tool to support the act of designing is a well-accepted strategy in some articles. Using ready-made and complete BIM models for subsequent collaborative work in design intervention can shorten the distance from first contact with a BIM tool.

The practical experience of more than one type of collaborative work, between teams or involving external actors, amid BIM tools proves to be enriching and has a strong

impact. Curriculum integration experiences, where the integration of disciplines is thought of at various times in the course, feeding the design process, point to a path of change in graduation. All these situations were classified into Category 2.

A design approach based on parametric components is defended as innovative and calls into question the one centered on concepts. In general, category 3 worked on parametric BIM for various BIM uses, such as climate analysis and studies of mass and solar radiation, and points to a new way of seeing the act of designing, highlighting the protagonism of the three-dimensional design form.

The articles classified in Category 4 point to the impacts of BIM on the learning process, project presentation, communication, and planning, reflecting the impact of the student's cognitive/social development on the project processes. Finally, category 5, on teaching BIM, brought the focus to the proposal of the inverted or semi-inverted classroom, with hybrid teaching methods, which can be the way to implement BIM in traditional teaching institutions.

Conclusion

This article aimed to investigate the teaching strategies of BIM applied to teaching architecture and urban design. Through a systematic review of the literature in the CuminCad repository, it was possible to gather a specific sample of experimental or exploratory methodology studies that disseminated results of theoretical/methodological approaches for appropriate didactics for teaching BIM in contemporary times. For this article, the CuminCad repository provided a homogeneity of studies presented, emphasizing articles published in the scientific events eCAADe and SigraDi, briefly bringing together advances and research results worldwide.

A wide range of approaches was found that could be classified into three main focuses: (i) curriculum; (ii) performance; and (iii) design quality. This grouping became appropriate for synthesizing the analyzed content, which had many references in common. For the discussion of the 29 studies found, the articles were grouped into analytical categories: (1) Computing Methods, (2) Integrative/Collaborative Methods; (3) BIM-parametric methods; (4) Personal Management Methods; and (5) Blended Teaching Methods. In this way, it was possible to envision five trends in the research universes, correlated with the three possible focuses, and to highlight the specificities of each BIM application format in teaching architecture and urban design.

Notably, the five categories, which emerged throughout the systematic literature review, demonstrate ways of inserting BIM in the teaching of architecture and urban design, which can be replicated in different contexts. Category 1 brought the possibility of deepening computing skills, and those already worked on teaching architecture and urban design. Category 2 gathered proposals for curricular integration through BIM tools to enhance collaborative work. Category 3 pointed to possible advances with a design based on parametric components. Category 4 gathered proposals for exploring the student's cognitive/social development in the design processes. Finally, category 5 brought experiments in hybrid design teaching methods to enhance the teaching of BIM.

About the diversity of initiatives that have been carried out in different realities of teaching architecture and urbanism design, the categories presented in this article reveal five main fronts of joint action and possible strategies to overcome the challenge of teaching design in the contemporaneity. It should be noted that the

research analyzed in this article when inserting modeling technology in the teaching of architecture and urbanism design, to some extent, points to the innovation aspects of the pedagogical practice since, in many cases, it was verified experiences that proposed a redefinition of space-time in the classroom, the relationship between the actors involved and the ordering of curricular matrices.

Finally, as a result of this research, case studies (empirical research) can be carried out so that the categories that emerged can be confronted with the practices that have been recurrently carried out in schools of architecture and urbanism. This study can contribute to disseminating discussions on pedagogical practices in teaching BIM applied to architecture and urban design to enable the incorporation of BIM based on the real needs of architects and urban planners in the digital age.

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