Pontifícia Universidade Católica do Rio de Janeiro

Alexandre Santana Cruz

Discussion of the possibilities to achieve a Nearly Zero Energy Building (NZEB) using the BIM approach

Dissertação de Mestrado

Dissertation presented to the Programa de Pós-graduação em Arquitetura e Urbanismo of PUC-Rio in partial fulfillment of the requirements for the degree of Mestre em Arquitetura.

Advisor: Profa. Elisa Dominguez Sotelino

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Abstract

Cruz, Alexandre Santana; Sotelino, Elisa Dominguez (Advisor). **Discussion of the possibilities to achieve a Nearly Zero Energy Building (NZEB) using the BIM approach.** Rio de Janeiro, 2020, 104p. Dissertação de Mestrado – Departamento de Arquitetura e Urbanismo, Pontifícia Universidade Católica do Rio de Janeiro.

An architecture that requires a huge energy demand goes against the concept of a Nearly Zero Energy Building (NZEB). Research on the subject indicates that high performing buildings can be achieved with an integrated design that combines energy efficiency strategies, such as high performing glass, with photovoltaic energy (PV). The Building Information Modeling (BIM) methodology can incorporate Building Performance (BP) analysis to support decision making of an integrated design, which is considered essential to achieve a successful NZEB. The present investigation includes a Systematic Literature Review (SLR) that guided the research. Based on the SLR, an Information Delivery Manual was developed that propose a new workflow in which the energy studies are performed in the early stages of design to achieve more energy efficient projects and take advantage of the collaboration intrinsic to the BIM methodology. Lastly, a hypothetical experiment of a commercial building is presented to illustrate the workflow proposed in the developed IDM. The Autodesk Revit software was used to model the building and the energy computer simulation was performed in the DesignBuilder software. It was found that for these two software tools to be interoperable, the model had to be exported from Revit in gbXML format. The design options in the experiment were based on window-to-wall ratio (30%, 50% and 100%), on the adopted glass, and on the photovoltaic system. The economic feasibility analysis was performed based in the Net Present Value (NPV) and the Internal Rate of Return (IRR). The results indicated that the use of the north facade for PV production combining with the PV roof system provided a nearly zero energy balance in most of the cases. Finally, all cases analyzed had a payback time of less than the PV module manufacturer guarantee (25 years), except for the case with 100% window-to-wall ratio and PV Glass in the north facade.

Keywords

BIM; Building Performance Analysis; Nearly Zero Energy Building; Building Attached Photovoltaics; Building Integrated Photovoltaics.

Resumo

Cruz, Alexandre Santana; Sotelino, Elisa Dominguez. **Discussão das possibilidades de obtenção de um edifício com balanço de energia próximo a zero (NZEB) usando a abordagem BIM.** Rio de Janeiro, 2020, 104p. Dissertação de Mestrado – Departamento de Arquitetura e Urbanismo, Pontifícia Universidade Católica do Rio de Janeiro.

Uma arquitetura que exige uma enorme demanda de energia contraria o conceito de um Edifício de Energia Quase Zero (em inglês *Nearly Zero Energy Building* - NZEB). Pesquisas indicam que edifícios de alto desempenho podem ser alcançados com um design integrado que combina estratégias de eficiência energética, como vidro de alto desempenho, com energia fotovoltaica. A metodologia BIM pode incorporar a Análise de Desempenho do Edifício para apoiar a tomada de decisão de um projeto integrado, essa abordagem é considerada essencial para alcançar um NZEB bem-sucedido. A presente investigação inclui uma revisão sistemática da literatura que orientou a pesquisa. Com base na SLR, foi desenvolvido um Manual de Entrega de Informações que propõe um novo fluxo de trabalho no qual os estudos de energia são realizados nos estágios iniciais do design para alcançar projetos com maior eficiência energética e aproveitar a colaboração intrínseca à metodologia BIM. Por fim, é apresentado um experimento hipotético de um edifício comercial para ilustrar o fluxo de trabalho proposto no IDM desenvolvido. O software Autodesk Revit foi usado para modelar o edifício e a simulação energética foi realizada no software DesignBuilder. Verificou-se que, para que esses dois softwares fossem interoperáveis, o modelo precisava ser exportado do Revit no formato gbXML. As opções de design foram baseadas na proporção de janela/parede (30%, 50% e 100%), no vidro adotado e no sistema fotovoltaico. A análise de viabilidade econômica foi realizada com base no Valor Presente Líquido e na Taxa Interna de Retorno. Os resultados indicaram que o uso da fachada norte para produção fotovoltaica combinado com o sistema fotovoltaico da cobertura forneceu um balanço de energia próximo de zero na maioria dos casos. Por fim, todos os casos analisados têm um tempo de retorno de investimento inferior a garantia do fabricante dos módulos fotovoltaicos (25 anos), exceto no caso com 100% de relação janela/parede e vidro PV na fachada norte.

Palavras-chave

Modelagem da Construção; Análise de desempenho do edifício; Edifício de Energia Quase Zero; Telhado Fotovoltaico; Fachada Fotovoltaica.

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List of abbreviations

AEC Architecture, Engineering, and Construction
BIM Building Information Modeling
BIPV Building Integrated Photovoltaics
BP Building Performance
DOE Department of Energy
EPBD Energy Performance of Buildings
EU European Union
HVAC Heating, Ventilation, and Air Conditioning
IDM Information Delivery Manual
LOD Level of Development
NZEB Nearly Zero Energy Building
PV Photovoltaics
SLR Systematic Literature Review
NZEB Nearly Zero Energy Building

1
Introduction

1.1.Motivation

The large increase in energy consumption required by buildings was not taken into account in the past because then its cost was negligible and there was little concern on how this would affect the environment. Nowadays, the energy cost and the side effects of the utilization of nonrenewable sources of energy have become issues of paramount importance for the design of sustainable commercial and residential buildings (KWOK et al., 2015).

The Nearly Zero Energy Building (NZEB) concept, which consists of buildings with their own renewable energy generation systems capable of meeting their annual net energy requirements (PACHECO, 2013), is a goal pursued by the European Union (EU, 2010) and the U.S. Department of Energy (DOE, 2015). More specifically, the energy required should be supplied mostly by renewable sources, being on-site or nearby production (EU, 2010). Since a concrete numeric value or ranges are not defined, these requirements lead to different interpretations. Thus, this allows governments and private entities to define their own NZEB requirements taking into account their country specific climate conditions, primary energy factors, ambition levels, calculation methodologies, and building traditions (ZEBRA, 2020).

According to KAEWUNRUEN et at. (2018), there are a few energy microgeneration methods available to achieve the NZEB (e.g. Photovoltaic (PV), Solar Thermal, Hydro and Wind power). Brazil has a predominantly renewable energy source, emphasizing hydroelectric en ergy generation that accounts for 66.6% of the domestic supply (MME, 2019). Unfortunately, hydroelectric plants are based on centralized energy generation, with limited growth capacity, and with long distances between the generation center and the consumption centers. The latter causes high energy costs and losses (DIDONÉ et al, 2014).

PV solar power has been regarded as one of the best renewable energy resources to mitigate the climate change effects (KUO et al., 2016). In Brazil, the global solar irradiation values occurring in any region are high, 1700-2500 kWh/m²/year, when compared to Germany, 1000-1300 kWh / m² / year (SOLARGIS, 2019), which makes PV an attractive microgeneration option. Even though there are unfavorable solar irradiation conditions in Germany, in 2019 PV generated 8.2% of the electricity consumption in the country (FRAUNHOFER, 2019). This is in contrast to Brazil, where the portion of PV production is only 0.54% (MME, 2019). However, some considerations must be taken when the buildings are located in urban areas, since PV systems are installed on the building´s envelope, which can be shaded by surrounding buildings. These shadows on the PV modules must be avoided, in order not to reduce their efficiency (DIDONÉ et al, 2014).

Some studies (FERRANTE; CASCELLA, 2016) claim that to achieve NZEB it is necessary to use an integrated design method that combines energy efficiency strategies, such as high performing glass, and solar photovoltaic energy (PV). Building Information Modeling (BIM) has been growing exponentially because of the integrated process that the methodology provides. Furthermore, the methodology can incorporate building performance (BP) analysis at an early stage of the project to support decision making, which is considered essential to achieve a successful NZEB. In terms of evaluation, building performance can be estimated either by field measurement or computer simulation (WILDE, 2019). A great advantage of computer simulation is that it can be used in any phase, enabling the testing of building solutions at low cost and without intervention (OLIVEIRA, 2012).

In this context, the use of BIM to develop projects that seek zero energy balance considering photovoltaic energy provides a promising scenario for the development of the construction and energy sectors.

1.2.Objective

The main goal of this study is to understand how a NZEB can be developed within a BIM environment. Specifically, it seeks to shed some light on how architects and PV specialists can collaborate in the early stages of design. Thus, the specific objective of this study is to develop an Information Delivery Manual (IDM) that entertains the main research goal and to evaluate through computer simulation the energy performance of a commercial building in terms of consumption and production (PV), considering the impact of shading and including the economic feasibility of design options in the pursuit of nearly zero energy balance.

1.3.Method

To reach the objectives, this study focuses on correlating BIM, BP and NZEB. A structured literature review was conducted in order to understand the current stage of development in this scientific area. When correlating the three main issues, it was found that few works clearly integrate the three areas. To further understand the connections between these fields, it was necessary to search these terms in a pairwise to help guide the research on the subject. The result of the SLR, is the main topic of this report. The gap found is that BP analysis is unlikely to occur in the early design phases of a BIM environment. In addition, the impact of shading is not addressed in PV production simulations. To help fill this gap, a new information exchange process is proposed in a BIM environment illustrated in an IDM which includes building energy consumption and production study in the early design phase. An experiment based on the proposed IDM was performed to simulate the decision-making process based in the scenarios and results of the building performance.

1.4.Research Structure

This document is divided in 6 chapters. Chapter 1 introduces the research, provides the motivation, the objectives and the method of the work. Chapter 2 briefly defines the concepts (BIM, BP and NZEB) and describes the structured literature review process, its steps and considerations. It will also condense the analysis of the SLR, provide the details of the most relevant research articles, and identifies the gap in which this research intends to contribute. Chapter 3 presents the proposed method, which consists of the proposed IDM and the hypothetical experiment. Chapter 4 presents the results of the experiment, provides comparisons and a discussion of the findings. Finally, Chapter 5 presents the main conclusions of this research and provides some suggestions for possible future research in the subject.

2
Structured Literature Review and Analysis

2.1. Brief Review of Concepts

2.1.1. Building Information Modeling

BIM is considered one of the most promising developments in the Architecture, Engineering, and Construction (AEC) Industry (SAIEG et al., 2018). The reason for that is the digital 3D models that designers can create in which include data associated such as physical and functional characteristics (SACKS et al., 2018). There are several benefits that BIM can provide, such as reduce design time, construction time and cost (OLAWUMI et al., 2018), however, what makes this methodology powerful is the ability to connect professionals through interdisciplinary collaboration.

Although 3D models with data is one of BIM's great potentials, sharing this information should be considered the major differential aspect compared to the conventional practice (EL-DIRABY et al, 2017). There are numerous types of BIM software and tools, however, the key issue is how they communicate with each other, i.e., how they “interoperate”. This is known as interoperability and it means “the ability of diverse systems and organizations to work together”. One possible solution for that is the use of Industry Foundation Classes (IFC) schema from buildingSMART that intends to promote open data exchange between different software (BUILDINGSMART, 2010).

While exchange information is useful, its amount and maturity are essential to indicate model development. Measuring the amount of information at key stages can be achieved through the use of the concept of Level of Development (LOD) (GERRISH et al.,2017). The description of this is given by The American Institute of Architects and The Associated General Contractors of America (2019), which an arbitrary scale from 100 to 400 is used to indicate the amount of information in the model. Table 1 provides the different LODs for each design stage. In this table the term Model Element is used to refer to the components of a building.

Table 1 - Design Stage vs Level of Development (Adapted from AIA and ACG, 2019)

Design Stage	Level of Development
Early Concept Design	LO100 – The Model Element may be graphically represented in the Model with a symbol or other generic representation
Late Concept Design	LOD200 – The Model Element is graphically represented within the Model as a generic system, object, or assembly with approximate quantities, size, shape, location, and orientation.
Early Detailed Design	LOD300 – The Model Element is graphically represented within the Model as a specific system, object or assembly in terms of quantity, size, shape, location, and orientation.
Late Detailed Design	LOD350 – The Model Element is graphically represented within the Model as a specific system, object, or assembly in terms of quantity, size, shape, location, orientation, and interfaces with other building systems.
Construction	LOD400 – The Model Element is graphically represented within the Model as a specific system, object or assembly in terms of size, shape, location, quantity, and orientation with detailing, fabrication, assembly, and installation information.

2.1.2.Building Performance

The Green BIM methodology is the effective combination of BIM and Building Performance Analysis in integrated design that seeks to promote a rational building design with environmental sustainability in mind (CHEN, 2018). Building Performance Analysis during the decision-making cycle improves design to ensure an optimized project with better environmental effectiveness (OHUERI et al., 2018); (OLAWUMI et al., 2018).

However, the lack of a common understanding of what constitutes a building´s performance is one of the reasons that prevents the progress of this methodology in the building industry. For instance, the term building performance is usually mentioned when addressing the problem of the energy performance gap (CLEVENGER et al., 2018). Nevertheless, this is also a term often used in the AEC sector, typically in association with issues like the energy efficiency of buildings, indoor environmental quality, thermal comfort or lighting (SACKS et al., 2018).

The common understanding of the building performance concept found in the literature is that it allows to quantify with metrics how well a building fulfils its functions (LAVY, 2011). According to Sacks et al. (2018), examples of building performance may involve aspects such as privacy; occupant satisfaction; acoustical, olfactory, visual and thermal comfort; indoor air quality; accessibility; aesthetics; etc.

Also, in terms of evaluation, building performance can be measured in different ways. There are four main approaches for this type of analysis: field measurement, building performance simulation, expert judgement, and stakeholder surveys (WILDE, 2019). A great advantage of computer simulation is that it can be used in the design phase, during construction or even in a building already built, enabling the testing of building solutions at low cost and without intervention (OLIVEIRA, 2012).

In general, computer simulation demands specific energy modeling characteristics that are not present in the digital architectural project, thus requiring remodeling. Nevertheless, the Green Building XML open schema was developed to facilitate data transfer to Building Energy Analysis tools, it was developed in by Green Building Studio Inc and funded by U.S. Department of Energy (GBXML, 2020). The file format to achieve this has the extension gbXML.

2.1.3.Nearly Zero Energy Building

The energy consumption in buildings accounts for a significant portion of energy production worldwide (AHSAN et al., 2019). Thus, the concept of NZEB has become a target for the construction industry. The definition of NZEB is reported using as basis the annual energy use for the building's operation (heating, cooling, ventilation, lighting, etc.), while the term 'net-zero energy' is frequently used for low annual energy balance of a grid connected building (HERNANDEZ; KENNY, 2010). Currently, the most common approach is to produce energy and use the electricity grid as a source to avoid the on-site electric storage systems (FERRANTE; CASCELLA, 2016).

The rapid increase in electricity demand around the world is one of the reasons that building performance has become a trend (BATTISTA et al., 2015). Besides that, minimizing energy consumption through building energy performance has become crucial for AEC industry because of the scarcity of resources and rising energy costs (KWOK et al., 2015).

According to Battista et al. (2015), the increasing number of people living in large cities and the expansion of new urban areas are reason to define new efficient models of built environment. In the EU, the building sector represents more than 40% of Europe's energy production. The European Commission has defined a target to reduce by 20% the energy consumption and increase by 20% the renewable energy consumption from 2020 on (PETRI et al., 2017). The EU Directive on Energy Performance of Buildings (EPBD) requires all new buildings to be Nearly Zero Energy by the end of 2020 (EU, 2010).

The general pathway to achieve a NZEB consists of two steps: first, reduce energy demand by means of energy efficiency measures, and second, generate energy to achieve the balance (KIM et al., 2015). However, there are cases study alleging that high performing and zero energy balance buildings cannot be reached by one technology alone (KAEWUNRUEN et al., 2019); (MELGAR et al. (2018). It is necessary an integrated design that combines energy efficiency strategies, such as high performing glass, with solar or wind energy microgeneration (FERRANTE; CASCELLA, 2016). Thus, it is clear that architects, engineers, and designers must consider working together in an integrated design process if they aim to deliver a NZEB.

2.1.4. Photovoltaics

PV is the conversion of sunlight into electricity using semiconducting materials. Some of the materials currently used for photovoltaic energy production include monocrystalline silicon, polycrystalline silicon, amorphous silicon, cadmium telluride, and copper indium selenide/sulfide (ELINWA et al., 2017). Photovoltaic Cells are considered the most promising source of clean energy because they generate electrical energy in the form of direct current by converting solar radiation, which is the most abundant resource on Earth (FITRIATY; SHEN, 2018).

Among the different sources of renewable energy, photovoltaics and solar collectors appear to be most suitable for use in buildings' envelope (DIDONÉ et al, 2014). The use of photovoltaic modules on the building level can done in two ways: Building Attached Photovoltaics (BAPV) and Building Integrated Photovoltaics (BIPV). The first is the most common approach, which the photovoltaic modules are attached to the surface of the building. The second configures the integration of photovoltaic technology in the building's envelope. This approach can offset the cost of some construction elements, adding to buildings new aesthetical features (NING et al., 2018a).

The BAPV require additional mounting systems and are typically used in retrofit (DIDONÉ et al, 2014). In general, due to large unused roof space, BAPV systems installed on roofs are being increasingly used (HABIBI et al 2019). BIPV system involves combining solar photovoltaic electricity technologies with typical building fabrics such as the roof or facades. In particular, the BIPV windows have become increasingly attractive due to their capability of generating electricity and yet allowing the incidence of daylight, which enhances occupants' visual comfort (CHAE et al., 2014).

However, there are currently some obstacles to the general adoption of these techniques. First, its high initial cost and second the development of a better architectural design approach to effectively explore different BAPV and BIPV applications for a good electricity productivity solution (KUO et al., 2016).

Nevertheless, in the PV design, the building's surroundings must be taken into account. This is because PV modules once installed could be shaded by trees, by surrounding buildings or even by themselves (RADMEHR et al, 2014). The shadows can significantly impact PV power outputs (LI et al., 2019). Since there are two basic types of PV applications BAPV and BIPV, the PV strategy demands that architectural and PV design may be performed collaboratively, rather than in isolation (NING et al., 2018a).

2.2.
Literature Research Method

In order to identify gaps in the state-of-the-art literature and to direct further research on the selected topic, this study began by carrying out a Structured Literature Review (SLR).

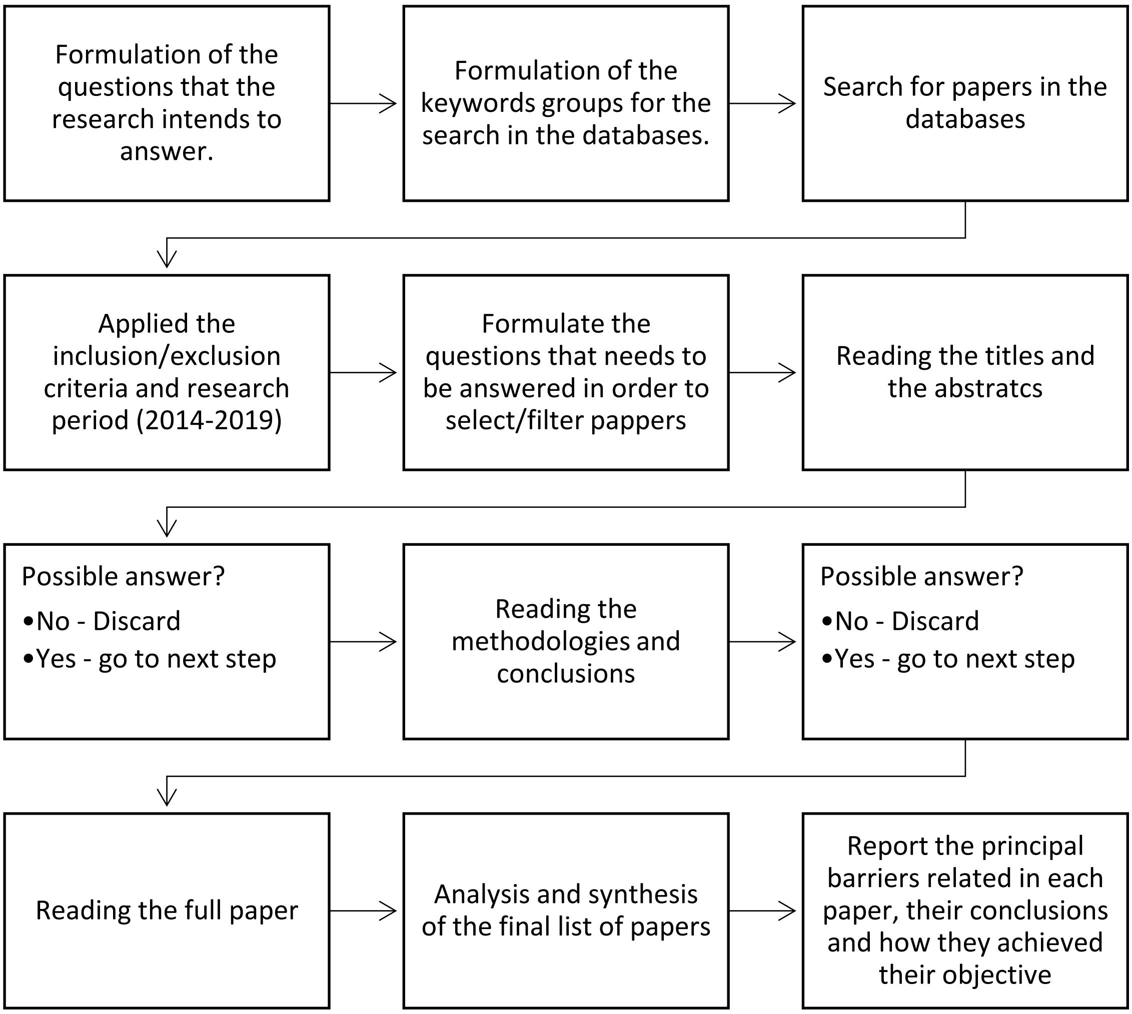
In order to do a SLR, first it was defined the evaluation criteria based on the research question that the review tries to answer. The precise definition of the evaluation criteria is fundamental because it makes the process transparent and shows the comprehensiveness of the review. It is essential to explain thoroughly the conduction of the review process, particularly regarding the selection of the literature and the choices made in relation to the use of specific search terms and databases (SAUNDERS et al.,2008).

An effective review creates a solid foundation for advancing knowledge (FARIA, 2017). According to Webster and Watson (2002), it occurs because of the solid and transparent way that review is structured, facilitating theory development, closing areas where there is a huge quantity of research, and uncovering areas where research is needed. Because all the benefits that an SLR adds to a literature review, it has increasingly been used in literature management (HALLINGER, 2013). The extra effort required for doing the SRL in comparison with a traditional literature review is the main disadvantage of this methodology.

Faria (2017) suggests a that a structured review be organized in five different stages: formulating the research questions, locating papers, selecting and evaluating papers, analyzing and synthesizing the contents of the papers, and reporting and using the results.

To overcome the additional effort of doing the SLR, some tools were used to support the process in this study, namely: Microsoft Word and Microsoft Excel. The search for the papers were done in the following databases: Engineering Village, Web of Science, Scopus, ScienceDirect and CAPES Periódicos. Table 2 illustrates the phases of the research and their activities during the review.

Table 2 – Research phases and their activities during the literature review



2.2.1. Question Formulation

To propose a workflow for BIM methodology implementation, it is necessary to understand how the involved areas relate to each other. Focusing in Building Information Modeling, Building Performance Analysis and their relation with Nearly Zero Energy Building, the current research formulated and considered the following question:

(1) How can Architecture design and Building Performance Analysis interact in a BIM environment in order to achieve Nearly Zero Energy Building?

2.2.2. Locating Studies

The first step to locate studies was to formulate the keywords that would drive the SLR. The keywords were divided into two groups, the first one is the main group and the second one is the group composed of words derived from the main group, as can be seen in Table 3.

Then using the Boolean operators “AND” and “OR”, these keywords were combined in a research string and used to filter the papers in the databases, as can be seen in Table 4.

The first attempted research filter was composed of three main groups and their derived words, characterizing papers that involved all four themes: Building Information Modeling, Building Performance, Nearly Zero Energy Building. In this first attempt, only one paper was found, so, the first SLR conclusion is that there is a gap in knowledge in this combination of areas, warranting more studies.

The next step was the confirmation of the existence of this gap. It was necessary to combine the words in two by two strings as can be seen in Table 3. There are many studies relating BIM and BP (142 papers); BP and ZEB (154 papers); but there are few relating BIM and NZEB (28 papers). At first sight, it is possible to conclude that there is a relevant gap in the latter. Since BIM methodology is a new topic and its growth depends on development of new studies, the integration between different areas becomes important. Thus, in this context, the research’s objectives become clear and appropriate.

Table 3 - Keywords

Main Group	Derivated Group
Building Information Modeling (BIM)	Green BIM IFC gbXML
Building Performance (BP)	Building Performance Analysis Building Energy Modeling Energy Simulation
Nearly Zero Energy Building (NZEB)	Zero Energy Building Net Zero Building Photovoltaic

Table 4 - Strings of Keywords

First Attempt	Second Attempt
BIM AND (Green BIM OR IFC OR…) AND BP AND (Building Performance Analysis OR Building Energy Modeling OR …) AND NZEB AND (ZEB OR NZB OR …)	BIM AND (Green BIM OR IFC OR…) AND BP AND (Building Performance Analysis OR Building Energy Modeling OR …) BIM AND (Green BIM OR IFC OR…) AND NZEB AND (ZEB OR NZB OR …) BP AND (Green BIM OR IFC OR…) AND NZEB AND (ZEB OR NZB OR …)

2.2.3.
Study Selection and Evaluation

According to SAUNDERS et al. (2008), conference proceedings and peer-reviewed articles are the most reliable sources for a literature review and only these sources should be considered in an SLR.

In the first and second phase of attempts, the research focused on applying appropriated filters to restrict some papers based on conditions of inclusion/exclusion. In so doing, the sample becomes more coherent, from which, conclusions can be drawn and gaps can be identified in the literature. Table 5 lists all the filters applied to the search engine.

Table 5 - Inclusion/Exclusion Criteria

Inclusion	Exclusion
Journal Articles	Not Journal Papers (Conference paper, e.g.)
From 2014 to 2019	Out of the inclusion period
AEC area	Non-AEC

After finding papers and applying the appropriated filters, Saieg et al. (2018) suggest that the study selection should be done in three steps:

- The first step is to read the tittles and the abstracts of each encountered study and to evaluate them.
- The second step includes reading the methodology and the conclusion of each study that passed in the first evaluation.
- The last step is reading the full text of the remaining papers after the second step.

These steps filter the located studies and the remaining papers compose the final list of papers relevant for this research. During the evaluation, only the papers that answered or could answer one of these three questions in any way were able to pass for the next step:

(1) How can BP be insert in the BIM Methodology?

(2) What impact does BIM methodology generate in a NZEB project?

(3) How can BP help a project achieve NZEB?

To illustrate and better understand these steps, Table 6 presents the findings and the application of filters. Each line represents the terms combination and the numbers of articles found is described in each column.

Table 6 - Evolution in number of articles using complete analysis

TERMS	Without Exclusion and Inclusion Criteria	With Exclusion and Inclusion Criteria	Title and Abstract Analysis	Methodology and Conclusion Analysis
BIM + BP	296	142	48	31
BIM + NZEB	73	28	12	12
BP + NZEB	478	154	57	22

Combining the findings and eliminating the “duplicated” papers, 65 papers were selected to carry out the complete analysis. Appendix A provides a list of all chosen articles.

2.2.4. Analysis and synthesis of results

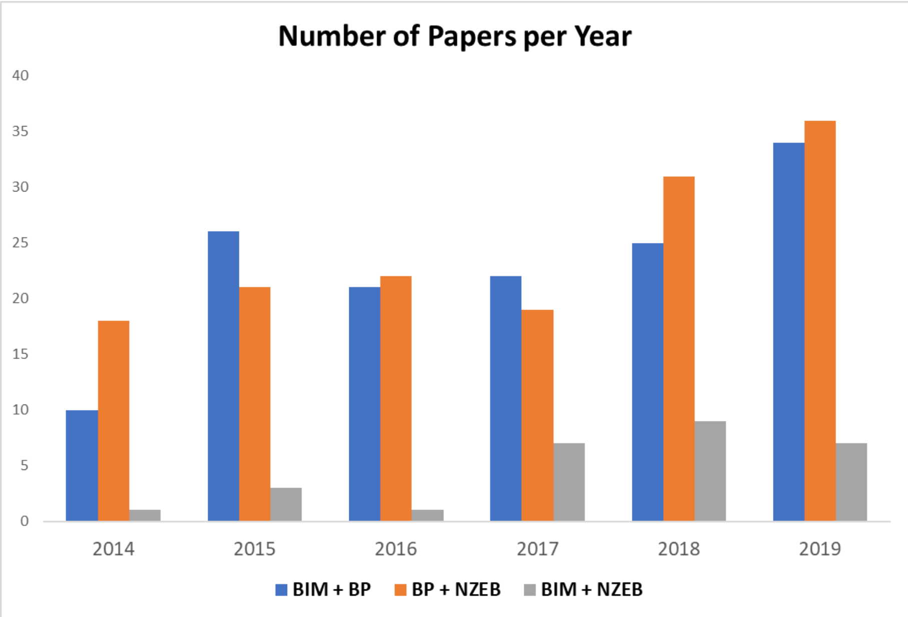
The results from the SLR are organized in three combinations of pairwise terms. The BIM and NZEB combination provided the smaller amount of published works (a total of 28 papers) when compared to the other two combinations. The BIM and BP combination returned 142 papers, while 154 papers were found under the BP and NZEB combination.

From Figure 1, since 2014 there is a substantial number of publications related to the two main combinations: BIM + BP and BP + NZEB. The interest in combining nearly zero energy balance and building performance analysis stands out in almost all the years under study, except in 2015 and 2017 which the BIM + BP combination has more publications. These two combinations had a noticeable increase in number of publications over the years. The interest in both areas became more evident probably because of the increasing concerns with environmental issues, the emergence of sophisticated simulation software, and the rise of energy price. It is important to highlight that in the last 6 years 296 articles were published related to the building performance topic alone.

Unfortunately, the number of published articles related to BIM + NZEB is in contrast when compared to the others two combinations. Another fact observed is the slight increase in published articles that combine these two topics in the last three years. However, the BIM + NZEB publications tendency curve is still far from the other two curves.

Currently, researchers have given more attention to how BP affects BIM and how BP can measure NZEB. Based on previously presented numbers, it is possible to infer that there is a potential knowledge gap in research combining BIM with NZEB. Since the BIM methodology stimulates the interdisciplinary and the exchange information between players, the BIM approach of this research seeks to understand how building performance analysis can share information to help nearly zero energy building achievement.

Figure 1 - Number of papers per year since 2014



2.2.5. Selected Articles Review

In this section, the 65 papers selected from the SLR are summarized and brief comments regarding their research proposals and findings are presented. To better understand, they were divided in three topics: BIM and BP papers, BIM and NZEB papers, and finally BP and NZEB papers.

2.2.5.1.BIM and BP

In general, building performance analysis through computer simulation happens due to the pursuit of energy efficiency. That means, predict the consumption of each design option to select the best wall insulation, the best performing glass, or the ideal opening percentage on a building's facades. OLAWUMI et al (2018) tried to evaluate the benefits of integrating BIM and sustainability practices in construction projects. Their study identified three most significant benefits of doing a BP Analysis: enhance overall project quality and efficiency, ability to simulate building performances and energy usage, and better design products and facilitate multi-design alternatives.

HABIBI et al, 2019 presented the re-roofing as one of the key options to reduce energy consumption and improve overall building performance. The solar capacity simulation was performed with HelioScope software and energy consumption in Integrated Environmental Solutions - Virtual Environment (IES VE) software. The retrofitting provided 15% of energy savings due to the insulation of the flat roof as well as offering the possibility of producing energy from the photovoltaic panels.

SHOUBI et al (2015) proposed some alternative materials for the envelope of a residential project. The simulations were performed using Autodesk Revit and Ecotect software packages. They found that the combination of reverse brick veneer, double glass, and a window-to-wall ratio (WWR) of 30% could reduce energy demand in 28%. OTI et al. (2016) investigated the impact of building orientation on energy consumption using Autodesk Revit, Green Building Studio (GBS) and Ecotect software tools. Based on their analyses, it was concluded that the energy consumption considering building orientation could save up to 5% of energy throughout its life cycle. JUAN; HSING (2017) used the same tools and developed three design proposals that target different service lives of 30, 50 and 100 years as based on the building's expected life. Their findings showed that under the service condition target of 100 years, it has lower life cycle costs (24% less) than the traditional design.

AHSAN et al. (2019) investigated the effectiveness of applying different passive cooling and compared the investments of the retrofitting. The different passive cooling techniques were based in parameters, such as type of insulating material, thickness of insulating material, single and double glazing, and WWR. The simulation software Autodesk Ecotect was used to predict annual energy consumption and their results indicate a possible reduction of energy demand of 35% with a payback period of 3 years.

Maciel; Carvalho (2019) investigated the energy benefit of opaque ventilated facades compared to cladding facades in residential buildings, in Brazil. To this end, computational simulations using Autodesk Revit and GBS were performed. The study evaluated 16 cities located in nine different climate zones, according to the Köeppen-Geiger classification. This research showed that passive cooling could offer electric energy savings from 8% to 43% yearly. This study brings the importance of building performance analysis at the early stage of design and encourages the use of data from the simulations as a decision-making tool for the design process. In a similar work, RAHMANI ASL et al.(2015) present an integrated framework for BIM-based Performance Optimization (BPOpt). The framework enables designers to explore alternatives of glass specifications. They used Dynamo for visual programming to generate design options within Autodesk Revit and GBS.

KIM et al. (2018) and ODUYEMI; OKOROH, (2016) analyzed building performance using Autodesk Revit and GBS. The variables considered in their study were building components such as construction materials for exterior walls and roofs, as well as WWR. Another similar approach was presented by ABHINAYA, (2017) In this work, they estimated that the energy consumption reduction of a house was 10% when using green roofing, autoclaved aerated concrete blocks, cork flooring and glazing with low emissivity coating. Also, NAJJAR et al. (2019) obtained a 15% improvement in the energy consumption in buildings due to WWR decrease.

Mcarthur; Sun (2017) compared the results of two simulations, the first was developed using Autodesk Revit and the model was exported to GBS and the second was based using only eQuest software. The results of both simulations were considered reliable as they were compared with in-situ case measurements and the deviations between the simulations and the measurements were 2.8% (GBS) and 6.2% (eQuest). It was highlighted that if the BP happens at an early design, it can provide new opportunities for designers to quantify potential energy savings.

CHEN et al. (2017) proposed a Green BIM-based decision-making cycle that can integrate the practical steps of BIM and BP analysis. They adopted Autodesk Revit with GBS for energy performance analysis. The optimized empirical model showed savings of 10% of energy.

JEON et al.(2018) explores simulations to quantify the impact of building envelope on energy use in a BIM environment. They used Autodesk Revit and GBS to performed energy simulation with varied envelope thermal properties under different climate conditions in pursuit of reliable energy analysis. From the results of the case studies, it was observed that the annual energy consumption of a residential building can deviate by 18–20% if thermal resistances of walls are not correctly defined. It would cause remarkable errors in building energy analysis and significantly overestimate the total energy consumption.

Lopes et al. (2017) proposed a building energy simulation using the DesignBuilder to explore the savings of occupant behavior. It was found that an inefficient user consumes 131% more than a reference user and a hypothetical efficient profile could save up 34% of the reference user energy consumption. This study only considers information modeling in an energy analysis program, but does not illustrate how the produced information can be shared with and helpful to other designers.

There are numerous types of BIM software and tools, however, the key issue is how they communicate with each other, i.e., how they “interoperate”. This is known as interoperability and it means “the ability of diverse systems and organizations to work together”. REEVES et al. (2015) list various existing Building Energy Modeling (BEM) tools and evaluate the usefulness of these tools. Among the thirteen evaluated tools, the top three were: Ecotec, GBS and IES VE, due to higher score on interoperability, usability, and available inputs and outputs. ZANNI et al. (2014) made a similar list and highlighted that BIM offers the possibility to reduce repetitive work by integrating information into common data formats such as the Industry Foundation Classes (IFC) and Green Building XML (gbXML).

LIM (2015) evaluated the interoperability between architecture modeling software (Autodesk Revit, Graphisoft Archicad and Bentley Architecture) and energy simulation programs (Ecotect, IES VE and DesignBuilder). The paper also mentioned IFC and gbXML as data formats for information exchange and concluded that one of the critical challenges in implementing BIM-based sustainability analyses is the lack of well-defined transactional process models and practical strategies for integration of information. CEMESOVA et al (2015), claims that IFC lacks a domain for energy simulations, and as a result, an extension was developed using externally coupled Java tool. The process of geometry extraction has been validated with several case studies and it was concluded that the amount of error was mostly due to differences in the initial BIM model setup, not due to the processing of IFC files. PATIÑO-CAMBEIRO et al. (2017) claims that the advantage of gbXML format over IFC is that the exportation is simpler and easier. On the other hand, the strength of IFC is the ISO standard (16739:2013), which has made it the prevailing format for BIM. These authors also modeled a university building in Revit using the 3D point cloud and used the gbXML format to export to

DesignBuilder. They concluded that the Revit-DesignBuilder interoperability was insufficient because of the manual improvements that complex elements demand. Thus, projects with complex shapes are compromised in this process.

CHEN et al. (2018) studied the interoperability between Autodesk Revit using gbXML and four different BES tools (i.e., Ecotect, EQUEST, DesignBuilder and IES-VE) and due to the complex shape of the building, in all cases there were misrepresented or overwritten information by the software. It was concluded, then, that the lack of sufficient interoperability between software tools is a barrier for an adequate flow of information from BIM for BES for buildings with complex shapes. The same is true when using IFC. For example, buildings with curved surfaces are not supported in IFC models, since they can only handle polyhedral geometries. Because of that, YING et al. (2019) presented an algorithm to automatically facet curved walls and convert their geometries into polyhedrons, so that they can be further processed in energy analysis tools.

GUZMÁN GARCIA; ZHU (2015) affirms that gbXML schema has been widely supported by many of existing building design software applications. In this work, an automated converter so that the gbXML format could be supported by the eQUEST energy simulation software. The converter has been tested in three real case studies and it was concluded that the converter reduced the time and effort losses in the AEC industry by lowering the amount of manual work required in the current information exchange.

RYU; PARK (2016) simulated the energy performance of a commercial building that seeks LEED certification. Autodesk Revit was used for modeling; the project was exported in gbXML format to Trace 700 software for energy simulation. It was reported that when using the gbXML format geometry adjustments still need to be made for the importation of the model. PAN et al. (2017) reached the same conclusions when investigating interoperability challenges and developed strategies for energy modeling of high-rise buildings applied to public housing in Hong Kong.

GARWOOD et al. (2018) presented a potential framework for quickly capturing and processing as-built geometry of large-scale buildings, to be utilized in building energy modeling (BEM). The interior of an industrial facility was laser-scanned to produce a point cloud. The sample was converted into a gbXML model in order to simulate energy consumption in IES VE. The simulated results were compared with in situ measured data and the model was considered calibrated due to a coefficient of variation of 3.66%. It was concluded that the gbXML format has been identified as a promising file format candidate for interoperability between different BEM packages.

JIN et al. (2018) investigated the impacts of BIM in cross-disciplinary teamwork design through information sharing. They created a workflow based on their experience and proposed that the building performance analysis occur in parallel with the architectural and structural designs, showing the BIM approach as a real interdisciplinary methodology, not just a software tool.

GERRISH et al. (2017) addressed the issues of information exchange in a BIM environment. In their work, a commercial building was modeled in Revit and later exported using IFC and gbXML formats. Both formats were tested in order to run the energy simulation in IES VE. In the exported files for both formats, there were geometry errors and material properties were lost. A method between BIM and BEM was specified and it was highlighted that during the concept design, the energy specialist is responsible for all the information in the energy model except for the geometric shape of the building. FARZANEH et al. (2018) suggested the same approach. Their study claimed that the BIM-BEM strategy avoids remodeling the building to create the Energy Model by sharing the architectural geometric shape to perform the energy analysis. It was concluded that the proposed framework may encourage architects and engineers to use BIM collaboratively for building energy simulations.

2.2.5.2.BIM and NZEB

The pursuit of more efficient design requires more than energy savings. Currently, the ability to produce energy on a building scale relies mainly on photovoltaic production. RADMEHR et al (2014) and ELINWA et al. (2017) explored people's preferences of Building Attached Photovoltaic (BAPV) and Building Integrated Photovoltaic (BIPV) in Northern Cyprus. Their results show that BIM related to PV Systems helped the contractors and house owner during the decision-making process to have a better financial and aesthetic understanding of the alternatives. Despite the fact that there are design options based on power generation capability and investments, the shading effect is mentioned, but not addressed directly in any project.

XU; YUAN (2018) presented a virtual model for simulation of sunlight's effect on building. They calculated the energy capacity of photovoltaic system in the roof and facade using Revit and THSWARE. The study takes into account the surrounding buildings to understand the shading effect on PV module and it concluded that to satisfy required cost savings, the PV panels could not be installed on the north facade.

KUO et al., (2016) investigated accuracy of Photovoltaics simulation in a BIM Environment. The Autodesk Revit software tool was used for architectural modeling and the Ecotect software was used to carry out energy analysis from the imported project in gbXML format. The case study simulated electricity production from four different positions of BIPV panel systems that were installed in a house located in the Industrial Technology Research Institute (ITRI), Hsinchu, Taiwan. The simulated results were compared with data measured on site. They concluded that the results predicted reasonably well the electricity production of BIPV. The surrounding buildings did not cause shading in the studied project; thus, they were not modeled to reduce computation complexity. However, the authors pointed out that shading and the angle of the BIPV module system can affect electricity production.

NING et al. (2018) proposed a uniform design platform for BIPV design and analysis: e-BIM, which is a plugin extension for Autodesk Revit. The platform is intended for architects, PV system designers and electricity professionals. The idea of the research is useful because PV modules are considered part of building envelope during the design process rather than being considered afterwards.

AMORUSO et al. (2018) discussed the framework for the refurbishment of a building in Seoul. Autodesk Revit and Rhinoceros with Grasshopper/ Ladybug/ Honeybee were used to simulate the building's performance. The BIPV panels installation considered the facades and the roof. Due to the total annual shading hours it was decided not to install PV panels on the facades. After renovation, the building's heating energy demand can be reduced by 57% and the cooling energy demand can be reduced by 11% compared to the existing building.

FITRIATY et al. (2017) and FITRIATY; SHEN, (2018) evaluated the energy generation of Photovoltaic (PV) installations on residential building envelopes using 3D visualization. The optimal location of PV panel was determined using Autodesk Revit to quantify the incident solar radiation. The results indicated that the optimal location for PV panels was on the roof. They also found that some walls of the building are potential spots to produce energy. They compared the actual energy consumption with the potentially available PV generation. It was concluded that photovoltaics on residential buildings could secure both current energy consumption and future energy demand. This research brings an analysis that can potentially help incorporate PV design in the design process easily.

MYTAFIDES et al. (2017) evaluated the energy saving of a university building in the Mediterranean climate. The study investigated alternative designs through GBS and Computational Fluid Dynamics (CFD) software. They applied thermal insulation at the building's envelope and glazing upgrade. Daylight analysis and solar analysis were performed; thus, sunshade awnings and photovoltaic installation were suggested in order to minimize energy consumption in pursuit of desirable interior thermal comfort conditions. It was concluded that the building is capable of producing the same amount of energy that it consumes with a retrofit cost payback of 8 years.

MELGAR et al. (2018) present an integrated architectural and energy microgeneration design. A structured methodology is proposed in order to help the decision-making process of a minimum energy building (MEB). The systematic workflow presented is based on the authors' knowhow of projects in subtropical climates areas. The proposed methodology is grounded on EU's guidelines for an NZEB building. The methodology in this work was applied to an isolated single-family house project named Casa Zaranda. The performance of the building is measured after construction in situ. The collected results were compatible with the requirements of an NZEB for European Union (EU, 2010). The workflow in the development of the project remained linear and without complete use of the BIM approach. In addition, there is no computer simulation during the early design phase to provide technical data for better interpretation of design options.

KAEWUNRUEN et al. (2018) highlight technical and financial feasibility of NZEB. The evaluation and improvement of the buildings were carried out. A digital model was created using Revit and the thermal properties were changed. The roof, wall, windows and doors were upgraded to a higher level of isolation in order to increased energy efficiency. The energy analysis was performed and the savings were calculated based in UK energy prices. The study concluded that PV technology and Wind Turbines were necessary to meet the energy demand of the NZEB Building. Also, the additional costs associated with improving the efficiency of the house yielded a 23-year payback period.

2.2.5.3.BP and NZEB

LEE et al. (2014) assessed the applicability of semi-transparent photovoltaics system in seven different cities, which classify the 6 types of the world climate (Zone 1 to 6) according to the ASHRAE standard. The variables in this study were: orientation, glass type and WWR (100/75/50/25%). According to the simulation results from the ESP-r program, it was concluded that PV windows could provide 12% to 22% of the total building energy consumption in the cities studied. CHAE et al. (2014) proposed a similar approach, but considered six different cities in US (Miami, Phoenix, Los Angeles, Baltimore, Chicago, and Duluth) and the WWR was 30% for all cases. The commercial building energy simulation model was conducted in EnergyPlus. It was concluded that in terms of energy savings, all the BIPV systems reduce the consumption of the building. As an example, in Los Angeles, it was possible to save 30% of the total HVAC system energy when compared with the use of double-pane clear glass system.

DO et al. (2017), evaluated the potential energy benefits of integrating semitransparent PV windows in a residential building in hot and humid climate. The energy simulation was done in eQuest. They found that the BIPV windows displayed great potential for energy savings: about 12–21% in annual energy use. In addition, the parametric study varying the WWR with the BIPV window concluded that the larger BIPV window provided more savings in annual total energy use. KAPSIS; ATHIENITIS (2015) investigated the potential benefits of semi-transparent PV windows on the energy, daylighting and thermal performance of commercial buildings, located in Toronto. The simulation methodology using Energyplus and Daysim concluded that semi-transparent PV module with 10% visible effective transmittance resulted in the lowest annual end-use electricity consumption.

AKSAMIJA (2016) studied the feasibility of achieving net-zero energy goals in retrofitting commercial buildings. A case study was presented to illustrate research process, design methods and results. The eQuest software was used to build and analyze energy model of the commercial complex. The retrofit strategies were able to reduce the energy demand in 50%. It was concluded that PV system could produce only 45% of the total energy demand. In order to achieve the energy renewable sources target, it was necessary to incorporate wind, biomass and hydro energy. A similar simulated result using DesignBuilder was found by Rey-Hernández (2018), the NZEB located at the university campus in Valladolid (Spain) demanded PV and Biomass system.

ABDULLAH (2017) presented a retrofit strategy by integrating optimized PV system in the form of responsive shading devices using a dual-axis solar tracking system. The office building, T1 EmpireWorld in Erbil, was selected as a retrofit case study and the energy simulations were performed using OpenStudio with EnergyPlus and Grasshopper/ Ladybug tools. The results showed that the PV integrated responsive shading devices can maximize the efficiency of PV cells by 36.8% in comparison to the fixed installation. The study proved that this retrofit method reduced total site energy consumption by 33.2% but the integrated system could provide only 15.39% of the energy demand of the building

LI et al. (2019) studied the energy production of roof PV systems through roof design. The helioscope software was used to perform the simulation, which was validated with real-time monitored data. Based on the verified model, the impact of different tilt angles and shading from surrounding obstructions upon energy generation were analyzed. The aesthetic design of five typical roof design patterns were considered (flat, shed, gable, hip, and butterfly roof). Findings indicate that: the shading of surrounding obstructions can reduce the energy generation of roof PV systems considerably, up to 24% energy loss; the optimal tilt angle should be close to the latitude angle of the studied location; and the shed roof design provides the maximum potential for solar energy generation.

BOT et al. (2019) considered the passive strategies, energy generated by the on-site PV and storage system to perform the simulation in the EnergyPlus software. The batteries with less storage power correspond to a bigger surplus of annual energy, while more storage power (for the same PV size system) reduces the energy surplus, and also grid dependence. BRUGGMANN (2018) designed and analyzed an office building located in Denver, Colorado using the OpenStudio Software. The PV modules installed in the roof and facade of the building ensured a net positive status on an annual energy balance. Furthermore, they conclude that, although electrical storage may not yet be economical given today's system costs, results show that the residual loads (difference between the electricity demand and the on-site electricity production) can be effectively managed and reduced. BINGHAM (2019) presented building envelope improvements as well as a renewable energy system in the form of the use of PV and battery storage simultaneously. EnergyPlus with an optimization tool (jEPlus + EA) was used. Besides the reduction in the energy consumption of 30%, it was concluded that the most feasible solutions do not incorporate battery storage.

CHARLES et al (2019) investigated the best energy efficiency measures of an existing two-story office building from the late 1960s located in Vancouver. The software used for the energy simulation of this building was SIMEB. In order to validate the results from SIMEB, the energy simulation was also performed in DesignBuilder. The results were very close, with only 0.5% annual difference. It was concluded that the improvement made on the building envelope in terms of airtightness and insulation reduced in 45% the annual energy consumed and the return on investment (ROI) to upgrade the building envelope were 7.7 years. The nearly zero energy building performance was possible with the addition of photovoltaic solar panel and solar heating to supply the total energy needs of the building, with a payback of 11.6 years.

ALKHATEEB; ABU-HIJLEH (2019) studied the potential of retrofitting an existing federal office building. Several measures were implemented in order to achieve NZEB goal, such as the integration of different grid-connected PV systems and heating, ventilation, and air conditioning (HVAC) system renovation. The IES VE energy simulation software was used. It was concluded that the passive strategies were able to reduce electricity demand by 14.7%, while the HVAC system renovation could reduce electricity demand by 63.2%. Finally, the BIPV approach required more area to reach the NZEB as opposed to the PV roof system that was able to cover the reduced energy demand.

BARBOSA et al. (2019) analyzed double skin facade and electricity generation from the PV systems in the roof (BAPV) and facade (BIPV). The 11-floor open plan office building was simulated in IES VE software in different climates in Brazil. It was concluded that the PV system could only provide from 15% to 30% of the energy consumption. FOTOPOULOU et al., (2018) evaluated the energy saving potential of the facade renovation on residential building. The simulation was performed in DesignBuilder and results indicated that facade renovations were a very powerful solution towards the zero energy balance in existing buildings since it could decrease in 50% the total energy consumption.

SHIN et al. (2019) studied a NZEB at the Fort Hood based in Texas, which is designed and constructed by US army. The US army required by law to make their facilities more energy efficient and the improvements reached of 37% to 50% of the energy demand in the renovated building model simulated by the DOE-2 software. KIM et al. (2020) studied the cost of NZEB design. The medium-sized office was simulated in Energyplus. The study was conducted for 15 different cities in the US. The payback time reached from 10 to 23 years. In only 3 cases, the payback time exceeded 25 years (Baltimore - MD, Albuquerque - NM and Fairbanks – AK).

DIDONÉ et al. (2014) evaluated the potential to transform Brazilian office buildings into Zero Energy Buildings (ZEB) in different climates using computer simulations. The PV system considered the roof and north, east and west facade. The simulations were carried out with the computer programs EnergyPlus and Daysim for two cities with different climatic zones of Brazil: Fortaleza - CE and Florianopolis - SC. The results showed that, in Fortaleza, more PV modules were necessary due to the higher energy consumption. In addition, the application of the Brazilian energy efficiency regulation for buildings allowed a reduction in energy consumption, however, others strategies were also necessary to reach ZEB.

ASCIONE et al. (2019) focused on a NZEB of a single-family house, constructed in south Italy and specifically designed for the Mediterranean climate. A model of the real Building developed in DesignBuilder was used for a comparison, under the same operational conditions. According to the results, the energy model can be considered well-calibrate and then capable of representing the behavior of real building both in term of energy demand and conversion from PV system.

XIA; LI (2019) studied the adoption of low carbon design strategies (i.e. natural ventilation, daylighting, shading, passive heating, PV and wind power) in the concept design phase and concluded that it has significant influence on the building performance. The study takes an office building in Shanghai as reference to perform the annual energy consumption by Designbuilder. According to the author, Designbuilder provides advanced modelling tools in an easy-to-use interface with Energyplus as calculation engine, which makes the computing process fast and results concise. It was concluded that, PV panels production could offset, at least 32.2% of the carbon emissions from the reference building.

CARPINO et al., (2017) studied the influence of housing occupancy patterns on the definition of residential NZEB in Italian climatic conditions. The dynamic energy simulations were carried out using DesignBuilder. It was concluded that the evaluation of energy performance of buildings should consider the user's behavior. If users have a wasteful behavior the energy balance is compromised since the consumption can increase up to 100%. GUERRA-SANTIN et al., (2018) presented an approach to nearly zero energy renovation considering user behavior. The study was simulated in Bink software and when considering scenarios based on behavior after renovation, the safer user behavior can reduce the heating demand in 34%. Since this study is focused on commercial building, the variation in user behavior is not considered because it cannot be well defined.

2.2.6. Overview and Definitions

If BP analysis happens at an early design, it can provide new opportunities for designers to quantify potential energy savings (MCARTHUR; SUN, 2017). In this phase it is important to set the project goals related to performance, which it is crucial to bring the discussion of energy efficiency concepts and the use of the BIM methodology (GERRISH et al., 2017); (FARZANEH et al., 2018).

In the various disciplines involved in a project there are several building elements that have a great impact on the building's energy performance (LAMBERTS, 2014). Some of these elements are: the type of opaque and transparent facade adopted in the building and the technological approach adopted to ensure the thermal comfort of the built environment. These elements and approaches are usually defined at the architectural scale, but are in the perview of or developed by other disciplines. Therefore, architects and engineers need to work collaboratively in the early stages of design (RAHMANI ASL et al., 2015) and the decision making should be based in the building performance.

The collaborative method that BIM offers makes it possible to incorporate BP analysis during the decision-making process to ensure an optimized project. This is the reason why BIM methodology is essential in the pursuit of high-performance buildings that is capable to meet a portion of its energy demand

This research defines NZEB based on EU's energy and environmental goals. To boost energy performance of buildings, the EU has established a legislative framework that includes the Energy Performance of Buildings Directive 2010/31/EU (EPBD) and the Energy Efficiency Directive 2012/27/EU. These directives aim to promote policies that help buildings achieve a high energy efficiency performance enabling consumers and companies to save energy and money.

There cannot be a single level of ambition for NZEB across the world. Flexibility is needed to account for the impact of climatic conditions on heating and cooling needs and on the cost-effectiveness of packages of energy efficiency and renewable energy sources measures. Table 7 provides the primary energy targets for offices by climate zone in Europe. The on-site renewable sources must meet between 30% and 66.7% of the building's energy demand according to Table 7 depending on the climate zone.

Table 7 - Primary Energy Targets for Offices (Adapted from EPBD, 2020)

Zone	Total Consumption kWh/(m².year)	On-site renewable sources kWh/(m².year)	Net primary energy kWh/(m².year)
Mediterranean	80 - 90	60	20 - 30
	Cities: Catania, Athens, Larnaca, Luga, Seville and Palermo.		
Oceanic	85 - 100	45	40 - 55
	Cities: Paris, Amsterdam, Berlin, Brussels, Copenhagen, Dublin, London, Macon, Nancy, Prague and Warszawa.		
Continental	85 – 100	45	40 - 55
	Cities: Budapest, Bratislava, Ljubljana, Milan and Vienna.		
Nordic	85 - 100	30	55 - 70
	Stockholm, Helsinki, Riga, Stockholm, Gdansk and Tovarene.		

The Köppen-Geiger climate classification is one of the most widely used climate classification systems and it divides climates into groups represented by two letters as can be seen in Figure 2. The hypothetical experiment occurred in Rio de Janeiro - Brazil and it has a climate similar to the city of Seville - Spain. Both cities have a tropical climate classified as “Am” by Köppen system with an average temperature of 23.2ºC and 27.1ºC respectively. Thus, the NZEB definition adopted in this research is based in the Mediterranean European climate zone which requires that 66.7% of the building’s energy demand be supplied by on-site renewable sources.

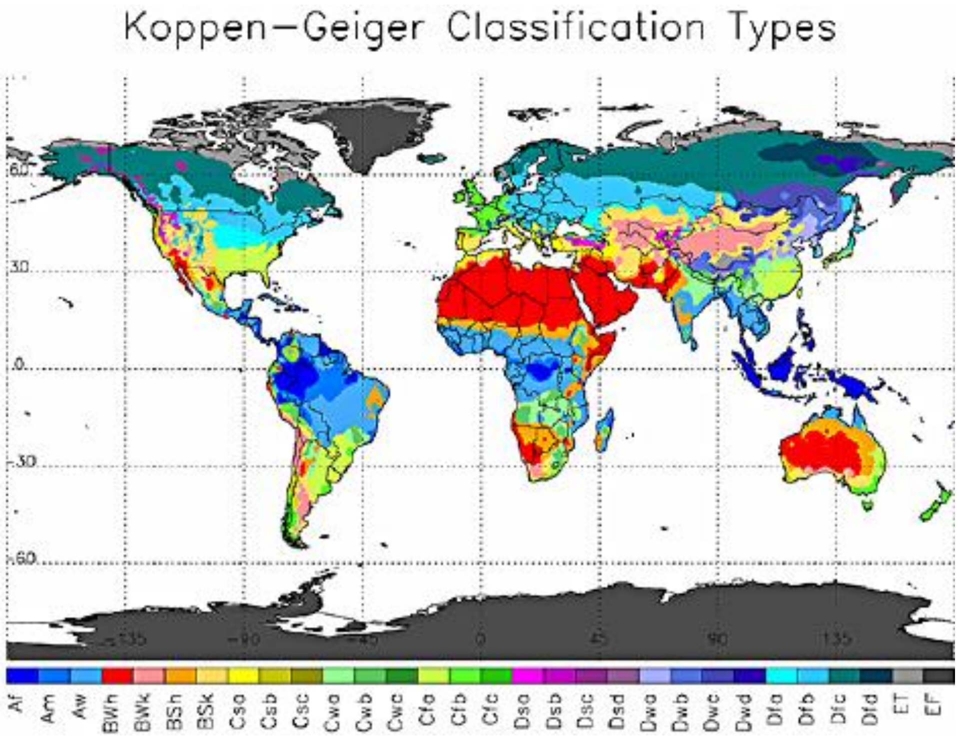


Figure 2 - Köppen-Geiger climate classification types

The energy demand can be estimated by computation simulation at any time and GERRISH et al. (2017) has developed a process with guidelines for energy simulation for different project phases (Bid, Concept Design, Schematic Design, Detailed Design, Construction and Use). Nevertheless, in this research only the Concept Design phase is considered. In Figure 3, originally proposed by Gerrish et al. (2017), it is possible to identify the players involved in this phase, namely architect, client, energy performance specialist and engineer. The tasks are identified by the colors of their corresponding players. The client is responsible for providing the project requirements. The Energy Performance Modeling (EPM) specialist is responsible for providing design advice to the architect so that he/she can develop design options considering the energy simulation results. It should be noted that for the EPM simulations, the architect provides a generic architectural model.

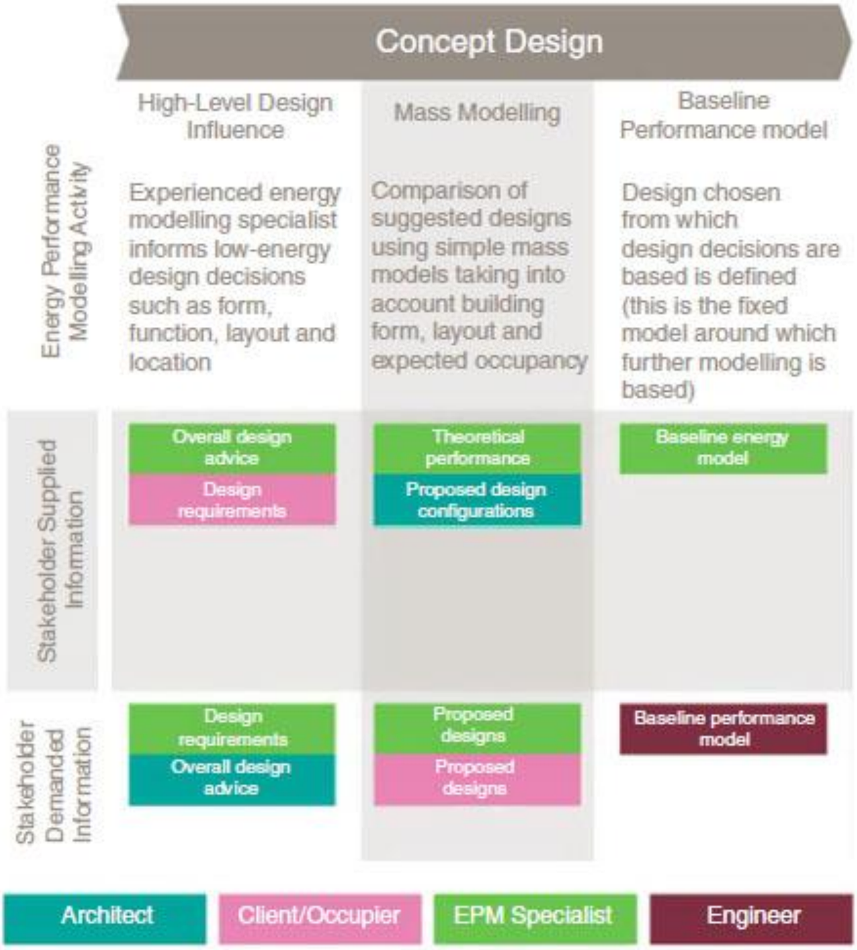


Figure 3 - Concept Design Process Map (Adapted from Gerrish et al., 2017)

The extent of the information exchange required in each stage can be measured using the LOD concept (AIA; ACG, 2019). In the concept design phase described above, the LOD required is 200. In this LOD, the Architect is responsible for creating the building shape with generic components with a low level of detail and information. It means that in this model, there are walls, doors, and windows, but without a specific definition of materials. However, However, since reliable energy analysis demands a high level of information combined with a low level of detail, the EPM Specialist is responsible for all information input such as materials definitions and occupancy schedule, except for the building shape.

BIM provides a method for sharing the necessary information of a project during its development (ZANNI et al., 2014). In addition, to maximize the benefits of BIM, the quality of communication between the players in this process must be improved. Therefore, if the requested information is available when needed, the project development process will be improved. To effectively integrate BIM into the project delivery process, it is important for the team to develop a detailed execution plan.

A BIM Project Execution Plan (BPEP) should define the scope of the project, identify the process flow for tasks, define the information exchanges between parties, and describe the required project and company infrastructure. A well-documented BPEP will ensure that all parties are clearly aware of the opportunities and responsibilities associated with the BIM project delivery process. Since there is no single best method for the BIM approach, each team must effectively design a tailored execution strategy by understanding the project goals, the project characteristics, and the capabilities of the players (COMPUTER INTEGRATED CONSTRUCTION RESEARCH GROUP, 2010). A common understanding of design processes can be reflected in a process map. This allows all players to clearly understand how their work processes interact with the processes performed by other players. Thus, a process map is extremely important because if successful, it can be replicated more easily (AKSAMIJA, 2016).

A process map within the BIM methodology is called the Information Delivery Manual (IDM) formalized by ISO 29481-1: 2016. The main functions of the IDM are: establish activities in the process with their logical sequence. Therefore, this process map describes the flow of activities to achieve a specific goal. And through this map it is possible to understand the activities, the players involved, and the necessary information to be consumed and produced. The exchange requirements are responsible to set boundaries of information contained in the process. The complete set that supports this business process is a Model View Definition (MVD), which describes the data exchange for a specific use or workflow. The ideal approach for developing a process map within IDM is Business Process Modeling Notation (BPMN), mainly due to its frequent use, the existence of various tools that work with this notation, and the ease of interpreting the process map (BUILDINGSMART, 2010).

3 Research Method

This chapter presents the proposed Information Delivery Manual (IDM), describes the building considered in the hypothetical experiment, indicates all the considerations for performing the energy simulations, and lists the tools used for the energy study.

3.1. Information Delivery Manual (IDM)

The IDM developed in this chapter aims to map the necessary information exchange between players during the concept design phase of a project that seeks to achieve the nearly zero energy balance. The NZEB is characterized by high energy performance and a low amount of energy usage, which for these buildings usually comes from renewable sources (EU, 2010). In this research, the adopted definition is based on near-zero annual energy balance of a grid-connected building. The energy simulation at the concept design phase is to provide the first magnitude of annual energy performance-based in the design options. The concept phase energy modeling requires the designer to make assumptions for a wide range of simulation inputs since information is not yet available. The proposed IDM incorporates a reliable building performance analysis that takes into account as input data for energy simulation:

- building´s geometry including the layout, configuration of spaces and functional use,
- building´s orientation,
- Thermal properties of all construction elements including walls, floors, roofs/ceilings, windows, doors, and shading devices,
- internal loads and schedules for lighting, occupants, and equipment,
- heating, ventilating, and air conditioning (HVAC) system type and operating characteristics based on comfort criteria and minimum fresh air requirements,

- weather data,
- technical information and schedules for Photovoltaics systems,
- electricity rates
- project cost

The output results of energy simulation may include:

- overall estimate of the energy use and generation of the building for compliance with targets,
- estimate of project cost and payback time,

The first hypothesis for the development of the IDM was the definition of the client's main requirement: to achieve NZEB in order to obtain environmental certifications and/or for personal or company concerns. The process map starts from the initial client request of a NZEB for which the development of the concept design demands the collaboration of Architectural and Building Performance Team. This collaboration aims to determine the feasibility of design options in the context of energy targets. Therefore, the proposed IDM contains a flow of information to be used by private companies or public institutions with the aim of developing a NZEB within a BIM environment considering energy efficiency and photovoltaic energy generation. The players and their main assignments in IDM are presented as follows:

Client: The client corresponds to private, public institutions or an individual who asks other companies and designers to develop a NZEB project. The client defines the requirements and budgets for the project development and selects a design option proposed by design teams.

Architecture Team: This player corresponds to the group of people in an architectural office or sector of a company hired to develop the architectural concept design. The Architecture Team is responsible for the architectural design that meets the client´s requirements and defines design options that will be analyzed by the Building Performance Team.

Building Performance Team: This player corresponds to a sector of a company that is composed of a multidisciplinary team, possibly formed by architects and civil and electrical engineers. This team is responsible for building performance analysis during the concept design. Their task brings the overall estimate of the energy use and generation for compliance with the targets. In addition, this Team should suggest upgrades for the project based on the performance values obtained from their analyses.

BIM Project Manager: The project manager corresponds to an individual, or a team that is responsible for coordinating the information exchanged between stakeholders, ensuring the transparency of the information and the interoperability of the models. In addition, this player provides modeling guidelines, determines technology requirements, as well as performs project quality control.

Planning Manager: This player is an individual or a sector of the company that specializes in constructability and planning. This team is responsible for evaluating the best construction techniques, preparing the budget, physical and financial schedules for the execution of the work.

3.1.1.Process Map

The proposed IDM uses the BPMN approach, which lanes are pools used to represent entities involved in a process and it can represent different departments and sectors in the same group. This occurs in order to enable workflow mapping from one sector or entity to another, which means, from one pool to another.

In the proposed IDM, the pools were used to represent the client and the other design teams. The design teams, which are responsible for the development of the project requested by the Client are the Architecture Team, the Building Performance Team, the BIM Project Manager and the Planning Team.

An event starts or ends at the pool and it is represented by circles. In this map, the rectangles represent tasks and the information generated appears as a sheet of paper. The workflow is defined by full arrows or dashed lines that traces the routes that depend on decisions (diamonds) (BUILDINGSMART, 2010).

The complete IDM is presented in Appendix B and a schematic version is presented in Figure 4. It maps the information exchanged and the tasks of each player in the development of an integrated project in the BIM environment, where digital models are shared for energy simulations and analyses.

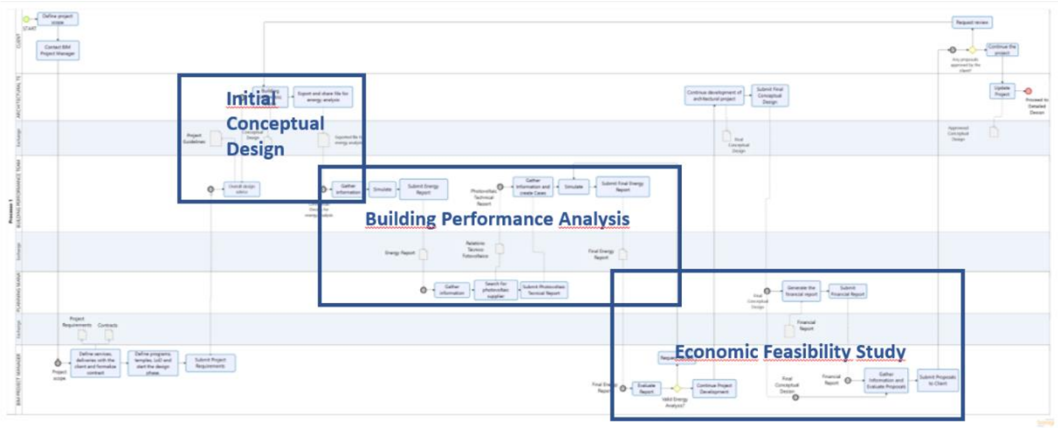


Figure 4 - IDM schematic version

The process map begins with the Client request of a project based in scope, such as its function, the technical requirements and the budget that the Client has to invest. At this moment, the energy compliance is demanded by the client, the NZEB target is mandatory. Therefore, the project requires a feasibility study of a building that is capable of producing an amount equal to or close to its operational energy consumption.

The process begins with the BIM Project Manager contacting the Building Performance Team after he/she receives the project requirements, then, the Building Performance Team develops a report to provide the overall energy-related design guidelines and suggestions that will be shared with the Architectural Team and Planning Manager Team.

The Architectural team begins to study the volume of the new building. After the formulation of some proposals, it is assumed at this point the architect has defined a building concept design complete with all the required building elements. All spaces must be named from their use, including functional and non-functional spaces (such as technical spaces, circulation spaces, shafts, etc.).

The Concept Design should include: the site and building location, orientation, and elevation; 3D geometry of adjacent buildings; 3D geometry of the building, including walls (exterior/interior), curtain walls, roofs, floors/slabs, ceilings, windows/skylights, doors, and shading devices; and space object defined by their use. At the end of this task, the requirements represent some of the input information for building performance analysis. Once the initial concept design task is finalized, the digital model must be prepared for energy analysis. The model is exported in the gbXML format for energy simulation. That process incurs in data reduction that needs to take place. Thus, the Architectural Team finally shares these digital models with the Building Performance Team.

From this concept models, the Building Performance Team must evaluate the building's energy consumption over a year. Therefore, this team is responsible for pointing out the energy efficiency guidelines and to provide design options based on energy efficiency simulations as well as an energy report that is sent to the Planning Manager Team.

At the beginning of this task, the following input is required: thermal properties of all construction elements; the internal loads and schedules for lighting, occupants, and equipment; HVAC system type, operating characteristics based in comfort criteria and minimum fresh air; and Weather data. The annual energy consumption is obtained from the simulation, which is the energy used during a whole year for heating, cooling, lighting, and building equipment.

At this point, the Planning Manager Team starts the search for suppliers of photovoltaic systems. After developing a technical list of suggested systems, this team shares this report with the Building Performance Team to initiate the photovoltaic potential study based on simulations. The following input is required: Modeling/set up photovoltaic elements systems based on the Planning Manager´s technical list. The Building Performance Team must develop a basic photovoltaic project to meet the building's demand and evaluate the building's energy production over a year.

Through the energy consumption of simulated scenarios and the identified photovoltaic potential, the search for energy balance close to zero occurs. The Building Performance Team may request modifications to the Architectural Team and the project will only follow the next step if the energy target is achieved.

After this step, the report generated verifying the nearly zero energy balance is submitted to the BIM Project Manager for analysis. The BIM Project Manager needs to evaluate the report and if there is any inconsistency, a review of all the simulation is requested. If the submitted report is consistent, this Team agrees with all the analysis and Architectural Team can proceed with the development of the project with a higher level of detail.

At the end, the final digital model of the concept design is shared with the Planning Manager Team. The Planning Manager Team makes the financial feasibility study of the proposed models. At this stage, the budget preparation is performed with payback time calculation based in the energy savings.

Finally, the concept design options are evaluated by the client. At this moment, the client must evaluate the options of the proposed scenarios and the developed budget to choose the one, considering the aesthetics, energy saving and payback time. If no proposed scenario meets client´s demand, the client may request review until a scenario is approved. Subsequently, the Detailed Design can be developed, but these steps are beyond the scope of this research and is not presented in the IDM.

3.2. Hypothetical Experiment

This section presents an experiment of a hypothetical project. The study will focus on the results of the simulations and the more efficient and optimized scenarios are compared and analyzed.

In general, the BP analysis usually happens after the construction in order to meet some certification criteria (RYU; PARK, 2016) or mainly in a process of retrofitting as presented by FOTOPOULOU et al. (2018), CHARLES et al. (2019) and AKSAMIJA (2016). However, in the proposed approach it occurred in the concept design phase in order to help its development. The experiment presented here is based in the IDM proposed in section 3.1.2.

The general path to achieve zero balance consists of two steps: first, reducing energy demand through energy efficiency measures, and then, generating energy to achieve the balance (KIM et al., 2015). In addition, the impact of the surrounding buildings and the shading they provoke is not addressed in most studies (RADMEHR et al, 2014) because it is case dependent and difficult to generalize. Thus, the present study simulation approach consists of two main stages: consumption and production taking into account the surrounding buildings.

3.2.1. Hypothetical Architectural Proposal

The experiment aims to simulate the development of the concept design of a typical commercial building in Brazil because the PV production curve is similar to the commercial sector energy demand curve (LEE et al. 2014). It is believed that there exists an inversely proportional relationship between number of floors and the potential of reach zero energy balance (CRAWLEY, 2016). DIDONÉ (2014) affirms that commercial buildings usually have a vertical and slender approach for which nearly zero energy balance target is challenging. The effort is due to the number of floors which increases energy consumption while the available reduced roof area, offering less possibilities for PV panel application.

Although commercial buildings have a high energy consumption, the high solar irradiation in Brazil represents a significant factor for the use of photovoltaic technology. In addition, despite the reduced roof area, there is the possibility of applying photovoltaic panels to both the wall and the window of the facades of these buildings (FITRIATY; SHEN, 2018); (KUO et al., 2016).

This research seeks to use recent findings, while addressing others relevant aspects that have been neglected in order to contribute to new developments. The experiment adopts the model used developed by BENDER (2018) as the hypothetical proposal from the Architectural Team in the IDM presented in Section 3.1.2.

BENDER (2018) model is a variation of the model presented by CARLO (2008). CARLO (2008) developed a research of the typical volume and other features of commercial buildings in 5 different cities in Brazil (Florianópolis, São Paulo, Salvador, Recife and Belo Horizonte). From the six listed commercial typologies (large offices, large stores, small offices, small stores, hotels and vertical offices), the reference model for large offices was chosen. From the picture shown in Figure 5 it is possible to visualize the architectural volume and the floor plan of the BENDER (2018) building. The adoption of this model characterizes the initial step in the development of the conceptual design in the IDM. It represents the building volumetric study made by the Architecture Team based on the project guidelines suggested by the Building Performance Team.

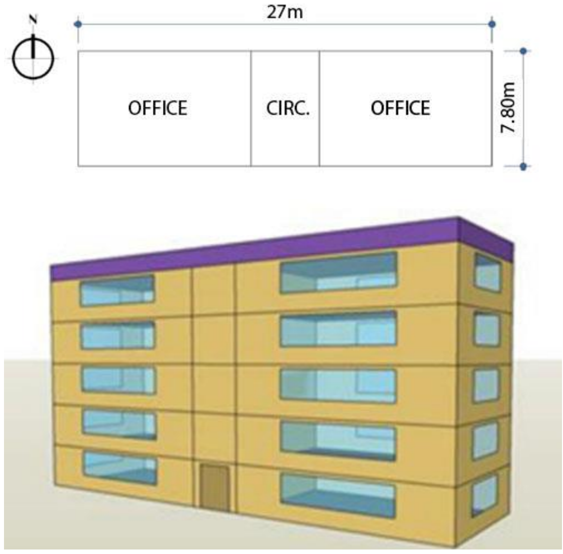


Figure 5 - Commercial Building (Adapted from Bender, 2018)

The model used as an initial volumetric suggestion in this study and has rectangular dimensions (27x7,8m). It is composed of 5 floors with 2.65m ceiling height and the largest facades are north-south oriented. On each floor there are two rooms and a centralized vertical circulation, which configures the three thermal zones. The office areas are conditioned while the central areas are not. Table 8 shows the specifications of the building elements proposed by BENDER (2018) that compose the building envelope - walls, roofs, slab and windows.

Table 8 - Constructive Materials Specifications (Adapted from Bender, 2018)

Constructive Materials Specifications		
Components	Materials	Thickness (m)
Walls	Mortar	0.02
	Brick	0.10
	Mortar + light painting	0.025
Roof	Fiberciment	0.006
	Extruded Polystyrene	0.03
	Fiberciment	0.006
	Air chamber	-
	Concrete Slab	0.10
Slab	Concrete Slab	0.10

	Mortar	0.002
	Ceramic floor	0.005
Windows	Glass	0.003

3.2.2.Building Performance Analysis

3.2.2.1.Design Options

As mentioned earlier, the present study simulation approach consists of two main stages: consumption and production. The following diagram (Figure 6) indicates all the cases studied in this work, which will be explained in detail in this section later on.

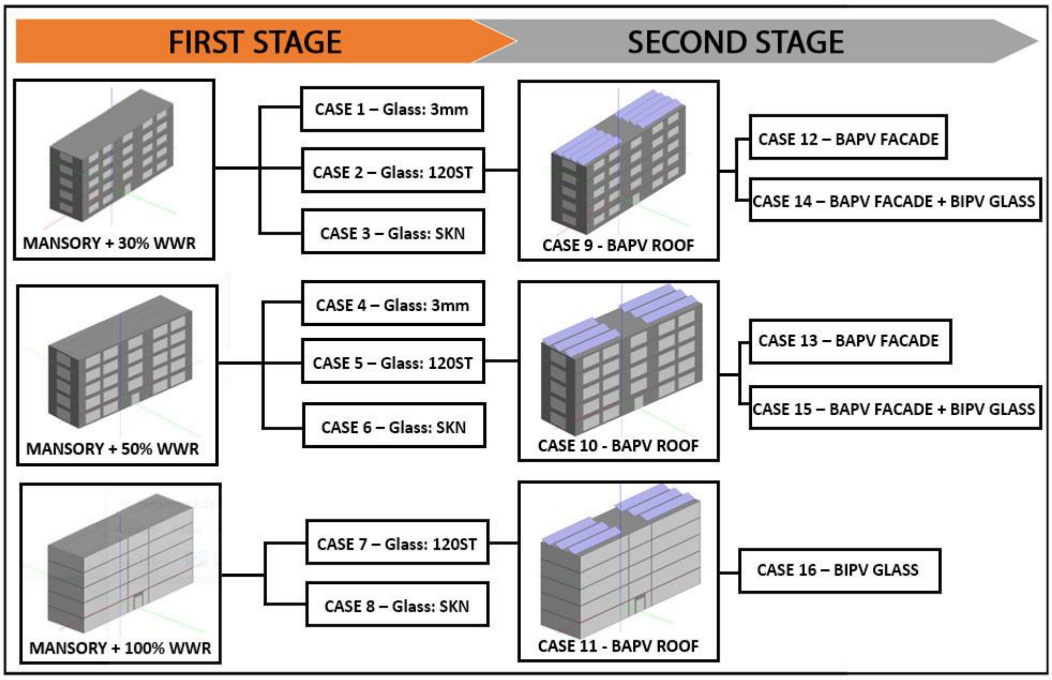


Figure 6 – Diagram of design options

In the present experiment, the Architecture Team develops three proposals which take into account only openings of the facade. This activity in the IDM reproduces the moment when the Building Performance Team receives the exported models in the desired format and must gather information to carry out the initial energy analysis. Thus, in this study the design options take into account the openings of the facade, which there are different possibilities of window-to-wall ratio and the adopted glass type. In order to optimize the Building Performance Team's work, the initial approach configures the hypothetical models into eight different design options. That type of approach is important to avoid assumptions from a wide variety of simulation inputs, since at this point, some information is not yet available in the digital model (GERRISH et al., 2017); (FARZANEH et al., 2018).

In the case of the transparent part of the building, the glass represents the most sensitive part of heat gain (ABHINAYA et al. 2017). It is responsible for significantly increasing the energy consumption of the building (NAJJAR et al., 2019); however, it also represents the most commonly adopted approach in new buildings in large centers. Because of that, three types of glass were selected to be used in this study: the common glass and the insulated medium and high-performing glasses. Table 9 provides all the data related to the three glasses used in the simulations.

Table 9 - Glass Type (Adapted from PKO, 2019)

<table>
<tr><th>Glass Type</th><th>External Light Reflection</th><th>Internal Light Reflection</th><th>Solar Factor (SF)</th><th>Light Transmission (LT)</th><th>Thermal Transmittance (U - W/m²K)</th></tr>
<tr><td rowspan="2">3mm (Single Glazed)</td><td>8%</td><td>8%</td><td>0,83</td><td>0,80</td><td>5,28</td></tr>
<tr><td colspan="5">Colorless Glass</td></tr>
<tr><td rowspan="2">120ST (Double Glazed)</td><td>24%</td><td>30%</td><td>0,33</td><td>0,21</td><td>2,6</td></tr>
<tr><td colspan="5">120 ST glass + air chamber + 6mm colorless glass</td></tr>
<tr><td rowspan="2">SKN (Double Glazed)</td><td>30%</td><td>22%</td><td>0,30</td><td>0,50</td><td>1,5</td></tr>
<tr><td colspan="5">SKN glass + air chamber + 6mm colorless glass</td></tr>
</table>

At this time, only the consumption of the building is considered, so there is no photovoltaic production yet. This task is performed to understand the energy saving potential based in the building envelope. The proposals are evaluated based in the results of the simulations and suggestions from this team are taken into account by the Architectural Team, since the building's performance seeks energy efficiency.

In this experiment, three proposals were developed in which the variable parameter is WWR. The range of transparent parts suggested at the building facade are 30%, 50% and 100%. Figure 7 shows the three architectural choices.

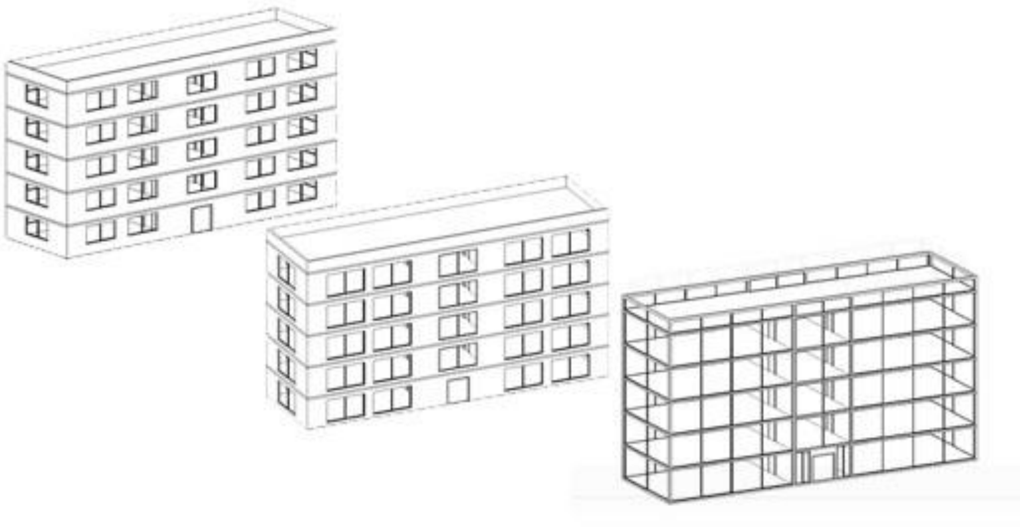


Figure 7 - Design Options from Architectural Team

Variations of these three architectural proposals configurations resulted in eight different design options, which are summarized in Table 10.

Table 10 - Design Options summarized at the first stage

Stage	Case	Wall	U e (W/m²K)	WWR	Glass	U g (W/m²K)	SF
Consumption	1	Mansory	2.4	30%	3mm	5.84	0.83
	2	Mansory	2.4	30%	120ST	2.6	0.33
	3	Mansory	2.4	30%	SKN	1.5	0.3
	4	Mansory	2.4	50%	3mm	5.84	0.83
	5	Mansory	2.4	50%	120ST	2.6	0.33
	6	Mansory	2.4	50%	3mm	5.84	0.83
	7	Curtain Wall	2.6	100%	120ST	2.6	0.33
	8	Curtain Wall	1.5	100%	SKN	1.5	0.3
Legend: Thermal Transmittance (U); Solar Factor (SF)							

In Case 1, there is masonry wall including light painting, with window-to-wall ratio equal to 30% with the 3mm glass. In cases 2 and 3 the only parameter changed was the type of glass, to medium (120ST) and high-performing (SKN) respectively. In Cases 4, 5 and 6, wall type remains but the WWR is equal to 50%. The glass type is respectively: 3mm, 120st and SKN. Finally, cases 7 and 8, represent the most common typology of new commercial buildings. In these two last cases, the WWR is equal to 100%, shifting only the type of glass respectively: medium (120ST) and high-performing (SKN). In the latter approach, the 3mm glass was not addressed because its presents very low performance for the building.

At this point, the second stage of Building Performance Analysis begins. The case with the lowest energy consumption for each of the WWR possibility was selected for the next step. Thus, only the most efficient cases from the first stage are selected from the three main aesthetic scenarios.

As specified in the IDM, the next activity to be performed by the Building Performance Team is the PV potential study. This task depends on the report of photovoltaic suppliers developed by the Planning Manager Team. From that report new scenarios considering PV systems are created. The scenarios differ from each other in terms of photovoltaics systems in the wall and window of the building, so eight more cases were defined to be tested according to Table 11.

Table 11 - Design Options summarized at second stage

Stage	Case	Envelope	WWR	Glass	BAPV	BIPV
Production	9	Mansory	30%	120ST	Roof	-
	10	Mansory	50%	120ST	Roof	-
	11	Curtain Wall	100%	120ST	Roof	-
	12	Mansory	30%	120ST	Roof + Facade	-
	13	Mansory	50%	120ST	Roof + Facade	-
	14	Mansory	30%	120ST	Roof + Facade	North Windows
	15	Mansory	50%	120ST	Roof + Facade	North Windows
	16	Curtain Wall	100%	120ST	Roof	North Wall
Legend: Thermal Transmittance (U); Solar Factor (SF)						

The study begins with the consideration of the roof for photovoltaic production (Building Attached Photovoltaics - BAPV), that represents the most commonly adopted solution. Then, since the north facade enables the extension of PV production, more configurations are suggested by the Building Performance Team based in Planning Manager Team’s Report of photovoltaic system. The north facade is considered, which address as a design option respectively: Building Attached Photovoltaics (BAPV) and Building Integrated Photovoltaics (BIPV).

Case 09, 10 and 11 consider only the roof for photovoltaics production (BAPV), with 120ST glass type and WWR respectively of 30%, 50% and 100%. Case 12 includes photovoltaic modules attached to the masonry (BAPV), 30% WWR and 120ST glass. In Case 13 the only parameter changed is the WWR shifted to 50%. For Cases 14 and 15, the PV glass (BIPV) is adopted only for the north facade. And finally, case 16, contains a 100% WWR with 120ST glass, except on the north facade, where PV glass is adopted (BIPV). It is important to highlight that for cases 12 to 16 there are photovoltaic modules in the roof (BAPV).

3.2.2.2. Computer Simulations

To accomplishment this research's goals, it was necessary to carry out energy performance computer simulation for the different design options. Thus, the models were developed using Autodesk Revit version 2019 software using LOD 200 as suggested by GERRISH et al.(2017) and FARZANEH et al. (2018). In this LOD elements in the model are generic and contain only geometry information (AIA; ACG, 2019). The models were, then, exported using the gbXML format as suggested by KAMEL; MEMARI (2018) and BOT et al. (2019). This step represents the Architectural Team tasks in the proposed IDM.

Computer simulations were developed using the DesignBuilder version 6.1.3.008 software tool due to its adherence in the academic environment (CHEN et al. 2018); (REY-HERNÁNDEZ et al., 2018); (FOTOPOULOU et al., 2018); (ASCIONE et al., 2019).

The consumption and energy production (kWh/year) was analyzed in each situation so that the energy balance between the total energy consumed and produced in the building could be evaluated.

As mentioned in the literature review, a reliable energy simulation depends on a high level of information, but a low level of detail in the digital model. For the simulation configurations, the input data was the following:

- Weather data, internal loads and schedules for lighting, occupants, equipment and HVAC system.
- Technical information and schedules for photovoltaics systems.

- Thermal properties of all construction elements including walls, floors, roofs/ceilings, windows.

In the experiment, the project is considered to be located in Rio de Janeiro and according to RTQ-C (INMETRO - INSTITUTO NACIONAL DE METROLOIA, 2010) the weather data used for the computer simulation process must, as a minimum, provide hourly values for all relevant parameters required by the simulation program, such as temperature and humidity, direction and velocity of the wind, solar radiation, etc. In this study, the weather data used was supplied to the DesignBuilder program in the EPW (EnergyPlus Weather data) file format provided by the US Department of Energy website. Table 12 provides the geographic information adopted in the simulation.

Table 12 - Geographic Infomation

Geographic Information of Rio de Janeiro	
Local	Rio de Janeiro - RJ
Latitude	-22.9035º
Longitude	-43.2096 º
Altitude	17m

The city of Rio de Janeiro is located in the Bioclimatic Zone 8 (ZBB8), as shown in Figure 8. The bioclimatic zone represents a homogeneous geographical region regarding the climatic elements that interfere in the relations between built environment and human comfort. In Brazil, there are eight bioclimatic zones (NBR 15220-3 - ABNT, 2005) and bioclimatic zone 8 represents about 53.7% of the Brazilian territory.

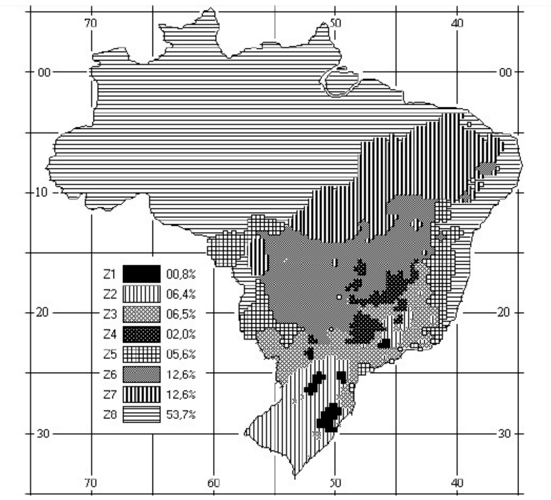


Figure 8 - Bioclimatic zone in Brasil (Adapted from NBR15220 - 3)

For internal loads and schedules for lighting, occupants, equipment and HVAC system, the configurations used were based on the work by CARLO (2008). The main data of internal loads are presented in Table 13.

Table 13 - Inputs for Internal Loads (Adapted from Carlo, 2018)

Inputs for Internal Loads	
Parameter	Values
Equipaments	9,60W/m²
Occupants	19,57m²/person
Lighting	6,70W/m²

It was considered that the building would only be used on weekdays (Monday through Friday). On Saturdays and Sundays, the building was considered unoccupied, with their systems shut down, except for photovoltaic production, i.e., the PV system generated energy over the seven days of the week. In terms of use, activities in the building were considered to begin at 8am and end at 6pm and that the equipment would be turned on during the same period of time. As for lighting, it was assumed their usage from 8am to 10pm. The air infiltration rates were considered half full renovation every hour. The temperature was set at 18ºC for heating and 24ºC for cooling and the air conditioning system was defined as auto size in the DesignBuilder program. The contact of the floor with the ground was considered isolated - underground parking (BENDER, 2018).

The specification of building components including the thermal properties has some limitations in DesignBuilder (OLIVEIRA, 2012). In this program, the components are composed of homogeneous layers, which is not necessarily the case in the real world. This is especially true with masonry components that are formed by heterogeneous layers. Thus, the walls were modeled in homogeneous layers from the equivalent material calculation, to obtain the same behavior as the heterogeneous layers (ORDENES et al., 2003).

The solution of the equivalent component for the walls, was to replace the brick material with two layers of brick divided by an air chamber to provide the same thermal properties as the original wall (BENDER, 2018). The solution approach is presented in Figure 9. The equivalent method proposed by ORDENES et al. (2003) and used by BENDER (2018) provides the composition of the walls as shown in Table 14.

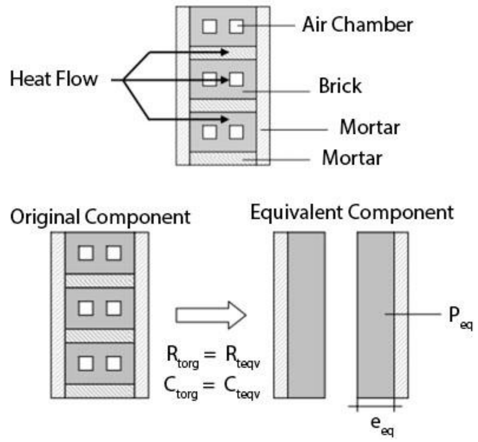


Figure 9 - Equivalent Method (Adapted from Ordenes, 2003)

Which

R_t: Surface to Surface Thermal Resistance (m^2K / W)

C_t: Thermal Capacity (kJ / m^2K)

e_{eq}: equivalent thickness (m)

p_{eq}: apparent mass density of equivalent layer (kg / m^3)

Table 14 shows the composition of the floor and roof, respectively. The only element that differed from BENDER (2018) was the roof. The fiber cement roof was replaced by a flat waterproof concrete roof. Thus, preventing that the inclination of the photovoltaic panels was determined by the tilted roof (LI et al., 2019).

Table 14 - Composition of the wall, floor and roof (Adapted from Bender, 2018)

Wall Composition			
Material	Thickness: m	Conductivity (λ) W/(m.K)	Density (p): kg/m^3
Mortar	0,025	1,15	2000
Brick Material	0,015	0,7	1600
Air chamber	Thermal resistance of 0,16 m^2K/W		
Brick Material	0,015	0,70	1600
Mortar	0,020	1,15	2000
Floor Composition			
Material	Thickness: m	Conductivity (λ) W/(m.K)	Density (p): kg/m^3
Concrete Slab	0,1	1,75	2200

Mortar	0,02	1,15	2000
Ceramic floor	0,005	1,05	2300
Roof Composition			
Material	Thickness: m	Conductivity (λ) W/(m.K)	Density (p): kg/m^3
Mortar	0,05	1,15	2000
Polyurethane	0,05	0,03	35
Mortar	0,035	1,15	2000
Concrete Slab	0,10	1,75	2200

The absorbance values of the outer surface of the walls and roof correspond to the finish color of these surfaces. The absorbance value 0.35 represents a light color, and the value 0.90 represents a dark color (black, for example). Thus, for the roof there is 0.60 absorbance value and for external wall 0.35. In addition, the emissivity is 0.90 for the roof and the outer walls (BENDER, 2018).

As mentioned earlier, this study developed 16 cases for simulation and analysis. Initially, eight different design options were configured. Table 15 presents the specifications of the building materials used in the composition of the external walls of Cases 1 through 8. All of them have thermal transmittance equals to 2.40W/m²K.

Table 15 - Wall composition of Case 1 to 8

Wall composition of Case 1 to 8			
Material	Thickness: m	Conductivity (λ) W/(m.K)	Density (p): kg/m3
Mortar	0,025	1,15	2000
Brick Material	0,015	0,7	1600
Air chamber	Thermal resistance of 0,16 m²K/W		
Brick Material	0,015		
Mortar	0,020	1,15	2000
Mortar	0,025	1,15	2000
Thermal transmittance (U) = 2.40W/m²K.			

The remaining 8 cases incorporate the PV modules in different ways as it will be described in detail later on in this chapter. Thus, this second stage of the simulations begins the study on the potential of photovoltaic production of the building.

The CanadianSolar CS6P - 260P modules were chosen to be used in the roof (BAPV), with polycrystalline (P-si) technology, dimension of 1638 x 982 x 40mm and efficiency of 15.88% (CANADIANSOLAR, 2019).

In order to verify the potential for PV generation on the roof, the module was configured in DesignBuilder at the “building level” on the Solar Collector toolbar icon of the software. The performance type selected was simple which the fraction of surface area with active solar cells is 0.95 because the frame. The efficiency was set as fixed based in the standard value of 15.88% and the rated electric power equals to 260W from the catalog.

The panels were placed with inclination equals to the latitude value of the city in order to reach their maximum efficiency (LI et al., 2019). In order to establish the required distance between the rows of panels in the roof to avoid shading, equations 1 and 2, proposed by CASTELLANO et al. (2015), were used. The calculation is based on solar elevation (α) of winter solstice (KIM et al., 2020). In these equations b is the length of the panel, β is the inclination of the panel in relation to the ground, and D is the required distance in order to avoid shading. Figure 10 provides a schematic of the layout.

$$D = b(\cos\beta + \sin\beta \,\text{cotan}\,\alpha) \quad (1)$$

$$d = D - b\cos\beta \quad (2)$$

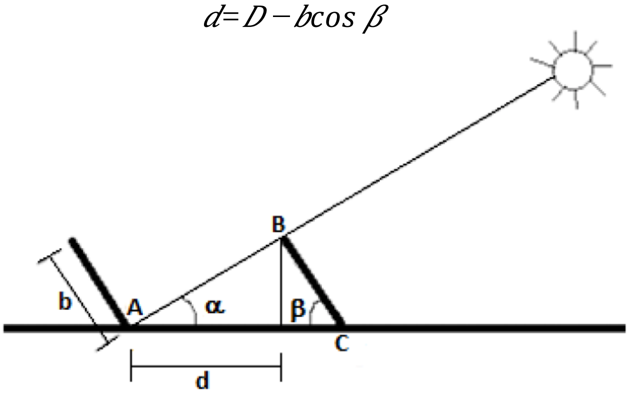


Figure 10 - PV Row Space (Adapted from Castello et al., 2015)

At the north facade, where photovoltaic modules were attached to the wall, the CanadianSolar CS6P – 260p Module was also considered. All the external walls of the north facade were modeled using the command Building Integrated Photovoltaics for construction. This command in the DesignBuilder software allows the configuration of PV generator elements considering also the others equivalent wall layers.

The wall configuration suggested by (BENDER, 2018) is given in Table 16. The first six layers of the wall represent the PV Modules components with all their thermal properties. In this study, the Canadian module was configured in the program using Building Integrated Photovoltaics in the most external layer of the wall. The PV module performance type selected was simple which the fraction of surface area with active solar cells is 0.95 because of the frame.

The thermal transmittance of the walls of the north facade was reduced because of the PV Module with air chamber in the facade. In cases 9 to 15 all the external walls have thermal transmittance equals to 2.40 W/m²K except for the north facade, which have the thermal transmittance equals to 1.75 W/m²K.

Table 16 - Composition of the PV wall of the north facade Case 9 to 15 (Adapted from Bender, 2018)

Composition of the PV walls of the north facade case 9 to 15			
Material	Thickness: m	Conductivity (λ) W/(m.K)	Density (p): kg/m3
Glass	0,004	1,13	2300
EVA	0,001	0,15	1800
Silício	0,00037	148	2300
EVA	0,001	0,015	1800
Tedlar	0,0002	0,24	2100
Aluminium	0,03	237	2700
Air chamber	Thermal resistance of 0,17 m²K/W		
Mortar	0,025	1,15	2000
Brick Material	0,015	0,7	1600
Air chamber	Thermal resistance of 0,16 m²K/W		
Brick Material	0,015	0,7	1600
Mortar	0,020	1,15	2000
Thermal transmittance (U) = 1.75 W/m²K.			

For the transparent part of the model, The Almaden Double Glass Panel with 40% degree of transparency was used. The Almaden – SEAC50T 245W was chosen to be used in the glass (BIPV), with monocrystalline (m-si) technology, dimension of 1662x 990 x 4mm and efficiency of 18.5% (ALMADEN, 2019). The glass of the north facade was modeled using the command Building Integrated Photovoltaics for glazing. The DesignBuilder glazing data consists of layers of panes interspersed with one or more layers of window gas. Given the program's setup limitations, the glass specification method was defined as simple. The 4mm Glazing with Solar Transmittance of 0.4, Visible Transmittance (VT) of 0.6 and Thermal transmittance (U) of 5.28 W/m²K was adopted.

The Almaden module was configured in the program using Building Integrated Photovoltaics in glass pane. The performance type selected was simple, for which the fraction of surface area with active solar cells is 0.60 given their 40% semitransparency. The conversion efficiency was set as fixed based in the standard value of 18,5% and the rated electric power was set to 245W following the catalog.

Finally, the site context was considered in the last five simulated cases. A total of five new simulations were performed to quantify the impact that surrounding buildings can have on the energy consumption and production of the building. Due to the dynamic and variable aspect of the surroundings, a random scenario of the downtown area in Rio de Janeiro was selected to understand the impact of shading (SANTOS, 2015). No specific location was selected and only the distance between buildings was considered. The adopted orientation was the same as in BENDER (2018) case, but adjacent buildings were added to the model.

For the spacing of the surroundings buildings, the main distances between buildings in the block formed by Souza e Silva Street and Sacadura Cabral Street were considered. The selected area is located in the Port region of Rio de Janeiro because it has the potential for expansion of the downtown area and, thus, provides an opportunity for the construction of new types of buildings (LI et al., 2019).The distances were collected using the Google Maps Measure Distance tool between points.

In order to simplify the hypothetical case, the adopted measures were 15 meters between the front blocks in the main avenue and 5 meters between adjacent the buildings. In Figure 11, the purple rectangles represent the adjacent buildings and the gray rectangle is the building being studied.

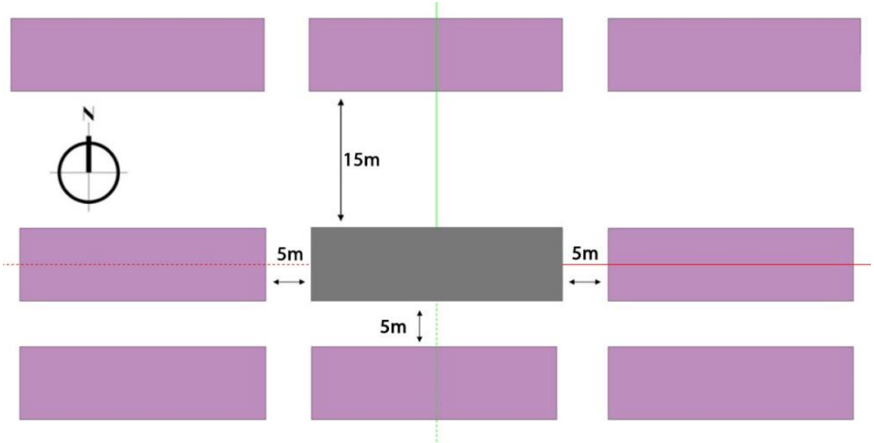


Figure 11 - Adjacent buildings in DesignBuilder

For the height of the surrounding buildings, two scenarios were considered. The first considered that they had the same height as the case study building, and second twice the height of the case study building, as can be seen in Figure 12. These two cases configure a medium and a dense urban environment, respectively. These Adjacent buildings were modeled using component blocks in DesignBuilder and their only purpose was to simulate shading.

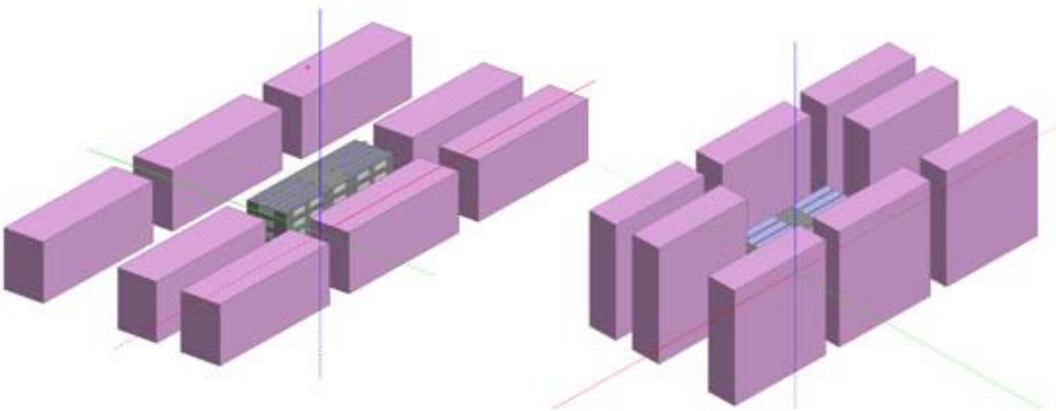


Figure 12 - Adjacent Buildings Perspective in DesignBuilder

Table 17 provides the information for all simulated cases with their envelope, glass, and PV approach properties.

Table 17 - All Cases Listed

Stage	Case	Envelope	U_e	WWR	Glass	U_g	FS	North Facade	U_{nf}	Glass North Facade	U_{gnf}	FS	BAPV	BIPV
First Stage: Consumption	1	Mansory	2.4	30%	3mm	5.84	0.83	-	-	-	-	-	-	-
	2	Mansory	2.4	30%	120ST	2.6	0.33	-	-	-	-	-	-	-
	3	Mansory	2.4	30%	SKN	1.5	0.3	-	-	-	-	-	-	-
	4	Mansory	2.4	50%	3mm	5.84	0.83	-	-	-	-	-	-	-
	5	Mansory	2.4	50%	120ST	2.6	0.33	-	-	-	-	-	-	-
	6	Mansory	2.4	50%	3mm	5.84	0.83	-	-	-	-	-	-	-
	7	Curtain Wall	2.6	100%	120ST	2.6	0.33	-	-					
	8	Curtain Wall	1.5	100%	SKN	1.5	0.3	-	-	-	-	-	-	-
Second Stage: Production	9	Mansory	2.4	30%	120ST	2.6	0.33	-	-	-	-	-	Roof	-
	10	Mansory	2.4	50%	120ST	2.6	0.33	-	-	-	-	-	Roof	-
	11	Curtain Wall	2.6	100%	120ST	2.6	0.33	-	-	-	-	-	Roof	-
	12	Mansory	2.4	30%	120ST	2.6	0.33	PV Module	1.75	-	-	-	Roof + Facade	-
	13	Mansory	2.4	50%	120ST	2.6	0.33	PV Module	1.76	-	-	-	Roof + Facade	-
	14	Mansory	2.4	30%	120ST	2.6	0.34	PV Module	1.77	PV Glass Module	5.28	0.4	Roof + Facade	North Windows
	15	Mansory	2.4	50%	120ST	2.6	0.34	PV Module	1.78	PV Glass Module	5.28	0.4	Roof + Facade	North Windows
	16	Curtain Wall	2.6	100%	120ST	2.6	0.33	-	-	PV Glass Module	5.28	0.4	Roof	North Wall

Thermal transmittance (U) - W/(m²K)

3.2.2.3.Photovoltaic Analysis

The photovoltaic potential suggested by DesignBuilder was validated using two methods. This is because DesignBuilder is popular for energy consumption analysis, but not popular for photovoltaic studies. Nevertheless, ASCIONE et al. (2019) presented predictions of photovoltaic production using DesignBuilder similar to field measurements.

The first validation method used the Azimuth angle, tilt and system size of the PV panels to get the annual total photovoltaic power output from some interactive website application calculators. There are several web site applications that can provide quick and easy access to solar resource and photovoltaic power potential data globally (SOLARGIS, 2019). The calculators that were used as reference for comparing the values provided by the DesignerBuilder were: Global Solar Atlas, National Renewable Energy Laboratory (PVwatts) and European Commission Photovoltaic Geographical Information System (PVGIS).

The other validation method was the PV generation calculation based in the study by FITRIATY; SHEN (2018). It was possible to calculate the amount of energy produced by each model in the desired period. The PV potential power (PVPP) available was calculated using Equation (3):

$$PVPP= G.PR.n^{o}.MP \tag{3}$$

where *G* is the incident irradiance (kWh/m²/Day) divided by the reference irradiance of 1 kW/m² expressed in number of hours (h) per day, PR denotes the system performance (inverter and connections), nº is the number of PV modules that fit in a given area, and MP is the module maximum power (kW). The irradiation data was provided by the Radiasol program and the system performance adopted was 0.80 as suggested by BENDER (2018) and DIDONÉ et al. (2014).

3.2.2.4. Economic Analysis

Following the sequence of the IDM activities, the Planning Manager Team must carry out the economic feasibility study of the project after the final energy report is validated by the BIM Project Manager. The building's energy consumption and production were predicted from the results of the simulations, this information was combined with the financial cost information obtained from suppliers in Rio de Janeiro, and a financial feasibility analysis was developed.

For financial evaluation three indicators were used: Net Present Value (NPV), Payback Time (PB) and Internal Rate of Return (IRR). The main variable of the financial scenarios was the payback period of 25-year investment, equivalent to the PV module manufacturer guarantee

Net Present Value (NPV) represent the future value of the money being invested (KAEWUNRUEN et al.,2018). It takes into account the risk or the lost opportunity of investing in another type of investment, commonly referred to as the time value of money. NPV is the financial indicator that shows the present value of future payments, when these are discounted at an interest rate from the initial investment. The interest rate adopted is the Brazilian National Index of Construction Costs in the Market - INCC accumulated in the last twelve months of 4,12%. The NPV was calculated using Equation (4):

$$NPV(i,N) = \sum_{t=0}^{N} \frac{FV}{(1+i)^t} \tag{4}$$

Where:

NPV is the Net Present Value;

N is the total number of periods;

i is the discount rate;

FV is the net cash flow at time t.

The Internal Rate of Return (IRR) reveals the rate of return from NPV cash flows received from an investment. Generally, the higher IRR value than more recommended is the investment. The IRR is calculated using Equation (5):

$$IRR = \sum_{n=0}^{N} \frac{Cn}{(1+r)^n} = 0 \tag{5}$$

which,

IRR is the Internal Rate of Return;

N is the total number of periods;

n is the positive integral;

r is the Internal Rate of Return.

Payback (PB) is the period of time between an initial investment made at time zero and the future time when the accumulated net profits equal the initial investment. The PB is calculated using Equation (6):

$$PB = \frac{(p-n)}{p} + ny \qquad (6)$$

Which,

PB = initial investment (R$)

n = the return value of the last negative cash flow

ny = the number of years passed before the last negative return occurs

It is important to highlight that, for the simulation and for the requested budgets, no particularities related to the aesthetic distribution were taken into account.

4 Results and Analysis

The experiment is a simulation of the energy consumption and production of a commercial building, performed during the development of the concept design. All the steps were based on the IDM presented in the section 3.12. This chapter provides the result and analyzes the potential of each tested design option.

4.1.Exporting gbXML

CHEN et al. (2018) and PATIÑO-CAMBEIRO et al. (2017) reported that information in models exported in gbXML format are misrepresented. In these cases, the models had very complex shapes. In this work, the export gbXML process proposed by KAMEL; MEMARI, (2018) was adopted, which is capable of representing simpler shapes like the one considered in this research. Nevertheless, extra green shade planes appeared during the process as can be seen in Figures 13 and 14. In order to overcome this situation, during the export process, the "import shade surfaces" and "merge coplanar surfaces" options were disabled. That activity is performed by the Architecture Team in the IDM after finishing the building volumetric study.

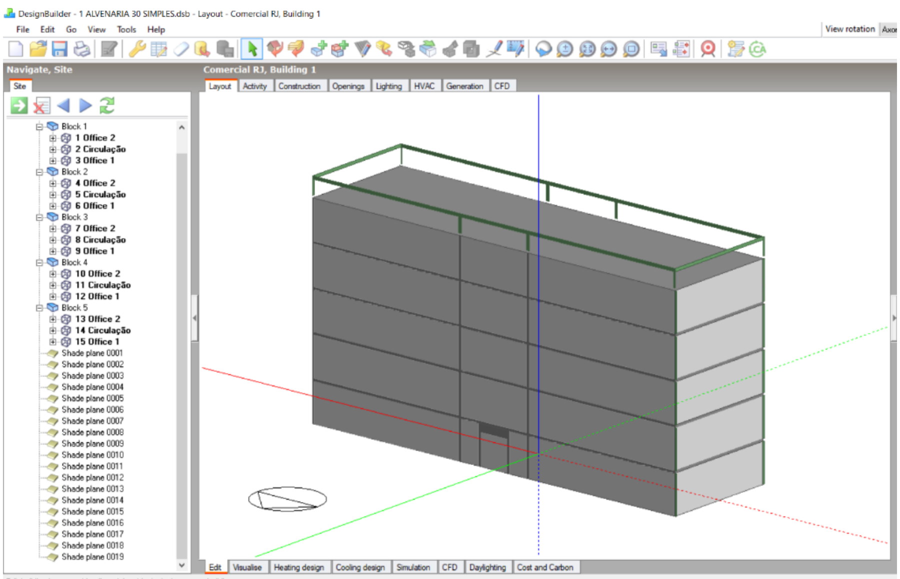


Figure 13 - DesignBuilder imported gbXML file

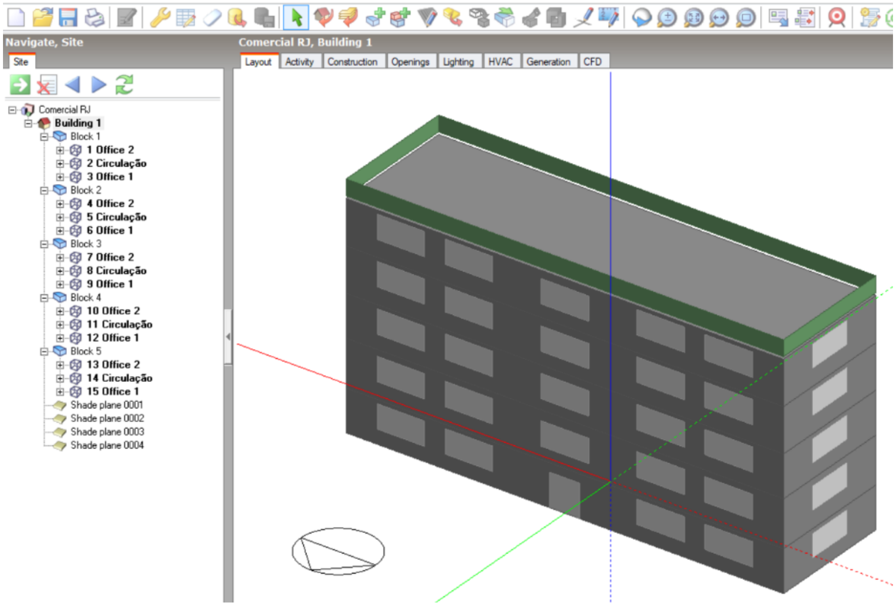


Figure 14 - DesignBuilder imported gbXML file 2

This study began by comparing the simulation results of two different modeling processes using case 01. The first is the most traditional one, the project is fully modeled in the DesignBuilder program and simulated – Case 0. The second option process, designed to be used in a BIM environment, the project is modeled in the Autodesk Revit, exported in gbXML format, imported into the DesginBuilder program, and then simulated – Case 1. From the results from DesignBuilder of the two models, it is possible to analyze the energy performance of the building through total consumption in Figure 15.

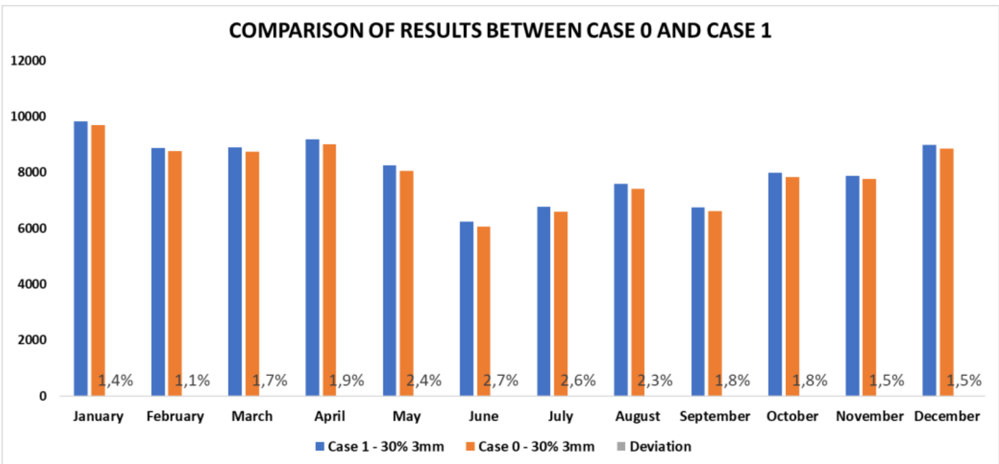


Figure 15 - Comparison of results between case 0 and case 1

The deviation found in these simulations was between 1% and 3%. This fact occurs due to the geometric dimension's variation between the models, due to the remodeling process. Since this is considered a small deviation, this research is developed based on the second process in which the gbXML format is used.

4.2.Computer Simulation

This section presents first the results for the cases where only energy consumption was calculated. This is followed by the presentation of the results for the cases where energy production is considered.

4.2.1.Consumption

In this first stage of the simulations, energy efficiency is the focus. Figure 16 shows the total energy consumption in blue (lighting, equipment, and HVAC), and the HVAC system consumption only in orange of each model. The results for the eight design options with distinct window-to-wall ratio (30%, 50% and 100%) and adopted glass type are shown in this figure.

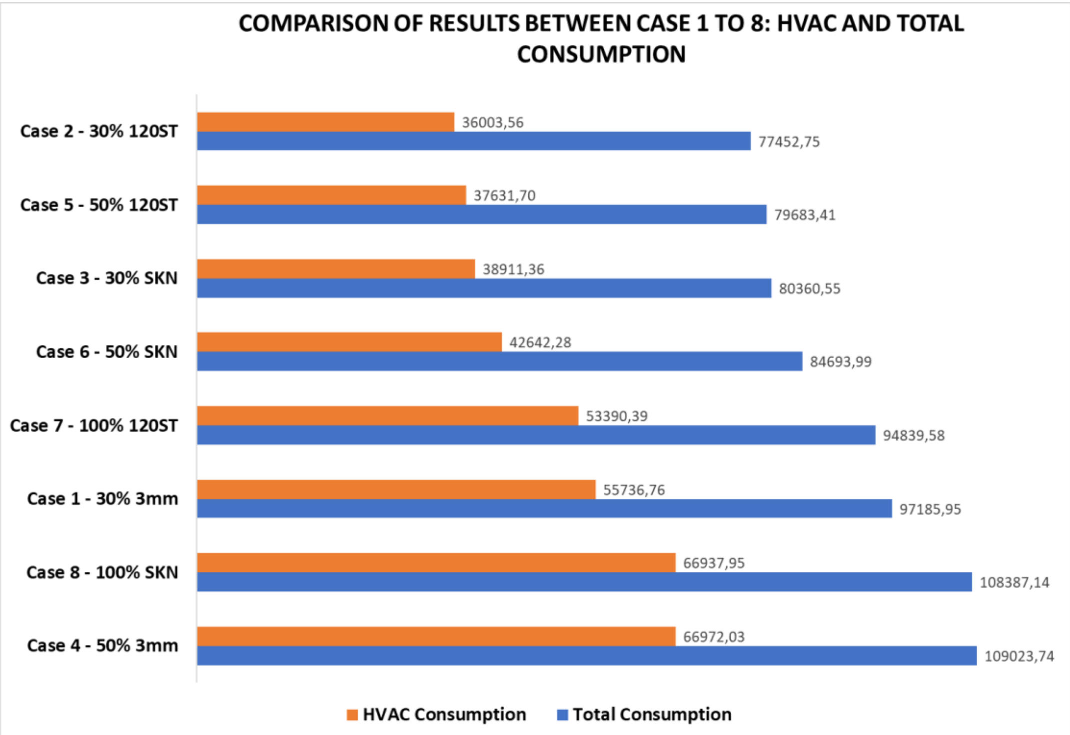


Figure 16 - Comparison of results between case 1 to 8: HVAC and Total Consumption

From Figure 16 it can be observed that the model with the lowest total energy consumption was the model in Case 2. This case contained 30% WWR and the adopted glass was the 120ST with thermal transmittance of 2.6 W/m²K.

Figure 17 presents a comparison between several of the cases. As can be seen, Case 5 differs from Case 2 only in the WWR (Analysis 1). The 50% WWR with 120ST guaranteed an increase of only 3% in the energy consumption of the building. Although the glass represents the most sensitive part of heat gain, in Case 5, the increase of WWR combined with medium performing insulated glass ensured an energy demand similar to Case 2.

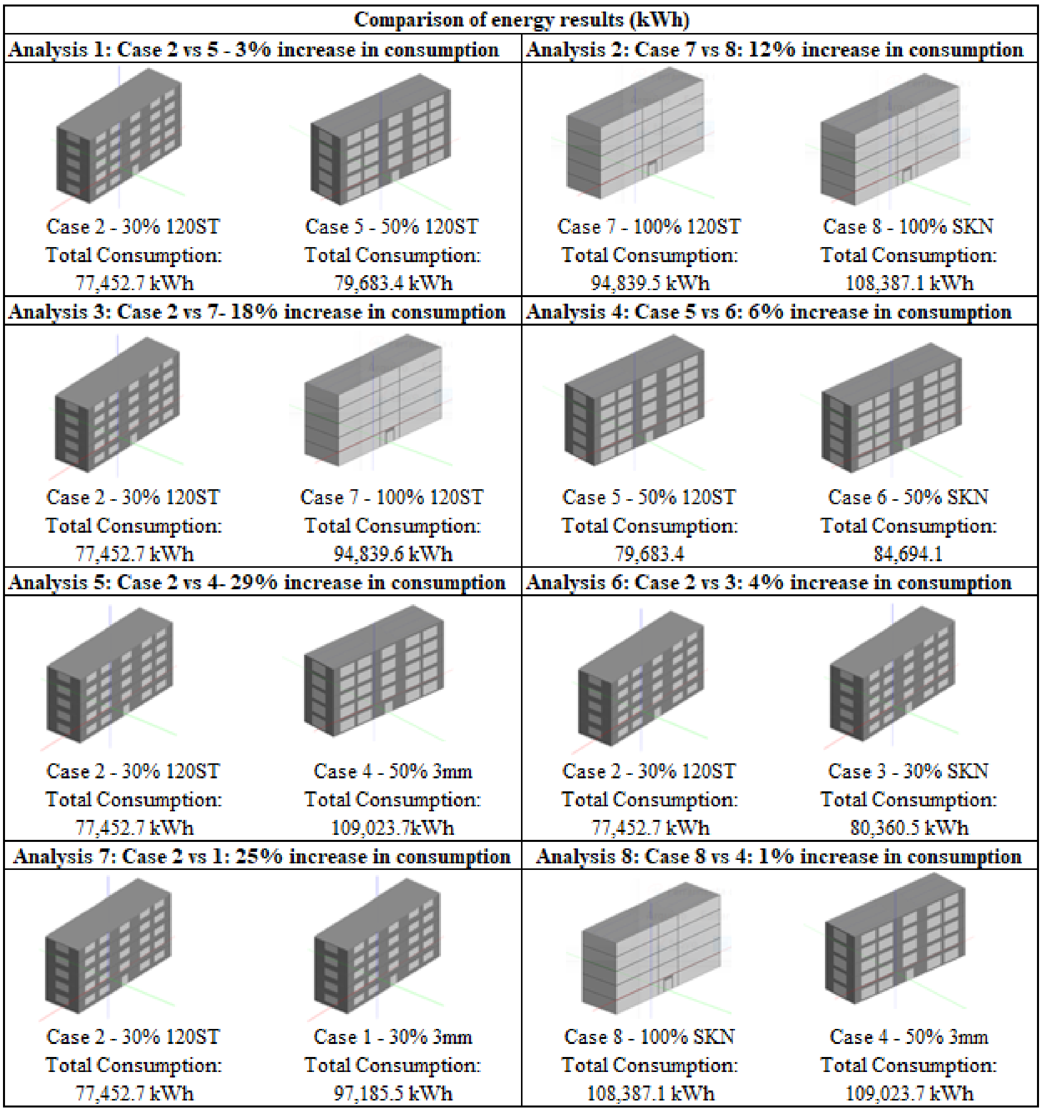


Figure 17 - Comparison of consumption

The 120ST Glass type provided the best performance for a given WWR (Cases 2, 5 and 7). Thus, it can be concluded that the 120ST glass is the best choice for this project. It can also be observed that the use of this insulated glass with a higher WWR, i.e., 100% (Case 7) has an impact on energy demand. The higher WWR raised the energy demand of the HVAC system. More specifically at Figure 17, there was an increase in efficiency of 18% when compared to Case 2 (Analysis 3).

The 3mm glass is responsible for the poor performance of Cases 1 and 4, because of its high thermal transmittance (U=5.84 W/m²K) and solar factor (SF = 0.85). A high value of these two parameters enables high heat transmission through conduction and it allows 85% of solar irradiation to penetrate the building, respectively, demanding more energy consumption by the HVAC system. This can be seen in Figure 17, which shows that the use of 3mm glass provided an increase of 29% in consumption when compared to the best performing case - Case 2 and the worst performing case - Case 4 (Analysis 5).

The insulated SKN glass with low thermal transmittance had also poor performance as well as can be seen for Cases 3, 6 and 8 in Figure 16. The highest consumption could be attributed to the high isolation of the glass, which may have caused overheating due to thermal insulation preventing heat dissipation and the natural cooling of the building at night.

Thermal insulation in commercial buildings is not always desirable, especially in hot climates (PACHECO, 2013). This is confirmed when comparing the use of SKN glass against the 120ST glass in Figure 17. As can be seen, in all the cases there was an increase in energy consumption: 4%, 6% and 12% for the cases with 30%, 50% and 100% WWR, respectively (Analysis 2, 4 and 6).

From the consumption analysis of the eight design options that was conducted in the DesignBuilder program, three cases are selected based on their energy consumption considering WWR. Thus, only the most efficient cases from the first stage were selected while maintaining the three design options. The selected cases are shown in Figure 18.

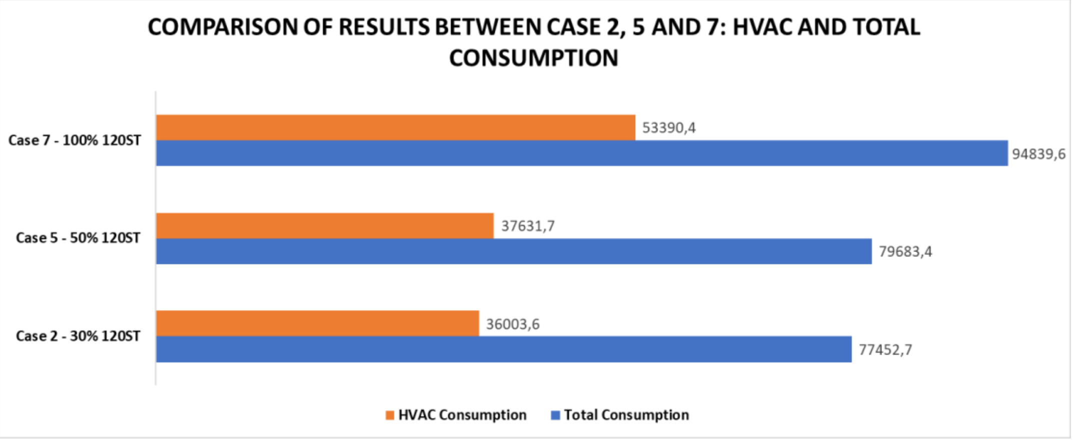


Figure 18 - Selected Cases from the first stage

4.2.2. Production

The second stage of the simulations focuses on PV energy production. As mentioned previously, the PV modules placed on the roof are installed with an inclination equal to the local latitude (22º) facing the North direction. Nevertheless, the inclination of the PV modules installed on the North facades have the same inclination as the facade (90º), which is not an ideal situation.

Figure 19 shows the results obtained with the Radiasol program, which was developed by the Federal University of Rio Grande do Sul (UFRGS). These values are based in the Solarimetric Atlas of Brazil database that generates hourly solar radiation data (BENDER, 2018). The graph shows the irradiation level when positioning the PV modules in the ideal inclination (22°) and the facade inclination (90°). These results confirm that there is a reduction in the annual generation potential (about 50% in the present study), due to the smaller amount of irradiation that reaches the surface when the PV module is installed with a tilt angle of 90°.

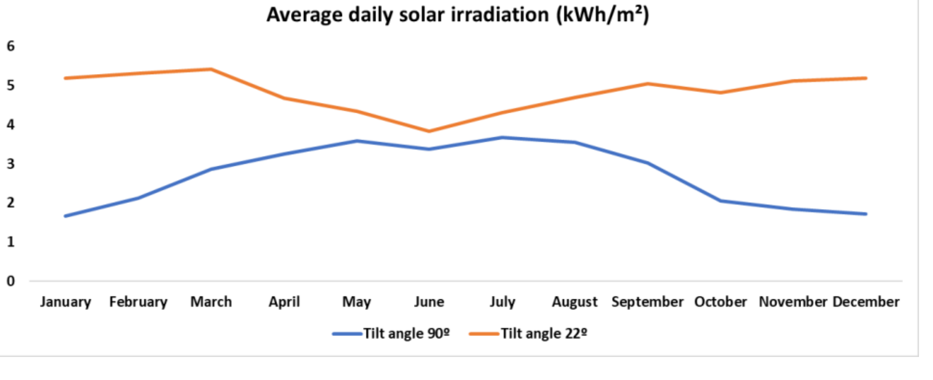


Figure 19 - Average daily solar irradiation from Radiasol Program

From Figure 19, it can also be observed that for the PV modules installed on the roof, there are peaks of irradiation in the summer months, while in the months from May to July (winter), the curve declines. On the other hand, the opposite occurs for the irradiation curve of the facade panels. In the winter period, the facade plane is more exposed to solar irradiation, even though the amount of radiation is lower when compared to the roof plane.

From the simulations with the PV modules in the DesignBuilder program it was possible to verify the total annual consumption and production of each design option. First, only the installation of PV modules on the roof were considered. The installation of the PV modules in the North facade was considered afterwards. Figure 20 shows the models developed in DesignBuilder for the three design options, which are referred to as Cases 9, 10 and 11 (originally called Cases 2, 5 and 7). The selected cases are the most efficient in terms of energy consumption from the three major aesthetic scenarios.

Figure 21 shows the total energy consumption, the HVAC energy consumption, and the energy production of the PV panels installed on the roof for the three cases. The obtained balance between consumption and production for the three design options are provided in the figure using percentages.

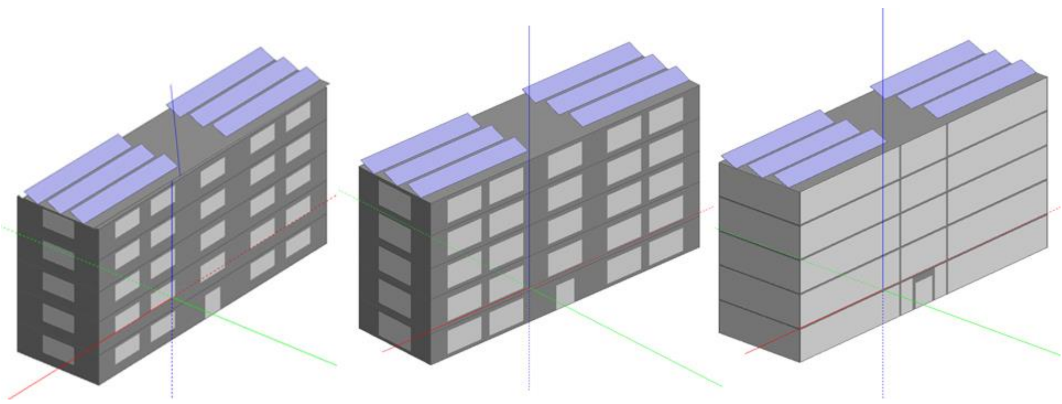


Figure 20 - DesignBuilder Models

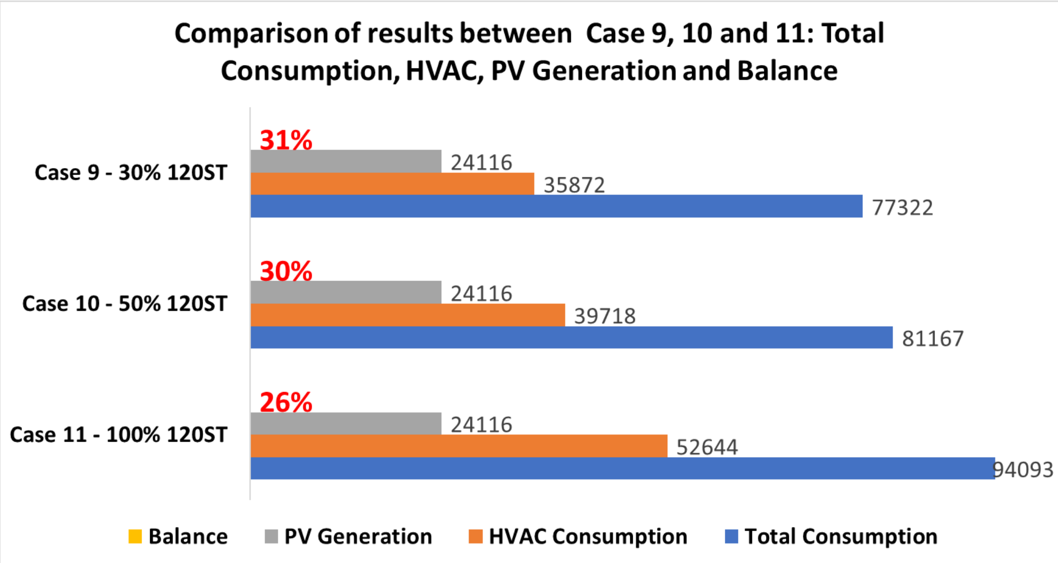


Figure 21 - Comparison of results between case 9 to 11

As can be seen from Figure 21, the production capacity of the photovoltaic system installed on the roof is the same for all three cases, as expected, since the roof area is the same in the three cases. However, due to the variation in energy consumption, energy balance is different for each case, i.e., 31%, 30% and 26% for Cases 9, 10, and 11, respectively.

Therefore, it can be concluded that considering only the roof for photovoltaic production is not enough for the project to achieve the desired NZEB target. Therefore, new design options needed to be considered. More specifically, the addition of PV modules on the North facade are entertained, which resulted in five more cases. The production capacity of the photovoltaic system installed on the roof is maintained, but the north facade is overlaid with PV modules at the walls and/or the windows, depending on the case. For the windows, the PV modules are replaced by PV Glass modules.

As the thermal transmittance of the wall is changed due to module overlay and the thermal properties of the north facade glass also changes because of the PV Glass, a new energy consumption must be predicted (Cases 12, 13, 14, 15 and 16) as shown in Figure 22.

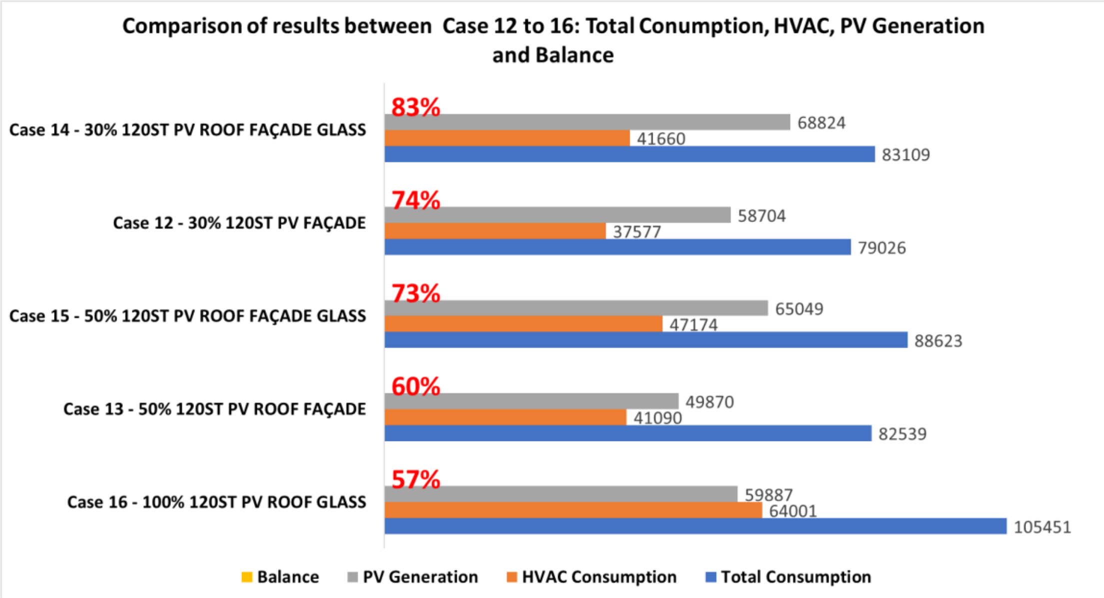


Figure 22 - Comparison of results between case 12 to 16

Figure 22 presents the new Total/HVAC energy consumption, the energy production, and the balance between consumption and production for the five design options. As can be seen from Figure 22, the use of the north facade for PV production provides a nearly zero balance for cases 12, 14, and 15. From this figure, one can conclude that the best proposal for reaching the nearly zero energy balance was that of Case 14, which was able of produce 83% of the energy demand and corresponds to the design option with the smallest WWR (30%). The second-best approach was the Case 12 with 74% balance, which is identical to Case 14 except that it does not include the PV Glass. The next most efficient is Case 15, which has the same characteristics as Case 14, but is the design option with 50% WWR. The balance in this case is of 73%. Cases 13 and 16 presented the worst energy balance, about 60% and 57% respectively. In Case 13 there is a 50% WWR and no PV glass was used. Finally, for Case 16 there was 100% WWR, so, there was only PV glass in the north facade.

It is important to highlight that, the north facade energy production brings a balance nearly to zero in most of the cases, however there is a slight variation in energy consumption for each case. Analyzing case 9 and case 12, it can be seen that there is a 2% increase in energy consumption (Figure 23). In the case 14 where 120ST glass is replaced by PV glass, there is a 5% increase in energy consumption compared with case 12 (Figure 23). In Case 16, where the 100% WWR north facade is replaced by PV glass, there is a 11% increase in energy consumption compared with case 11 (Figure 23). On possible explanation for this increase is that the PV glass may provide poor insulation, which may have increased the need for cooling.

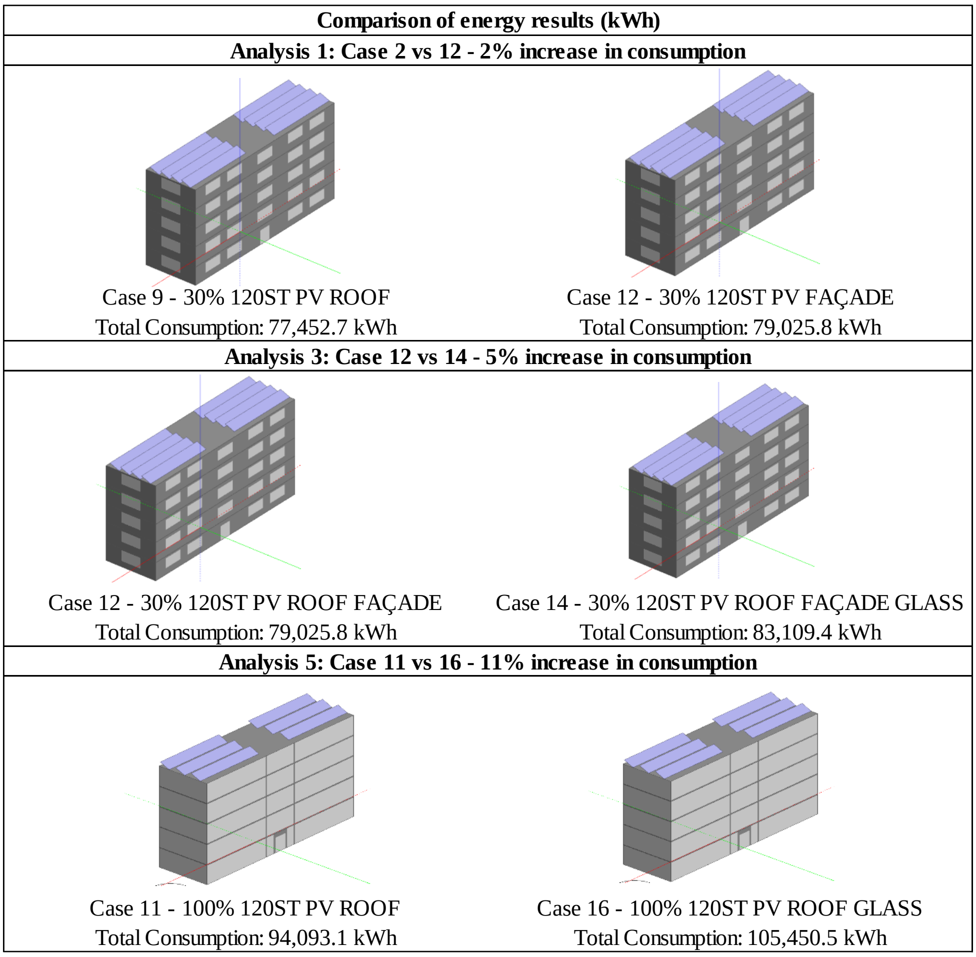


Figure 23 - Comparison of consumption between case 9 and case 12

The photovoltaic potential calculated by DesignBuilder has been verified through two validation methods. The first method was collecting the annual photovoltaic power output from some websites (Global Solar Atlas, National Renewable Energy Laboratory (PVwatts) and European Commission – PVGIS) based in Azimuth Angel, Tilt and System size of the PV panels. The other method, is the monthly and annual PV generation calculations based on the data from Radiasol program.

Figure 24 provides the comparisons of the results obtained by the different tools. The obtained percent difference between the results varied from 3% to 7%, as shown in the figure. These differences may be due to the fact that each tool uses a different database. However, since this difference is very low, it can be concluded that DesignBuilder has sufficient accuracy for the initial analysis of photovoltaic system production.

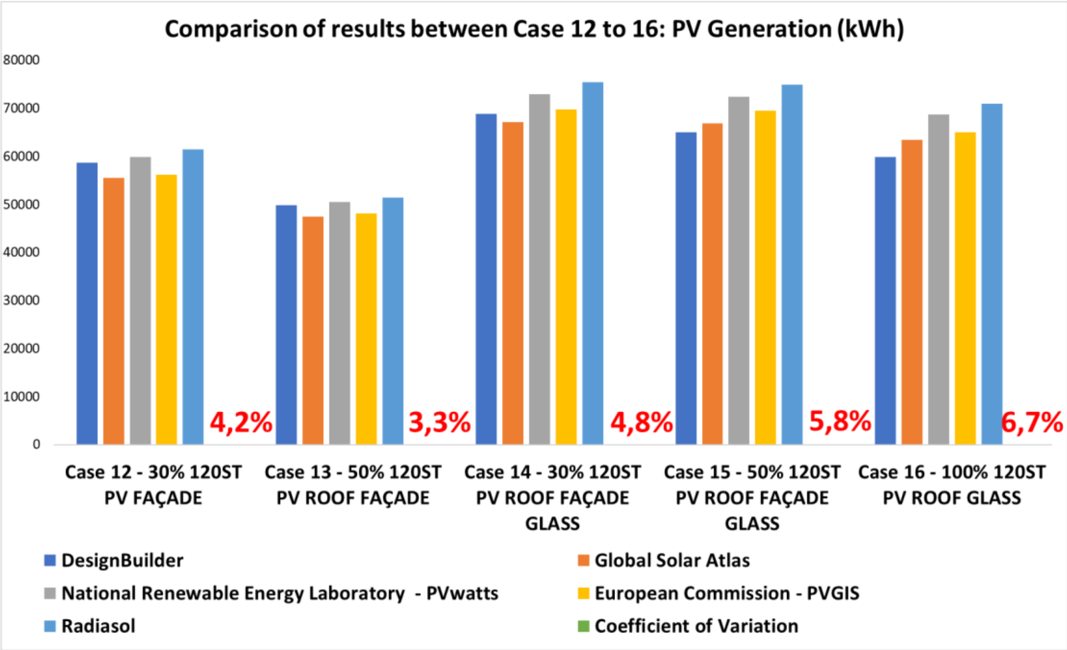


Figure 24 - Comparison of Results between Case 12 to 16: PV Generation

The final simulations considered the site context. A total of five new simulations are carried out to quantify the impact that surrounding buildings can have on the energy consumption and PV production of a building. The height of the surrounding buildings was considered to be twice the height of the hypothetical case in order to configure a rough and dense urban environment.

In the first scenario in which the surroundings buildings have the same height as the case study building, shading caused a small reduction in the energy balance, approximately 5%. This leads to the conclusion that the impact of shading in PV energy production is only an issue in dense urban environment. The analysis of the results will, thus, concentrate on the second scenario.

From Figure 25 it is possible to see the new Total/HVAC energy consumption, the PV production, and the balance between consumption and production for the five design options considering the impact of shading.

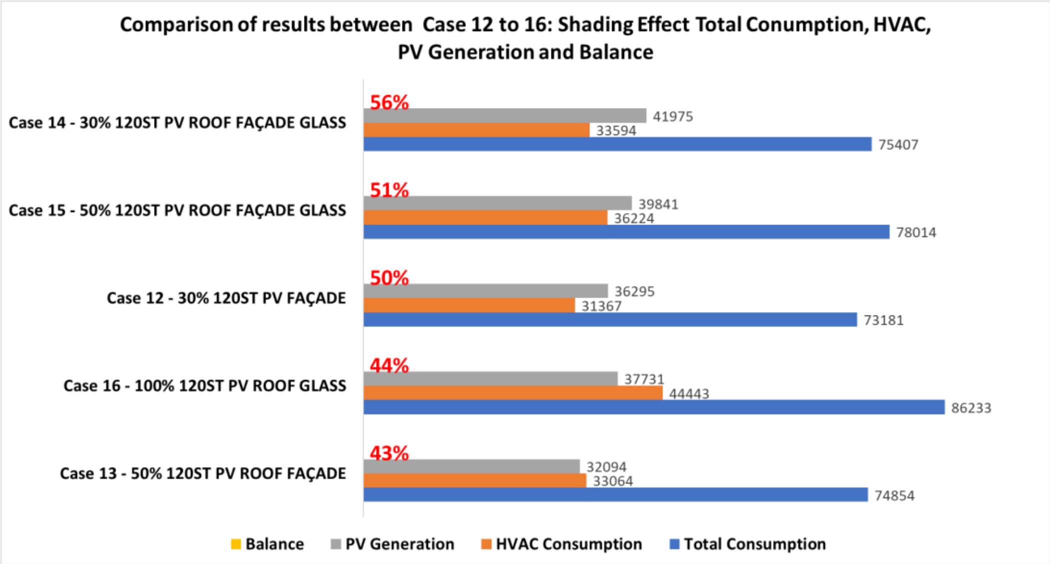


Figure 25 - Comparison of results between case 12 to 16 considering the shading effect

As can be seen from Figure 25, the new values found for the energy balance significantly compromise the nearly zero energy balance target. The new energy balance for cases 14, 15, 12, 16 and 13 were respectively: 56%, 51%, 50%, 44% and 43%.

From Figure 26 it is possible to understand the influence of shading in the total consumption for each design option. The reduction in energy consumption varied from 7% to 18%. Case 16 with 100% WWR had the greatest energy savings, about 18% of reduction in the energy consumption due to shading effect.

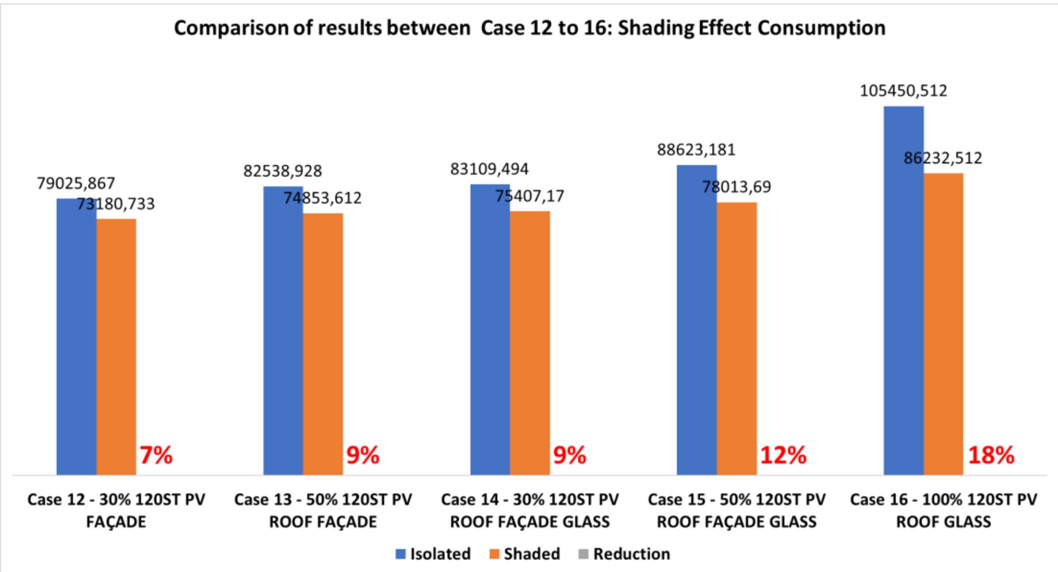


Figure 26 - Consumption considering the shading effect

The impact of shading benefits energy consumption as lower irradiation exposure demands less energy from the HVAC system. However, the impact of shading was detrimental to photovoltaic production. The lower incidence of irradiation in the photovoltaic panels compromises the production that affects the energy balance.

In Figure 27, it is possible to understand the influence of shading on photovoltaic production. In general, it caused reduced energy production by about 40% in each case.

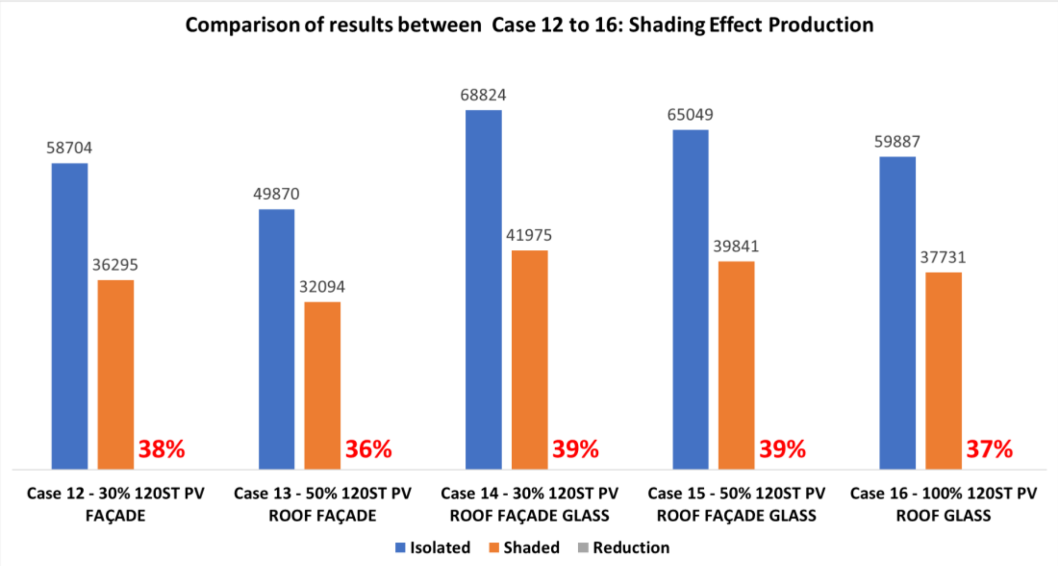


Figure 27 - PV production considering Shading Effect

4.3.Economic Analysis

Following the method, budgets of PV systems for roof and facade were developed based on supplier’s data from Rio de Janeiro and surrounding regions. The electricity rates of the local utility in December 2019 were also verified. Table 18 presents the costs obtained from PV systems suppliers for each case.

Table 18 - PV System Budget

BUDGET		
Module Type	Technical specifications	Cost
PV ROOF (Case 12 to 16)	Canadian CS6P - 260P Installed Power: 17.1kWp	R$ 68.500,00
PV FACADE (Case 12 to 14)	Canadian CS6P - 260P Installed Power: 46.8kWp	R$ 190.000,00

PV FACADE (Case 13 to 15)	Canadian CS6P - 260P Installed Power: 34.32kWp	R$ 140.000,00
PV GLASS (Case 14)	Almaden - SEAC50T 245W Installed Power: 17.64kWp	R$ 80.000,00
PV GLASS (Case 15)	Almaden - SEAC50T 245W Installed Power: 29.4kWp	R$ 120.000,00
PV GLASS (Case 16)	Almaden - SEAC50T 245W Installed Power: 58.8kWp	R$ 250.000,00

The PV system considered includes cost of the modules, an inverter, the electrical design and installation. The PV roof system for Cases 12 to 16 includes 66 modules (260Wp) with an installed power of 17.1kWp. The same module was used for the façade in Cases 12 to 15, but with different system size. For cases 12 and 14, there are 182 modules attached in the façade with an installed power of 46.8kWp. In Cases 13 and 15, there are 132 modules attached in the façade with an installed power of 34.32kWp. For the PV glass system, Case 14 includes 72 modules (245Wp) with an installed power of 17.64kWp. For case 15, the PV glass system includes 120 modules with an installed power of 29.40kWp. And finally, in the Case 16 the system includes 240 modules with an installed power of 58.8kWp.

Table 19 shows the cost of the complete PV system for each case. The complete system includes the photovoltaic system on the roof and in the north facade (wall or window or both).

Table 19 - Complete PV Project Cost

Case	Complete PV Project Cost
Case 12 - 30% 120ST PV FACADE	R$ 258.500,00
Case 13 - 50% 120ST PV ROOF FACADE	R$ 208.500,00
Case 14 - 30% 120ST PV ROOF FACADE GLASS	R$ 338.500,00
Case 15 - 50% 120ST PV ROOF FACADE GLASS	R$ 328.500,00
Case 16 - 100% 120ST PV ROOF GLASS	R$ 318.500,00

In order to verify the economic feasibility, three indicators were used: Net Present Value (NPV), Payback Time (PT) and Internal Rate of Return (IRR). In order to have a coherent analysis the installed PV system were analyzed separately.

Photovoltaic panels installed on the roof suffer less from the shading than panels installed on the north facade. In addition, the optimal tilt angle of the roof modules set ups a better energy output than the 90° tilt panels on the north facade.

At Table 20 provides a summary of the initial investment, energy production, energy savings, NPV, IRR and PT for all cases. As, can be seen from the table a high value was found for NPV and IRR associated with a low value of payback time. This can be interpreted as good indicators, favoring the investment.

Table 20 - Summary of Economic Results

Case	Initial Investment (R$)	Energy Production (kWh/year)	Energy Savings	Net Present Value of the Project - NPV	Internal Rate of Return - IRR	Payback Time - PT
12 to 16 - Only the PV Roof System	R$ 68.500,00	24116,146	R$ 19.597,74	R$ 233.811,02	29%	3,9
12 to 16 - Only the PV Roof System (Shading Effect)	R$ 68.500,00	18703,361	R$ 15.199,10	R$ 165.958,37	22%	5,1
12 - Without PV Roof	R$ 190.000,00	34587,962	R$ 28.107,56	R$ 243.581,81	14%	8,1
12 - Without PV Roof (Shading Effect)	R$ 190.000,00	17591,413	R$ 14.295,49	R$ 30.519,40	6%	19,6
13 - Without PV Roof	R$ 140.000,00	25753,568	R$ 20.928,38	R$ 182.837,14	14%	8,0
13 - Without PV Roof (Shading Effect)	R$ 140.000,00	13390,841	R$ 10.881,93	R$ 27.862,60	6%	18,7
14 - Without PV Roof	R$ 270.000,00	44708,35	R$ 36.331,79	R$ 290.447,22	13%	9,1
14 - Without PV Roof (Shading Effect)	R$ 270.000,00	23271,24	R$ 18.911,14	R$ 21.719,60	5%	22,0
15 - Without PV Roof	R$ 260.000,00	40932,924	R$ 33.263,73	R$ 253.119,89	12%	9,6
15 - Without PV Roof (Shading Effect)	R$ 260.000,00	21138,118	R$ 17.177,68	R$ 4.979,57	4%	24,2
16 - Without PV Roof	R$ 250.000,00	35770,46	R$ 29.068,51	R$ 198.405,16	11%	10,8
16 - Without PV Roof (Shading Effect)	R$ 250.000,00	19027,551	R$ 15.462,55	-R$ 11.477,71	4%	Impracticable
Energy rate = R$ 0.81 and Discount rate = 4.12%						

4.4. Analysis of the Results

Table 21 summarizes all the results. It is possible to see the results of energy consumption, production, balance, PV roof system cost, PV North Facade system cost, Payback time for PV Roof System and Payback time for PV North Facade system.

From Table 21, it can be seen that Case 14 has the best performance, both for the building in isolation (referred to as isolated) as well as for the building with its surroundings (referred to as shaded). Case 14 had an energy balance of 83% which is considered nearly to zero. It had a payback for the roof and north facade of 3.9 years and 9.1 years, respectively for the isolated case. For the shaded case, the energy balance reached 56% and a payback of 5.1 years and 22 years for photovoltaic systems.

Case 12 was the second-best option. The only difference from Case 14 is the absence of PV Glass in the north facade. That difference decreased energy balance by only 10% and payback in 1 year. The energy balance for Case 12 was 74% and the payback time for PV system at the north facade was 8.1 years.

Cases 13 and 15 are similar to cases 12 and 14, with the only difference that they have WWR of 50% instead of 30%. Increasing window opening had a very small impact on consumption, production, balance, and payback time. This means that although the glass represents the most sensitive part of the building, if the glass type is selected based on its performance, the 50% WWR design option can achieve a performance level similar to 30% WWR.

Without compromising the performance of the building, Case 15 can be offered to the Client with an energy balance of 73% for isolated context or 51% for the shaded situation. The payback for this case is 9.6 years or 24.2 due to the impact of shading.

In general, the impact of shading can compromise the photovoltaic potential of the facade to up to 27% and duplicate the payback time of the PV project. For example, for Case 13 the energy balance of the isolated case was 60% and with the impact of shading it decreased to 43%. The payback time in the isolated case was 8 years and with the impact of shading it increased to 18.7 years. Thus, it is possible to conclude that the study of the site context is essential for the development of a nearly zero energy balance project.

Finally, there is Case 16 with 100% WWR, which had the worst performance compared to the others cases. The balance found was 57% for the isolated context and 44% for the shaded situation. The payback time for the north facade investment was 10.8 years for the isolated context. However, in the shaded situation, due to the low energy production and the high cost for system implementation, the project was considered impractical. That means, within 25 year the energy savings would not pay for the system implementation value. In addition, in terms of benefits due to shading, it was possible observe a reduction of energy consumption in Case 16. Lower exposure to solar irradiation from the curtain wall gave better performance. Once again, it can be concluded that the study of the site context is essential to the development of a nearly zero energy project since lower irradiation exposure enables larger transparent openings without compromising the energy performance of the project.

Table 21 - All summarized Isolated and Shaded Cases

Case	Context	Consumption (kWh/year)	Production (kWh/year)	Balance	PV Roof Project Budget	PV North Facade Project Budget	Payback Time Roof (years)	Payback Time Facade (years)
Case 12 - 30% 120ST PV FACADE	Isolated	79026	58704	74%	R$ 68.500,00	R$ 190.000,00	3,9	8,1
	Shaded	73181	36295	50%	R$ 68.500,00	R$ 190.000,00	5,1	19,6
Case 13 - 50% 120ST PV ROOF FACADE	Isolated	82539	49870	60%	R$ 68.500,00	R$ 140.000,00	3,9	8,0
	Shaded	74854	32094	43%	R$ 68.500,00	R$ 140.000,00	5,1	18,7
Case 14 - 30% 120ST PV ROOF FACADE GLASS	Isolated	83109	68824	83%	R$ 68.500,00	R$ 270.000,00	3,9	9,1
	Shaded	75407	41975	56%	R$ 68.500,00	R$ 270.000,00	5,1	22,0
Case 15 - 50% 120ST PV ROOF FACADE GLASS	Isolated	88623	65049	73%	R$ 68.500,00	R$ 260.000,00	3,9	9,6
	Shaded	78014	39841	51%	R$ 68.500,00	R$ 260.000,00	5,1	24,2
Case 16 - 100% 120ST PV ROOF GLASS	Isolated	105451	59887	57%	R$ 68.500,00	R$ 250.000,00	3,9	10,8
	Shaded	86233	37731	44%	R$ 68.500,00	R$ 250.000,00	5,1	Impractical

5 Conclusions and Future Work

The following conclusions can be drawn from the present research:

- The SLR - Structured Literature Review guided this study and showed that there is a growing adoption of the BIM methodology and an interest in the development of more efficient projects, with low energy consumption and the ability to generate its own energy. Although no research has been found that collectively addresses all concepts, this possibility is evident and even cited in some studies.
- The SLR also revealed that in order to generate its own energy at the building scale, the photovoltaic technology is the preferred technology. Although photovoltaic modules are usually installed in the roof area. Currently, there are some architectural possibilities of integration of PV modules in other parts of the building due to its modularity – BAPV and BIPV.
- The BIM approach provided an environment in which energy performance could be considered in the early stages of design. In this research, computer simulations were used to predict the best solutions for a project based on energy consumption.
- In order to perform energy analysis in the selected BIM environment, i.e., using Revit and DesignBuilder it was necessary to use of the gbXML file format to promote the interoperability between the two software tools.
- It was found that reliable energy analysis demands a high level of information in terms of energy related properties, while requiring low level of architectural detail. Thus, the energy simulation at LOD 200 was found to be appropriate for the demands an energy specialist would require.

- In terms of energy efficiency, although the glass represents the most sensitive part of heat gain, the 50% WWR combined with medium performing insulated glass 120ST (U=2.6 W/m²K) ensured an energy demand almost identical to the case with 30% WWR. In addition, the insulated SKN glass with low thermal transmittance (U=1.5 W/m²K) showed poor building performance, which may have caused overheating due to thermal insulation preventing heat dissipation and the natural cooling of the building at night.
- In term of PV production, based in the Radiasol database, the PV modules in the north facade (tilt angle 90°), presented a reduction in the annual generation of the system by approximately 50%, due to the smaller amount of irradiation that reaches this surface when compared to the PV modules installed on the roof (tilt angle 22°),
- The simulations in the DesignBuilder program were compared with online applications and calculations using Radiasol program data. Due to the close agreement in the results, it was concluded that DesignBuilder has sufficient accuracy for the initial analysis of photovoltaic production.
- Analyzing the photovoltaic modules installed on the roof, energy production was able to meet the energy demand up to 31% of the cases under analysis. This means that the roof PV system alone is not able to reach a nearly zero energy balance for the project. The use of the north facade for PV production combining with the PV roof system provides a nearly zero energy balance in most of the cases reaching from 57% to 83% of the energy demand of the building.
- Considering the impact of shading, new values were found for the energy balance that compromised significantly the nearly zero energy balance target. The new values ranged from 43% to 56% depending on photovoltaic system size and WWR. In general, the impact of shading reduced energy production by 40% in each case. Because of the shading, the reduction in energy consumption varied

from 7% to 18%. The 100% WWR case benefitted the most, i.e., by 18% in energy savings due to shading.

- For the isolated case, the PV roof system would be paid in 3.9 years. The PV system installed at the north facade would be paid in 8 years depending on the system size. Also, the PV system for the north facade that includes PV glass would be paid in at least 9 years depending on the system size. The PV system for the north facade that is all PV glass would be paid in 10.8 years.
- Considering the impact of shading, there were significant changes in payback time. The PV roof system would be paid in 5.1 years. The PV system installed at the north facade would be paid in 18 years depending on the system size. Also, the PV system for the north facade that includes PV glass would be paid off at least in 22 years depending on the system size. The case with PV system for the north facade that is all PV glass becomes impractical because would not be paid in 25 years.

For future work, it is suggested that this method to be applied to other Brazilian bioclimatic zones, in order to verify the photovoltaic potential in different regions of the country. The developed method could be applied to buildings of larger magnitude and with different typology such as residential. It is suggested the study of the interference of photovoltaic glass in the issue of lighting consumption, since semi-transparent modules allows natural lighting.

Finally, as limitations of the study, regarding photovoltaic system, in DesignBuilder the simple mode is area based, so the panel alignment and cuts were disregarded in the simulations, as well as in the budget.

6
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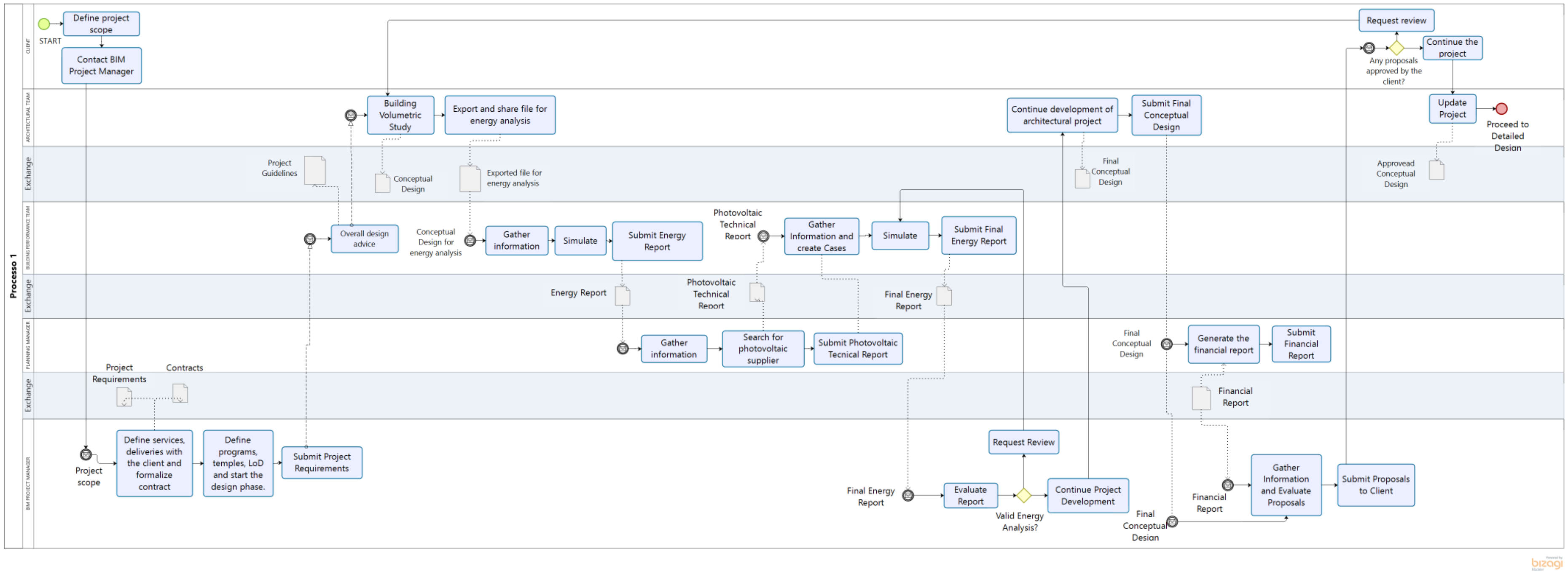
Appendix A

Nº	Title	Author
1	3D insolation colour rendering for photovoltaic potential: Evaluation on equatorial residential building envelope	(FITRIATY et al., 2017)
2	A building information modeling-based study of sunlight simulation in calculation of solar energy potential for sustainable building	(XU; YUAN, 2018)
3	A digital-twin evaluation of Net Zero Energy Building for existing buildings	(KAEWUNRUEN et al., 2018)
4	A feasibility study on a building's window system based on dye-sensitized solar cells	(LEE et al., 2014)
5	A framework for evaluating WTP for BIPV in residential housing design in developing countries: A case study of North Cyprus	(RADMEHR et al., 2014)
6	A framework for NZEB design in Mediterranean climate: Design, building and set-up monitoring of a lab-small villa	(ASCIONE et al., 2019)
7	A framework for producing gbXML building geometry from Point Clouds for accurate and efficient Building Energy Modelling	(GARWOOD et al., 2018)
8	A study of the potential benefits of semi-transparent photovoltaics in commercial buildings	(KAPSIS et al., 2015)
9	A study on the LEED energy simulation process using BIM	(RYU; PARK, 2016)
10	Alternative energy solutions using BIPV in apartment buildings of developing countries: A case study of North Cyprus	(ELINWA et al., 2017)
11	An algorithm to facet curved walls in IFC BIM for building energy analysis	(YING; LEE, 2019)
12	An assisted workflow for the early design of nearly zero emission healthcare buildings	(SLEIMAN et al., 2017)
13	An investigation of the impact of building orientation on energy consumption in a domestic building using emerging BIM (Building Information Modelling)	(ABANDA; BYERS, 2016)
14	Analysis and comparison on the potential of low-carbon architecturaldesign strategies	(XIA; LI, 2019)
15	Assessment and remodelling of a conventional building into a green building using BIM	(ABHINAYA et al., 2017)
16	Automated Building Energy Modeling and Assessment Tool (ABEMAT)	(KAMEL et al., 2018)
17	Behavioral variables and occupancy patterns in the design and modeling of Nearly Zero Energy Buildings	(CARPINO et al., 2017)
18	BIM-based approach to simulate building adaptive performance and life cycle costs for an open building design	(JUAN; HSING, 2017)
19	BPOpt: A framework for BIM-based performance optimization	(ASL et al., 2015)
20	Building energy performance evaluation of building integrated photovoltaic (BIPV) window with semi-transparent solar cells	(CHAE et al., 2014)
21	Building performance modelling for sustainable building design	(ODUYEMI; OKOROH, 2016)

22	Case study of the upgrade of an existing office building for low energy consumption and low carbon emissions	(CHARLES et al., 2019)
23	Challenges for energy and carbon modeling of high-rise buildings: The case of public housing in Hong Kong	(PAN et al., 2017)
24	Considering user profiles and occupants' behaviour on a zero energy renovation strategy for multi-family housing in the Netherlands	(GUERRA-SANTIN et al., 2018)
25	Deep renovation in existing residential buildings through façade additions: A case study in a typical residential building of the 70s	(FOTOPOULOU et al., 2018)
26	Defining the sustainable building design process: Methods for BIM execution planning in the UK	(ZANNI et al., 2014)
27	Design and development of energy efficient re-roofing solutions	(HABIBI et al., 2019)
28	Design of solar systems for buildings and use of BIM tools: Overview of relevant geometric aspects	(DEVETAKOVIĆ et al., 2019)
29	Development of a Building Information Modeling-parametric work flow based renovation strategy for an exemplary apartment building in Seoul, Korea	(AMORUSO et al. 2018b)
30	Disrupting the Status Quo with Early-Stage BIM-Based Energy Modeling	(MCARTHUR; SUN, 2017)
31	e-BIM: a BIM-centric design and analysis software for Building Integrated Photovoltaics	(NING et al., 2018b)
32	Energy Analysis at a Near Zero Energy Building. A Case-Study in Spain	(REY-HERNÁNDEZ et al., 2018)
33	Energy benefits from semi-transparent BIPV window and daylight-dimming systems for IECC code-compliance residential buildings in hot and humid climates	(DO et al., 2017)
34	Energy performance of buildings with on-site energy generation and storage – An integrated assessment using dynamic simulation	(BOT et al., 2019)
35	Energy performance of PV integrated office buildings with fan-assisted double skin façades under tropical climates	(BARBOSA et al., 2019)
36	Estimating energy savings from behaviours using building performance simulations	(LOPES et al., 2016)
37	Evaluation of the energy performance of a net zero energy building in a hot and humid climate	(SHIN et al., 2019)
38	Framework for Using Building Information Modeling to Create a Building Energy Model	(FARZANEH et al., 2018)
39	Green BIM-based building energy performance analysis	(CHEN et al., 2017)
40	Guidelines for using building information modeling for energy analysis of buildings	(REEVES et al., 2015)
41	Identifying and prioritizing the benefits of integrating BIM and sustainability practices in construction projects: A Delphi survey of international experts	(OLAWUMI; CHAN, 2018)
42	Improving the energy production of roof-top solar PV systems through roof design	(LI et al., 2019)
43	Integrating Parametric Analysis with Building Information Modeling to Improve Energy Performance of Construction Projects	(NAJJAR et al., 2019)
44	Interoperability from building design to building energy modeling	(GUZMÁN GARCIA; ZHU, 2015)
45	Investigation of interoperability between Building Information Modelling (BIM) and Building Energy Simulation (BES)	(CHEN et al., 2018)

46	Multidisciplinary energy assessment of tertiary buildings: Automated geomatic inspection, building information modeling reconstruction and building performance simulation	(PATIÑO-CAMBEIRO et al., 2017b)
47	Net-zero energy building design and life-cycle cost analysis with air-source variable refrigerant flow and distributed photovoltaic systems	(KIM et al., 2020)
48	Operational energy of opaque ventilated façades in Brazil	(MACIEL; CARVALHO, 2019)
49	PassivBIM: Enhancing interoperability between BIM and low energy design software	(CEMESOVA et al., 2015)
50	Potential for retrofitting a federal building in the UAE to net zero electricity building (nZEB)	(ALKHATEEB; ABU-HIJLEH, 2019)
51	Predicting energy generation from residential building attached Photovoltaic Cells in a tropical area using 3D modeling analysis	(FITRIATY; SHEN, 2018)
52	Project-based pedagogy in interdisciplinary building design adopting BIM	(JIN et al., 2018)
53	Quantifying the impact of building envelope condition on energy use	(JEON et al., 2018)
54	Reducing the Operational Energy Consumption in Buildings by Passive Cooling Techniques Using Building Information Modelling Tools	(AHSAN et al., 2019)
55	Reducing the operational energy demand in buildings using building information modeling tools and sustainability approaches	(SHOUBI et al., 2014)
56	Regenerative design and adaptive reuse of existing commercial buildings for net-zero energy use	(AKSAMIJA, 2016)
57	Retrofits for energy efficient office buildings: Integration of optimized photovoltaics in the form of responsive shading devices	(ABDULLAH; ALIBABA, 2017)
58	Strategies towards Net Zero Energy Office Buildings in Brazil with emphasis on BIPV	(DIDONÉ et al. 2014)
59	The promise of BIM for improving building performance	(HABIBI, 2017)
60	Toward Grid-Friendly Zero-Energy Buildings	(BRUGGMANN; HENZE, 2018)
61	Towards a BIM-enabled sustainable building design process: roles, responsibilities, and requirements	(ZANNI et al., 2017)
62	Transformation of a university building into a zero energy building in Mediterranean climate	(MYTAFIDES et al.,2017)
63	UhuMEB: Design, construction, and management methodology of minimum energy buildings in subtropical climates	(MELGAR et al., 2018)
64	Using BIM capabilities to improve existing building energy modelling practices	(GERRISH et al., 2017)
65	Whole building optimization of a residential home with PV and battery storage in The Bahamas	(BINGHAM et al., 2019)

Appendix B


Processo 1
START
Define project scope
Contact BIM Project Manager
Request review
Any proposals approved by the client?
Continue the project
Update Project
Proceed to Detailed Design
Building Volumetric Study
Export and share file for energy analysis
Continue development of architectural project
Submit Final Conceptual Design
Exchange
Project Guidelines
Conceptual Design
Exported file for energy analysis
Final Conceptual Design
Approvead Conceptual Design
Overall design advice
Conceptual Design for energy analysis
Gather information
Simulate
Submit Energy Report
Photovoltaic Technical Report
Gather Information and create Cases
Simulate
Submit Final Energy Report
Energy Report
Photovoltaic Technical Report
Final Energy Report
Gather information
Search for photovoltaic supplier
Submit Photovoltaic Tecnical Report
Final Conceptual Design
Generate the financial report
Submit Financial Report
Project Requirements
Contracts
Financial Report
Project scope
Define services, deliveries with the client and formalize contract
Define programs, temples, LoD and start the design phase.
Submit Project Requirements
Request Review
Final Energy Report
Evaluate Report
Valid Energy Analysis?
Continue Project Development
Final Conceptual Design
Financial Report
Gather Information and Evaluate Proposals
Submit Proposals to Client
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