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BIM AND PARAMETRIC DESIGN APPLICATIONS FOR BUILDINGS' ENERGY EFFICIENCY: AN ANALYSIS OF PRACTICAL APPLICATIONS

APLICAÇÕES DE BIM E DESIGN PARAMÉTRICO PARA EFICIÊNCIA ENERGÉTICA DAS EDIFICAÇÕES: UMA ANÁLISE DE APLICAÇÕES PRÁTICAS

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Abstract

The buildings' sector accounts for a large share of energy consumption on a global scale. This scenario generates the need to design and construct more efficient buildings and also requires new policies and incentives. The greatest opportunities for integrating energy efficiency strategies in construction occur at the design stage, in which decisions that will have significant impacts on the building's life cycle are taken. Therefore, the use of Building Information Modeling (BIM) is considered, as well as parametric design: new design technologies that allow the analysis of multiple scenarios to support the decisions during the design stage. The purpose of this study is to provide, through a literature analysis, an overview about practical applications of BIM and parametric design for buildings' energy efficiency in a recent research scenario. Studies were categorized according to their main approach and the main software used. In addition, benefits provided by the use of the technologies adopted were highlighted.

Keywords: BIM, parametric design, energy efficiency.

Resumo

O setor das edificações representa uma grande parcela do consumo energético em escala global. Esse cenário gera a necessidade de projetar e construir edificações mais eficientes energeticamente, além de exigir novas políticas e incentivos. As maiores oportunidades para integrar estratégias de eficiência na construção ocorrem na etapa de projeto, na qual concentram-se as decisões que terão impactos significativos no ciclo de vida da edificação. Para tal, considera-se o uso de *Building Information Modeling* (BIM), ou modelagem da informação da construção, e do design paramétrico: novas tecnologias de projeto que possibilitam a análise de múltiplos cenários para apoiar as decisões ainda na etapa de projeto. O objetivo deste estudo é proporcionar, por meio de uma análise da literatura, uma visão geral sobre aplicações práticas de BIM e design paramétrico para a eficiência energética de edificações em um cenário recente da pesquisa. Foram analisados estudos que utilizaram BIM e design paramétrico para a eficiência energética, tanto de modo isolado como associado. Os artigos foram categorizados de acordo com sua abordagem principal e

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principais *softwares* utilizados. Além disso, foram destacados benefícios encontrados no uso das tecnologias adotadas.

Palavras-chave: BIM, design paramétrico, eficiência energética.

INTRODUCTION

The buildings' sector (residential and commercial) accounts for more than 30% of the energy consumption of all sectors of the economy (International Energy Agency, 2015; World Energy Council, 2013). Besides, it accounts for half of global electricity demands and 30% of CO_2 emissions (International Energy Agency, 2015). In terms of progress, the overall use of electricity in buildings has grown by an average of 2.5% per year since 2010, when CO_2 emissions from buildings started to increase at a rate of approximately 1% per year. However, two-thirds of all countries still do not have mandatory energy codes for this sector (International Energy Agency, 2017).

In order to reduce the share of energy consumption and the related environmental impacts, it is possible to adopt solutions in order to make buildings more energy efficient (Li *et al*., 2013). From an architectural point of view, energy efficiency can be described as a characteristic of a building that represents its potential in providing, with reduced energy consumption, thermal, visual, and acoustic comfort to its users. Thus, a building becomes more efficient than another when it provides the same environmental conditions while consuming less energy (Lamberts *et al*., 2014).

The energy consumption of buildings can be influenced by factors related to the building itself, such as its solar orientation, shape, enveloping system, heating and cooling mechanisms, shading and glasses (Pacheco *et al*., 2012), or by external factors, such as temperature, air humidity, atmospheric pressure, irradiation, precipitation, and winds (Pulselli *et al*., 2009). In addition, climate changes, such as global warming, can also have a significant impact on the buildings' energy consumption and CO_2 emissions (Ren *et al*., 2011).

In order to achieve greater advances in the energy performance of buildings and to reduce their impacts on a global scale, new policies, regulations, materials, technologies, tools and methodologies must be developed, and the use of renewable energy sources must be encouraged and disseminated while requiring greater interests from designers, professionals, and users (Soares *et al*., 2017). In the context of buildings' design, there are different ways of making them more efficient, such as by applying passive strategies, including distinct architectural solutions, or through the use of renewable energy sources like solar or wind power (Li *et al*., 2013).

The greatest opportunities to integrate efficiency strategies in the construction industry occur at the design stage, where performance-related decisions are analyzed and determined, which will have significant impacts on the building's performance (Wang *et al*., 2006). Thus, quantifying the environmental impacts and simulating the building's energy consumption in the early design stage become a crucial factor that helps determining solutions to generate more efficient buildings (Jalaei and Jrade, 2014).

For this purpose, it is worth highlighting the possibilities offered by the recent design methodologies, such as Building Information Modeling (BIM) and parametric design. In this study, the term parametric design refers to the use of visual programming language tools to create complex geometries or to insert new functions in modeling software, since BIM software may also be considered parametric modeling platforms. Both methodologies mentioned present a set of processes and practices that allow the analysis of multiple scenarios and alternatives in early design stages (Eastman *et al*., 2011; Kolarevic and Malkawi, 2005), enabling the definition and selection of optimized solutions, including those related to energy performance aspects.

The purpose of this paper is to analyze practical applications of BIM and parametric design for buildings' energy efficiency in recent research. It should be noted that, due to this study's focus being applications, concepts and definitions related to BIM and parametric design were not explored.

METHODOLOGY

For the development of this study, papers from journals and proceedings of relevant conferences in the field of Architecture, published from 2010 to present date, were found in online databases through the use of the search terms "BIM AND *energy efficiency*" and "*parametric design* AND *energy efficiency*". Firstly, the intent was to verify how the presented technologies are mainly being used and, secondly, to encourage their use through the presentation of a framework of positive results and benefits found in their applications. In addition, the tools or software most widespread in the analyzed context were pointed out.

The analysis procedure primarily involved the classification of the articles in terms of their main purpose, considering the three following categories, created by the authors: Application Analysis, Methodology or Strategy Proposal, and Tool development. Subsequently, the papers were classified according to the main topics covered by them.

That said, the main topics identified among the studies, which represent the second categories applied, also created by the authors based on the preliminary analysis, were:

- S — energy simulations: when the main topic of the paper was the development of energy simulations;
- G — efficiency of the geometry, shape or volume: when the main topic was related to the analysis of the geometry, shape or volume of the building for energy efficiency purposes;
- L — lifecycle analysis: when the studies performed lifecycle analysis of a project;
- R — retrofit: when retrofits were developed or designed for existing buildings in order to improve their energy performance;
- I — daylight optimization: when authors took actions to improve daylight and consequently reduce energy consumption of lighting;
- E — renewable energy sources: when the paper deals mainly with the use of renewable energy sources;

- F — envelope, facades or shading devices: when authors analyze aspects of the envelope, façade or shading devices of the building and their impacts on its energy efficiency.

- P — design process: when the main topic of the paper is about aiding design process for energy efficiency related purposes.

After the categorization according to the main topics discussed in the studies, we also identified and adopted the following categories in order to summarize the main software used by the authors: Modeling, Simulation, Programming, and Optimization. It should be noted that, in the stated categorization, the term "Simulations" refers to software that adds data related to efficiency aspects, allowing the achievement of energy performance results and the subsequent analysis to determine design solutions.

This study is divided into three main chapters, the first being the presentation of studies that dealt with the use of BIM concerning energy efficiency. Secondly, parametric design applications found for similar purposes are presented, followed by studies that dealt with the association of the three addressed variables: BIM, parametric design and energy efficiency. Finally, comparative tables are presented as results, according to the proposed categorizations.

BIM APPLICATIONS FOR ENERGY EFFICIENCY

Ma *et al*. (2011) identified a way of improving the design of rural houses in South Korea, which usually have standardized characteristics, through the use of BIM. The authors analyzed the effect of using a greenhouse attached to a house on its energy consumption. Through the study, it was possible to identify that, when attaching a greenhouse with certain dimensions and specific optimum characteristics, it is possible to increase building energy efficiency by 16.39% when compared to the same building without the greenhouse.

In the same country, Ryu *et al*. (2011) applied variations to lateral and longitudinal dimensions and solar orientation of a 60-floor commercial building through the use of BIM, in order to find an optimized geometry in terms of energy consumption regarding heating and cooling loads. By using the optimum solar orientation and dimensions determined by the authors, it became possible to obtain a reduction of 2.88% of the building's energy consumption. The authors also point out that this value may seem low, but when considering long-term effects (throughout the year or when considering entire building's life cycle), the values become significant.

The impacts of solar orientation on the buildings' energy consumption were also observed by Abanda and Byers (2016), but in a small-scale building. Study findings show that solar orientation influences energy consumption in buildings, since, for a 30-year period, significant reductions of the building's electricity (17,056 kWh) and gas (27,988 MJ) consumption were verified by comparing the worst and best solar orientations.

In order to illustrate data such as those pointed out by previous studies mentioned, Jeong *et al*. (2013) have developed, through the Autodesk Revit Application Programming Interface (API), a way of representing the results of buildings' energy simulations based on color scales, offering new opportunities for developing more efficient projects using BIM.

Kota *et al*. (2014) sought to develop a method for incorporating daylighting analysis in a BIM environment and to validate it by means of a prototype. The authors proposed a direct interoperability integration between the software Autodesk Revit, Radiance and Daysim. The prototype proved to be accurate and reliable, but its main limitation was its restrict applicability to Revit, making it not possible to be applied on other BIM platforms.

Another relevant BIM platform in the market, ArchiCAD was used in the study of Alam and Ham (2014), which proposed the use of BIM for energy analysis of a building in comparison to another method widely diffused in Australia, the FirstRate 5. The authors verified that using BIM, despite the modeling complexity, enabled energy analysis of three applied case studies, mainly due to the incorporation of thermal information in the components and precision of virtual models.

As for the initial stages of architectural design, Çavusoglu (2015) looked for opportunities offered by BIM for the concept of performance analysis and parametric form-finding. The author performed an implementation study with several participants, who evaluated the efficiency of Autodesk's Vasari tool, discontinued since May 2017 (Autodesk, 2017a). The effectiveness of the energy model and energy analysis was the most powerful capacity of the tool highlighted by the participants.

In the context of energy simulations, it is possible to create specific BIM models for this purpose with sectored thermal zones. This approach is defined as Building Energy Modeling (BEM) in the study of Gourlis and Kovacic (2017), which presents the BIM and the respective BEM models of two industrial buildings adopted by the authors as case studies. Their findings show that, for energy simulations, simplified models containing only relevant information to the analysis (BEM models) minimize the inconsistencies when compared to more complex BIM models. Despite some obstacles highlighted by the authors, they pointed out that BIM has great potential for lifecycle analysis of buildings.

In this context, Shadram *et al*. (2016) have developed an automated process for lifecycle assessment and for the verification of the energy embedded in the materials supply and have verified, by means of a prototype, that buildings' energy use and carbon footprint can be reduced in early design stages. As for the carbon footprint, Lu *et al*. (2015) developed a tool for its determination in the buildings' design process based on a BIM platform. Through the API, new functions were inserted to provide real-time information. Furthermore, Ahuja *et al*. (2016) performed a qualitative analysis of 16 case studies and confirmed that the BIM adoption leads to better design results, especially when involving lean and environmental aspects.

However, energy analysis in BIM platforms are not restricted to the design stage, but they can also be used to verify the feasibility of retrofits in existing buildings, as pointed out by authors Spiegelhalter (2014) and Giuda *et al*. (2015). Both studies used BIM to retrofit educational buildings, and the main advantages of its use were the possibility of incorporating accurate information and the analysis of future scenarios for existing buildings. In the case of Spiegelhalter (2014), a potential emission reduction of 30% was verified.

The authors Kuo *et al*. (2016) highlighted another possibility for the usage of BIM: the analysis of using renewable energy sources. The study consists on an analysis of the use of BIM to estimate the electricity production of building-integrated photovoltaics (BIPV). The results were compared to data referring to 3 years of measurements, which proved their credibility and effectiveness.

Ilhan and Yaman (2018) have proposed a tool called the green building assessment tool (GBAT) based on the Industry Foundation Classes (IFC) format to include sustainability information in BIM models to be evaluated during the design process, helping to achieve environmental certifications, such as Building Research Establishment Environmental Assessment Method (BREEAM). The BREEAM certification was used as an example for validating the tool through a sample design. Based on the example presented, the authors conclude that relevant environmental data that can be used for environmental performance certifications can be processed automatically and used to inform the design process.

PARAMETRIC DESIGN APPLICATIONS FOR ENERGY EFFICIENCY

This section describes already developed researches about parametric design applications for buildings' energy efficiency.

Anton and Tănase (2016) described a design experience based on performance criteria by using generative algorithms in association with other simulation software, such as Ecotect, EnergyPlus and Daysim, in order to influence the architectural form in early design stages. The authors pointed out that this method can lead to a synergy between performance and the designer's creative process. Furthermore, Touloupaki and Theodosiou (2017) proposed a methodology for using parametric design for a comprehensive exploration of performance-based design alternatives. Their proposal emphasizes the importance of dynamic control offered by parametric modeling on geometry and components, which allows the evaluation of multiple variables at the same time.

The great design challenge, according to Gerber and Lin (2013), focuses not only on geometry complexity, but on how to incorporate performance feedbacks. The authors developed a tool to observe the connection between geometric complexity and efficiency aspects, obtaining improvements of up to 50% in energy performance results, which were often related to non-intuitive and complex architectural forms. Assessing energy efficiency from a different angle, Vannini *et al*. (2012) performed volumetric adjustments in buildings to optimize solar incidence in photovoltaic panels, verifying that volumetric optimizations effectively result in a higher energy production.

In this context, Hillukka (2011) used parametric design to verify the effects of building volume manipulations in the climatic conditions of its indoor environments, concluding that there is a moment in which the energy exchanges stabilize for a specific volume. Das and Dutt (2012) also sought to optimize a building's design for more sustainable solutions. The authors verified the effects of modifications in the building's volume and facades in its energy consumption and in comfort levels of the environments, and concluded that the use of parametric design was very efficient for this purpose.

Choo and Janssen (2014) present a methodology, as well as some variants of it, and perform demonstrations of their applications for evolutionary optimization of semi-transparent building integrated photovoltaic facades, improving their energy production and consequently reducing the building's energy consumption.

When it comes to facades, Queiroz *et al*. (2015) explored, through parametric design, the distribution of shading devices with different geometric attributes on the envelope of a building in Recife. The simulations showed that the distribution of shading devices on the envelope conferred a certain uniformity of solar incidence. With a similar purpose, Sheikh and Gerber (2011) developed a methodology and a tool for creating intelligent skins to improve daylight performance in buildings. Findings showed that automation of independent tilt angles of the system can improve daylight performance by 2 to 2.5 times. In this context, Felippe *et al*. (2015) developed a parametrization algorithm for daylight and energy consumption simulation, which considers space-related variables such as geometry and surfaces' reflectance, and also their effect in the urban context, like location and surroundings.

BIM, PARAMETRIC DESIGN AND ENERGY EFFICIENCY

In this section, papers that combined BIM and parametric design to assess buildings' energy efficiency are presented.

Kim *et al*. (2015) analyzed a new methodology for energy performance analysis in buildings with kinetic façades integrating BIM, parametric design and simulations. The results indicate that kinetic façades can consume less energy regarding the index of openings, when compared to equivalent static façades. By the same perspective, Chen and Huang (2016) developed a similar study, but also using physical models and sensors, as well as Shen and Lu (2016), who created a physical model of a system called Parametric Adaptive Skin System (PASS) to interact with virtual models, aiming to increase the use of natural sunlight in buildings. Both BIM and the visual programming language tool (Dynamo) used presented themselves as powerful instruments for kinetic facade designs with an emphasis on performance.

Asl *et al*. (2014) have developed a BIM-based system for cloud-based energy analysis, allowing rapid assessment of hundreds of design alternatives and connecting with parametric visual environments for agile and accurate space adaptations. The authors point out that the integration of parametric modeling with BIM provides a more efficient process for optimized design in terms of performance. Regarding optimization, Asl *et al*. (2015) detected a gap related to multidisciplinary optimization tools based on BIM. Therefore, the authors developed the Optimo tool for Dynamo and presented an initial validation of its optimization function. Optimo can be considered equivalent to Grasshopper's Galapagos (Grasshopper 3D, 2017) optimization plug-in.

In terms of performance results, Gerrish *et al*. (2017) used visual programming language to establish the potential of using BIM as a tool for a building's performance visualization and management in the design and operation stages, resulting in a methodology based on simulation data, sensors and interviews with designers and users. However, the authors emphasize that, in order for BIM to be effectively used as a performance management tool, one must seek patterns of use for structuring information, and professionals and users need to adapt to the impacts of these new technologies on their roles.

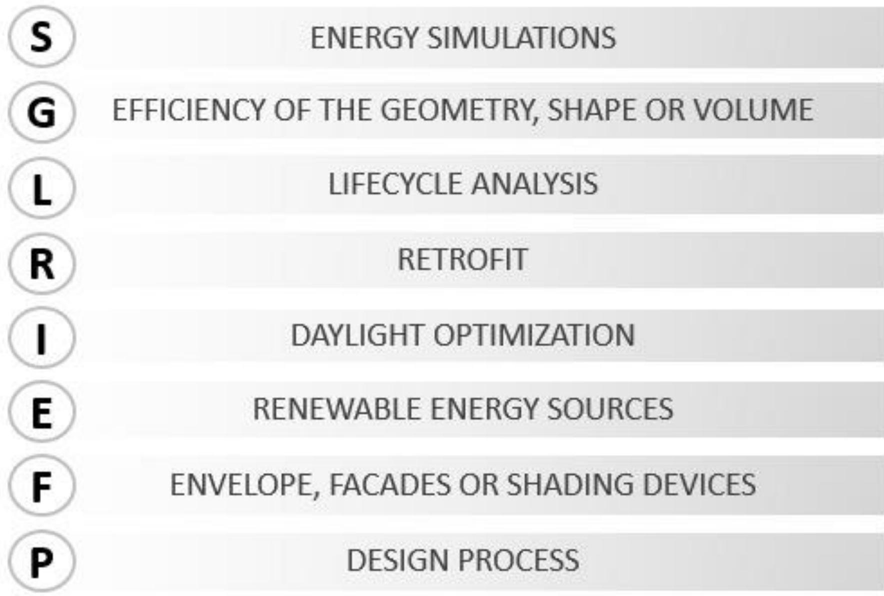
RESULTS AND DISCUSSIONS

According to the information introduced at the beginning of this study, the papers described in previous chapters were categorized according to their main approach (first, according to their main purpose and, secondly, to the topics addressed) and the main software used. In addition, benefits resulting from the applications of the adopted technologies mentioned by the authors were gathered to synthesize their main benefits. The categorization of papers and the synthesis of benefits will be presented in the subsequent items.

Main approach of the studies

The studies were classified, according to their main approach, in three key categories initially stated: Application Analysis, when case studies were carried out; Methodology or Strategy Proposal; and Tool Development. Regarding the main topic of the papers, they were categorized accordingly to the categories presented in Figure 1, which are expressed by the indicated capital letter.

Figure 1: Categorization of the papers' main topic.



Figures 2 and 3 show the summary and categorization of the papers according to their main topic and approach, respectively. It is possible to observe that most of the studies about BIM and energy efficiency made application analysis and dealt with design process and energy simulations. Other topics, such as the efficiency of the geometry, shape or volume, retrofit, daylight optimization, lifecycle analysis, and renewable energy sources have also been addressed by the studies.

When using parametric design concerning buildings' energy efficiency, no predominance of one main topic or approach was observed among the analyzed papers, which carried out application analysis and methodology proposals, as well as tool development. As for the use of parametric design, it is worth noting that issues related to facades' energy efficiency were addressed, a topic that was not verified among the studies that used BIM alone, probably due to its common use for geometric explorations.

As for the use of BIM associated with parametric design for energy efficiency issues, it was verified that most of the studies presented methodology or strategy proposals and dealt mainly with design processes or facades.

Figure 2: Main topic of the studies.

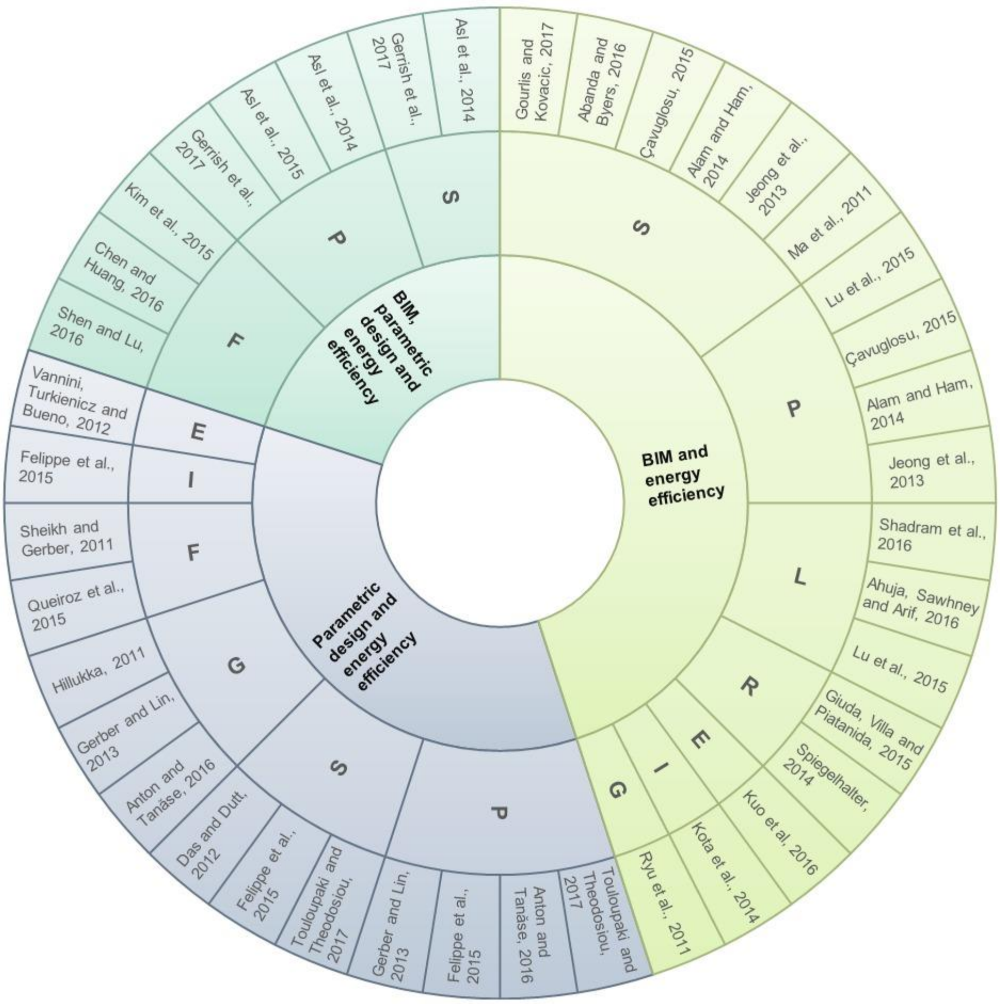
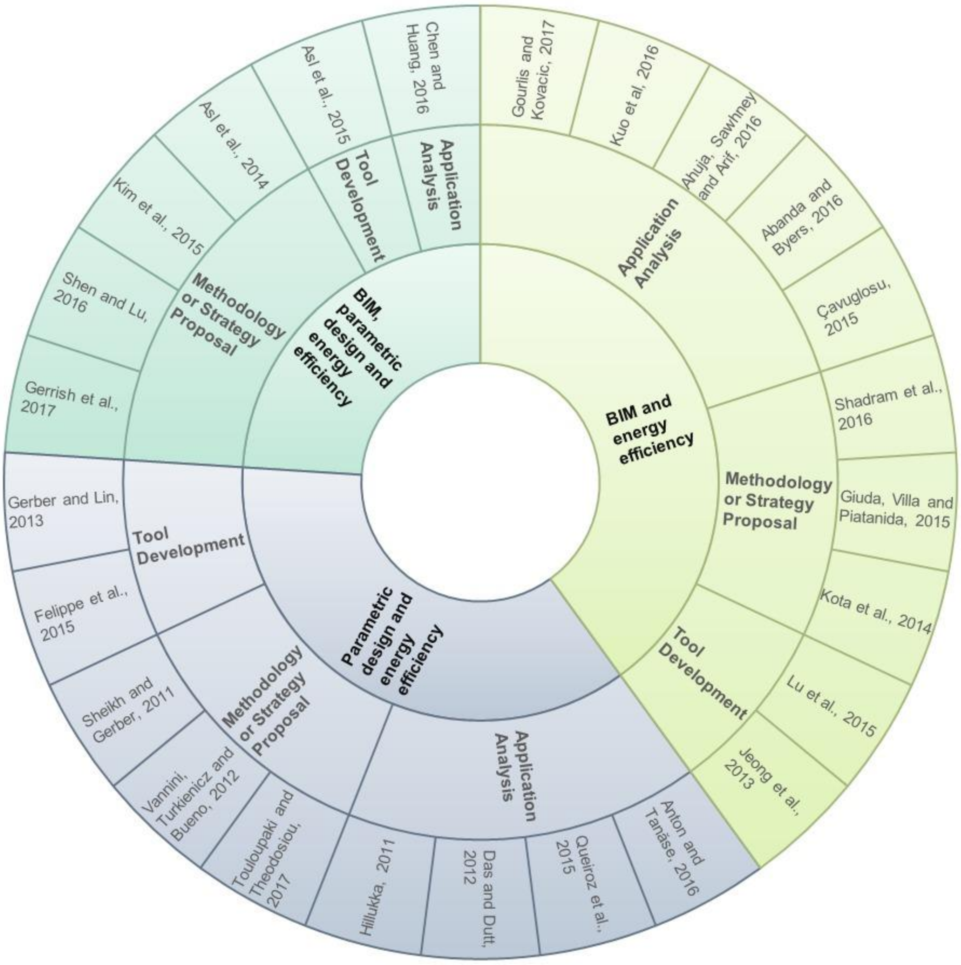


Figure 3: Studies' main approach.

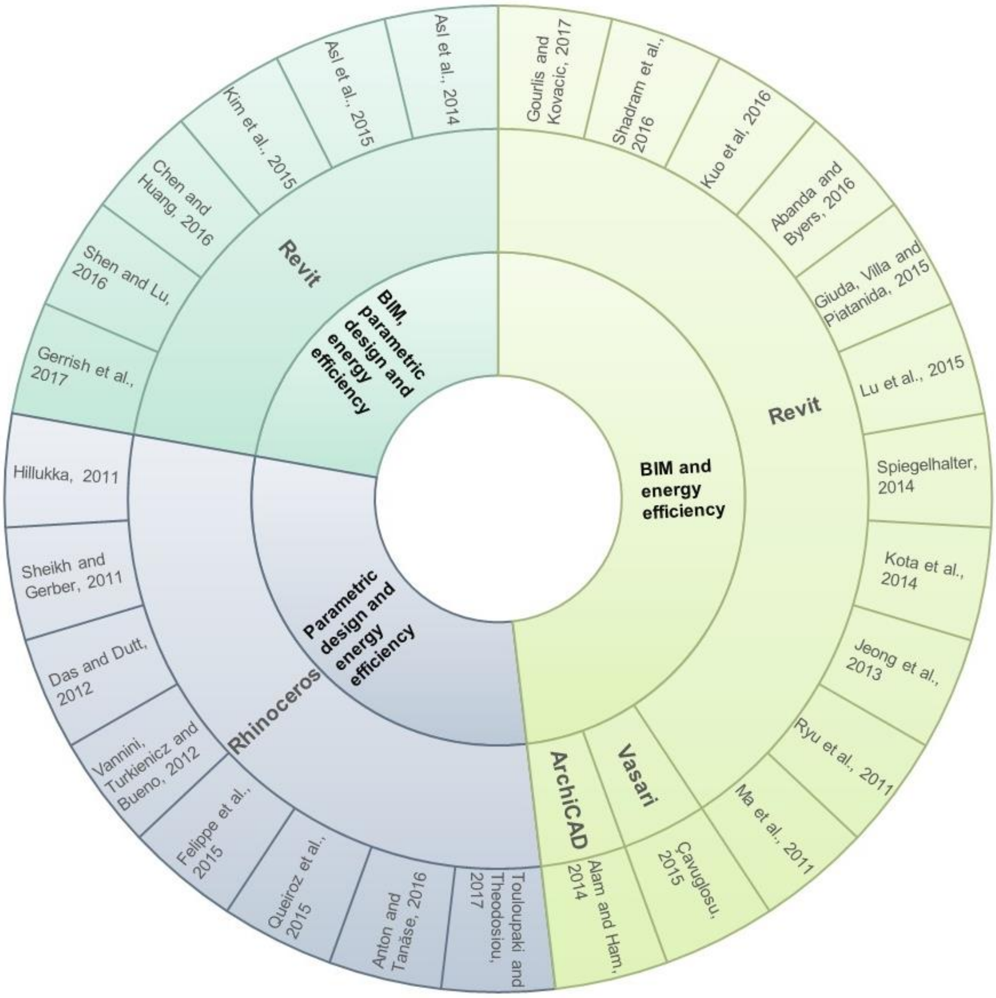


Software

Figures 4, 5 and 6 show the main software used in the studies of the three analyzed cases for modeling, simulations and visual programming, respectively. In papers about BIM alone, it turned out that Autodesk's Revit was widely used for modeling and prevalent in all but three of the studies, which used Graphisoft's ArchiCAD and Autodesk's Vasari. For the same situation, there was no prevailing software for simulations, but it is possible to highlight the use of Green Building Studio (GBS), also developed by Autodesk, and Ecotect software, which was recently discontinued and had its former functions integrated to Revit and GBS itself (Autodesk, 2017b).

For the isolated use of parametric design, a predominance of Rhinoceros modeling software was verified, associated with its visual programming plug-in Grasshopper. In this case, DIVA and Ladybug plug-ins were the most used tools for simulations. However, when using parametric design in association with BIM, Revit and its extension Dynamo were predominant in the studies analyzed.

Figure 4: Main software used for Modeling.



As for the integration between parametric design and BIM software, there are two possible workflow protocols: VPL tools can be accessed as extensions for BIM platforms by the same developers, as with Revit and Dynamo, by Autodesk, and as with AECOsim and GenerativeComponents, by Bentley Systems. Regarding Grasshopper, it can be linked to the BIM platform ArchiCAD by an interoperability package developed by Graphisoft (Graphisoft, 2018). As reported previously, in the studies analyzed, the use of Dynamo and Revit was predominant, which could possibly be due to Dynamo being already included in the latest versions of Revit, dispensing the use of additional tools. Although the same happens when it comes to GenerativeComponents and AECOsim, the tools weren't used in any of the analyzed studies.

Figure 5: Main software used for Simulations.

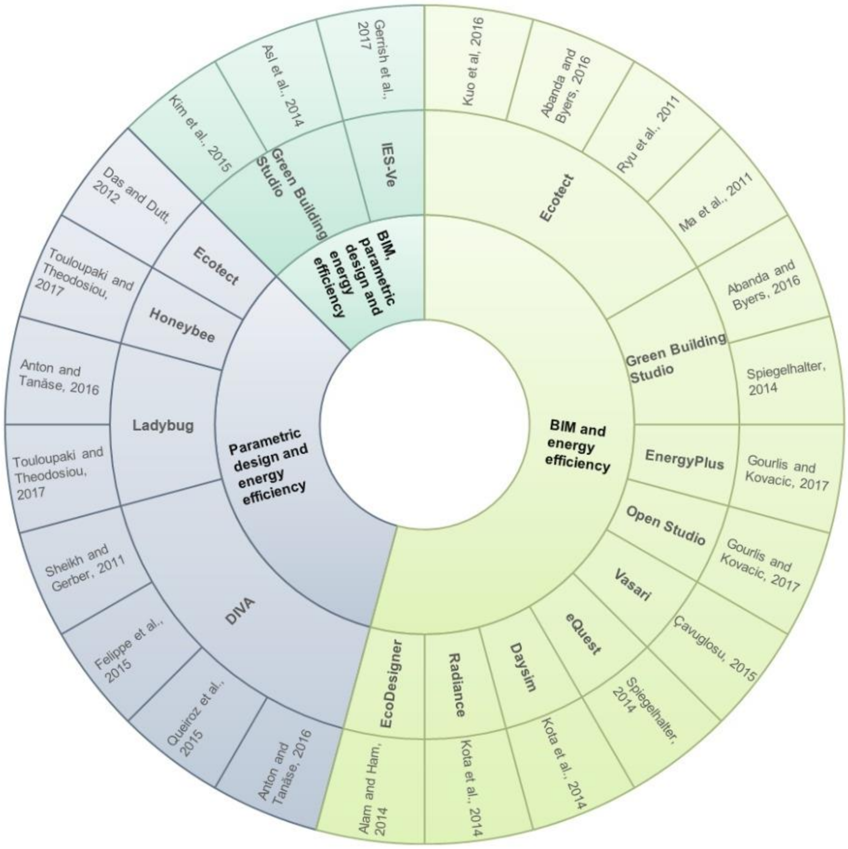
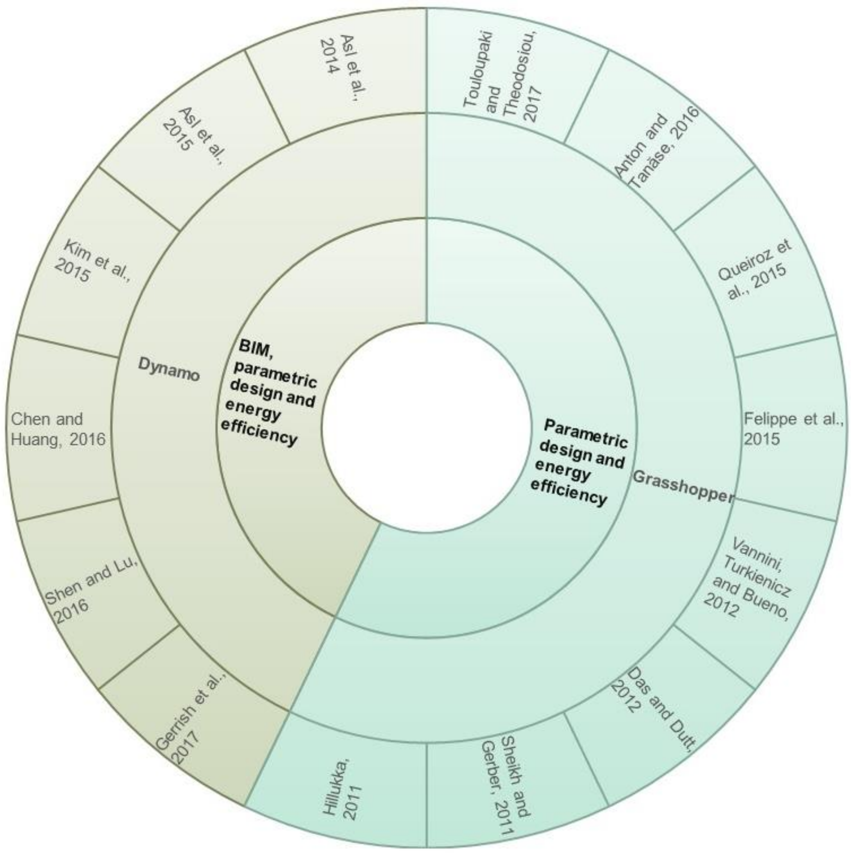


Figure 6: Main tools used for Visual Programming.



It is worth highlighting that, in the case of parametric design for energy efficiency, there was another category of software used for Optimization that is not presented in the Figures, in which four of the studies used the Grasshopper plug-in Galapagos. When using BIM and parametric design, no optimization tools or plug-ins were used. Actually, one of the papers is about the development of a tool for this purpose in Dynamo, the Optimo plug-in (Asl et al., 2015).

BIM and parametric design benefits for buildings' energy efficiency

The development of the mentioned studies allowed to identify aspects that compose benefits or advantages presented by the use of the adopted design technologies. When considering BIM alone, the main benefits mentioned were: analysis of multiple scenarios and possibilities (Spiegelhalter, 2014, Abanda and Byers, 2016, Kota *et al*., 2014, Kuo *et al*., 2016); reduction of rework and consequent increase in productivity (Alam and Ham, 2014; Ahuja *et al*., 2016; Çavuglosu, 2015); incorporation of accurate information (Kota *et al*., 2014; Kuo *et al*., 2016; Gourlis and Kovacic, 2017; Ilhan and Yaman, 2018); interoperability (Giuda e tal., 2015; Kota *et al*., 2014), and quantity takeoff (Shadram *et al*., 2016).

Regarding benefits of parametric design, the main ones mentioned were: analysis of alternatives and immediate feedback (Sheikh and Gerber, 2011; Das and Dutt, 2012; Felippe *et al*., 2015; Queiroz *et al*., 2015; Anton and Tănase , 2016, Touloupaki and Theodosiou, 2017); optimization of solutions by genetic algorithms (Gerber and Lin, 2013); dynamic control over multiple parameters (Touloupaki and Theodosiou, 2017); interdisciplinary design environments (Anton and Tănase, 2016), and reduction of errors caused by manual processes (Felippe *et al*., 2015).

Concerning the associated use of BIM and parametric design, the integration was mentioned as a facilitator of the performance-based design process (Asl *et al*., 2014). In addition, it was verified, through the studies analyzed, that there is a relation of complementarity in their functions, which generates more complex design environments with greater opportunities and possibilities.

The insertion of BIM and parametric design technologies in the design process allows to obtain a process of pre-rationalization of a future building's design, through the application of geometric rules and simulations in an iterative procedure in order to produce architectural solutions that include the analysis of quantitative and qualitative aspects of the building (Kolarevic and Malkawi, 2005; Ceccato, 2012).

However, it is worth highlighting that this approach requires an integration among the agents involved in proposing solutions for the project. In this sense, what prevails in the AEC industry are contractual relationships with more segregated and rigid characteristics, configuring a process that can be named as post-optimization: after the definition of the architectural design, simulations are performed in a complementary way and have little influence on the already determined solutions (Anton and Tănase, 2016).

Thus, in order for the benefits of integrating these technologies to be effectively achieved, it becomes necessary to review how design process is conducted. A sequential process where the architect finishes the architectural design and passes it on to individual contributions of each of the other involved parties does not allow to reach the pre-rationalization of the future building's design and the respective absolute benefits of including the presented digital workflows in the design process (Ceccato, 2012).

CONCLUSIONS

This literature analysis was carried out with the purpose of providing an overview of practical applications of BIM and of parametric design for energy efficiency of buildings. Based on the analysis performed, it was possible to diagnose that the studies that dealt with the connection between BIM and energy efficiency have essentially carried out application analysis of the technology for a certain purpose related to energy efficiency. However, when its use is associated to parametric design, there is a predominance of design methodology or strategy proposals. In contrast, when parametric design was used alone for energy efficiency issues, there was no major purpose that prevailed among the studies, showing a variety of approaches.

Considering this scenario, it is possible to assume that the associated use of BIM and parametric design technologies provides means to develop improvements for the design process in construction industry, since strategies, methodologies and tools have been developed and proposed. Thus, the associated use of these methods can provide to the designer a greater autonomy for developing and using their own design methods, especially when it comes to analyzing performance aspects of the future building and adapting design according to them.

In terms of software used, the findings are expressive. As for modeling, the use of Revit predominates, either when using BIM alone or in association with parametric design, where the predominant visual programming tool was its extension Dynamo. In both cases, it is not possible to identify an expressive predominance of a simulation tool. On the other hand, from the standpoint of parametric design alone, Rhinoceros modeling software and its Grasshopper visual programming plug-in stand out. In this case, the most commonly used tools were Grasshopper plug-ins, such as Diva, Ladybug and Honeybee for simulations and Galapagos for optimization.

Thus, nowadays Grasshopper can be considered the most popular parametric modeling tool when compared to Dynamo or Generative Components, based on the analyzed studies. However, due to the fact that its interoperability with BIM tools requires the use of a specific tool, although possible with ArchiCAD, the context changes when associating parametric design and BIM, since Dynamo becomes the most used tool. In this case, as previously pointed out, that possibly happens due to the fact that the Dynamo is already inserted in the latest versions of the BIM platform Revit.

Furthermore, it was possible to identify that BIM and parametric design present significant advantages for the incorporation of energy efficiency aspects in the design of buildings. Among them, there is the possibility of analyzing scenarios with immediate feedback, as well as to increase the productivity as a consequence of rework reduction. It was also verified that there is a relation of complementarity when considering the functions provided by BIM and parametric design, bringing new opportunities and possibilities to the design process.

However, as previously highlighted, to reach this level of application in professional practice, adopting new digital tools is not enough. The iterative process between design and simulation requires a collaborative and integrated approach for design process. Thus, at an industry level, the segregation of design process and the traditional contractual relationships need attention, since they possibly and apparently make it difficult to achieve the real and absolute benefits of the mentioned digital technologies.

Finally, it is worth pointing out as well that the number of studies analyzed was relatively small, since the topics covered are recent, especially when it comes to the association of BIM and parametric design for energy efficiency, and the literature on the subject is still rather scarce. Therefore, more in-depth studies are needed for further conclusions and possible correlations with the performed analysis.

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