SYSTEMATIC REVIEW OF CURRENT ACADEMIC PRODUCTION OF THE CONCEPTS OF BIM, THERMAL PERFORMANCE, ENERGY EFFICIENCY AND SUSTAINABILITY

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Abstract. This paper aims to discuss the current applications of Building Information Modelling along with Thermal Performance, Energy Efficiency, and Sustainability. It proposes one integrative matrix of concepts, containing information about the practical applications of high-impact papers within the academic knowledge, exposing the discussion to other stakeholders such as constructors, students, and managers. With the integrated matrix the study aims to present a state-of-the-art synthesis in terms of BIM applied, along with energy and thermal efficiency and sustainability, which may aid BIM practitioners in developing BIM applications in the context presented. This paper will perform a critical review of the existing literature, using the science web knowledge base, analysing works published between 2018 and 2021, with a higher impact factor. This research has a focus on works that perform practical applications of BIM tools to perform thermal performance and energy efficiency analysis, presenting the sustainability factor as a topic of discussion. After the systematic review, the works are selected to compound the integrated matrix was analyzed in pursuance of clarify its practical applications. After selecting 29 (20% of the most relevant) high-impact academic papers, they were schematized in an integrated matrix that summarizes the discussion about the applications of each paper. The paper provides qualitative data about the current applications of BIM, summarizing high-impact applications into an integrated matrix, allowing BIM practitioners and academics to use these results to find new applications, authors, discussions, and data more efficiently.

Keywords: BIM, thermal performance, energy efficiency, sustainability.

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REVISIÓN SISTEMÁTICA DE LA PRODUCCIÓN ACADÉMICA ACTUAL DE LOS CONCEPTOS DE BIM, RENDIMIENTO TÉRMICO, EFICIENCIA ENERGÉTICA Y SOSTENIBILIDAD

Resumen. Este documento tiene como objetivo discutir las aplicaciones actuales del Modelado de Información de Construcción junto con el Rendimiento Térmico, la Eficiencia Energética y la Sostenibilidad. Propone una matriz integradora de conceptos, que contiene información sobre las aplicaciones prácticas de trabajos de alto impacto dentro del saber académico, exponiendo la discusión a otros actores como constructores, estudiantes y gestores. Con la matriz integrada, el estudio tiene como objetivo presentar una síntesis de vanguardia en términos de BIM aplicado, junto con la eficiencia energética y térmica y la sostenibilidad, que puede ayudar a los profesionales de BIM a desarrollar aplicaciones BIM en el contexto presentado. Este artículo hizo una revisión crítica de la literatura existente, utilizando la base de conocimiento de la web científica, analizando trabajos publicados entre 2018 y 2021, con un factor de impacto más alto. Esta investigación tiene un enfoque en trabajos que realizan aplicaciones prácticas de herramientas BIM para realizar análisis de desempeño térmico y eficiencia energética, presentando el factor sustentabilidad como tema de discusión. Después de la revisión sistemática, los trabajos seleccionados para componer la matriz integrada fueron analizados con el fin de aclarar sus aplicaciones prácticas. Luego de seleccionar 29 (20% de los más relevantes) trabajos académicos de alto impacto, estos fueron esquematizados en una matriz integrada que resume la discusión sobre las aplicaciones de cada trabajo. El documento proporciona datos cualitativos sobre las aplicaciones actuales de BIM, resumiendo las aplicaciones de alto impacto en una matriz integrada, lo que permite a los profesionales y académicos de BIM utilizar estos resultados para encontrar nuevas aplicaciones, autores, discusiones y datos de manera más eficiente.

Palabras clave: BIM, rendimiento térmico, eficiencia energética, sostenibilidad

Introduction

Sustainability-oriented buildings have integrating design flexibility as one of the key design aspects (Cavallieri, Dell'osso, et al., 2019). Healthy buildings are directly related to the safety and health of their users. Building evaluation in this context has grown over the years (Ding, Niu, et al., 2020). Decisions based on sustainability, maintenance in time, and occupational operations in time represent three ways to reduce energy consumption (Ghaffarianhoseini, Zhang, et al., 2017).

Energy efficiency is not only related to energy consumption reduction but also includes building-user comfort maintenance (Ghaffarianhoseini, Zhang, et al., 2017). It is recommended to reduce the building's energy consumption to reduce the building maintenance operational costs, increase its economic performance, reduce the environmental impact and increase the sustainability of the entire chain, taking into account the reduction of consumption. (Ding, Niu, et al., 2020).

In the natural resource consumption and BIM context, the thermal performance and building energy efficiency studies arise, suggesting that one can improve building thermal and energy performance using BIM integrated simulations with a focus on reducing electricity consumption. The present paper is inserted in the bibliographic research on recent studies, classified in the last 5 years, according to its relevance, to acknowledge how BIM technology has been approached when related to the thermal performance and energy efficiency issues.

Post-occupation energy consumption represents the largest proportion of a building's energy consumption, and user behavior is a key factor in the retrofit assessment study (Ghaffarianhoseini, Zhang, et al., 2017). Energy consumption is one of the great environmental impact agents, and the simulation application has been presented as a useful tool for sustainable

design (Li, Ma, et al., 2020). Each building has a different thermal performance and contributions to energy consumption, and the implementation of renewable energy generation systems will not always be sustainable, considering the importance of simulations regarding the thermal and energy performance of buildings (Yi, Braham, et al., 2017).

However, barriers to the simulation programs' integration to BIM are identified, as there is a loss of information in the interoperability process between the tools (Li, Ma, et al., 2020). The problem of interoperability has been addressed by the various developers of public research programs and organizations (Montiel-Santiago et al., 2020). It is considered that according to the interoperability-related problems that have been minimized, increasingly more accurate energy models and simulations tend to be obtained (Utkucu and Sözer, 2020).

In terms of thermal performance, the reduction of energy consumption through the reduction of air conditioning consumption systems in buildings is amenable to application. The use of air conditioning is directly related to the reduction of ambient humidity, in addition to registering greater satisfaction and lesser environmental impact by users in cases of hybrid ventilation and conditioning systems (De Oliveira Et Al., 2021). Studies show the potential of using a non-mechanical conditioning system in the thermal comfort felt by users and presents itself as a more sustainable solution (Yi, 2018).

The choice for low-cost construction systems with low thermal performance is a source of increased energy consumption, in contrast to the fact that better construction systems tend to present a reduction in operating costs (González Mahecha, Rosse Caldas, Et Al., 2020). In other words, the use of great envelopes in a building can increase the energy life cycle in terms of a building's use/cost by more than 50%, reducing the environmental impact by up to 3 times - including the impact to heat transmission of materials to the medium (Najjar, Figueiredo, et al., 2019). In some cases, the retrofit of facades presents itself as the greatest potential for reducing energy consumption by reducing the demand for mechanical systems, a sector in which there is a greater need for technologies aimed at increasing the performance of facade materials (Alkhatib, Lemarchand, et al., 2021).

Method

The methods adopted for the development of this paper were based on three main steps, as seen in the Figure 1. The first is the study of currently published papers in the Building Information Modelling, Energy Efficiency, and Sustainability field, selecting papers published between 2017 and 2021 in the Web of Science platform.

Due to the significant number of papers published on BIM, some filters were applied, being used mostly Boolean operators and keywords for the sake of finding the most appropriate research regarding a theme.

The Keywords' definition was made after determining the problem and the knowledge gap that this paper intends to investigate, associating the words Building Information Modelling, Energy Efficiency, and Sustainability.

Search Mechanisms

To define the most relevant articles that jointly address the themes of Building Information Modeling, Energy Efficiency, and Sustainability, a literature scan using a search algorithm called "string" was carried out to filter publications on the Web Of Science platform;

the string adopted: TS (Building Information Modelling) AND TS (Energy Performance) AND TS (Sustainability).

The research resulted in a total of 154 publications, consisting majorly of high-impact papers in relevant journals. Among these 154, a total of 29 articles are selected according to a crescent order of impact, according to the Pareto logic, of the sufficient representative share, being 20% a significant amount of papers, able to consistently represent the concepts and development of the currently published papers.

Figure 1

Framework of Research
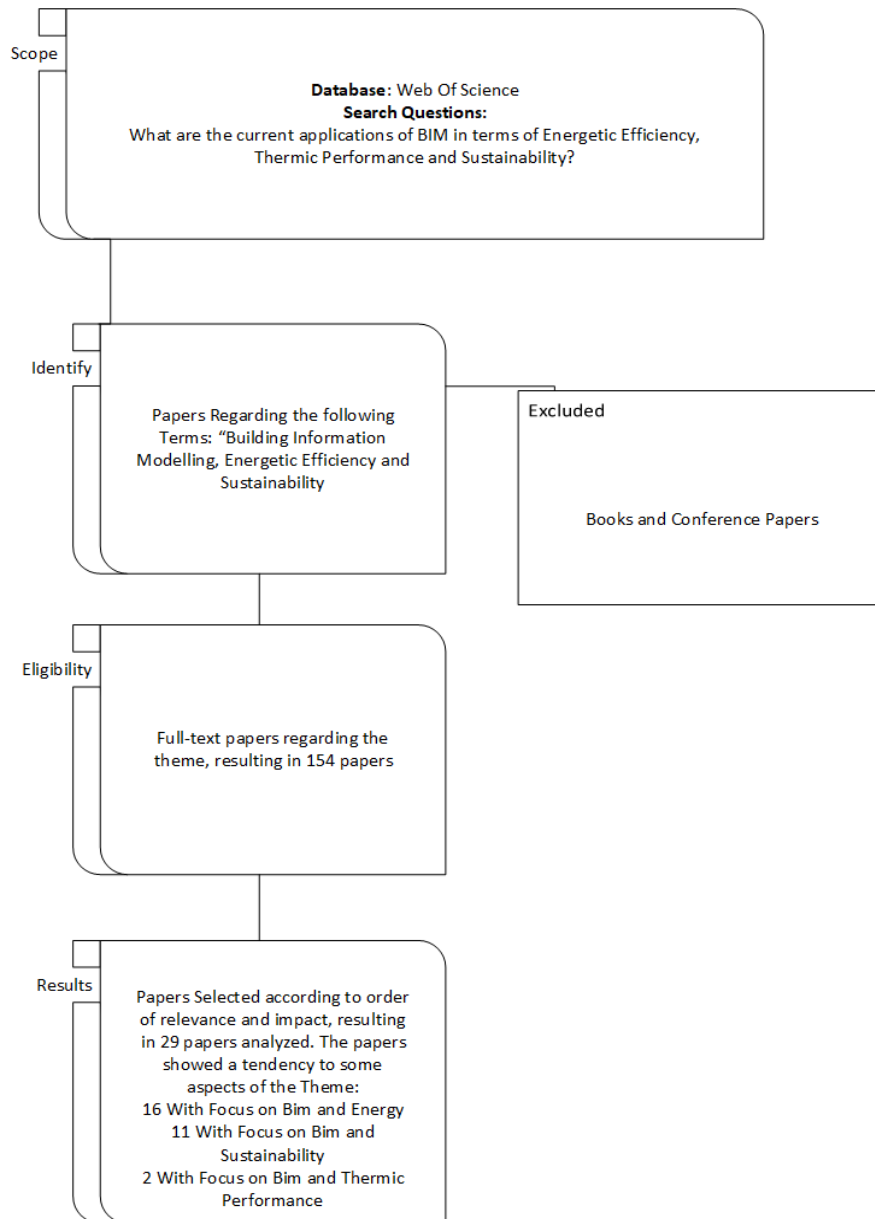
Analysis of The Papers

After being selected, the papers are individually analyzed, allowing each article's synthesis definition, with short answers to the questions: (I), Does the paper present a sustainable improvement along with BIM? and (II), Does the paper present a framework for BIM Application?

The results regarding these two questions allow the review to identify and characterize the content and focus of the current papers regarding the theme.

Analysis of Clusters and Bibliometric Data

Even though this paper does not intend to exclusively present a systematic review of the BIM topics, Energy Efficiency, and Sustainability to introduce the actual state of the art in the field, bibliometric information is presented and discussed in the next session, in clusters of keywords for the string adopted.

Matrix of Applications

The result of the research is a matrix that translates the results and synthesizes them into the key concepts of the most relevant papers to allow one elucidative review of the state of the art of research in Building Information Modelling applied in the improvement of Energy Efficiency and Sustainability. To demonstrate a complete and integrated result, three matrices are presented.

The Matrix of Classification brings an Index and resumes the BIM practical application presented in the paper. The Integrated Matrix is related to the association of the most common problematics presented in the 29 papers, regarding Sustainability, Thermal Performance, and Energy Efficiency, to the most common practices adopted within BIM to present a solution to those problems.

The Matrix of Discussions summarizes the relation between the problem presented in each paper and how BIM was applied to solve those problems, to bring a contribution in terms of allowing BIM students and professionals to find references that present a solution within BIM to the several difficulties in adopting green criteria.

Results

Bibliometric Data

The most relevant year of publishing was 2019, with 45 papers published, while 2017 was the year with the fewest papers published. As 2021 is the current year of this paper's publishing data, most of papers are still being published. The years before 2019 presented a crescent in the numbers of papers published until 2020, where the total of published papers severely reduced as shows the Figure 2 and Figure 3, which may have occurred due to the covid 19 pandemic.

Figure 2

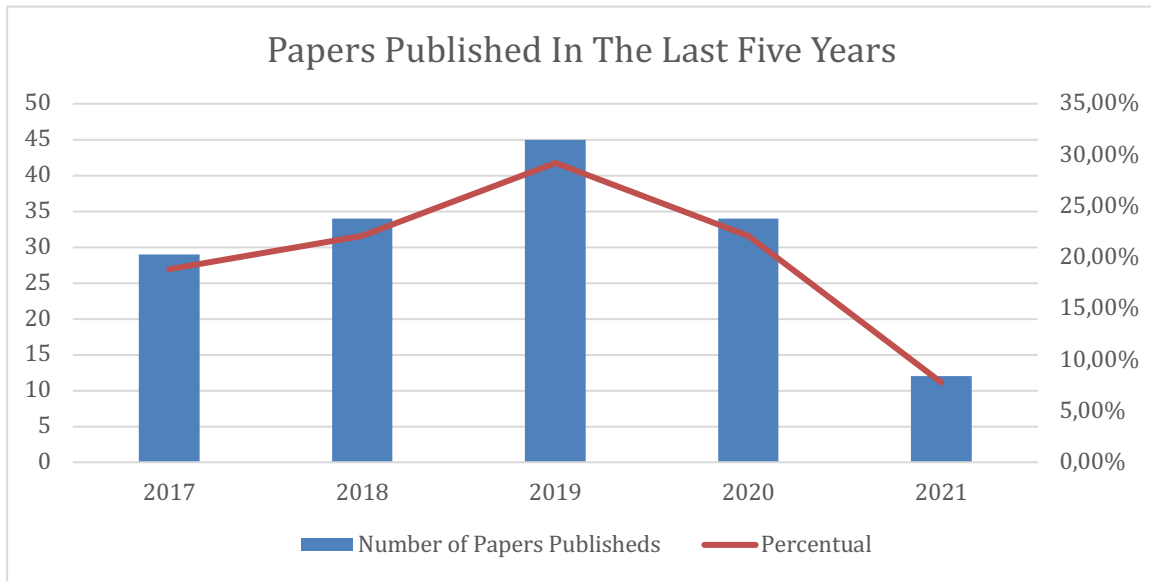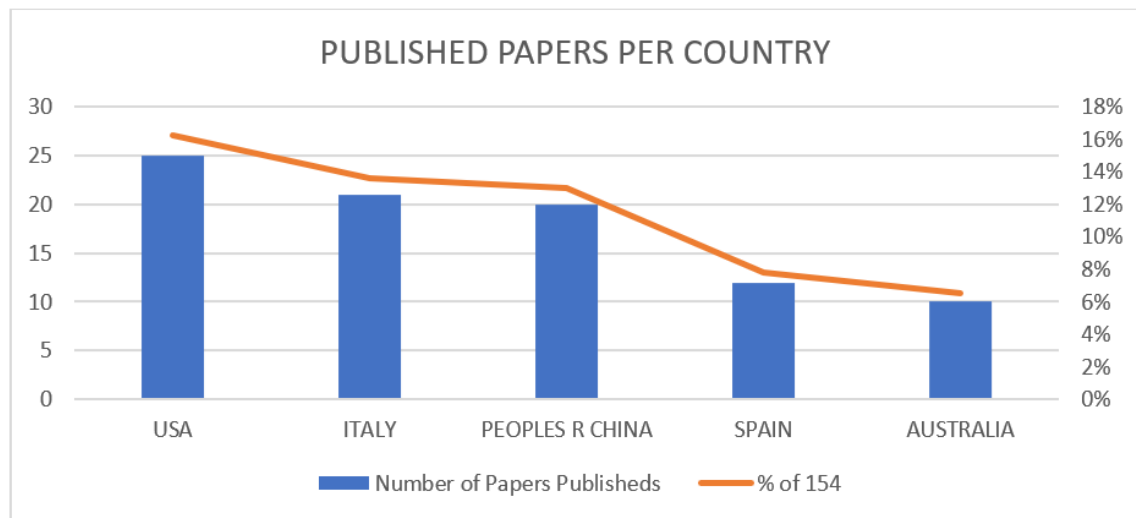*Publishing in the last 5 years*

Figure 3

Published papers per country

The country with the most papers published was the United States of America, followed by China and Italy. Malaysia, even being a relatively small country, has a high ranking with a considerable number of publishing in the field of BIM, Energy efficiency, and Sustainability, however, was not among the countries with most papers published. The most relevant Authors were Passer, Cavalliere, and Haddad, each with 4, 3, and 3 papers published, respectively, as seen in Figure 4.

Figure 4

Published papers per author
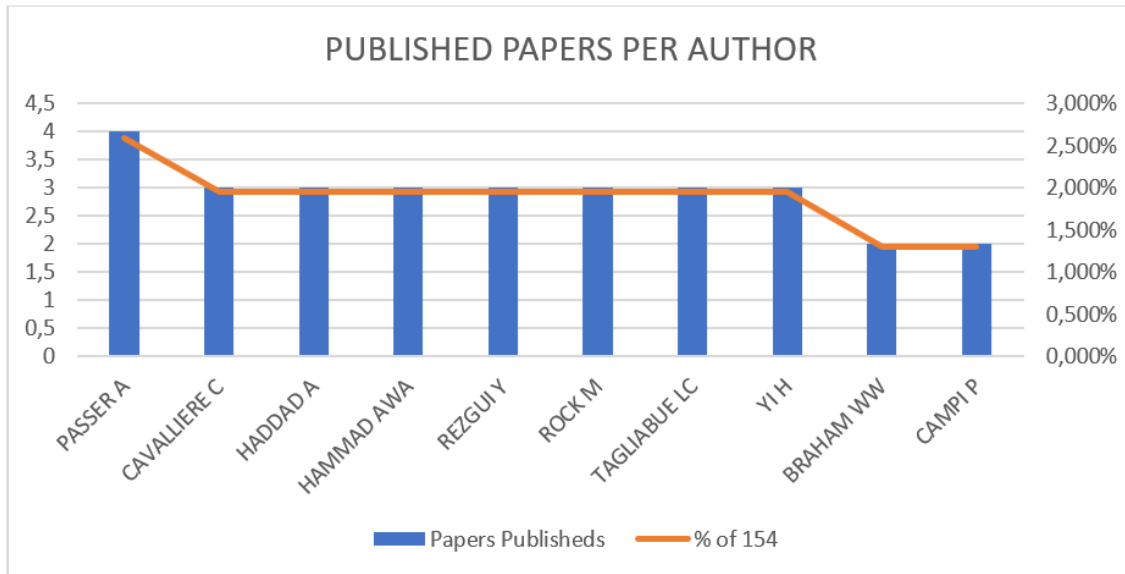
The analysis of the Clusters of the 154 papers from the Web Of Science Platform was obtained from results of the string applied in the Web of Science Platform, which related to the topics of BUILDING INFORMATION MODELLING, ENERGY PERFORMANCE, and SUSTAINABILITY.

The cluster is generated from the correlation of common concepts cited in the title and abstract of the papers, which allow the researcher to establish a correlation between the interconnection of the concepts in the cluster and the current state of development of those concepts in the academy. The software used to generate the Cluster is VOSVIEWER 1.6, the counting method is the binary method, which means that only a term's presence or absence in a paper count.

Of a total of 5186 terms in the papers, only 30 of them present reoccurrence in at least 20 papers, and to generate the cluster, only 60% of the most relevant terms will be selected.

The correlation between terms has at its center as the most interconnected terms Performance and Building, which are the core concepts of the papers. The term Life Cycle Assessment indicates that there is a strong influence of papers discussing the Life Cycle of Buildings considering sustainability as a relevant criterion to define building performance. Sustainable criteria such as Environmental Impact are concepts widely connected to the field of study.

Figure 5

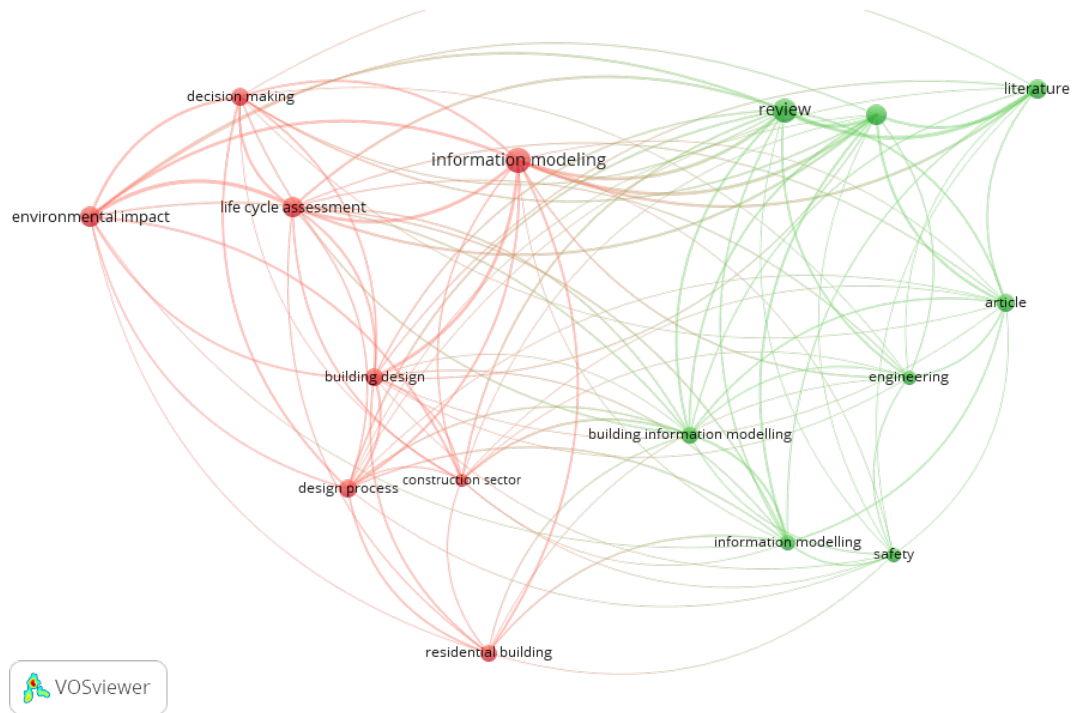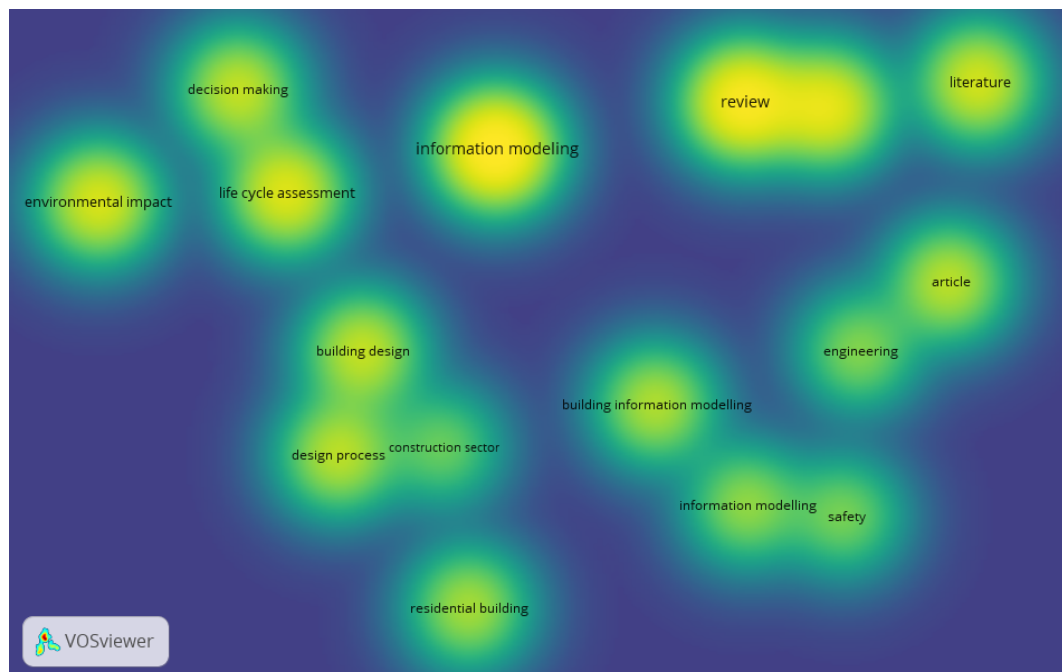*Interconnection Between Clusters*

Figure 6
Density of Clusters

The cluster in Figure 5 and Figure 6 presented demonstrates the concern of the published papers with the correlation between energy efficiency, Building Information Modelling, and Sustainability. BIM is seen as an intermediary concept between general performance and

sustainable concepts as it is connected to the general concepts of civil construction, performance, and the environment.

Figure 6 translates the density of the concepts, being the general terms of Building, Performance and, Sustainability more common than Life Cycle Assessment, Energy Efficiency, and Environmental Impact. That result is expected since general terms are more often occurrent in different papers. This indicates, however, that environmental impact criteria are not widely occurrent in the papers, not being as relevant as most common concepts of civil construction.

Current Discussions in BIM and Sustainability

Beach et al. (2017) discussed the problem caused by the lack of frameworks and parameters for defining sustainability. The absence of well-defined methodologies for defining sustainability parameters in projects causes the AEC (Architects, Engineers, and Constructors) to sometimes overlook those criteria to reduce costs (Raouf And Al-Ghamdi, 2018).

There is also a high volume of information required for defining and optimizing sustainability in civil construction Cavalliere et al. (2019) stated that the high number of variables in sustainability analyses is a factor that makes the analysis even more complex.

The industry sometimes does not accept the elevated costs of acquiring and integrating all information required for some of the most common green certifications or implementing sustainable criteria in retrofitting buildings.

Relevant papers published in the last five years, however, have presented some solutions to fill those gaps. Petri et al. (2017) presented a framework of two major steps toward defining a practical methodology for optimizing sustainability in projects.

Ozarisoy and Altan (2018) proposed the adoption of two commercial plug-ins used in the Autodesk Revit software, "Green Building Studio" and "Insight 360", alongside a well-defined methodology to assess the Sustainable criteria of the retrofitted buildings.

Current Discussions in BIM and Thermal Performance

The most relevant papers found in this research are not exclusively related Thermal Performance, but they regard to Thermal Performance as a part of the energy efficiency study. Within the 29 most relevant papers concerning BIM, Energy, and Sustainability, only two treat the Thermal Performance with utmost relevance as a more individual discipline of civil construction projects.

Pessoa et al. (2021) performed a systematic mapping of the literature to find the gaps in thermal performance analysis in 3D printed buildings. A systematic review paper being among the most relevant papers means that there is still an incipient field in the area.

Current Discussions in BIM and Energy Efficiency

Cavalliere (2019) discussed the need for a more automatized application method for energy efficiency criteria in buildings, as most of the usual methods are currently applied manually, which increases the project cost.

Zou et al. (2017) stated that the actual methods of determining energy consumption are not precise, the real consumption in some cases being 2,5 times greater than predicted.

The main problems in this field of study are like those related to BIM and Sustainability. The lack of practical frameworks, and the need for high information volume required, are the most common problems presented in the most relevant papers.

Montiel - Santiago et al. (2020) claimed a poor use of BIM 6D in current applications, proposing a framework of BIM 6D use in sanitary buildings, such as hospitals. Thus, the current

discussion in energy efficiency, thermal efficiency, and sustainability presents mostly the same problems and some similar solutions.

Tabla 1
Matrix of Classifications of the Papers Analyzed

Index	Year	Author	Category of Paper	BIM Element Applied	Impact On Sustainability
1.	2017	Ioan Petri, Sylvain Kubicki, Yacine Rezgui , Annie Guerriero and Haijiang Li	Case Study	BIM was used in modelling for testing hypotheses.	The paper proposes a practical framework for optimizing energy efficiency criteria, which may subsidize knowledge and know-how for less toxic gas-emitting projects.
2.	2018	Shaohua Jiang, Na Wang and Jing Wu	Application	Use of criteria inside BIM to evaluate the project	The presented method allows the integration of pre-defined certification criteria regarding sustainability in an automated way, which allows a greater diffusion of projects with sustainable bias.
3.	2018	Bertug Ozarisoy, Hasim Altan	Application	Incorporation of different plugins with the capability of assessing the development of innovative projects	Retrofitting is a way to adapt a building to a certain need without generating the impacts of a new construction, the incorporation of a methodology that allows an efficient analysis can reduce costs and favor the adoption of sustainable criteria.
4.	2018	Ayman M. I. Raouf and Sami G. Al-Ghamdi	Literature Review	This paper is a systematic review, without direct application.	Understanding the theoretical mechanisms that allow qualitative assessments of green buildings is essential to apply such techniques. The dissemination of knowledge in terms of systematic review allows for greater adoption of the concepts of sustainable bias.
5.	2018	Luís P. Sanhudo and João P. Martins	Application	Use of automatized pre-defined criteria inside BIM applications	Allowing greater speed in building projects' elaboration with a sustainable bias is an attraction for the market to adopt sustainable practices.
6.	2020	Mariangela Zanmi and Kirti Soenanto	Application	Incorporation of flowcharts inside a BIM application with defined criteria for projects assessment.	This work collaborates with sustainability by defining clear mechanisms and established processes for using BIM to specify sustainable criteria in previous stages of the project.
7.	2019	Ernesto Velázquez, Denis Bruneau, Zakaria Aketouane, and Jean-Pierre Nadeau	Application	This paper is a framework proposal, without direct application.	The work aims to assist and subsidize professionals in the development of sustainable projects, through practical definitions to determine improvements in this regard.
8.	2017	Yabin Jiménez-Roberto, Juan Sebastián-Sarmiento, Adriana Gómez-	Application	BIM Models can be used to test efficiency criteria due to the possibility of testing projects combinations.	Practical bias papers allow the market to find subsidies for practical applications, which distinguishes the

		Cabrera, Gabriel Leal-del Castillo			implementation of sustainable methodologies.
9.	2017	Egwunatum I. Samuela, Esther Joseph-Akwarab, Akaigwe Richard	Case Study	BIM Models can be used to test post-construction consumption due to the possibility of using BIM platforms to evaluate several different criteria.	The work presents theoretical and practical flowcharts for incorporating BIM for energy consumption analysis and a correlation proving the applicability of BIM, which provides the market with subsidies and more security in the adoption of analysis methodologies in sustainable terms.
10.	2017	Lorenzo Belussia, Ludovico Danzaa, Matteo Ghellerea, Giulia Guazzia, Italo Meronia, Francesco Salamonea	Application	BIM Platforms can be used to perform analyses in larger and integrated projects in urban areas.	Determining methodologies for analyzing the sustainability of projects allows a more significant diffusion among professionals and academics, which can make sustainability analysis in urban projects a more applied topic.
11.	2018	Carmine Cavalliere, Guido Raffaele Dell'Osso, Alessandra Pierucci, Francesco Iannone	Application	BIM platforms can be used to aid the development of projects in early phases with sustainable criteria.	Frameworks may support the adoption of analyzes by professionals and academics, which can assist in knowledge dissemination and sustainable projects practice.
12.	2017	Lufan Wang and Nora M. El-Gohary	Application	BIM can incorporate automated tools for analysis that allows more efficient analysis.	Machine Learning practices aim to meet the demand for more agile and efficient projects through information collection and application. More agile processes can enable more applications with sustainable bias on the market.
13.	2017	Abhinaya K.S., V.R. Prasath Kumar, L. Krishnaraj	Case Study	BIM Platforms often allow the user to incorporate parameter analysis to attend to certain criteria, which allows for an early evaluation of impacts.	Parameters and practical applications serve as a subsidy for subsequent implementations, which diffuses the practice of applying sustainable criteria in a BIM environment.
14.	2020	S. M. Hosseini, R. Shirmohammadi, A. Aslani	Case Study	BIM Platforms can integrate secondary plugins to optimize project parameters.	The paper contributes to the adoption of sustainable practices when reporting an analysis of the readjustment of buildings, which has different complexities related to construction, which can subsidize and encourage the readjustment instead of the demolition and construction of new projects from a sustainable perspective.
15.	2019	G. Stegnar and T. Cerovsek	Application	BIM can be used to provide more reliable information about different criteria.	The paper is an addition to the definition of criteria for energy remodeling of existing buildings. Remodeling buildings in terms of energy efficiency is a way to improve the sustainable criteria of existing buildings, which

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					complements the progress towards sustainable civil construction.
16.	2020	Cheng Fan, Da Yan, Fu Xiao, Ao Li, Jingjing An, and Xuyuan Kang	Application	BIM can be complemented by Big Data, assessing and integrating information on the assessment of different projects.	Identifying more agile and less costly ways to define the project life cycle is an efficient way to allow the market to adopt this sustainability bias more easily.
17.	2021	S. Pessoa, A.S. Guimaraes , S.S. Lucas, and N. Simoes	Review of Literature	This paper is a systematic review, without direct application.	Still, insipient issues demand that their knowledge gaps be filled so that in fact they advance. The article, however, does not focus on sustainable issues, but rather on the identification of the state-of-the-art regarding the construction system.
18.	2019	Haidar Alhaidarya, Adil K. Al-Tamimia, and Hashim Al-Wakil	Case Study	BIM can be used to provide reliable quantitative analysis in terms of consumption of resources.	The work allowed an efficient analysis, which subsidized in practice a reduction in energy consumption through efficient thermal performance analysis.
19.	2018	Hwang Yi	Case Study	BIM can be integrated with different formulations to take into consideration human factors in the definition of project parameters.	The work focuses on the anthropocentric analysis of the energy analysis of a building, which is a distinct bias in relation to the usual application.
20.	2018	Patrick X.W. Zou, Xiaoxiao Xu, Jay Sanjayan, Jiayuan Wang	Review of Literature	This paper is a systematic review, without direct application.	The reliability of methodologies in analysis is one of the main challenges to be overcome for a concept to be applied in the market and generate observable results in society. In this context, the work contributes to improving the assertiveness of analyzes through a framework.
21.	2020	Cheng Fan, Da Yan, Fu Xiao, Ao Li, Jingjing An, Xuyuan Kang	Application	BIM can parametrize analysis integrating Big Data into its core.	Facilitating analysis processes, allowing them to be carried out without the need to provide information, can attract practical applications of methodologies across the market, spreading the methodology.
22.	2020	Yu Qian Ang, Zachary Michael Berzolla, Christoph F. Reinhart	Application	BIM can be integrated with georeference software to optimize models, parametrizing several urban criteria.	The energy efficiency of cities is still a deficient Sector. The work proposes a practical methodology that allows an efficient analysis. Agile definitions in the definition of criteria tend to allow easier absorption of concepts by the market.
23.	2019	Carmine Cavalliere, Guido Raffaele Dell'Osso, Fausto Favia, Marco Lovicario	Application	Applying Visual Programming Language in a BIM envirnoment allows the user to calculate several different criteria in projects.	This paper can assist building maintenance managers to define criteria for assessing the health of their buildings, allowing for the appropriate maintenance criteria adoption.

24.	2020	Zhikun Ding , Jindi Niu , Shan Liu , Huanyu Wu C, Jian Zuo	Application	BIM can be integrated with other software to perform integrated analysis of economic, environmental, and post-construction analysis.	The article provides a framework for adopting BIM based on 96 published articles allowing for reliability in terms of the framework presented, which can foster the diffusion of these concepts.
25.	2017	Ali GhaffarianHoseinia, Tongrui Zhanga, Okechukwu Nwadigoa, Amirhosein GhaffarianHoseinib, Nicola Naismitha, John Tookeya, Kaamran Raahemifarb	Application	BIM can be used to calculate the efficiency of the project throughout the whole life cycle of the building.	Practical models can foster market applications, mainly due to the practical bias of the implemented application.
26.	2019	Abdullah Badawy Mohammed	Case Study	This paper does not perform a practical application of BIM.	Practical models can foster market applications, mainly due to the practical bias of the implemented application.
27.	2020	Francisco Javier Montiel-Santiago, Manuel Jesús Hermoso-Orzáez, and Julio Terrados-Cepeda	Case Study	BIM can be applied in different constructions, such as sanitary buildings, to perform efficiency analysis.	BIM has a potential that is still underutilized to define energy analysis. Papers that contribute to the dissemination of the application of BIM 6D favor other applications of this methodology.
28.	2019	Mohammad Najjara, Karoline Figueiredo, Ahmed W.A. Hammadb, Assed Haddada,	Application	BIM can be incorporated to calculate the energy efficiency of the whole life cycle of the building.	Sustainability and energy efficiency are sometimes not evaluated in the building's operating stage. It is necessary to develop papers that work on the complete building life cycle, especially in the stage considered to be the most critical in terms of energy consumption.
29.	2019	Premjeet Singh and Ayan Sadhu	Application	BIM can be applied to test hypotheses in the project, evaluating how distinct modifications impact a building's energy efficiency.	Simple changes, such as orientation in relation to the sun and sealing materials, can have a considerable impact on the energy efficiency of a building.

The integrated matrix listed in Table 1 is a relation of the most common problems presented in the papers regarding Sustainability, Thermal Performance, and Energy Efficiency, with the most common solutions adopted within BIM. Aiming to solve those problems, the integrated matrix refers to the indexed numbers in the Matrix of Classifications regarding how they combined different solutions and contributed to solving particular problems.

Table 2

Integrated Matrix of Problems and Adopted Solutions within BIM regarding SUSTAINABILITY, ENERGY EFFICIENCY, and THERMAL EFFICIENCY

		Solution Adopted Within BIM				
		Definition of Frameworks for BIM Applications	**Incorporation of Secondary Softwares**	**Use of BIG DATA**	**Use of VPL**	**Use of Digital Twin**
Problematics	**Sustainability**					
	Lack of models of project analysis	1., 8., 15.	3.,			1., 3.
	Complexity of implementing the information needed in the project	2., 15.,	2., 3.,	12.,		
	Testing Hypotheses to define project modifications are exhaustive	15.,	5., 14.,			1.,2.,5.,9.
	Lack of models for urban analysis	10.,	10.,			6.,
	Implementing sustainable criteria is difficult due to lack of data	7.,9., 11.,		12., 16.,		
	Current non-BIM methods of sustainability analysis within projects are demanding	8., 15.,	13., 14.			9.,
	Depratonization of sustainable criteria	7., 11.		12.,		11.,
	Difficulty in implementing sustainable criteria in early project phases	7., 8., 15.	13., 14.,	16.,		9.,
	High number of variables needed to be analyzed to implement sustainable criteria	7., 8.,11.		12., 16.,		9.,11., 13
	Thermal Performance					
	There is a lack of information in defining thermal performance criteria in 3D printed houses	17.,				
	Lack of methodologies for thermal performance analysis	18.,	19.,			
	Lack of consideration of human factors in thermal performance	19.,	19.,			
	Energy Efficiency					
	High volume of information needed to perform an evaluation	21.,	24.,	21.,	23.,	27.,28.,29.,
	Difficulty of integrated analysis in urban areas		22.,		23.,	22.,
	Lack of automatized methods for calculating energy efficiency within building projects		24.,		23.,	27.,28.
	Difficulty in calculating energy efficiency along the whole life cycle of the building	25.,	24.,		23.,	27.,28., 29.

Observation: The numbers above are related to the index presented in Matrix 01

The integrated matrix in Table 2 presents a descriptive synthesis of how each paper indexed is related to how the BIM solution is adopted to solve one or more particular problems regarding Sustainability, Thermal Performance, and Energy Efficiency. The Discussion Matrix presented in Table 3 is related to a more descriptive and qualitative evaluation of how each paper solved the problems, with a more accurate description of the problems and solutions adopted in terms of applications.

Table 3

Discussion Matrix of Problems and Adopted Solutions within BIM regarding SUSTAINABILITY, ENERGY EFFICIENCY, and THERMAL EFFICIENCY

Index	Year	Author	Problem	Application
1.	2017	Ioan Petri, Sylvain Kubicki, Yacine Rezgui, Annie Guerriero, and Haijiang Li	In civil construction, there is a high volume of carbon emission, demanding sustainable solutions, which optimize the design of buildings.	The paper presents a framework for BIM, to assure the energy efficiency of buildings, through two steps. Parameters and energy consumption data are obtained first, and then framework processes and optimization for modelling readjustments.
2.	2018	Shaohua Jiang, Ph.D, Na Wang, and Jing Wu	There is difficulty in carrying out evaluations of effectiveness in terms of green construction in building projects. Most of the sustainability assessments are carried out manually.	The paper presents the incorporation of the concept of ontology with BIM, the so-called Information-Rich BIM, which will allow obtaining the multidisciplinary information necessary for Green-Building certification.
3.	2018	Bertug Ozarisoy, Hasim Altan	The study of energy efficiency in homes is sometimes deficient due to the difficulty in carrying out analyses. In reforms, there is an even more significant difficulty.	Two commercial plug-ins were used, with Revit, during the remodeling modeling process, the "Green Building Studio" and "Insight 360", to assess the sustainable criteria of the renovated building.
4.	2018	Ayman M. I. Raouf and Sami G. Al-Ghamdi	Within an academic bias, there is an absence of academic works that bring systematic reviews that associate the use of BIM with green building qualification tools.	In this work, there is a systematic mapping associating the theoretical concepts of certification in green buildings using BIM.
5.	2018	Luís Pedro Neves Sanhudo and João Pedro da Silva Poças Martins	There is a difficulty in the manual realization of sustainability indices in building projects. This delay implies an increase in terms and costs that many times the market does not allow.	BIM can be applied as a tool for qualitative assessment of sustainability criteria in buildings, already pre-defining certifications in automatically.
6.	2020	Mariangela Zanmi and Kirti Soenanto	There is depratonization of how to carry out preliminary design analyzes of sustainability criteria, which makes the adoption of sustainable criteria elements taken into account only in later stages of the project.	The Green BIM Box technique allows the definition of a clear computerized flowchart for preliminary checks of sustainability criteria.
7.	2019	Ernesto Velázquez, Denis Bruneau, Zakaria Aketouane, and Jean-Pierre Nadeau	It is necessary to adopt a holistic methodology for building project evaluation that complies with sustainable criteria, which allows subsidizing better solutions in terms of project sustainability.	In this work, the authors propose a work methodology composed of 36 key elements that allow defining the design criteria, 16 elements that allow defining sustainability criteria, and a method for calculating the parameter of 7 simulation models.

8.	2017	Yabin Jiménez-Roberto, Juan Sebastián-Sarmiento, Adriana Gómez-Cabrera, Gabriel Leal-del Castillo	The construction sector has had a problem related to the definition of appropriate solutions for different client need, with the adoption of sustainability criteria implemented after the project definition.	The work proposes a practical analysis of the performance in sustainable terms in Colombia in terms of sustainability, determining energy consumption, energy incorporated into the project and carbon emissions.
9.	2017	Egwunatum I. Samuela, Esther Joseph-Akwarab, Akaigwe Richard	There is a market view about the potential application of BIM to optimize the analysis of projects in terms of sustainability, verifying the amount of carbon emitted, verifying operations for the use of the building that consumes less energy, and other criteria. However, there is a lack of knowledge and methodologies to implement this in terms of project analysis.	The work analyzes the possibility of using BIM-based methodologies for sustainability analysis. The building's energy analysis tool allows for a more economical post-construction in terms of energy consumption.
10.	2017	Lorenzo Belussia, Ludovico Danzaa, Matteo Ghellerea, Giulia Guazzia, Italo Meronia, Francesco Salamonea	Cities have a macro role, possibly the biggest impact factor, in terms of sustainability, and analysis models for the definition of sustainability criteria for urban projects are lacking.	The work defines a methodology for analyzing sustainability criteria in city projects, with a practical framework later corroborated with a case study for the city of Bologna.
11.	2018	Carmine Cavalliere, Guido Raffaele Dell'Osso, Alessandra Pierucci, Francesco Iannone	The high number of variables in sustainability analyses is a factor that makes building analysis even more complex. The lack of practical subsidies, frameworks, and methodologies regarding sustainable criteria adoption tends to prevent a greater diffusion of sustainability among designers.	The work defines subsidies for practical analyses of buildings in terms of sustainability.
12.	2017	Lufan Wang and Nora M. El-Gohary	A sustainable analysis challenging due to the difficulty of finding enough information to support it. This high need for information makes projects expensive and slow, which sometimes makes them unfeasible for the market.	The work proposes a BIM methodology using Machine Learning. The program will study the building, its components, the city's history, and its conditions. The model already allows a more practical and automated forecast of carbon emissions and energy consumption.
13.	2017	Abhinaya K.S., V.R. Prasath Kumar, L. Krishnaraj	There is a shortage of academic articles that present practical applications, correlating analyses of sustainable bias with practical applications.	The author performs, through the Autodesk Revit Software, a parameter analysis, implementing green materials and components for modeling and immediately evaluating their impacts on the sustainable character of the building.
14.	2020	S. M. Hosseini , R. Shirmohammadi & A. Aslani	One of the main CO2 emission sources in the country where the work was developed is fossil fuel burning, mainly caused by civil construction.	The paper proposes BIM use in conjunction with the DesignBuilder program to define sustainable parameters in a readjustment of the facilities at the University of Tehran.
15.	2019	G. Stegnar , T. Cerovsek	There is a large volume of information about the building necessary for an adequate analysis of energy efficiency and sustainable criteria, which makes it	The paper proposes a progressive methodology for implementing BIM to define accurate information about building energy efficiency.

			difficult to apply sustainable criteria in energy remodeling of existing buildings because the necessary information is unknown.	
16.	2020	Cheng Fan, Da Yan, Fu Xiao, Ao Li, Jingjing An, Xuyuan Kang	There is a significant amount of information to be obtained to carry out a life cycle analysis of a building, which sometimes makes this process unfeasible due to an inherent increase in costs and in the time for preparing analyzes.	The work proposes a simplified approach for defining sustainable criteria with a lower volume of data, using of Big DATA for the complementary definition of parameters.
17.	2021	S. Pessoa, A.S. Guimaraes , S.S. Lucas, N. Simoes	3D printing is still a neophyte process in engineering, and its performance in terms of thermal efficiency needs to be further verified.	The work performs a systematic mapping in the literature, aiming to determine the current state-of-the-art on the theme of thermal performance in 3D printing.
18.	2019	Haidar Alhaidarya, Adil K. Al-Tamimia, and Hashim Al-Wakil	Climate change has shed light on the topic of thermal performance, mainly because this discipline is directly related to energy efficiency.	The article proposes a practical methodology for defining a model of energy consumption in a BIM environment, taking into account Infrared Thermography.
19.	2018	Hwang Yi	Few academic papers consider the human factor when calculating energy efficiency, not considering dynamic factors as to the heat flow.	The work carried out a study of 4 different scenarios, with different degrees of human occupation, allowing to characterize human influence on the energy efficiency of different environments.
20.	2018	Patrick X.W. Zou, Xiaoxiao Xu, Jay Sanjayan, Jiayuan Wang	According to the authors, in several works collected, the energy consumption of a building can be up to 2.5 times higher than the usual project estimates, which causes a tremendous deficiency in energy demand.	The work collected 227 relevant publications that proposed to carry out energy efficiency analyses, and based on these, we sought to create a framework that allows greater assertiveness in energy demand forecasts.
21.	2020	Cheng Fan, Da Yan, Fu Xiao, Ao Li, Jingjing An, Xuyuan Kang	The high number of necessary information sometimes makes an adequate analysis of energy efficiency unfeasible.	The paper uses the concepts of BIG DATA to parameterize energy efficiency analysis criteria, simplifying the computational analysis process in a BIM environment.
22.	2020	Yu Qian Ang, Zachary Michael Berzolla, Christoph F. Reinhart	The analysis of energy efficiency in cities has a low volume of published works, with a gap in academic production in this regard.	The article proposes an integrated framework between BIM and other georeferencing software to define optimized models, allowing parameterizing energy efficiency criteria in urban projects and defining energy consumption.
23.	2019	Carmine Cavalliere, Guido Raffaele Dell'Osso, Fausto Favia, Marco Lovicario	It is challenging to define sustainable criteria for a building, mainly due to the predominance of laborious manual models to establish these criteria.	The article uses VPL (Visual Programming Language) in a BIM environment to automatically calculate sustainability criteria in building projects.
24.	2020	Zhikun Ding, Jindi Niu, Shan Liu, Huanyu Wu C, Jian Zuo	The health of a building is a topic of increasing popularity, according to the authors. It is necessary to define criteria to define criteria for safety, environmental preservation, and energy efficiency.	The paper performs an analytical hierarchy process, incorporating other software and methods to determine criteria, such as thermal comfort, environmental performance, and economic and maintenance performance. This set of analyses makes it possible to assess the health of a building.
25.	2017	Ali GhaffarianHoseinia, Tongrui Zhanga, Okechukwu Nwadigoa, Amirhosein	It is necessary to balance the demands of the users with energy efficiency criteria, being essential to obtain an adequate performance concerning the life cycle of	The article investigates the potential of BIM for calculating energy efficiency and defining the environmental performance of the building's life cycle.

		GhaffarianHoseinib, Nicola Naismitha, John Tookeya, Kaamran Raahemifarb	the building. Manual definitions of this criterion are sometimes insufficient for more accurate life cycle definitions.	
26.	2019	Abdullah Badawy Mohammed	According to the author, there is no well-known model for analyzing sustainability criteria and analyzing the life cycle of buildings that allow to obtain the benefits inherent to BIM.	The author lists a series of environmental performance indicators, characterizing design aspects and relating them to BIM, further demonstrating the potential for joint application of different BIM platforms.
27.	2020	Francisco Javier Montiel-Santiago, Manuel Jesús Hermoso-Orzáez and Julio Terrados-Cepeda	One of the least used aspects of BIM is the orientation towards the energy efficiency analysis, mainly due to the absence of academic production and frameworks for implementing this aspect at work.	The article proposes a framework for using BIM 6D for energy analysis in sanitary buildings, in this case, hospitals. The paper defined a high potential for improving energy efficiency in simple elements, such as lighting. This analysis is possible through the use of BIM.
28.	2019	Mohammad Najjara, Karoline Figueiredo, Ahmed W.A. Hammadb, Assed Haddada,	The building's operational demand is, according to the authors, the largest share of energy consumption throughout the building's life cycle, which is a fundamental factor for optimizing energy performance and efficiency.	The authors develop a framework for optimizing energy efficiency criteria, through parameters adoption through more sustainable design alternatives.
29.	2019	Premjeet Singh, Ayan Sadhu	The current demands of society imply the increasing consumption of electric energy. The older houses have anti-economic and deficient criteria in terms of energy efficiency.	The authors propose simple modelling criteria in a BIM environment using Audodesk Revit in Buildings and analyzing the changes caused by distinct modifications in its consumption and energy efficiency.

Conclusions

The most relevant papers published in the field of BIM, Thermal Efficiency, and Energy Efficiency regarded a great concern about the needs of a high volume of information required to address the optimization of civil construction projects in terms of sustainability and efficiency.

Most of the authors also addressed the problem of the lack of practical framework as a barrier to the implementation in the AEC industry. However, the technological advancements and the use of BIM present a form of reducing costs and work time in implementing those criteria.

The use of Machine Learning presented the potential of gathering common information of several different buildings in the sake of defining parameters and fill the large volume of information required. The use of Big Data also presents a role in filling this gap to address the role of providing more information.

The adoption of energy efficiency frameworks allows the users to follow a more practical and well-defined model to analyze energy consumption in buildings, the reliability of the demand calculations being a current concern.

The common concerns are related to (I) The large information volume needed and the high cost and work necessary to implement the discussed criteria, (II) The lack of practical frameworks that analyze critical success factors and present well-defined steps for practical

applications. The solutions are related to (I) Addressing a practical model and implementation methodology of solutions in the fields discussed, (II) Applying Big Data to fill the information gaps in common buildings, (III) Implementing secondary software or Visual Programming Language.

A gap was identified, from the 29 most relevant papers in the web of science database, only 14 of them presented a valid application of BIM in terms of Sustainability, Energy efficiency, or Thermal performance, and only 9 of them analyzed cases to bring improvement to the sector. This allows us to conclude that there is a great potential for more significant BIM applications in the sector, which may be achieved with a better understanding of the relevance of sustainable criteria within the early phases of projects.

From the 29 papers reviewed, 13 presented a sustainable improvement using BIM tools or applications, while 20 presented a framework for BIM application. This indicates a still neophyte stage of academic development, most papers being about concepts and frameworks and a minor fraction about practical applications.

However, there is a considerable advance in the discussions presented in the most relevant papers in the last five years, which implicates an accelerated evolution of BIM and Sustainability current debate. In terms of scientific contribution, this paper presents a Review of Literature that summarizes in a practical approach how the BIM can be used to solve complex problems regarding Sustainability, Thermal Performance, and Energy Efficiency, allowing academics and professionals to find frameworks, case studies, applications and literature that aids in the solving of those problems listed in the paper.

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