UNIVERSIDAD DE ALMERÍA

# DOCTORAL THESIS

## Sustainability of Energy in universities: The University of Almeria as a Case of Study

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Almería, June 2021

***Sustainability of energy in universities: The University of Almeria as a case study***

**INTERNATIONAL SCHOOL OF DOCTRORATE**

Greenhouse Technology and Industrial and Environmental

University of Almeria

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# ESCUELA INTERNACIONAL DE DOCTORADO

Tecnología de Invernaderos e Ingeniería Industrial y Ambiental

Universidad de Almería

# TESIS DOCTORAL

La sostenibilidad energética en las universidades:

la Universidad de Almería como caso de estudio

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# Sustainability of Energy in universities: The University of Almeria as a Case of Study

## Summary

Building Information Modeling (BIM) is increasingly demanded in the architecture and engineering fields. In fact, building information model (BIM) provides an intelligent model-based process that connects AEC (architecture, engineering, and construction) professionals and helps them to design, build, and operate building infrastructure. This concept began to be formed since professionals started using computers in the act of designing and planning for construction, and it hasn't stopped evolving ever since to incorporate more advanced technologies and expand its areas of operation to reach fields like asset management, the sustainability of energy and other different areas. In this thesis, a bibliometric analysis is first carried out to explore the data extracted from all scientific publications related to BIM in Scopus database during the period 2003-2018 to describe the different attributes of BIM and BIM in Universities, which are developed in statistical study and cluster mapping forms.

This doctoral thesis aims to benchmark energy use in universities with Mediterranean climates, the University of Almeria campus is used as a case study, and different types of buildings we develop a benchmarking system based on normalized ranking to review the energy use of the different types of facilities in the University, Macro-scale energy consumption data during the period 2011-2018 were gathered alongside cross-sectional building information. Eight years of daily outdoor temperature data were recorded and collected. Energy use models have been developed to identify which parameter correlates more with energy use. The weather factor has been found out to be the most influential on the overall energy consumption.

The campus of the University of Almeria has also decreased energy consumption in 2020 to unprecedented levels, due to the closure of its campus facilities during the Covid-19 outbreak. As a second major objective, data on the different energy performances of the University's structures under these circumstances have been analyzed. This analysis opens up new perspectives for the study of energy consumption in universities.

# La sostenibilidad energética en las universidades: la Universidad de Almería como caso de estudio

## Resumen

El modelado de información de edificios (BIM) es cada vez más demandado en los campos de la arquitectura y la ingeniería. De hecho, el modelo de información de edificios (BIM) proporciona un proceso inteligente basado en modelos que conecta a los profesionales de la arquitectura o ingeniería y les ayuda a diseñar, construir y operar la infraestructura de los edificios. Este concepto comenzó a formarse desde que los profesionales empezaron a utilizar los ordenadores en el acto de diseñar y planificar la construcción, y no ha dejado de evolucionar desde entonces para incorporar tecnologías más avanzadas y ampliar sus áreas de actuación hasta llegar a campos como la gestión de activos, la sostenibilidad de la energía y otras áreas diferentes. En esta tesis primero se realiza un análisis bibliométrico, se han analizado de todas las publicaciones científicas relacionadas con BIM en la base de datos Scopus durante el periodo 2003-2018 para analizar los diferentes atributos de BIM y BIM en las Universidades, que se desarrollan en forma de estudio estadístico y de mapeo de clústeres.

Esta tesis doctoral tiene como objetivo la evaluación comparativa del uso de la energía en las universidades con climas mediterráneos. Se utiliza el campus de la Universidad de Almería como caso de estudio. Los diferentes tipos de edificios se emplean para desarrollar un sistema de evaluación comparativa basado en la clasificación normalizada para revisar el uso de la energía de los diferentes tipos de instalaciones en la Universidad. Se recogieron datos de consumo de energía a macro escala durante el período 2011-2018 junto con información constructiva de cada edificio. Se registraron y recopilaron ocho años de datos diarios de temperatura exterior. Se han desarrollado modelos de uso de energía para identificar que parámetro se correlaciona más con el uso de energía. Se ha comprobado que el factor meteorológico es el que más influye en el consumo energético global.

El campus de la Universidad de Almería también ha disminuido el consumo de energía en 2020 a niveles sin precedentes, debido al cierre de sus instalaciones en medio del brote de Covid-19. Como segundo gran objetivo se han analizado los datos de los diferentes rendimientos energéticos de las estructuras de la Universidad bajo estas circunstancias. Este análisis abre nuevas perspectivas para el estudio del consumo energético en las universidades.

# Sustainability of Energy in universities:
# The University of Almeria as a Case of Study

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# CHAPTER I

# INRODUCTION

### 1.1 Introduction

Construction and operating buildings often encounter many unpredictable issues which are mainly related to the design and planning phase. Consequently, the BIM concept was created to anticipate and avoid these technical anomalies. This concept has known several improvement stages since the deployment of computers to aid in the creation of a design, but it wasn't until the '90s when BIM started to gain traction as companies began to develop BIM tools such as modeling programs and computer-aided design software (CAD 2D, 3D), its core function was to provide users with the ability to integrate, simulate and visualize the geometric and non-geometric information of a facility [1]. Architecture, Engineering, and construction (AEC) advancement contributed to the ability to create more complex structures which have led to the adoption of BIM even further. In the 2000's several software like (Archicad, Revit, Navisworks, Sketchup) were commercially promoted to back up the application of BIM, these programs will be enhanced later to be able to analyze and optimize the designs [2]. The Governments of the U.K, Finland, and Germany were one of the first states to make the use of BIM mandatory in certain fields as BIM area of operation started to extend to be applied in infrastructure projects (roads, bridges, public sanitation, and public transportation) since it became possible to generate and manage a facility by digitizing the physical and functional information of a facility [3,4,5].

BIM has been widely adopted in many multi-disciplinary such as social fields which include (education, management, and economics), the environment field that includes (environmental science, sustainability, and energy) and the computer science field which includes (information and communication technology, semantics, and interoperability [6,7]. To address the issues brought by manual review, various structured analysis has been developed in this thesis using a clustering tool. These reviews aim to reveal the hidden connections of various knowledge domains, which is critically important to the development of BIM, by addressing gaps in the literature and proposing new studies that are distinct enough from existing work to make a viable contribution [8]. The bibliometric analysis aims to underlie BIM structure and review the state of the art of its research and future trends. This thesis has been conducted as a comparative analysis of BIM global and BIM in university to measure the influence of publication in the scientific community. The bibliometric approach is designed to outline quantitative and accurate connections among different reviews [9].

BIM trends as many other concepts are mainly heading towards the adoption of digital technology, big data, robotics, smart models, and machine learning. Advancement in Information technology and software industry is enabling architects and designers to draw designs for complex structure such as expressionist and parametric architecture style [10], furthermore, robotics progress is allowing the machines to make the shuttering panels that form the wavy shapes of the parametric style. BIM concept has gone even farther when it comes to the integration of new technologies [11]. For instance, artificial intelligence integration is feeding parametric modeling to not only create unusual architecture but also to optimize inputs like the amount of daylight, viewpoint to the ocean or other natural landscape, and cost of construction through algorithms that generates iterative designs providing different options for designers, in the case of skyscrapers every floor is optimized according to its geospatial location [12]

Despite the effort of the world states and organizations to meet the United Nations sustainable development goals (SDG7), our climate is still changing rapidly and greenhouse levels are continuing to rise, Global energy demand increased by 2.1% in 2017, and related $CO_2$ emissions grew by 1.4% in 2017, reaching a historic high of 32.5 Gigatonnes (Gt) TWB [13], the proposal set by the European Union Commission to cut greenhouse gas emissions by at least 55% by 2030 is an ambitious and cost-effective path to achieve climate neutrality by 2050. Buildings utilities are responsible for over 38% of the total final energy use in Europe against 31% in the world, and they are responsible for 30% of the global CO2 emissions in Europe against 28 % in the world. Over the last decade, the European Commission released the first legislative instrument aimed to improve the building's energy performance: the "Energy Performance of Building Directive" (EPBD) was introduced in 2002 and updated in 2010 EU Energy in Figures (2020) [14,15].

The first edition of the prioritizes the legislations around new buildings, to adopt technical aspects that must be planned in the design phase like building orientation, openings for a suitable amount of daylight, envelope insulation, and reserved spaces for photovoltaic panels to ensure efficiency by design. The revised document in 2010 focused more on the existing building stock since they represent the large influencer of the overall energy consumption of the building sector within the EU-15 member states, the renovation cost of the existing building stock has three to six years pay-back. In 2019, two-fifths of the building's efficiency investment was in Europe, where energy efficiency investment growth has outpaced construction activities in some countries [16]. Annual UK efficiency investment grew by 2.3% since 2016, while construction investment saw no growth. Renew or strengthened support for buildings efficiency investment was advanced in Norway Spain and Switzerland. The European Commission has stated that the annual EU building's efficiency investment must rise to EUR 177 billion by 2030 [17].The energy progress report that has been released by the International Energy Agency in 2019 encourages the notable improvements that have been made in the energy efficiency by the EU. However, the global rate of primary energy intensity improvement still lags behind, and estimates suggest there has been a significant slowdown in 2017 and 2018. Strengthening mandatory energy efficiency policies, providing targeted fiscal or financial incentives, leveraging market-based mechanisms, and providing high-quality information about energy efficiency will be central to meet the goal [18].

The international energy market has known major fluctuations inflicted by the Covid-19 pandemic in 2020, energy demand and oil prices went down. Spain was among the first countries to be overwhelmed by the outbreak during the first wave, and the country experienced the largest contraction in the first half of the year (12.8 percent) among major advanced economies. Education institutions had been closed in the country during this period, and the development of "sustainability of energy in buildings" could contribute to relieving the crisis and based on the data collected in the University of Almeria during 2020, we aim to identify potential impacts of the Covid-19 on the energy use of the University [19, 20].

The energy transfer process from resources to the end-users faces many challenges and can take considerable energy losses, the system-level assessment and planning provide the overall function of the process stages [17]. Besides, an everyday tremendous amount of energy is lost in utilities with devices that set unused with power on [18]. Companies are creating energy software that is connected to plug devices, these applications operate as a centralized system that gathers data and turn the plugs on and off [19]. Furthermore, the implementation of technologies like IoT devices, Smart grids, Big data is changing drastically HVAC and lighting systems. Today, they incorporate sophisticated sensors and computer networking programs to monitor and adjust building systems to reach optimal energy usage [20]. These new technologies are called building automation systems, they control, monitor, troubleshoot, and collect data on the building's performance [21]. In the past the lack of data about energy usage led to inefficiency throughout the process of generating, delivering, and using energy, now that the necessary means to extract, store, and analyze a tremendous amount of data are available, solutions are uniquely delivered that could be transformed into consumer insight. Furthermore, professionals are dealing with volume (amount of data), velocity (speed of data), and variety (types of data), three components of Big data that are processed by constantly storing managing comparing, and analyzing this data in real-time to create patterns that could drive the strategic decision making to optimize utilities [20]. Therefore, the adoption of new technologies could contribute to tackle the climate change issue and drive down the carbon emissions.

Public buildings such as universities, schools, and hospitals are challenged to manage the exponential growth of their energy demand and transform their buildings into energy-efficient ones [22]. Acting as models for communities, universities are supposed to provide innovative solutions through research in order to support the sustainability and reduce the carbon footprint, [23]. One of the key operating aspects for universities is related to enhance students' and teachers' comfort levels, which may have a significant effect on energy demand. Thus, visual, acoustic, and thermal comforts should not be considered as luxuries but rather as a basic standard for schools [24]. However, maintaining indoor quality will eventually lead to significant growth of electricity consumption, therefore, transforming university locals into energy-efficient ones is a necessity ANSI/ASHRAE/IES Standard 100-2015. In Spain, the current Building Technical Code (referred to as CTE in Spanish) establishes restrictive set point temperatures that ensure high levels of thermal comfort [25]. In this thesis, we develop a benchmarking system based on normalized ranking to review the energy use in the University of Almeria.

## 1.2 Objectives

The bibliometric study aims to underlie BIM structure and review the state of the art of its research and future trends. we conducted as a comparative analysis of BIM global and BIM in university to measure the influence of publication in the scientific community. The bibliometric comparative study has been conducted to map the background of the overall work published concerning BIM and draw the research area clusters this scientific field is grouped around. Furthermore, given the importance BIM has for sustainability, we aim to determine which works of BIM are used in universities to contribute to their sustainability.

The University of Almeria campus is used as a case for energy benchmarking to evaluate the campus energy performance and to classify its locals according to their building category. In this thesis the University of Almeria campus is used as a study case for energy benchmarking to evaluate and classify the energy performance of its locals, this study is presented as an energy management system to guide decision-makers to achieve an optimal energy use.

### 1.3 Methodology

The methodology that has been developed in the bibliometric study was first to extract the data and the statistics provided by filtering the main query of all publications related to BIM and BIM in universities in the Scopus database were used to extract the data and provide the statistics by filtering the main query of all publications related to BIM and BIM in universities. These acquired sets of publications have been classified based on the following characteristics: the number of publications per year, distribution by subject area, document category, institution, and by country. The records were consecutively processed using excel sheets, as well as the generation of the result corresponding graphics.

VOSviewer Software was deployed to detect the network community in the form of interconnected clusters. Network techniques such as co-word mapping have been used to generate document co-citation analysis and, keyword co-occurrence analysis, in order to reorganize the unstructured data objects in the BIM literature to identify patterns for evolution, and growth of BIM topics in scientific literature.

Community network detection relies on interrelations between different groups, and the results have to be structured clearly to be easily interpreted, otherwise more parameters should be adjusted. The most significant clusters of the keyword co-occurrence analysis besides building information model are construction, interoperability, virtual reality, collaboration and construction management, visualization, and automation, these fields evolves around the managerial aspect of BIM which is crucial to achieve sustainability by creating an optimal design, and by constructing and operating the facilities in an efficient manner.

The methodology that has been developed in the benchmarking study was first to collect energy use and weather data, as well as the number of occupants, for the last eight years.

The extensive weather data set will be used to develop heating degree days and cooling degree days, their sum would be considered as the weather factor. Since, the network size input varies on yearly basis, other inputs like outside temperature and energy consumption had to be lined up on the same sequence to be able to test the correlation with macro-scale energy data. Statistical regression is conducted to build patterns and identify the variable that correlates strongly with energy use.

Multiple regression model is established to identify the reference point of the total energy use for a given average input. In the benchmarking study we proceed by splitting the buildings portfolio by the following six categories to classify the campus locals within their own category and comparing them to the level of reference of universities in the Mediterranean climate that is set up in the detailed tables for the 2003 Commercial Buildings Energy Consumption Survey (CBECS).

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# CHAPTER II

## Bibliometric Maps of BIM and BIM in Universities: A Comparative Analysis

# Bibliometric Maps of BIM and BIM in Universities: A Comparative Analysis

## 2.0. Abstract

Building Information Modeling (BIM) is increasingly important in the architecture and engineering fields, and especially in the field of sustainability through the study of energy. This study performs a bibliometric study analysis of BIM publications based on the Scopus database during the whole period from 2003 to 2018. The aim was to establish a comparison of bibliometric maps of the building information model and BIM in universities. The analyzed data included 4307 records produced by a total of 10,636 distinct authors from 314 institutions. Engineering and computer science were found to be the main scientific fields involved in BIM research. Architectural design are the central theme keywords, followed by information theory and construction industry. The final stage of the study focuses on the detection of clusters in which global research in this field is grouped. The main clusters found were those related to the BIM cycle, including construction management, documentation and analysis, architecture and design, construction/fabrication, and operation and maintenance (related to energy or sustainability). However, the clusters of the last phases such as demolition and renovation are not present, which indicates that this fields until needs to be further developed and researched. With regard to the evolution of research, it has been observed how information technologies have been integrated over the entire spectrum of internet of things (IoT). A final key factor in the implementation of the BIM is its inclusion in the curriculum of technical careers related to areas of construction such as civil engineering or architecture.

## 2.1. Introduction

The growing requirements for establishing sophisticated buildings are making AEC (Architecture Engineering and Construction) projects more complex, while technological advances are helping the participants to collaborate more effectively during the construction process. In fact, the building information model (BIM) provides an intelligent model-based process that connects AEC professionals and helps them to design, build, and operate building infrastructure [1]. This tool allows professionals to design 3D models that incorporate data associated with physical and operational properties, which will help architects, engineers, and contractors to work on a coordinated digital model, giving everyone a better insight into how their work fits in the overall project [2]. BIM systems encourage greater cooperation between stakeholders through a unique integrated model during the design and construction stages. Adopting BIM in the construction industry will lead eventually to a better planning and preparation process by detecting conflicts between elements and improving coordination. In addition, it will help reduce time costing errors and help decision makers to increase their efficiency during the construction phase, and finally will help facilities management with future changes and renovation work.

BIM is the result of an international collaborative progress starting from Japan and moving to Europe and all the way to Northern America, so the history of this concept is not attributed to one name or one place alone. Although the BIM concept has existed since the 1970s, its development went through many steps until this term was first used officially to identify this notion [3]. The first commercial software known as computer-aided manufacturing (CAM) was developed by Dr. Patrick J. Hanratty in 1957. This numerical control machining technology has progressed to become computer-aided manufacturing

[4]. Then, he immersed himself in computer-generated graphics and in 1961 developed DAC (Design Automated by Computer), which became later the first system that used CAM/CAD (Computer-Aided Manufacturing / Computer-Aided Design) interactive graphics [5]. The Augmenting Human Intellect paper where the BIM foundation was first documented was published by Douglas C. Englebart in 1962. With the incorporation of object-based systems, this BIM tool allowed architects to introduce several features and specifications for a building. This new advance made the fusion of parametric manipulation and a relational database possible and as a result the 2D illustration of the current design was formed [6]. Afterwards, 3D representations were developed with the Building Description System (BDS) illustrated by Charles Eastman et al. (1975). In their publication, they describe a generic prototype of BDS and consider the perspectives of parametric design and 3D representations with a "single integrated database for visual and quantitative analysis" [7].

After two years, the requirement to integrate building elements and monitor data accuracy was considered, in order to be used as a tool for estimating structural design costs. The Graphic Language for Interactive Design (GLIDE) tool was developed to implement this utility that allows for more reliable and accurate designs. However, both BDS and GLIDE have limited themselves to including only the design stage of the project, which would not allow the immersion of the different stages of the project life cycle [8]. By the year 1984, personal computers began building modeling programs, which included the first BIM (2D CAD) software used worldwide. However, this software wasn't operational until 1986, when Robert Aish used it in large and complex projects such as the renovation of the Heathrow airport terminal [9]. In the 1990s, several companies began to develop BIM tools, such as the Lawrence Berkeley National Laboratory [10]. Autodesk also began using the BIM concept in 2002 when it purchased the Texan company Revit Technology Corporation [11]. The Graphisoft company created the teamwork concept so that team members would be able to easily share BIM data with each other [12].

The complication of buildings and structures, increased construction and the imperative need to reduce design time, the increase in international design cooperation, and other factors led to the accelerated development of computer design tools.

By the early 2000s, objects and shapes have fully incorporated different type of data in the same file, meaning the designer, contractors, engineers and the owner could all work collaboratively on one centralized collaborative model. Objects and shapes had completely incorporated different types of data into the same file, allowing the designer, contractors, engineers, and owner to work collaboratively on a centralized collaboration model. BIM platforms such as the one shown in reference [13] have been created to incorporate parametric flexibility and sculpture geometry that supports NURBS (non-uniform rational B-spline) surfaces, and provides software that larger teams of architects and engineers can use to collaborate on an integrated model based on using a coherent system rather than a set of separate drawings. The new software works with all the information concerning the construction project, while the 3D model can include architectural, structural, electrical, sanitary, plumbing, Heating, Ventilating and Air Conditioning (HVAC) installation, and fire alarm system designs. All of these layers are merged into a BIM file that can be accessed by project holders at any time and from any location [13,14]. Advanced parametric techniques are then introduced into the BIM software [15], which can process complex and contemporary architectural shapes, enabling designers to create curved and complex architectural shapes. With the advancement of computational design technologies, more unique building designs will be realized [16–21].

BIM 4D modeling is employed in combination with the Geographic information system (GIS) to create a safe execution sequence of the process in order to enhance the visual tracking of construction supply chain management [22–24]. This can only prove that the BIM platform has a great potential to integrate various innovative operations related to construction. However, to improve the monitoring of the construction process [25,26], companies are using remote sensing technology to develop an approach called defect management for automatic quality inspection.

In the last decade, BIM technologies have improved greatly with the help of information modeling, meaning it is now possible to solve problems that were unimaginable years ago [27]. These technologies have introduced designer supervision, construction cost planning, risk management, etc. State-of-the-art architecture with unique structures and hazardous facilities, whose projects are subject to mandatory government expertise, can be addressed without great difficulty with the help of these powerful tools [28].

Northern European countries such as Finland adopted BIM regulations, e.g., Common BIM Requirement 2012 (COBIM). In 2016, the U.K became in the first country to legally mandate the use of BIM [29] for public funded projects. Germany is mandating BIM for all transportation projects so teams can collaborate and work in the same model [17,19], which will be useful in so many ways such as dealing with predictive risks and maintenance, improving g timelines and cost savings, as well as asset tracking and facilities management. Government agencies are using BIM software to plan and operate diverse forms of physical infrastructure, such as public sanitation, communication utilities, electricity grids, roads, bridges, and ports [3]. Several European and Asian countries, as well as Australia, and the USA have demanded the use of BIM in projects or have published formal standards of good practice [30]. A study at the Northumbria University campus used BIM to improve the collection of data and its accessibility for facilities management [31]. The digital representation of public infrastructure will not only help authorities to manage its current artworks but also will help them to plan better for future projects to avoid interference and unpredicted modifications.

A BIM execution plan for project implementation would help to explain the details of the necessary checklist and standards [32], such as ISO/TC 59/SC 13. These standards form the foundation for accurate and efficient communication and commerce that are required by the off-site construction industry [33]. Regrettably, this is not usually part of the contract. As such, that Northumbria University campus study had revealed insightful implications into significant legal aspects or contract provisions that need to be included in BIM contracts [34]. As an example, in the literature, it is possible to find engineering, procurement, and construction (EPC) contracting, which enables a contractor to be responsible for all works associated with the design, procurement, erection, and testing of a facility [35]. It is possible to find hydro-supported structures [36] being used as offshore wind turbines [37]. Some authors even propose the application of blockchain or smart contract [38] technologies as a possibility for this type of contract [39,40].

With the growing awareness of society and its contribution to maintaining sustainable systems, the construction industry has taken on this social concern and buildings are now designed with energy efficiency in mind. For this purpose, BEM has been combined with BIM. With this combination, the construction industry has the tools needed to solve problems related to the integrated energy analysis of buildings [41,42]. Another objective is the promotion for the construction of green buildings, the practice of building in a way that safeguards the natural environment [43].

Environmental sustainability concerns are frequently addressed as a complement to building design by pursuing ad hoc approaches to project implementation [44]. As a consequence, the most common problem in reaching a sustainable construction result is the lack of the right information at the right time to make crucial judgments. Furthermore, the design of these high performing buildings is a non-linear, complex, iterative, and multi-disciplinary process that requires efficient collaboration between interdisciplinary teams from the first stages to achieve sustainable outcomes [45]. Construction practitioners make extensive use of performance analysis tools to predict and quantify sustainability issues from the earliest stages of design and significantly improve quality and cost over the life cycle of a building [45]. There are very extensive and recent review studies on BIM and sustainability [46], noting that little work has been conducted about how it could be applied in refurbishment and demolition; but highlighting that BIM can improve social sustainability in two main areas: BIM provides a better facility design for a society's high standard of living. BIM transforms conventional practice, which is often highly fragmented, into a better collaborative effort that strengthens the working relationships among project participants. And this review [46] concludes that future policies of BIM for sustainability should consider improving the interoperability issue among BIM software and energy-simulation tools.

From an engineering point of view, it is important to reflect the complexity of new ways of working. This mixed set of knowledge, skills, and attitudes is essential to strengthen productivity, entrepreneurship, and the pursuit of excellent performance in an environment increasingly based on technologically advanced and sustainable outcomes [47]. A clear example of this involves developing effective measures using a "project-based learning" technique to improve student learning outcomes for the implementation of BIM in the area of sustainability [48]. Therefore, innovative concepts such as sustainability, green concepts, planning processes, or project execution are key aspects to evaluate the key benefits of BIM, and these concepts should be integrated in order to advance their curricula [49].

In this study, there are two objectives. to the first is analyze the background of the whole work published in relation to the BIM subject as bibliometric maps of this subject, and to see which clusters this scientific field is grouped around. And the second objective, given the importance it has for sustainability, is to determine which works of BIM are used in universities to contribute to their sustainability.

The previous published studies of bibliometric analysis on BIM focus on very specific aspects. For example, a study by Badrinath et al. (2016) [33] focuses on how the BIM is taught and then used for communication and visualization. That study was based on the bibliometric analysis of 445 BIM articles, but above all it was based on double keywords not covering the whole subject, these keywords were: "academic BIM education", "BIM curriculum", and "BIM course". Although the work is interesting, it is focused on a very specific area, which is academic BIM education. It was concluded that the case studies and experiences were the dominant type of publication.

In the literature there are other works focused on bibliometric studies of the BIM, but all of them make a subjective classification, and are based on databases other than those used of this study, for example in the WoS™ Core Collection [50] or Web of Science [51]. And although some of them open an important temporal window, from 1990 to 2016 only 567 publications appeared, and the ones which analyzed the relevant topic only numbered 445 [52].

Through Scopus, it is possible to find some bibliometric work but in a very short period of time (2006–2016) [53]. Although it uses community or cluster detection, it found only 4 clusters for 1031 available studies, it is notable that this work was looking for the specific topic of BIM-based Construction Networks (BbCNs). On the subject of the research, it was discovered that collaboration was a concept researched in isolation and without strong connections to other key areas of BIM research. Other works based on Scopus are state of the art revision works [54], and the database was therefore not used only to have a list of published works, but also to develop a bibliometric analysis. However, Scopus covers a wider range of journals in the area of construction project management than the WoS and contains more recent publications than other databases [55].

## 2.5 Research Methodology

The flowchart of the research methodology is shown in Figure 1. In this study, all the publications (4307) were collected from Elsevier Scopus database. This platform is useful for bibliometric studies because it allows you to download massive information for numerous bibliometric analysis. The search was conducted in March 2019 to extract research publications that include the following citations "BIM" or "BIM in University" and "Building Information Model" or "Building Information Model in University "in the title, abstract and/or keywords within the period (2003–2018). The following search queries were used: (TITLE-ABS-KEY ({BIM} OR {Building Information Model}), and another one specific for plant: (TITLE-ABS-KEY ({BIM} OR {Building Information Model} AND {Universit*}). Thus, in the first query all the published works on BIM have been found, and the second query acts as a filter on the first, where only those works that deal with the subject of the university remain. It should be noted that the subject categories are the result of the Scopus indexation.

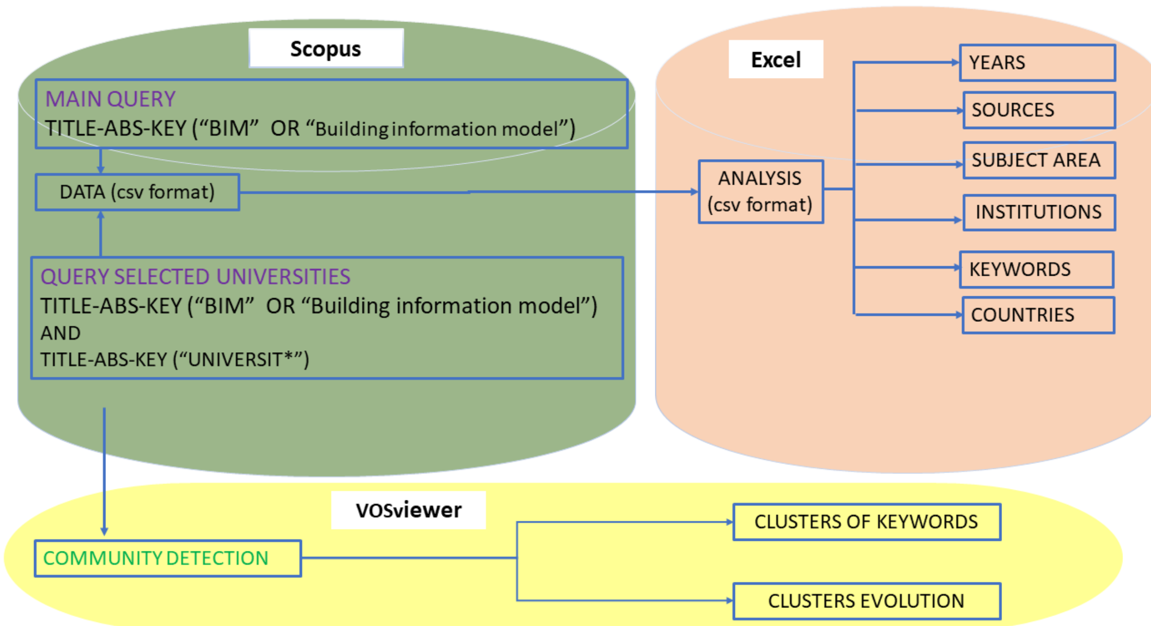


**Figure 1.** Flowchart of the information search and analysis.

*2.2.1. Data Collection*

The main query provides information such as the source of publications according to their authors, institutions, as well as their geographic locations. The publications acquired have been classified based on the following characteristics: the number of publications per year, distribution by subject area, document category, institution, and by country. The word frequency analysis is carried out to reflect the research field, and the core subject of BIM literature keywords are extracted and collected by filtering the main query. The records were consecutively processed using excel sheets, as well as the generation of the result corresponding graphics.

*2.2.2. Community Detection*

Community detection is a procedure that identifies geographic locations, trends, and other parameters of a large group of elements that interact with each other. This relationship between elements could vary in intensity that transcribes their dependency on each other. These multiple interdependent nodes evolve around one central core that is highly cohesive, while the density of interactivities decreases as we go far from the center. This structure is called a cluster, and the union of multiple clusters form from a complex network, which usually comes out in the form of a neural network. In this work we have proceeded by using Sw VOSviewer to detect the network community. This tool illustrates the most significant clusters based on the hierarchical connectivity algorithms [37]. This community detection software, VOSviewer, is free software available online that allows the direct import of data in the csv format exported from Scopus and also allows the figures to be exported to a large range of graphical formats. The VOSviewer delivers three displays: network visualization as clusters, overlay visualization as temporal evolution, and density visualization. In all of these cases, the parameters chosen for the analysis were: normalization method (association strength), layout (attraction 2, repulsion 0), clustering (resolution 1.00, minimum cluster size 1), and rotate (90 degrees).

## 2.3. Results and Discussion

### *2.3.1. Evolution of the Number of Publication Over the Years*

We can observe in Figure 2 that the evolution of BIM in university publications is relatively weak compared to BIM global, which has a parabolic pattern over the period studied. The figure also shows that scientific production started to increase substantially since 2007. The total number of BIM and BIM in university publications are 4307 and 274, respectively (3.36%).

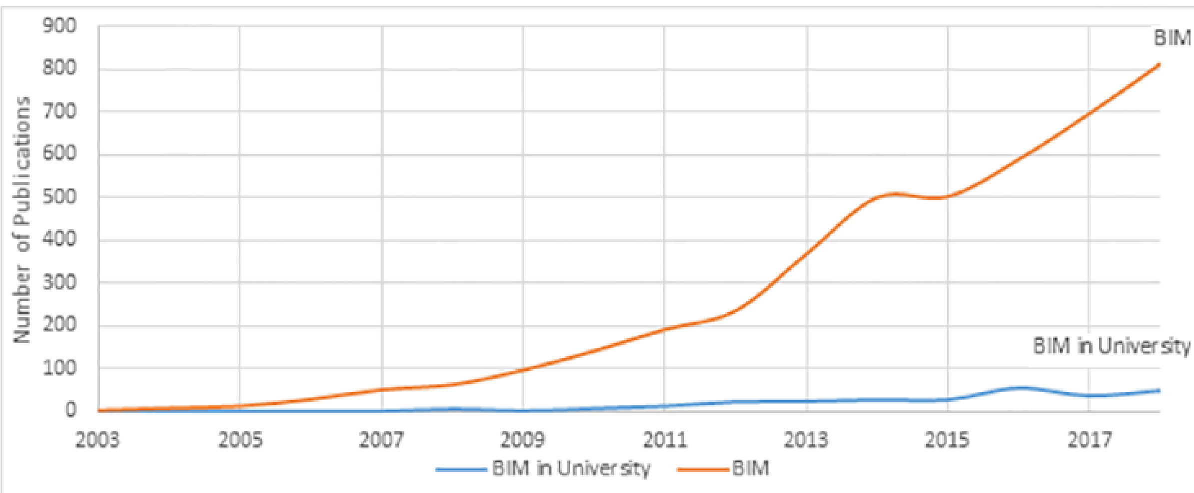


**Figure 2.** Evolution of the scientific production of BIM (2003–2018).

### *2.3.2. Distribution of Output in Subject Categories*

Based on the Scopus classification, the distribution of publications on BIM research fields covered a total of 22 subject areas, see Figure 3. The largest number of documents corresponds to engineering (3234 records, 44%), computer science (1423 records, 20%), and business management and accounting (494 records, 7%) while the fourth largest number is for social sciences (389 records, 5%), the fifth is for mathematics (341 records, 5%) and the sixth is for environmental sciences (250 records, 3%). It is worth mentioning that a document can be related to more than one field of research at the same time. These six areas count for about 85% of all publications (Figure 3). The distribution of publications on BIM in the university research area reduced the number of subject areas, enclosing only 18 subject areas. The four first areas were the same as those showed by the global BIM research field. The first highest area according to number of publications was engineering (218 records, 43%), computer science was the second highest area (68 records, 13%), business management and accounting was the third highest (52 records, 10%), and social science was the fourth highest (48 records, 10%). Arts and humanities were in the fifth position (22 records, 4%), while energy accounted for the sixth position (17 records, 3%). BIM studies are mainly focusing on engineering and computer science, which involves architecture, mechanical structure design, and construction. It can be concluded that they are essentially the same categories that are given significance in both cases.

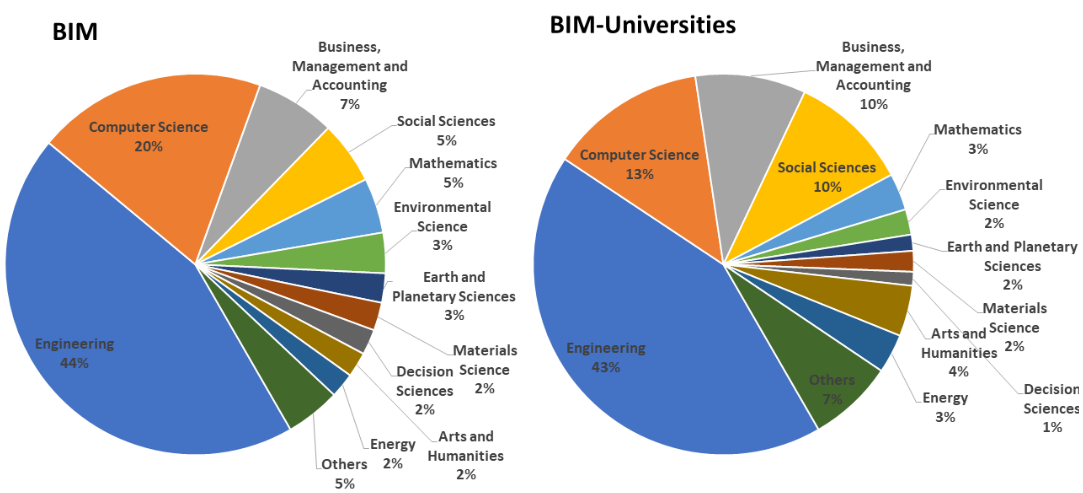


**Figure 3.** Distribution (%) of worldwide research of BIM and BIM in universities by subject area.

### *2.3.3. Types of Publications*

The most common means used in scientific diffusion are journal articles. However, in the case of BIM, conference papers are the type of publication that counts for the biggest share with 49%, followed by scientific articles with 41% and articles in review with 3%, followed by books and book chapters with 3%. Figure 4 shows the percentage of the types of scientific production distributed on the building information model theme.

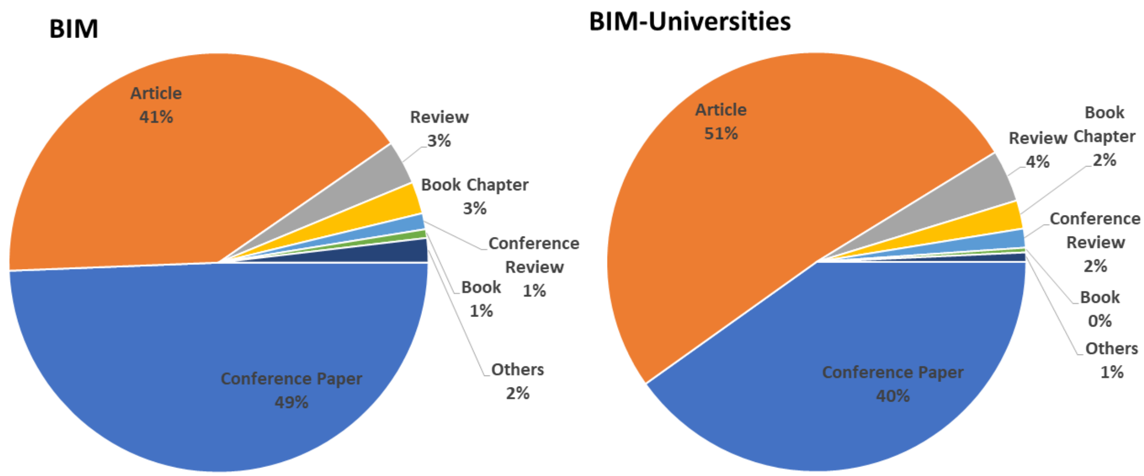


**Figure 4.** Distribution by publication type related respectively for global BIM and BIM in universities.

Regarding BIM in universities, scientific articles are the type of publication that counts for the largest share of BIM in university publications with 51%, followed by conference papers with 40%, articles in review with 3%, while books and book chapters had 2%. Figure 4 shows the percentages of the types of scientific production distributed on BIM in universities. It is remarkable that in the case of the universities the topic of BIM is predominant in the articles, while for BIM in general the topic is predominant in the conference papers. In general, the higher the percentage of conferences, the more novel the topic is. And when the percentage of books and book chapters is high, this indicates a topic that is scientifically established. BIM is therefore shown to be very novel, given the large percentage of conference paper in both cases.

*2.3.4. Distribution by Countries and Institutions*

If the distribution by country of the publications in BIM is represented (see Figure 5), it can be seen that the 10 highest countries are: the United States (20%), the United Kingdom

(10%), China (9%), Australia (6%), South Korea (6%), Germany (5%), Canada (4%), Malaysia (3%), Italy (3%), and Taiwan (3%). It can be seen that almost 40% of publications are grouped in the first three countries.

BIM research has been produced in more than 160 institutions. Table 1 shows the top 20 the most productive institutions, with more than 4307 publications covering the BIM concept in the period studied. The first sixteen institutions (10% of total institutions) are from the USA, Australia, the UK, South Korea, China, Italy, Malaysia, Israel, and Germany. They are represented by the following affiliations: the Georgia Institute of technology (USA), Curtin University (UK), University of Florida (USA), University of Salford (UK), Kyung Hee University (South Korea), Pennsylvania State (USA), Hong Kong Polytechnic University (China), Politecnico di Milano (Italy), University Tongji University (China), Hanyang University (South Korea), Universiti Teknologi Malaysia (Malaysia), Cardiff University (UK), University College London (UK), Tsinghua University (China), Israel Institute of Technology (Israel), and the Technical University of Munich (Germany). Universities from the USA have the most representations with 988 publications, UK has the second highest production with 518 records, while China has the third highest rank with 460 publications. BIM in university publications have been produced in the same number of institutions as the global BIM.

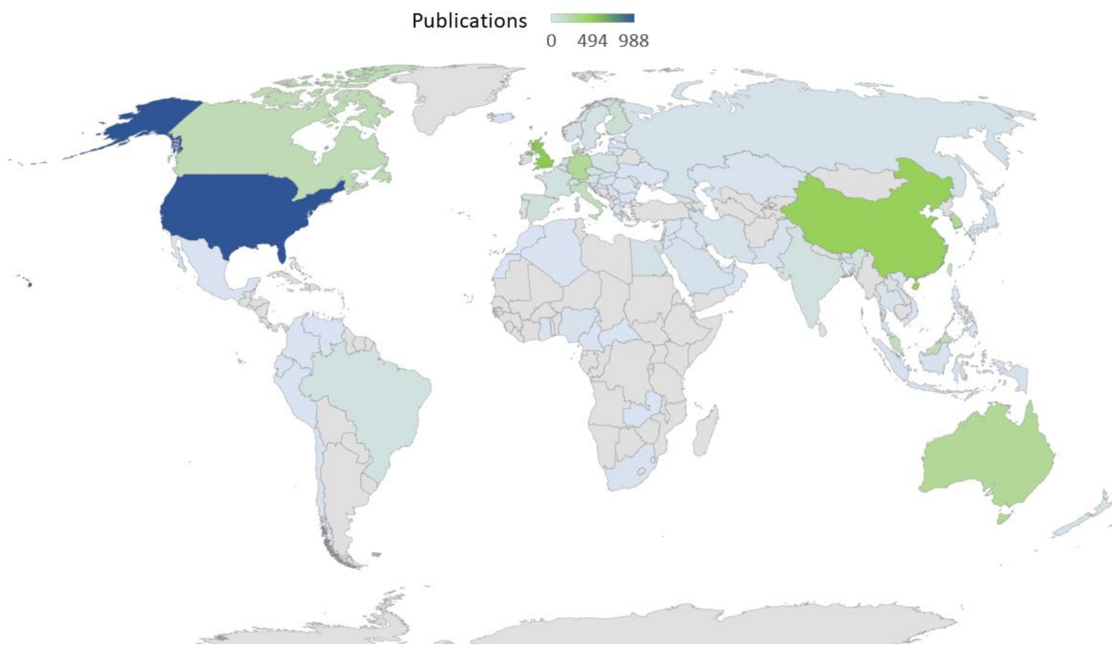


**Figure 5.** Distribution by countries of BIM publications.

**Table 1.** Classification of research institutions by record and countries.

| BIM | | | BIM in University | | |
|---|---|---|---|---|---|
| **Affiliation** | **Country** | **N** | **Affiliation** | **Country** | **N** |
| Georgia Institute of Technology | USA | 10<br>1 | Pennsylvania State University | USA | 9 |
| Curtin University | UK | 98 | Hong Kong Polytechnic University | China | 9 |
| University of Florida | USA | 93 | Tsinghua University | China | 8 |
| University of Salford | UK | 68 | Arizona State University | USA | 6 |
| Kyung Hee University | South Korea | 56 | Ceské vysoké ucení technické v Praze | Czech The Czech Republic | 5 |
| Pennsylvania State University | USA | 55 | National Taipei University of Technology | China | 4 |
| Hong Kong Polytechnic University | China | 54 | University of Southern California | USA | 4 |
| Politecnico di Milano | Italy | 49 | Vilniaus Gedimino technikos universitetas | Lithuania | 4 |
| Tongji University | China | 49 | Universidade de Lisboa | Portugal | 4 |
| Hanyang University | South Korea | 48 | Helsingin Yliopisto | Sweden | 3 |
| Universiti Teknologi Malaysia | Malaysia | 47 | University of Texas at San Antonio | USA | 3 |
| Cardiff University | UK | 46 | National Taiwan University | Taiwan | 3 |
| UCL (University College London) | UK | 43 | University of Salford | UK | 3 |
| Tsinghua University | China | 43 | University of Wyoming | USA | 3 |
| Technion—Israel Institute of Technology | Israel | 42 | Universitat d'Alacant | Spain | 3 |
| Technical University of Munich | Germany | 41 | International University of Florida | USA | 3 |

However, the BIM in university research area had more than 274 publications in the studied period, although this number remains small in comparison to BIM global. The sixteen most productive institutions (10% of total institutions) have been developed in the following countries: the USA, the Czech Republic, the UK, China, Lithuania, Spain, Portugal, and Sweden, all of which are represented by the following universities: Pennsylvania State University (USA), Hong Kong Polytechnic University (China), Tsinghua

University (China), Arizona State University (USA), Ceské vysoké Ucení technické v Praze (Czech Republic), National Taipei University of Technology (China), University of Southern California (USA), Vilniaus Gedimino technikos Universitetas (Lithuania), Universidade de Lisboa (Portugal), Helsingin Yliopisto (Sweden), University of Texas at San Antonio (U.S.A), National Taiwan University (Taiwan), University of Salford (UK), University of Wyoming (USA), Universitat d'Alacant (Spain), and the Florida International University (USA). Institutions from the USA are the most highly represented with 79 publications, the second country had 28 publications, while Chinese universities had the third rank with 18 publications.

*2.3.5. Relationships between Countries*

Figure 6 shows the labeled clusters with the relationships between the countries of the various publications. This is generally determined by the co-authorship of articles, i.e., authors from different countries who wrote the same article. Each element represents a country and the size of these elements is determined by the total number of publications of this country. The network counts 10 communities, their rank order respectively is the USA, the UK, China, Australia, Germany, South Korea, Italy, Spain, Finland, and Taiwan. It is observed that in the clusters of these countries, there is a major correlation with nearby or neighboring countries, which is not frequently found in scientific subjects. Examples of this include the USA with Canada, China with Hong Kong, Germany with Austria or Switzerland, the UK with Ireland, Finland with Norway, or the Czech Republic with Poland.

The countries that are in the middle of the cluster are the ones who are linked with the most nodes. Language plays a key role in the interconnections between countries. The largest community is the one that evolves around the USA. These publications are written mostly in English in more than 92% of cases, although the Chinese language has also appeared in 5.5% of publications since 2006, while other languages numbered less than 1% and included Japanese, Dutch, German, Polish, Russian, Spanish, and French.

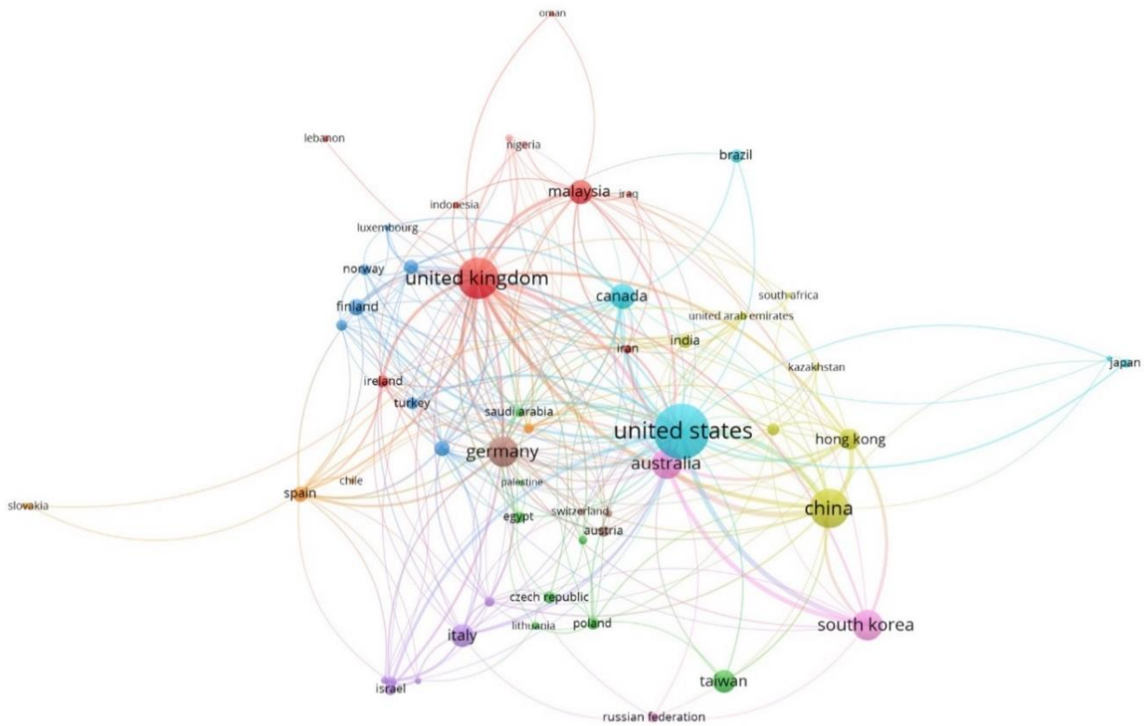


**Figure 6.** Countries network of BIM publications.

*2.3.6. Keyword Analysis*

The keywords analysis identifies the common interests of the researchers and their work. In this section we analyze the keywords acquired from the main query as well as their frequency of appearance in every article during the period studied. If the main keywords associated with the theme of the global BIM are analyzed, those of Table 2 are obtained, where the 15 main keywords have been selected. The words of the search itself, such as BIM or Building Information Modeling or Building Information Modelling, have not been taken into account (since it is written in both forms almost equally frequently). It is noted that the general main search keywords are also the first keywords of the particular search in universities. However, in the latter case there are, as expected, issues related to teaching: Students, Curricula, Teaching, Education, or Engineering Education.

**Table 2.** Main keywords related with both queries.

| BIM | N | BIM in Universities | N |
|---|---|---|---|
| Architectural Design | 3075 | Architectural Design | 168 |
| Information Theory | 1295 | Information Theory | 66 |
| Construction Industry | 935 | Construction Industry | 41 |
| Buildings | 671 | Students | 40 |
| Construction | 642 | Buildings | 39 |
| Project Management | 602 | Curricula | 38 |
| Information Management | 458 | Project Management | 37 |
| Structural Design | 458 | Teaching | 37 |
| Life Cycle | 377 | Construction | 35 |
| Construction Projects | 354 | Education | 35 |
| Sustainable Development | 291 | College Buildings | 34 |
| Office Buildings | 279 | Information Management | 30 |
| Design | 255 | Engineering Education | 27 |
| Computer Aided Design | 239 | Surveys | 20 |
| Decision Making | 224 | Life Cycle | 19 |

The more interesting data are the keywords College Buildings, which show that BIM is starting to also be applied for the construction of university buildings, while global BIM is mainly focused on office buildings. If a visual representation is made with clouds of the keywords, then Figures 7 and 8 are obtained. These figures show where a particular study has to be done for automation, sustainable development, or industry foundation classes (IFC).

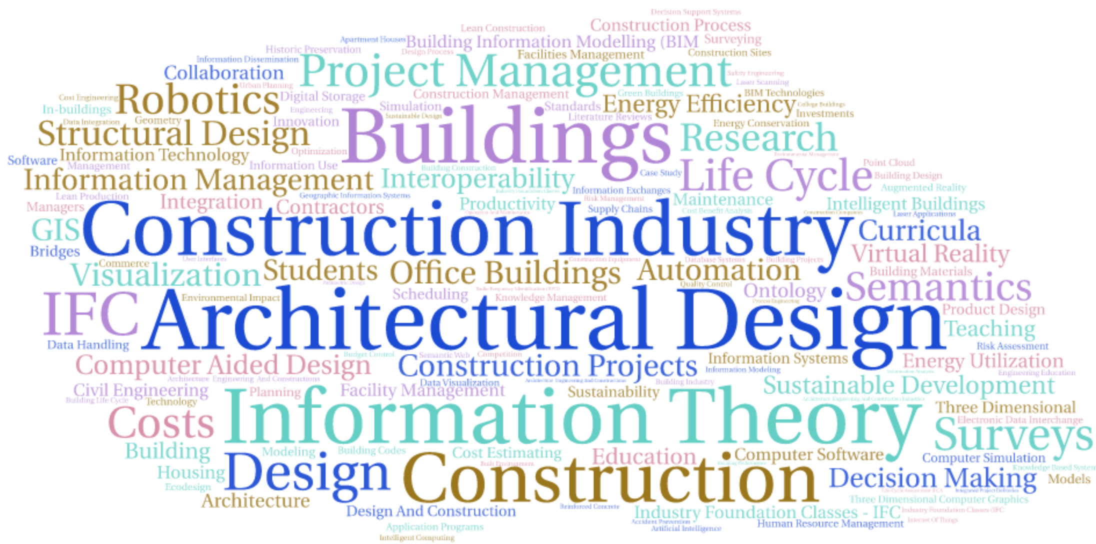


**Figure 7.** Word cloud of keywords related to BIM (global query).

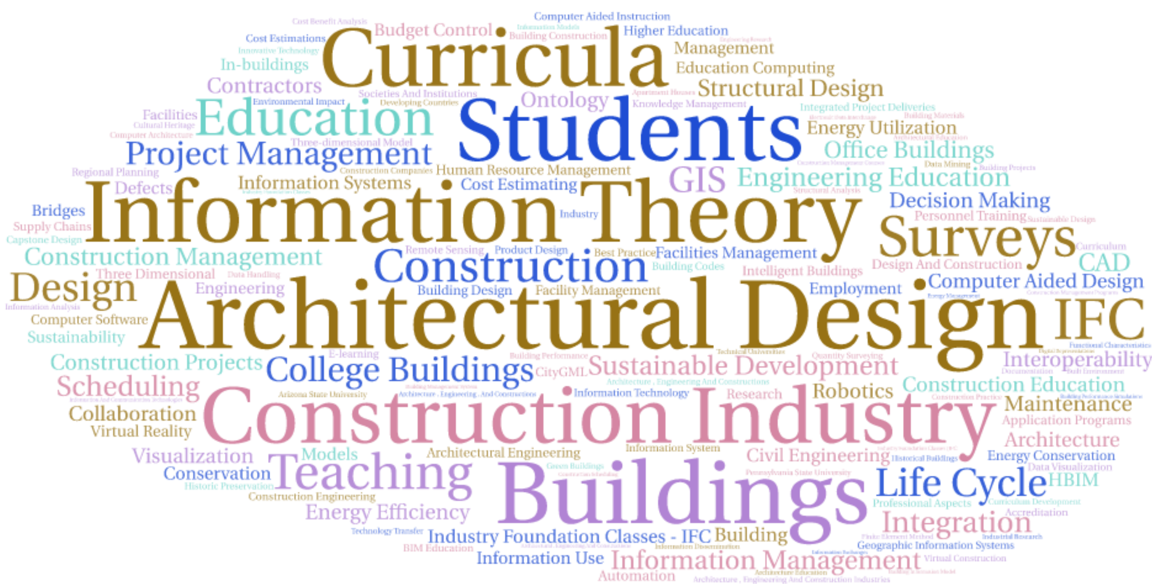


**Figure 8.** Word cloud of keywords related to BIM in universities.

Figure 9 shows the evolution of the following keywords: automation, sustainable development, and IFC. The three-keyword records were correlated during the greater part of the period studied. In addition, automation and sustainable development had approximately the same level of variance in the same value until 2013, when the gap started to grow wider between them. The automation record continued to increase remarkably until it reached 94 records in 2018. IFC had been scoring a lower score than sustainable development until the year 2018, when IFC obtained 53 records and sustainable development obtained 33 records.

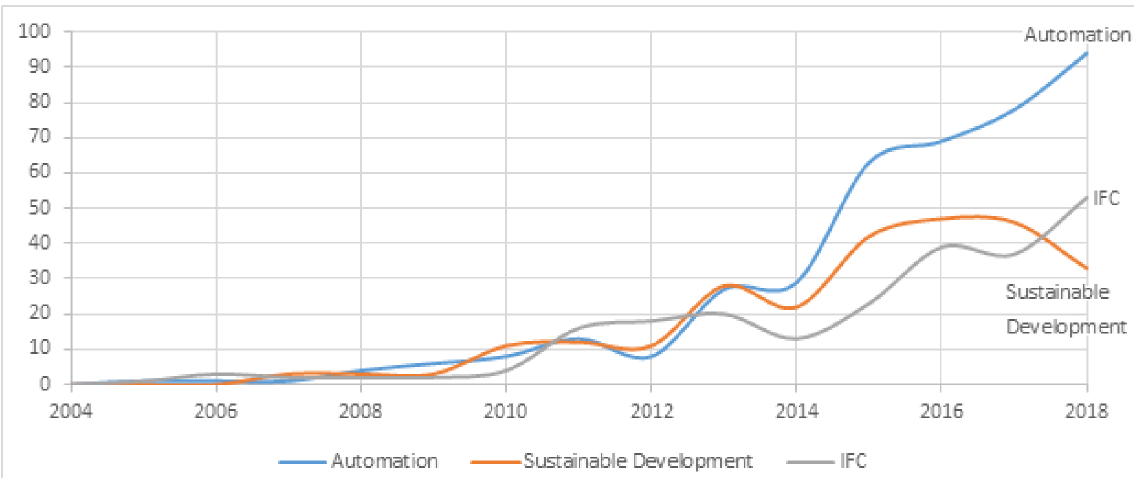


**Figure 9.** Countries network of BIM publishers and their community detection.

The major topics in Table 3 and Figure 10 constitute the structure of BIM. Management is the first topic that most relevant keywords evolve around, while the technology of BIM plays a crucial role in improving the interaction between different contributors and the ways in which they manage various aspects of the project development and BIM implementation during the building life cycle.

**Table 3.** Main keywords used by the communities detected in the topic BIM.

| Cluster | Color | Main Keywords | Topic |
|---|---|---|---|
| 1 | Red | Construction management —Collaboration – Information technology—Bim adoption | Construction management |
| 2 | Green | Interoperability-Facility management—Industry foundation classes —Internet of Things | Documentation and Analysis |
| 3 | Blue | Architecture—Virtual Reality—Education—GIS | Architecture and Design |
| 4 | Orange | Lean construction—Implementation—Adoption – Benefits | Construction/Fabrication |
| 5 | Yellow | Energy efficiency—sustainable design—Leadership in Energy and Environmental Design—energy simulation—Building performance | Operation and maintenance |

Figure 10 illustrates numerous keyword clusters in the form of a neural network with different colors, where the co-occurrence of keywords occurs at least 5 times. Each node is a keyword, and the link thickness between nodes represents the degree of connection. The BIM keywords analysis has identified six communities using a community detection algorithm and Table 2 shows their main clusters by their order of importance. The most significant clusters besides building information model are construction, interoperability, virtual reality, architecture, collaboration and construction management, visualization, and automation. These communities provide a general indication of the fields that are related to BIM, which are diverse and technology oriented.

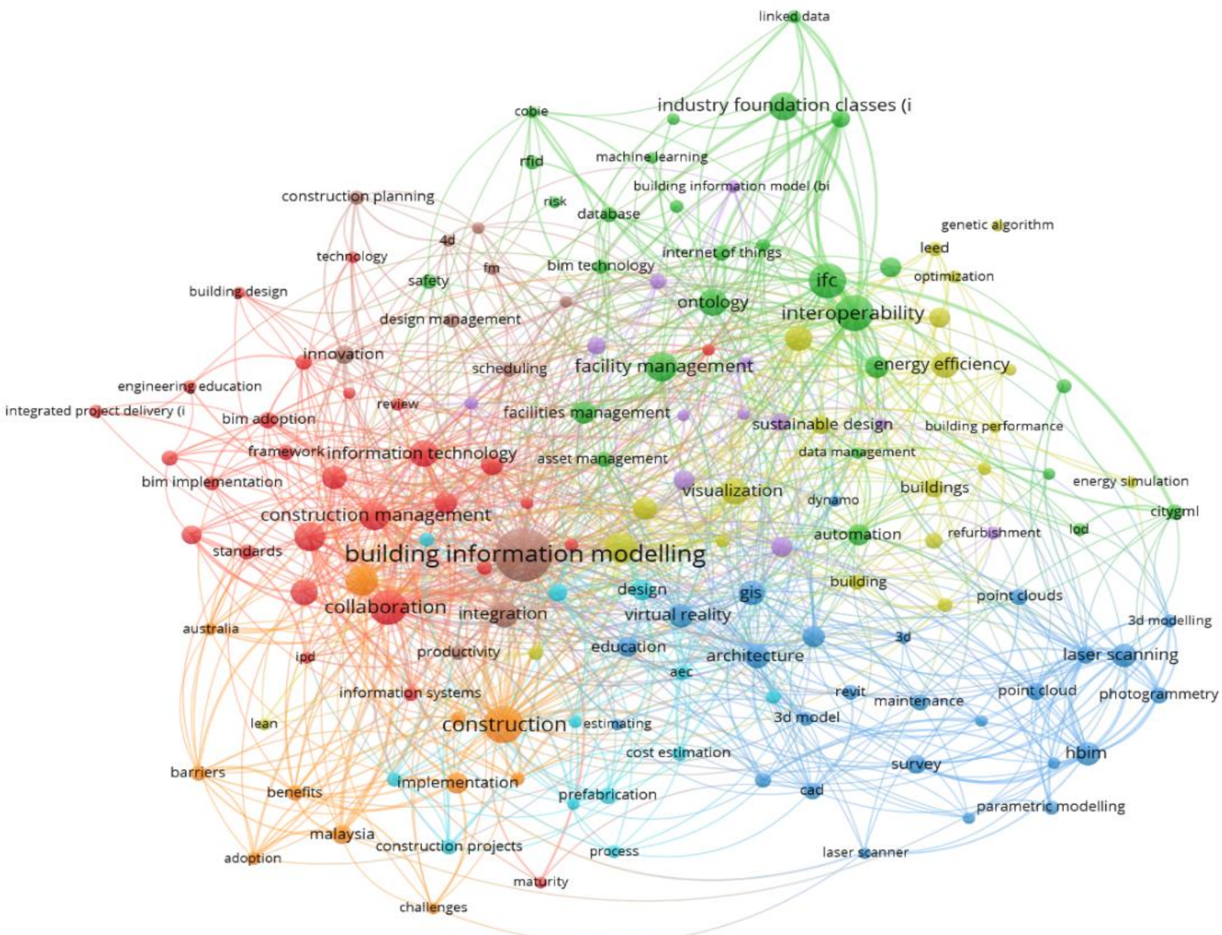


**Figure 10.** Keywords co-occurrence network related to BIM worldwide.

Analyzing the first cluster, in red in Figure 11, where only keywords with a minimum of 15 co-occurrences have been highlighted, it can be seen that it is related to construction management, collaboration, information technology, and BIM adoption. This shows that BIM is not only useful for geometric modeling of a building's performance but can also assist in the management of construction projects [56]. Some works highlight the synergy between facility management and BIM as a basis for multidisciplinary collaboration [57]. Within this community or cluster, the information technology that is developing object-oriented Computer Aided Design (CAD) tools compatible with BIM can be found, such as analysis tools, model verifiers, and facility management applications [58]. It should be remembered that the main difference between BIM technology and conventional 3D CAD is that the latter describes a building through independent 3D views, such as plans, while BIM uses all the information related to the building, including its physical and functional characteristics and information about the project life cycle, in a series of "smart objects" [59].

The second cluster, in green in Figure 12, where only keywords with a minimum of 15 co-occurrences have been highlighted, is shown to be associated with interoperability, facility management, industry foundation classes, and IoT. BIM is an expansive area of knowledge inside the architecture, engineering and construction industry [60]. An example of this is building automation, e.g., for on-site assembly services in prefabricated buildings with IoT, where the IoT-enabled platform can provide various decision support tools and services to different stakeholders [61]. As an example of industry foundation classes, it is possible to find works where various standards have been published, leading up to the 10-year development of industry foundation classes [62].

The cluster related to architecture, cluster 3 with the color blue in Figure 13, where only keywords with a minimum of 15 co-occurrences have been highlighted, has architecture; virtual reality, education, and GIS as the main related keywords. BIM offers the potential to achieve a lower project cost, increase productivity and quality, and reduce project turnaround time [58]. There are several great examples in the literature of the integration of architecture and GIS showing benefits such as reusability and extensibility [63]. Virtual reality is relevant because it allows us to make a 3D reconstruction of architecture appearance [64]. Both areas are very important in teaching, e.g., for the teaching of architecture through augmented reality [65,66].

The orange cluster four in Figure 14, is mainly related to the keyword's lean construction, implementation, and adoption benefits, cost/benefit analysis, awareness raising, and education and training, all of which are important activities to address the challenges of BIM usage. From the analysis of numerous works related to BIM, it was inferred that the benefit of BIM most frequently relates to cost reduction and control throughout the project life cycle, but significant time savings were also reported. The costs of BIM focused primarily on the use of BIM software [67]. Of course, the benefits are proportional to the form of implementation of the BIM [68].

The last cluster, in yellow in Figure 15, where only keywords with a minimum of 15 co-occurrences have been highlighted, focuses on the keywords: Energy efficiency, sustainable design, leadership in energy, environmental Design, energy simulation, and building performance. For a sustainable building, the use of its energy always involves customers and designers [69]. This includes important aspects of environmental design, e.g., to determine what the forecast CO2 emissions are from the building and whether it will meet the performance criteria [70]. It should be noted that retrofitting of existing buildings offers significant opportunities for reducing global energy consumption and greenhouse gas emissions [71,72]. Therefore, a model based on BIM that can enhance the post-occupancy assessment processes and meet the industry standards for sustainable buildings would be useful.

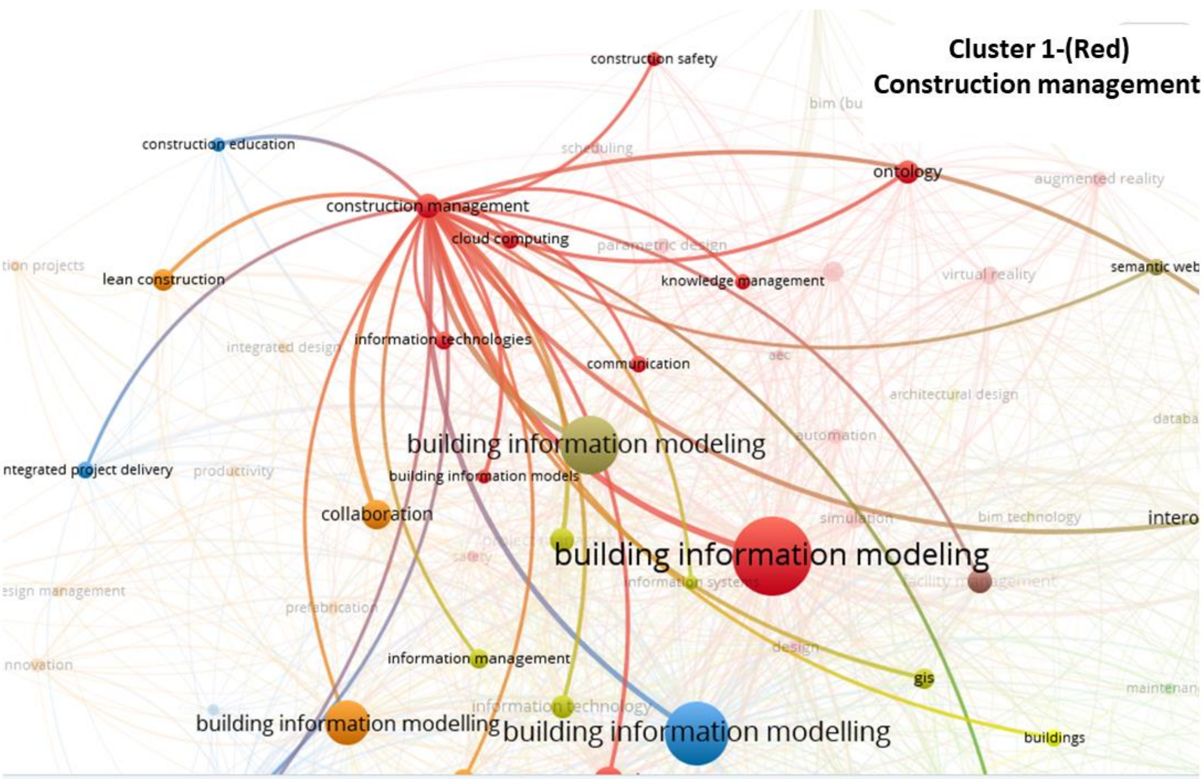


**Figure 11.** Keywords co-occurrence for cluster 1 (Construction management).

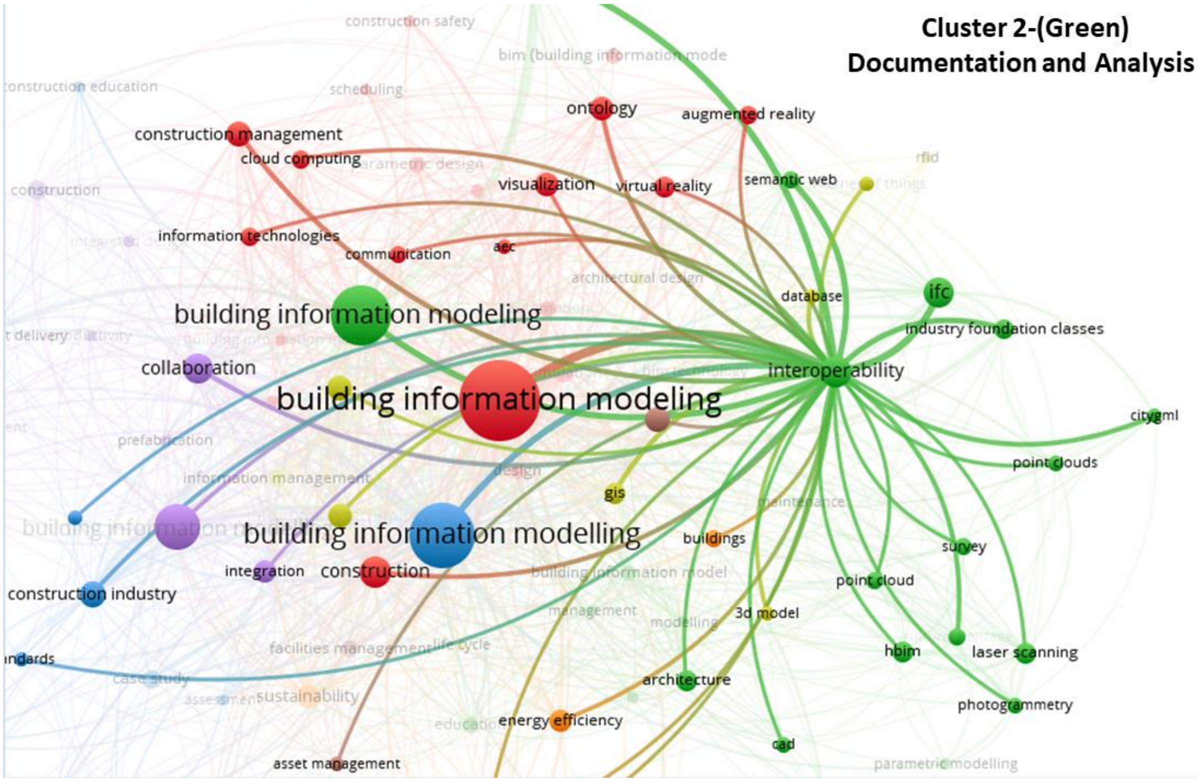


**Figure 12.** Keywords co-occurrence for cluster 2 (Documentation and Analysis).

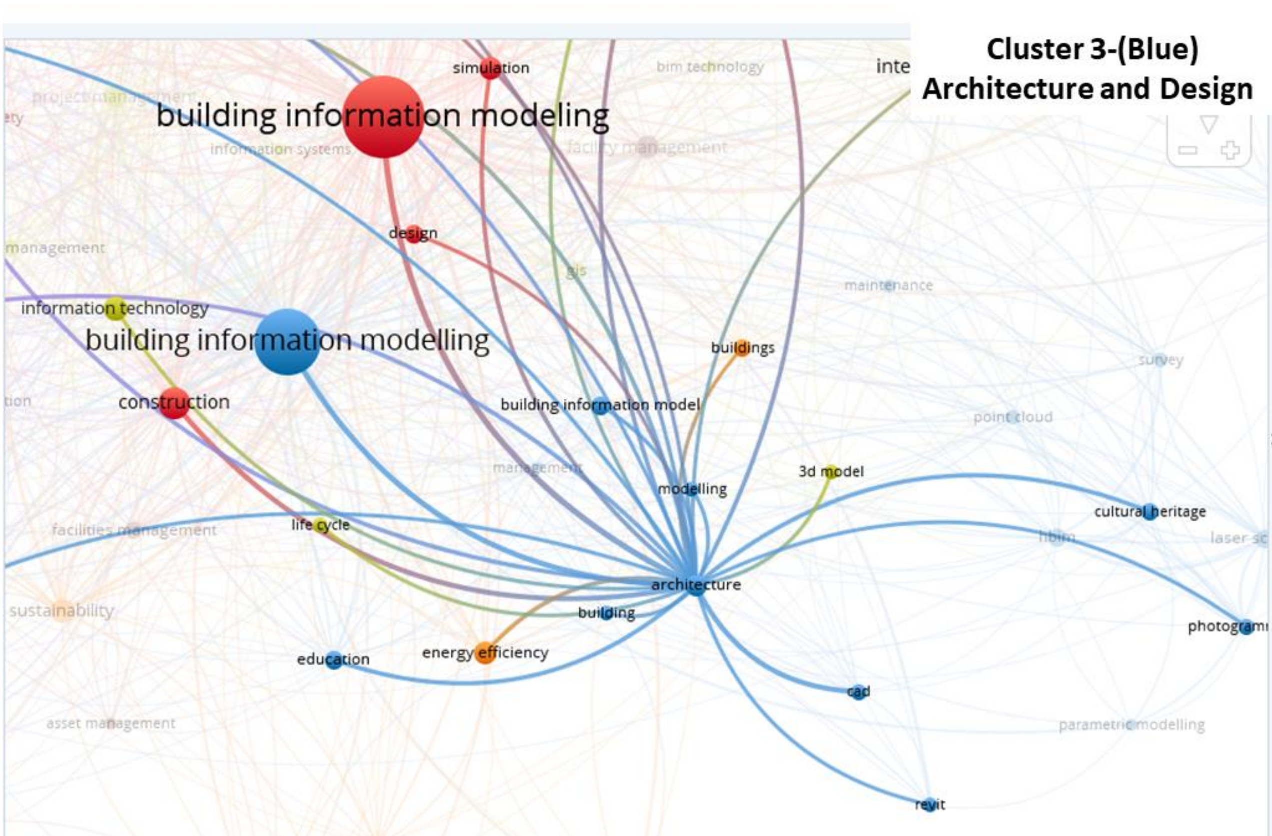


**Figure 13.** Keywords co-occurrence for cluster 3 (Architecture and Design).

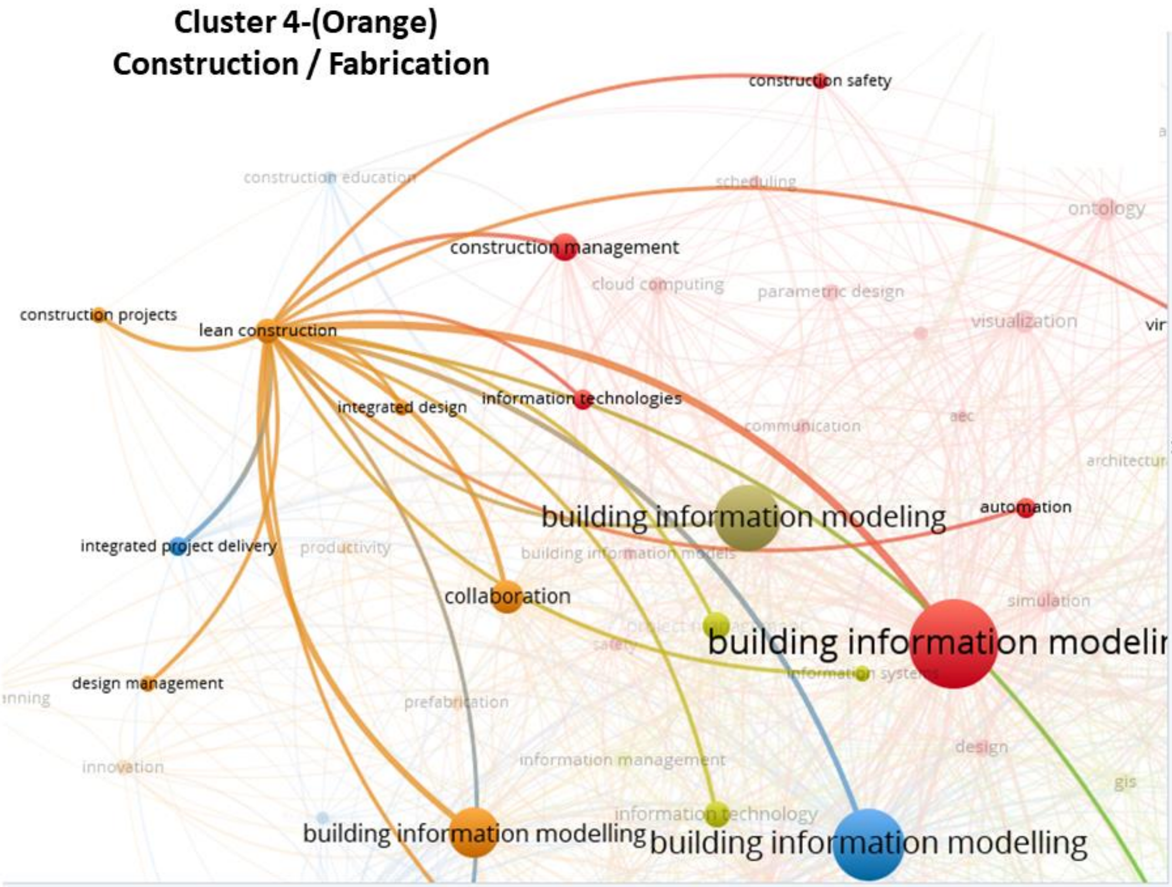


**Figure 14.** Keywords co-occurrence for cluster 4 (Construction / Fabrication).

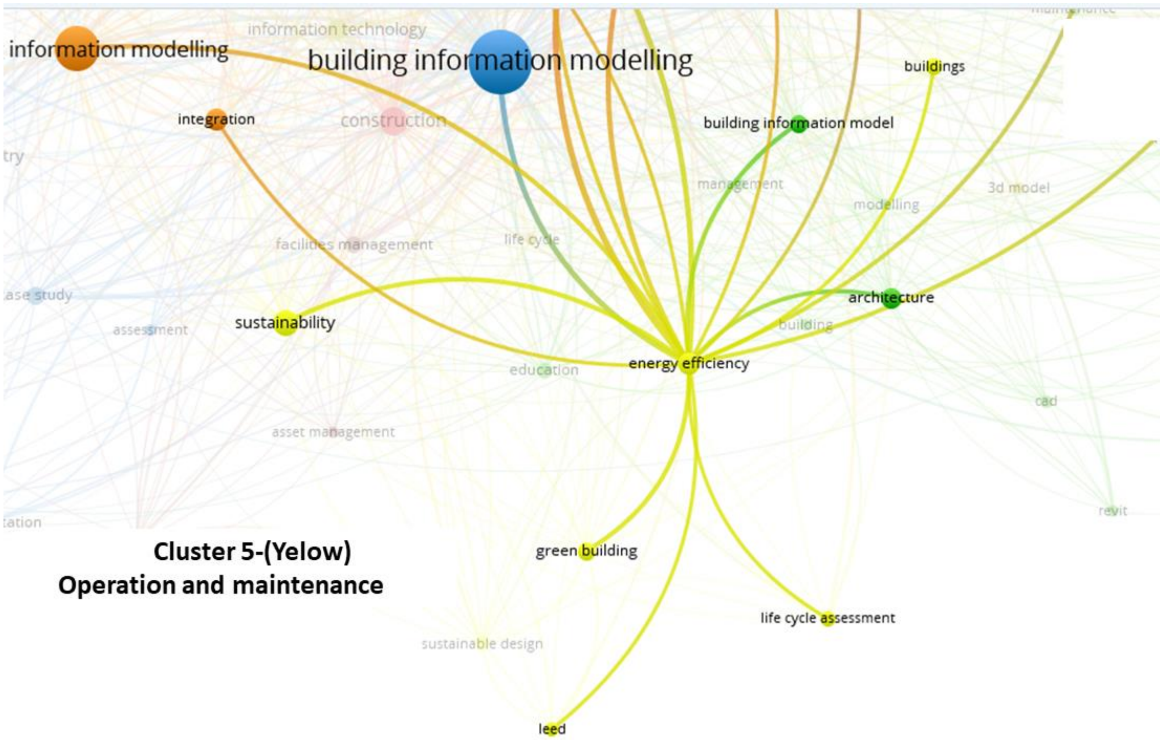


**Figure 15.** Keywords co-occurrence for cluster 5 (Operation and maintenance).

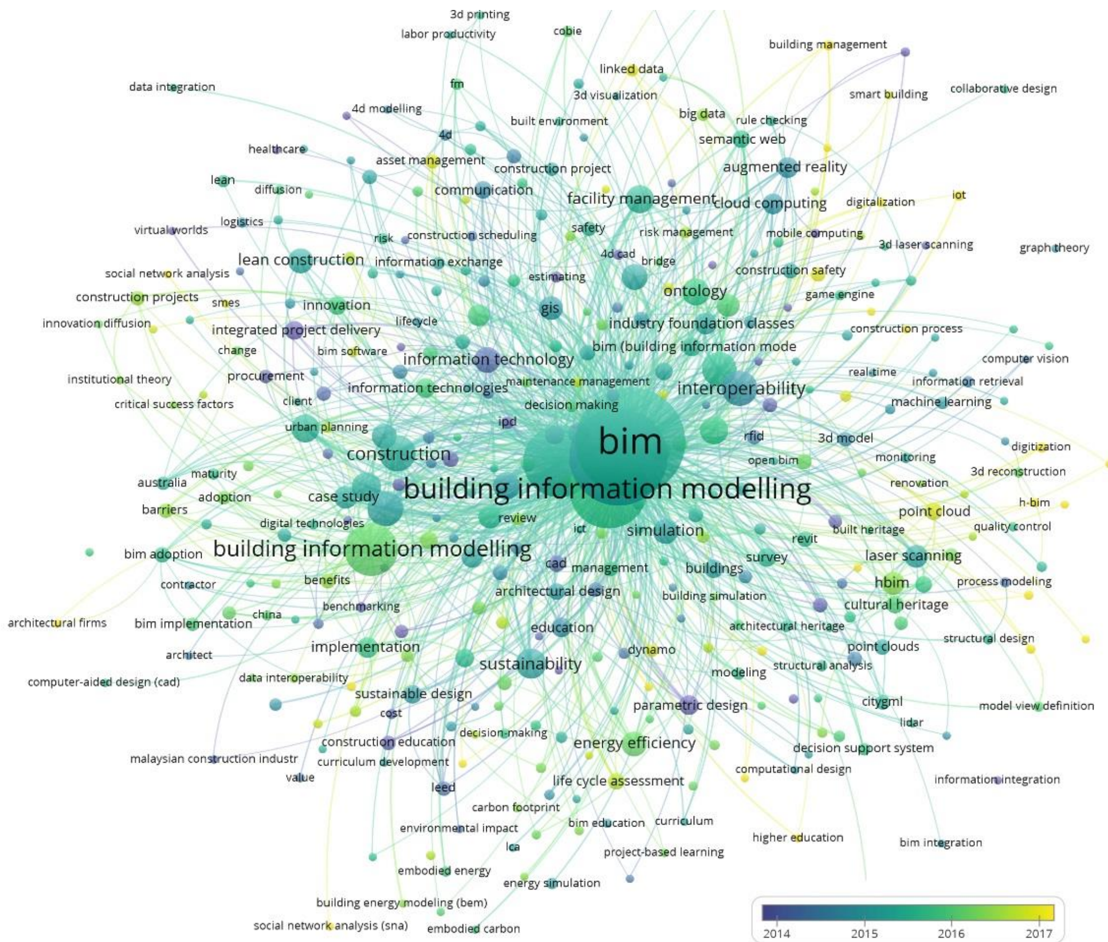


**Figure 16.** Evolution BIM research (2014–2017).

The network analysis illustrates the evolution of BIM within the period from 2014 to 2017 (Figure 16). It shows that all the major clusters spread from the central communities that represent BIM in different designations, while this analysis also reveals the structure of the current network and the composition of the future trends.

Of the whole studied period of BIM research, i.e., from 2003 to 2018, the period with the highest rate of evolution in BIM research found is from 2014 to 2017. In those years, the keywords were (indicated by purple in the year 2014): cad, parametric design, information technology, built heritage or integrated project delivery. In the years 2015–2016 (indicated in green) the main keywords were: lean construction, GIS, facility management, energy efficiency, or sustainability. The end of the evolution period (yellow, the year 2017) is shown by frequent keywords used: social network analysis, IoT, safety, SMES as the acronym for Small and Medium-sized Enterprises, and higher education. This evolution shows how information concepts and technologies have been incorporated into the research of the BIM as the IoT, obtaining importance in the curricula of students of higher education in careers such as engineering and architecture as a key factor for BIM implementation. [73–75].

### 2.4. Discussion

Countries like China, the UK, Canada, South Korea, Germany, the USA, Australia and Italy are among the top publishers of both BIM global and BIM in universities. The geographic location plays a major role in the composition of most of the clusters. The UK's cluster is larger than more than six countries outside of the European continent combined. In addition, China is the leader in research about BIM within the Asian continent. The collaborating work of authors shapes the bibliometric map of BIM through numerous parameters, while citation network analysis of the cited references indicates a wide range of subjects in this field of research such as computer science, engineering, business, management and accounting. These different subjects show the diversity of this research area. The keywords analysis provided a list of diverse words related to themes like architectural design, construction management, interoperability, lean construction, virtual reality, visualization, robotics and sustainability development. The extensive amount of data that is generated to improve the facilities management requires multidisciplinary applications of BIM. Therefore, the use of advanced technology is emerging in order to be able to respond properly to market challenges. BIM applications are moving towards IoT, safety, digitalization, smart building, social network analysis, and point cloud. Thus, automation will play a significant role either in providing a highly accurate 3D model for the existing buildings, or in providing a system that measures, collects, and analyzes data of the key performance metrics based on the IoT concept. Furthermore, a digitally empowered framework will enable the decentralization of facilities management for single or multiple buildings [20,21], and could provide a finished product to end-users for cognitive building operation. In term of safety, professionals and researchers are working to develop an approach to integrate the risk factor in building an information model. The tool will be able to detect and quantify automatically any potential risk within the construction site and the life cycle of the project [17,19,26]. Several studies have applied social network analysis (SNA) to investigate major risks related to the act of building and to identify the network structure of all the contributor relationships [26]. Other research suggests using risk factors integration from an online application called the Safety in Design Risk Evaluator, which measures risks at the item-level in multistory buildings with a 4D building information model and a construction timetable [31]. Therefore, BIM trends as many other concepts are mainly heading towards the adoption of digital technologies, big data, IoT, smart models, and machine learning. The expertise areas extracted from the co-occurrence network include interoperability, IFC, lean construction, BIM implementation, energy efficiency and BIM education. Most of these fields are technology based, which has led to a fast-growing knowledge of BIM and its sub-areas that we can see in the evolution pattern. Therefore, BIM education should be constantly upgraded to deliver a valuable knowledge of this dynamic platform.

BIM should be understood as cycle where are all the phases related to the building industry. These phases are: programming, conceptual design, analysis, documentation, fabrication, construction, construction logistics or management, operation and maintenance, demolition, and renovation. The clusters obtained in the previous section reflect almost all of these phases of the BIM, but the cluster of demolition and renovation are missing. This gap in BIM research is already pointed out by some recent works [76]. This shows that these two fields of research within the BIM; although they are currently not fully developed.

### 2.5. Conclusions

This bibliometric approach can meaningfully contribute to the ongoing manual review of BIM. Conference papers are the main source of scientific publications, followed by scientific article and reviews. Experts and researchers mostly contribute to expanding BIM literature through these channels, and the rest are published through book chapters, conference reviews and article publications. The scientific contribution in this study refers to 4307 articles associated with BIM, where only 6.4% of these articles related are to BIM in universities and 46% is published in just three countries, which are the USA, UK, and China. The bibliographic records provide users with necessary data about the affiliation of different articles. Furthermore, four out of sixteen universities are present for both of the research topics BIM and BIM in universities. Georgia Institute of Technology and Pennsylvania State University are the leaders in this emerging area of research. It is also observed that the countries that made the usage of BIM mandatory in the regulation of construction are the ones which have the most interest in researching and developing this concept. The five clusters obtained in BIM research are those of the cycle in which all phases related to the construction industry are found: construction management, documentation and analysis, architecture and design, construction / fabrication, and operation and maintenance (related to energy or sustainability). However, the clusters of the last phases such as demolition and renovation are not present, which indicates a field that still needs to be developed and researched. With regard to the evolution of research, it has been observed how information technologies have been integrated with IoT. Finally, a key factor in the implementation of the BIM is its inclusion in the curriculum of technical careers related to construction such as civil engineering or architecture. Therefore, in order to remain up to date and meaningful, education in construction needs to take advantage of the opportunities and overcome the challenges presented by BIM. This bibliometric analysis provides a general overview of the subject in order to concentrate on the strategies that are still relevant and to open up promising new lines of research. This work opens new perspectives for the use of the BIM in universities, which has been found to be less extensively covered than BIM at a global level.

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# CHAPTER III

## Benchmarking Energy Use at University of Almeria (Spain)

# Benchmarking Energy Use at University of Almeria (Spain)

**3.0 Abstract**

Several factors impact the energy use of university campus buildings. This study aims to benchmark the energy use in universities with Mediterranean climates. The University of Almeria campus was used as a case study, and different types of buildings were analyzed. The second goal was to model the electricity consumption and determinate which parameter correlate strongly with energy use. Macro-scale energy consumption data during a period of eight years were gathered alongside cross-sectional buildings information. Eight years of daily outdoor temperature data were recorded and stored for every half hour. This dataset was eventually used to calculate heating and cooling degree-days. The weather factor was recognized as the variable with the greatest impact on campus energy consumption, and as the coefficient indicated a strong correlation, a linear regression model was established to forecast future energy use. A threshold of 8 GWh has been estimated as the energy consumption limit to be achieved despite the growth of the university. Finally, it is based on the results to inform the recommendations for decision making in order to act effectively to optimize and achieve a return on investment.

**Keywords:** benchmark; campus energy consumption; heating and cooling degree-days; energy model; occupancy rate.

### 3.1. Introduction

Fuel constraints are a relevant issue in both industrialized and developing countries and are related to energy prices and accessibility of energy services [1]. Public buildings such as universities, schools. and hospitals are challenged to manage the exponential growth of their energy demand and transform their buildings into energy efficient ones. The design of buildings should logically be adapted to the lowest energy consumption levels, but in most cases, it is necessary to focus on existing buildings [2]. Therefore, the reduction of both energy consumption and $CO_2$ emissions from buildings is one of society's main targets today [3]. In Spain, there is a climatic classification according to the technical code of the building that contemplates these issues, which has been mandatory since 2006 [4]. Acting as models for communities, universities are supposed to provide innovative solutions through research in order to support the sustainability and reduce the carbon footprint [5]. One of the key operating aspect for universities is related to enhance students and teachers comfort levels, which may have a significant effect on their performance [6]. Visual, acoustic, and thermal comforts should not be considered as luxuries but rather as basic standard for schools [7]. However, maintaining indoor quality will eventually lead to a significant growth of electricity consumption; therefore, transforming university locals into energy efficient ones is a necessity. To ensure that these locals have optimal energy performance, researchers and professionals have developed management systems such as energy benchmarking and energy audit [8].

The energy benchmarking technique allows us to compare the energy consumption of buildings by dividing the key performance metric by gross floor area [9]; this index is usually expressed in (kBtu/ft$^2$/yr or kWh/m$^2$/yr), and it is labeled as Energy Use Intensity (EUI) or Energy Intensity (EI). This gives the opportunity to the portfolio manager to track the key performance metric overtime [8]. EUI is expressed as energy per square meter per year. It is calculated by dividing the total energy consumed by the building in one year by the total gross floor area of the building. The main benefit of using EUI is that the performance of a building can be compared with similar buildings across the country. EUI can vary significantly depending on building type; therefore, it is necessary to calculate it in buildings used in which there is no data so far. Energy audit is a tool that allows building owners and managers to determine which energy efficiency measures meet their sustainability goals and their investment return criteria [10]. The energy efficiency directive (201/27/EU) requires the auditing of the energy performance of old schools to assess them and propose future retrofitting if necessary [11]. In Italy, over 28% of schools are energy inefficient [12]. A previous experiment executed an energy management program in a high school located in Dubai, UAE [13], and its results show that energy performance can be basically improved by 35%. Many evaluation programs for green schools have been designed to assess managers towards sustainable solutions, like the program whole-school approaches, this initiative integrated different elements of school life such as governance, pedagogical methods, curriculum, resource management, school operations and grounds [14]. In the case of the University in Spain, particular studies have been carried out for the Universidad Politecnica de Valencia (UPV) in order to predict electricity consumption patterns in buildings [15] or the use of algorithms using demand and generation forecasts and costs of the available resources, so the benefit obtained in a whole year is five times higher, with a percentage of participation in demand response programs (DRPs), which is accepted as 60.27% or higher [16]. At this same university, with the use of energy efficiency measures (EEMs), in three different types of buildings (a research building (Building 8G), a teaching and staff building (School of Telecom Engineering building 4P), and a greenhouse building 8I-8J), the savings representing about 10% of total annual energy consumption [17].

HVAC and lighting systems have drastically changed in the last decade. Today, they incorporate sophisticated sensors and computer networking programs to monitor and adjust building systems and energy usage. These new technologies are called building automation systems, and they control, monitor, and collect data on the buildings performance technology [18,19]. University campuses serve different functions by providing spaces such as teaching rooms, academic offices, laboratories, restaurants, and sport facilities. This research outlines the classification of categories by their ECs and EUIs. The building category that influences substantially the overall EC of the University by 47% even though it covers only 27% of its total GFA. This category is the science and research category, and it is also the most energy intense by an average EUI 119.5 kWh. Similar results were reported by a study that was ran to support the ASHRAE standard 100. It has determined the EUI median for 18 major categories by climate zone in the USA, according to CBECS 2003. The national median of the laboratory has the highest energy intensity on a university campus (98 kWh/m$^2$). Our case study provides an opportunity to treat a diverse dataset of buildings. A study carried out in Australia reported that laboratory energy intensity was the highest among other categories, and it was three times higher than non-laboratory buildings [20]. In addition, another study divided laboratories into different classes of science, applied science, and intervention, and the results show that the HVAC and electric appliances load, as well as the long operating hours, are the main reasons behind the high energy consumption of this category [21].

The quantity of energy used in universities can change from a country to another, as a recent study in Taiwan has demonstrated that gross domestic product (GDP) of the country has a positive correlation with the energy consumption [22]. Furthermore, a study carried out by Catherine and Byrne et al., (2014) summarized the major factors that significantly impact university buildings' energy use are as follows: occupancy rate, HVAC load and artificial lighting, number of computers and electric equipment, and weather conditions [23]. The influence of these various parameters on the energy use and their correlated relationship to each other define the stochastic nature of the EC. This paper focused on two parameters—weather and the size of the active network inside the campus. The choice of those variables was made based on an energy survey that was conducted inside the campus and the analysis of energy consumption patterns over the last eight years. Unlike many previous studies that focused on modeling the occupant behavior and its influence on the EC, this study tested the impact of the network on a yearly basis. We gathered the number of occupants active inside the university, including the number of students, professors, and administrative staff, and since this parameter varies during the academic year, we had to line up the two other parameters in order to have them all on the same sequence. Then, we tested the correlation with both variables (the number of occupants and the sum of CDD and HDD) with macro-scale energy data. On the other hand, energy benchmarking seeks to give a reference value by defining reliable indicators, we split the buildings portfolio by the following six categories: research, administration office, teaching and seminary room, library, sport facility, and restaurants. This will allow us to benchmark within the same category and identify the benchmark value of each category. These values could be used in the future to define a national baseline for universities or in the Mediterranean region. As the majority of studies have proven that outdoor conditions are the main variable that influences energy use, in this study, we will test the correlation of the total EC with the size of network from one side and with the sum total of the HDD and CDD during each academic year. Moreover, identifying the variable that has the strongest correlation is primarily in order to take suitable actions to achieve better energy management.

### 3.2. Materials and Methods

The University of Almeria is a Spanish Public University located in the south coast of Spain, with the coordinates of latitude 36°49′45″N and longitude −2°24′16″E, see Appendix A. The university campus spreads on a surface of 17 hectares and has 33 buildings (see Figure 1). In the 2018–2019 academic year, the university offered 38 different degree programs, with 883 lecturers and 13,547 students.

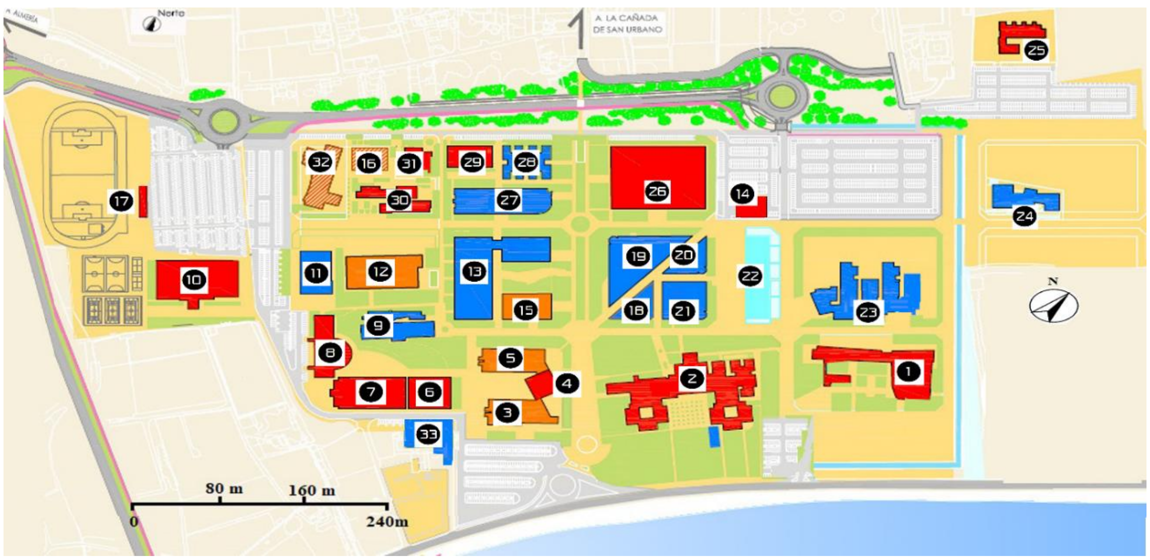


**Figure 1.** The University of Almeria ground plan.

Almeria is a coastal city located on the southern region of Spain, the climate is particularly arid and semi-continental, with relatively dry warm winters with an average temperature at *16*°C *(*60°F*)* and hot summer with an average temperature of 28°C *(*80°F*).* The most daily sunshine hours are scored in July and the wettest month is January with an average of 30mm of rain and an annual average percentage of humidity of 61.0% [24,25].

The dataset used in this analysis consists of (1) daily outdoor temperature scored every half hour during the last eight years, (2, (2) Total energy consumption on a monthly basis and gross floor area data from 2011–2018 (Table 1), (3) campus buildings' energy consumption data during the last three years 2016–2018 (Table 2), (4) the average EUI within each category (Table 3), (5) Building energy performance classification of all the buildings by category (Table 4), the number of students, professors, and administration staff per academic year (Table 5). Figure 2 outlines the methodology flow chart, starting from defining objectives to collecting data to developing results.

**Table 1.** Monthly evolution in energy consumption of the university campus per year.

| | Campus Monthly EC (kWh) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Month/Year** | **2011** | **2012** | **2013** | **2014** | **2015** | **2016** | **2017** | **2018** |
| **January** | 722,623 | 717,867 | 706,880 | 708,499 | 765,785 | 702,918 | 773,539 | 770,454 |
| **February** | 689,088 | 746,940 | 672,895 | 657,712 | 737,049 | 693,787 | 652,036 | 725,147 |
| **March** | 729,218 | 685,622 | 681,843 | 689,979 | 728,747 | 666,108 | 706,072 | 716,676 |
| **April** | 573,686 | 571,444 | 630,393 | 597,792 | 640,762 | 644,299 | 580,052 | 680,127 |
| **May** | 700,648 | 687,262 | 644,661 | 667,437 | 717,944 | 672,034 | 713,215 | 730,265 |
| **June** | 762,909 | 765,368 | 656,218 | 696,597 | 798,527 | 761,444 | 936,273 | 740,233 |
| **July** | 737,705 | 724,290 | 707,900 | 703,602 | 877,181 | 776,462 | 801,608 | 704,690 |
| **August** | 550,274 | 527,979 | 487,813 | 513,183 | 597,359 | 545,341 | 617,208 | 608,966 |
| **September** | 760,301 | 6933 | 731,827 | 753,425 | 785,407 | 837,467 | 821,574 | 645,724 |
| **October** | 693,375 | 654,832 | 727,983 | 710,872 | 721,047 | 742,409 | 780,345 | 699,640 |
| **November** | 640,273 | 632,938 | 647,683 | 671,644 | 623,533 | 685,437 | 705,548 | 757,993 |
| **December** | 621,586 | 629,833 | 627,630 | 683,565 | 616,653 | 645,593 | 691,188 | 872,744 |

**Table 2.** Space category, energy consumption, and gross floor area.

| Space Category | Building | EC (kWh/year) | | | GFA (m²) |
|---|---|---|---|---|---|
| | | 2016 | 2017 | 2018 | |
| Administration Office | 1 | 226,192 | 220,042 | 239,366 | 5880 |
| | 2 | 329,354 | 331,988 | 320,119 | 11,430 |
| | 18 | 64,759 | 63,880 | 62,840 | 2620 |
| | 19 | 196,189 | 208,161 | 188,432 | 8290 |
| | 20 | 64,553 | 56,955 | 56,261 | 2450 |
| | 21 | 104,633 | 129,335 | 122,294 | 4605 |
| | 8 | 141,530 | 143,240 | 144,591 | 3994 |
| Teaching and Seminary Room | 3 | 300,566 | 330,608 | 327,658 | 5585 |
| | 5 | 120,802 | 137,864 | 142,172 | 5611 |
| | 15 | 107,047 | 119,255 | 123,319 | 4118 |
| | 12 | 137,493 | 161,042 | 152,614 | 6016 |
| | 4 | 13,273 | 13,938 | 16,132 | 12 |
| | 23 | 156,424 | 168,703 | 151,046 | 6,605 |
| | 27 | 296,197 | 362,304 | 369,768 | 8,618 |
| | 11 | 68,441 | 59,409 | 51,887 | 3,089 |
| Research Building | 9 | 176,596 | 178,167 | 156,995 | 5487 |
| | 30 | 812,983 | 809,544 | 842,943 | 4301 |
| | 28 | 388,289 | 384,574 | 361,428 | 4828 |
| | 29 | 734,370 | 788,962 | 796,318 | 4975 |
| | 16 | 156,650 | 186,889 | 150,348 | 2100 |
| | 31 | 294,533 | 246,824 | 199,478 | 1072 |
| | 24 | 280,959 | 465,018 | 478,491 | 3089 |
| | 13 | 735,213 | 767,650 | 691,523 | 12,341 |
| Library Building | 26 | 905,166 | 19,215 | 947,826 | 16,194 |
| | 32 | 2311 | 213,344 | 202,611 | 2026 |
| Sports Facilities | 10 | 257,182 | 155,856 | 306,779 | 5548 |
| | 7 | 89,013 | 76,623 | 78,963 | 3280 |
| | 17 | 49,892 | 38,184 | 32,967 | 547 |
| Restaurant Buildings | 33 | 42,169 | 41,811 | 61,249 | 1190 |
| | 6 | 43,690 | 52,910 | 62,919 | 1280 |

*Correlation Approach*

There is a lack of data for most of the electric components and the physical characteristics of the university buildings (building materials, building geometric sizes). Thus, the given data set of observations gives us the opportunity to establish a statistical approach that allows us to measure the relationship between two variables by defining there correlation coefficient, which will provide us with a straightforward interpretation of the two variables on the overall electricity consumption on a yearly basis. This method relies on historic values of overall energy consumption and background knowledge of the input variables that influence perception. In this case study, we define the first explanatory variable occupancy rate as the total number of students, professors, and administration staff for the academic year. If we get a weak correlation, we proceed by dividing the number of occupants into two groups, students and staff (professors and administration staff), and then test them separately. The second explanatory variable is the weather explanatory variable, defined as the sum of the heating and cooling degree-days during one academic year; its unit is in degrees Celsius.

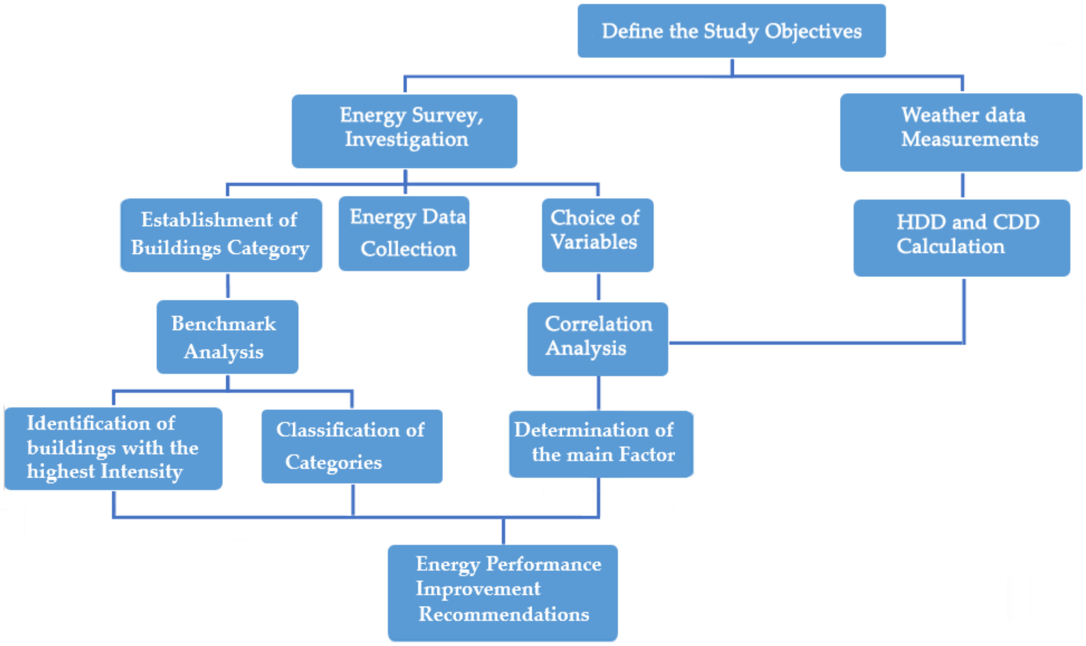


**Figure 2.** Methodology top-down chart.

Heating and cooling degree-days (HDD and CDD) are defined as the differences between the average daily outdoor temperature T(o/d) and corresponding base temperatures Tb [26]. The base temperature for heating and cooling is different from place to place. It also depends on the type of building (household, administration, hospital). In this case study, the CDD temperature base is (T(b, CDD) = 28 °C) and the HDD temperature base is (T(b, HDD) = 14 °C). These assumptions are based on a survey conducted inside the campus [24,25]. Note that the temperature base values indicate the outside temperature, and there is usually a minimum of two degrees of difference between the inside and outside temperatures. We sum up both variables on a sequence of every academic year so that it can be lined up with the quantity of interest (EC).

$$\mathrm{CDD} = \mathrm{T}(\mathrm{o}/d) \quad T(\mathrm{b},\mathrm{CDD}) \quad \text{if} \quad T(\mathrm{b},\mathrm{CDD}) > T(\mathrm{o}/d) \quad \text{then} \quad \mathrm{CDD} = 0 \qquad (1)$$

$$\mathrm{HDD} = \; T(\mathrm{b},\mathrm{HDD}) \quad \mathrm{T}(o/d) \quad \text{if} \quad T(\mathrm{b},\mathrm{HDD}) < T(\mathrm{o}/\mathrm{d}) \quad \text{then} \quad \mathrm{HDD} = 0 \qquad (2)$$

The extensive weather data set will be used in this paper to develop and validate statistical models. The complex nature of EC inside buildings and the lack of the data of most components of buildings drive us to a black box model that relies on a simple input and output system [27]. The statistical model of the linear regression is set up according to the Formula (3):

$$Ei = b \times (Xi) + a \quad (3)$$

where $Ei$ is the annual energy consumption corresponding to the academic year $i$, the input $Xi$ is the explanatory variable, $b$ is the slope, $a$ is the y-intercept [28].

## 3.3. Results

### *3.3.1. Benchmark Analysis*

Table 3 contains values of the electricity performance metrics of all the categories in the campus, and they are cited in Table 3 from the highest to lowest intensity. Average EUIs were calculated by first calculating the average in the three years of each building. Then, we sum up the EUIs within the category, and we dived them by the number of facilities of each category. The section of others is excluded from the benchmark study because it includes three buildings (14,22,25) that represent, respectively, a warehouse, a parking garage, and a nursery. These buildings have a weak EC, do not have an impact on the campus EC, and do not fit into any of the major categories. The EUI averages represent benchmark values of the cited categories in the Mediterranean climate.

**Table 3.** Average energy use index per year and average energy consumption of each space category.

| Building Category | Average EUI (kWh/m$^2$·Year) | EC (kWh) |
|---|---|---|
| Research | 119.50 | 3,694,915 |
| Library | 82.67 | 1,169,721 |
| Sport facilities | 47.30 | 361,820 |
| Restaurant | 41.11 | 101,583 |
| Teaching and seminary | 28.99 | 1,295,988 |
| Administration Office | 28.78 | 1,38,239 |
| Others | - | 28,007 |
| Public Lighting | - | 416,812 |

Figure 3 and Figure 4 summarize as percentages the total EC by categories and the sum total GFA by categories. The research and science category have the biggest share by 47% of the EC, even though it accounts for only 27% of the gross floor area (GFA), followed by the teaching and seminary category that accounts 17% of the EC and 26% of the GFA, the library category that accounts 15% of the EC and 7% of the GFA, the administration office category that accounts 15% of the EC and 27% of the GFA, by the sport facilities category that account 5% of the EC and 6% of the GFA, and finally the restaurant category that accounts 1% and 2% of the GFA. These distribution shows that there is no direct relation relationship between EC and GFA because each category has its own characteristics.

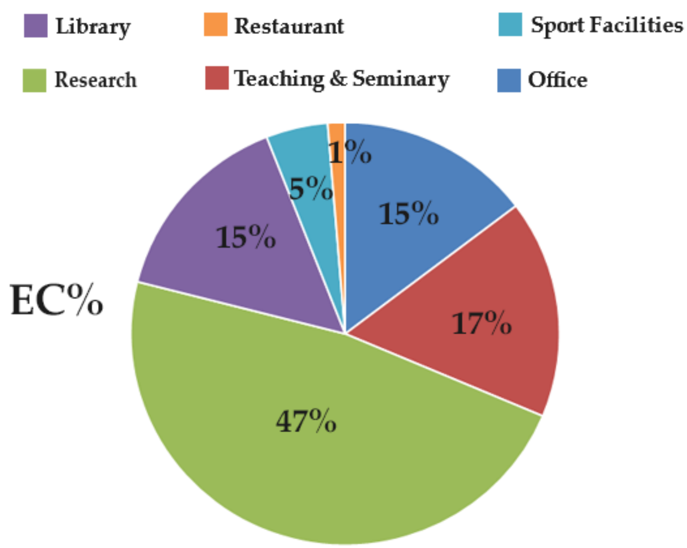


**Figure 3.** Energy consumption (EC) proportion of all the categories.

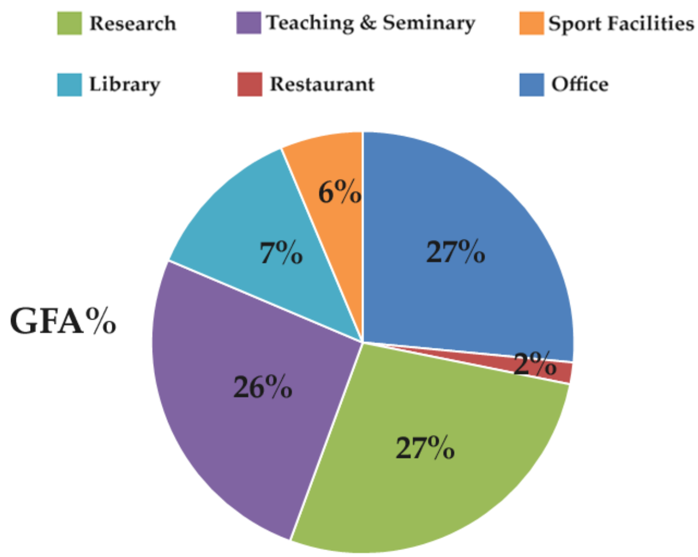


**Figure 4.** Gross floor area (GFA) proportion of all the categories.

Figure 5 summarizes the energy consumption evolution by building category from 2016 to 2018. The evolution of the total sum campus EC had a minimum value in 2016, then had peaked in 2017, and had medium value in 2018. Figure 5 reveals that all the categories followed the overall trend, except restaurant and sport facilities, where both categories account combined 6% of the total EC. Research building EUI varies from 32.5–230.3 kWh/m$^2$. Furthermore, its facilities include spaces like academic offices, computer rooms, and laboratories, and those spaces are characterized by a longer period of operation and a large number of computers, laboratory freezers, and other electric equipment. However, the majority of research buildings have a value superior to 80 kWh/m$^2$; the highest intensity value—230.3 kWh/ m$^2$—was scored by the solar energy center building (31). One of the reasons behind this high consumption is that a lot of research takes place in the center, and the researchers and students working on solar chemistry and water detoxification use several compressors with high energy consumption that cannot be powered small solar field installed on the roof of the building. The technology of information and communication center building (30) has the second highest value 188.3 kWh/m$^2$, and the lowest value was scored by the engineering school building (9).

Library building EUI varies from 62.4–105.3 kWh/$m^2$. This category is the second most energy intensive. Their locals include spaces like reading rooms, computer rooms, and common spaces and are characterized by a centralized air conditioning system, longer operating time, a high number of occupants (especially during the exam period), and a substantial number of computers and laptops.


**Figure 5.** Energy consumption evolution by building category.

Sport facilities are the third biggest consumer of energy by GFA, and their EUI varies from 28.02–69.9 kWh/$m^2$. It contains spaces like swimming pool, a covered multitask hall, and gym rooms.

Restaurant buildings had the fourth highest energy intensity, and their EUI varies from 35.13–41.34 kWh/$m^2$. They are characterized by longer operating time and different electric equipment.

Teaching and seminary rooms had the fifth highest energy intensity, and their EUI varies from 13.59–59.2 kWh/$m^2$. This category includes spaces like regular classrooms, computer rooms, and room theaters, and it is characterized by a high number of occupants. Four buildings out of eight have similar EUI values, which are close to average energy use index of this category. The lowest value is scored by building (4), a seminary building that has a low operating frequency, while the highest value is scored by building (3), which is an exception in this category because of its infrastructure that includes a water pumping system to get rid of the used water for the whole campus.

Administration offices are the least energy intensive category, and their EUI varies from 23.3–32.5 kWh/$m^2$. They include offices, meeting rooms, and common spaces and are characterized by a low number of occupant and shorter operating time.

Figure 6 outlines the scatter plot of the average EUI during last three years. In the function of the average EC, we can observe that only five buildings (31,30,29,24,32) have an EUI superior to the EUI median of universities (MU) in the Mediterranean climate given by the 2003 CBECS data [9]. Twenty-five buildings from our portfolio have an energy intensity inferior than the M.U, and 19 out of those 25 buildings are three time less intense than the k–12 schools in hot and humid zones [9]. In addition, the scatter plot demonstrates that four buildings (30,29,13,26) have an EC greater than $7.0\times10^5$ kWh. These facilities belong to the research and library category. However, two of those big consumers have EUI values bellow the MU, and the category that has shown more harmony in their sample of buildings is the restaurant category, which include two properties that has almost identical values in their EC, GFA, and EUI.

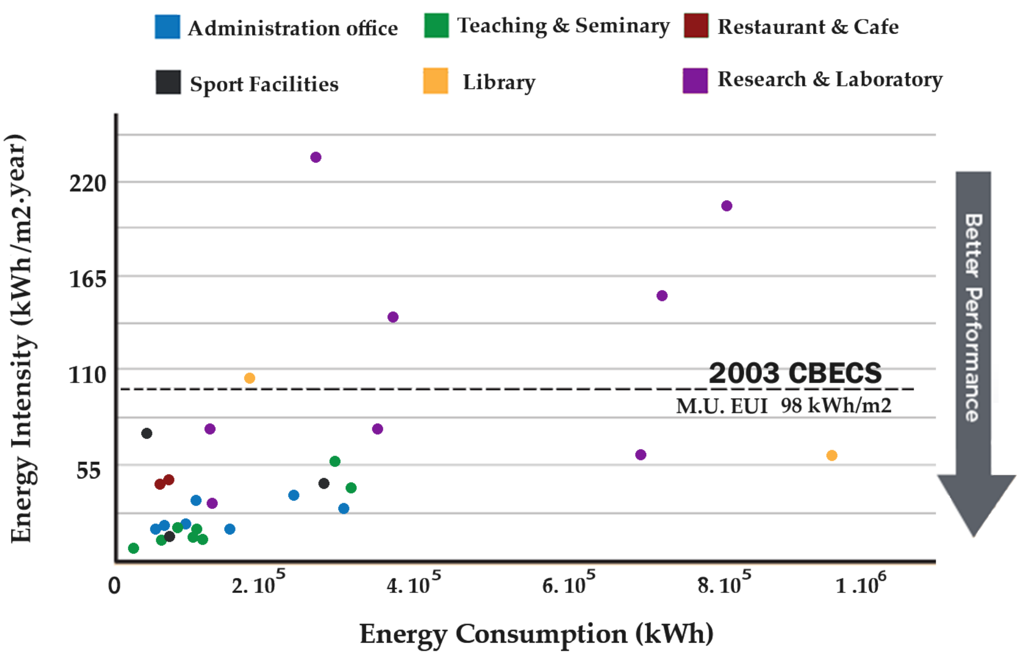


**Figure 6.** Scatter plot of energy use intensity (EUI) as a function of energy consumption (EC) by buildings category.

Table 4 outlines the classification of energy performance of all the buildings within each category. This classification is a useful tool for managers because it reports insights into which of the building should be prioritized in term of investments to achieve efficiency. Managers an divide the portfolio of every category into three groups (poor practice, usual practice, and best practice).

**Table 4.** Building energy performance classification of all the buildings by category.

| Building Category | Energy Performance Classification<br>Poor Practice <===> Best Practice | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Research** | **31** | **30** | 29 | 24 | 16 | 28 | 13 | 9 |
| Library | 32 | 26 | - | - | - | - | - | - |
| Sport facilities | 17 | 10 | 7 | - | - | - | - | - |
| Restaurant | 6 | 33 | - | - | - | - | - | - |
| Teaching and seminary | 3 | 4 | 27 | 15 | 12 | 23 | 5 | 11 |
| Administration Office | 1 | 8 | 2 | 21 | 18 | 20 | 19 | - |

*3.3.2. Case Study*

Figure 7 summarizes the campus yearly energy consumption from 2011 to 2018. The overall energy consumption has been varying in the range of 7.93–8.8 GWh, and it has a known growth of 9% since 2011. However, the patterns do not represent a clear trend through the calendar years; this is one of the reasons we decided to proceed with the academic years since we have the data of the campus monthly EC (Table 1).

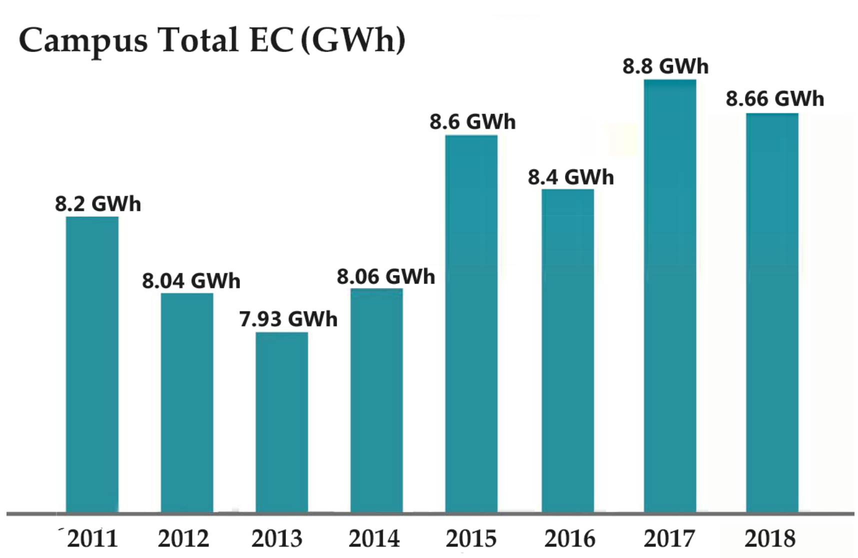


**Figure 7.** Campus yearly consumption 2011–2018.

Campus energy consumption data on a monthly basis (Table 1) shows that the evolution over the years is generally the same, which means that it plunges and peaks in the same period of the year. The peaks usually happen during the months of May and June. In this period, campus buildings make substantial use of HVAC systems, and some buildings like the library start operating for a longer period because of the exam period. The down trend starts in October after the weather begins to be cooler, and in the beginning of July, it plunges to hit the lowest values in August—during this period, the campus is practically empty, and the majority of the university buildings are non-operational because of the summer vacation.

*3.3.3. Correlation Analysis and Regression Model*

Data presented in Table 5 sums up the inputs and the outputs used for the correlation analysis and regression model which corresponds to weather parameters (CDD and HDD), the number of occupants (the number of students, professors, and administration staff), and the EC of the campus.

**Table 5.** Inputs and outputs used for the correlation analysis and regression model.

| Academic Year | CDD & HDD (°C) | N of Occupants | N of Staff | | EC (kWh) |
|---|---|---|---|---|---|
| | | | N of Professors | N of Administrative Staff | |
| 2011–2012 | 1456.30 | 15,062 | 475 | 806 | 8,142,307 |
| 2012–2013 | 1225.90 | 14,978 | 476 | 698 | 7,799,209 |
| 2013–2014 | 1091.20 | 15,234 | 477 | 732 | 7,969,924 |
| 2014–2015 | 1449.40 | 15,295 | 475 | 752 | 8,682,860 |
| 2015–2016 | 1220.40 | 15,417 | 468 | 791 | 8,209,033 |
| 2016–2017 | 1398.80 | 15,392 | 464 | 780 | 8,690,909 |
| 2017–2018 | 1417.70 | 15,680 | 468 | 809 | 8,675,213 |
| 2018–2019 | 1664.20 | 15,166 | 482 | 883 | 8,453,842 |

Figure 8 outlines the scatter plots of EC sum total of the campus in function of the following variables: CDD and HDD, number of occupants, number of students, and number of staff. In the case of the correlation of outdoor temperature with EC, *EC (Kwh) = 1204.8 CDD&HCC (°C) + 7·10* $^{6}$, its *correlation* coefficient of 0.72 indicates a positive correlation. According to the scatter plot of the number of occupants, its correlation coefficient of 0.62, which also indicates a positive correlation *(EC (Kwh) = 1073.9.7 N—8·10* $^{6}$*).* However, the remaining scatter plots represented a weak correlation, especially for the number of students. In addition, the number of occupants is the main factor behind the excessive consumption.

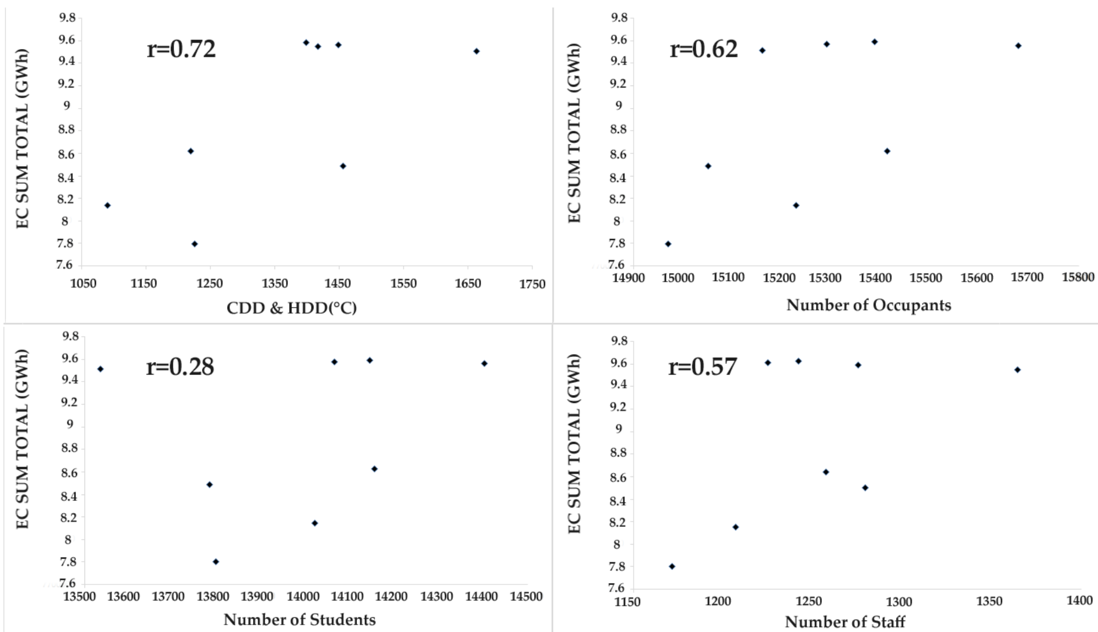


**Figure 8.** Scatter plots with their correspondent coefficient of correlation.

Figure 9 outlines the linear regression model of the total EC as a function of CDD and HDD. Both variables are statistically related because the *correlation* coefficient is 0.719. Figure 10 shows the energy thresholds of good practice of the University of Almeria.

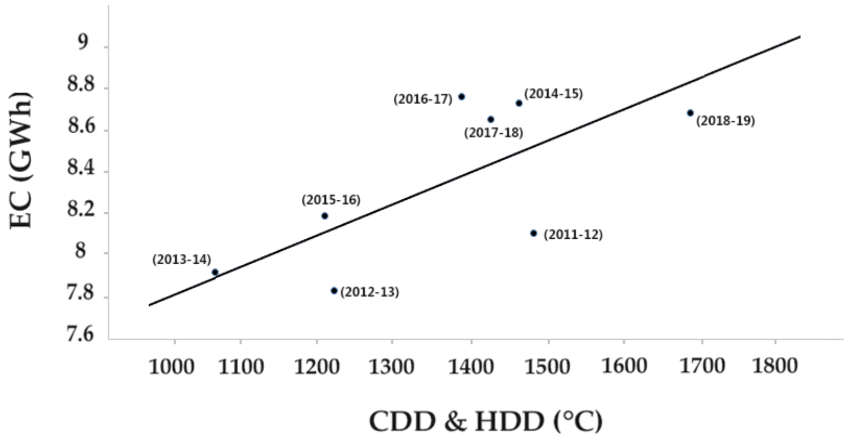


**Figure 9.** Linear regression model of EC in function of CDD and HDD.

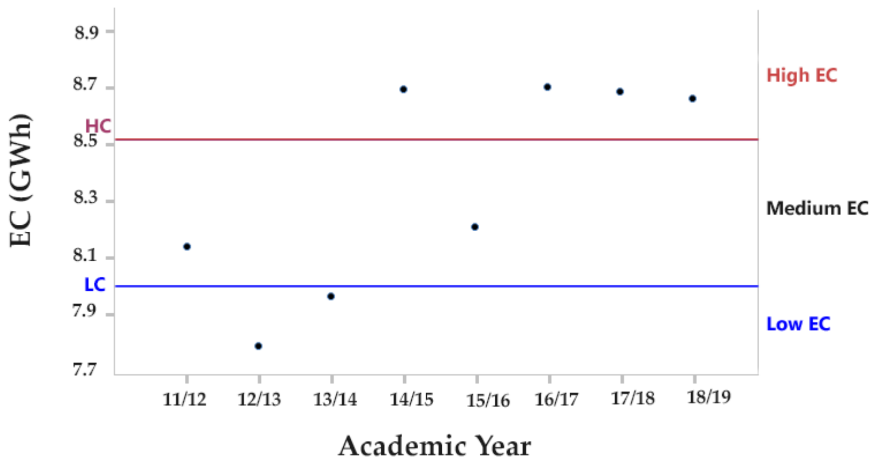


**Figure 10.** Scatter plot of the total EC in function of academic year

$$Lc = \frac{\mathrm{Min1(EC)1} + \mathrm{Min2(EC)} + \mathrm{Min3(EC)}}{3}$$

$$Hc = \frac{\mathrm{Med1(EC)1} + \mathrm{Med2(EC)} + \mathrm{Med3(EC)}}{3}$$

### 3.4. Discussion

*3.4.1. Benchmark Analysis*

Dividing campus facilities into categories allows us to compare buildings based on their utility and to identify the category that has the lowest and largest *energy consumption* by GFA. The category that scored the highest EUI average in this case study is the research and science category by an average metric score of 119.5 kWh/m$^2$, which is inferior to the laboratory intensity median given by CBECS 2003 data by Oak Ridge National Lab and the Department of Energy, which is 226 kWh/m$^2$ for the Mediterranean climate [9]. In another comparative study, which was conducted at the regional scale in the state of California (Mediterranean climate), they showed that some laboratories scored the highest energy intensity with a value of 909.5 kWh/m$^2$, and it is four times bigger than the state average energy intensity [29–31]. The results in our study have proven that this category can provide a wide range of energy intensity, which makes it worthy of more in-depth study. The observations indicate that the longer operation hours inside the facilities of the research and science category, its heavy plug load materials (like ultra-low freezers and incubators), and other laboratory equipment are the reason behind the high intensity. In addition, the high number of computers used are the reason behind the high intensity. The second most intense category is the library category, which accounts for only 7% of the total GFA but contributes to 15% in of total EC. The buildings in this category peak during the months of the preparation of exams, especially in the summer session, when their EC becomes three times higher, unlike the teaching and seminary rooms, which have a slight increase during the same period when the teaching days are relatively lower. Our portfolio have an EUI inferior than 50 kWh/m$^2$ (Figure 6), which is the equivalent of one third of the k–12 schools in hot and humid zones. This brings back the question of which is more energy intense—

schools or universities—and how much can the weather parameter contribute to the increase of electricity consumption. Thus, there are several parameters other than the weather to take into consideration, such as occupancy rate, number of COM, plug load, and operating time, that are responsible for the EC gap between different categories. On the other hand, simulation techniques represent one of the efficient alternatives to evaluate the energy performance of a building regardless of its utility. This method was used to develop a benchmark analysis based on models of equipment and system performance, which proved that plug loads and HVAC are some of the biggest influencers of high energy consumption in laboratory buildings.

*3.4.2. Correlation Analysis*

Despite the complexity of EC in university campuses, we were able to demonstrate that outdoor temperature and number of occupants positively correlate with the overall energy use, which confirmed our choice of variables. Nevertheless, another study that developed a simulation of the building occupants' decision-making and information communication process found that the network size has no significant impact on the EC [32]. Still, that result needs to be confirmed in non-residential building, especially in cases like schools and universities, where the number of occupants changes substantially over the year. On the other hand, a study that was conducted on 10 universities in the US and confirmed that EC correlates highly with outdoor temperature [33]. Weather variations can easily change cooling and heating use by 20–30% [34]. The estimation of the occupancy rate for each building remains challenging, especially in this case study because of the irregular patterns of the student movement inside the campus, which is not only related to the classes or other scheduled activities. Nonetheless, some studies used $CO_2$ measuring, relative humidity, and acoustic sensors to estimate occupancy [35–37]; however, those techniques are hard to implement in our case of study because of the several components that the buildings incorporate. On the other hand, many studies [38,39] have focused on the behavior of occupants rather than the size of active occupants. In order to evaluate the energy saving potential, one study developed an occupancy model of individuals moving in and out in offices [40], while another study found an alternative to analyze occupancy patterns using physical-statistical approaches to improve energy demand forecasting [35,41]. Still, identifying how occupant's behavior influences EC is complex because of the stochastic nature of individual actions [37].

The five buildings (31,30,29,24,32) from our portfolio scored a higher energy intensity than the university in a Mediterranean climate median. Installing solar panels on the roof as a backup is highly recommended since the campus is located on southern coast of Spain, where the yearly sum of global irradiation is over 1900 kWh/m² [41]. Therefore, efforts and investments have to prioritize these facilities because they are driving the high consumptions and there is a considerable gain potential to achieve from their high energy intensity.

If a model with the two explicative variables (N and CDD&HCC) is established and a multiple regression is conducted, Equation (4) is obtained.

$$\mathrm{EC\ (Kwh)} = 1050.375608\ \mathrm{N} + 1172.322578\ \mathrm{CDD\&HCC\ (°C)} - 9320518.243 \quad (4)$$

with $R^2 = 0.83$. If the model obtained is plotted (see Figure 11), the range of expected energy consumption can be found according to the parameters of number of occupants (N) and CDD and HCC in °C. Therefore, a threshold of 8 GWh has been estimated as the energy consumption limit to be achieved for 15,000 persons and for a CDD and HCC of 1350 °C, both factors being the average of the last eight years.

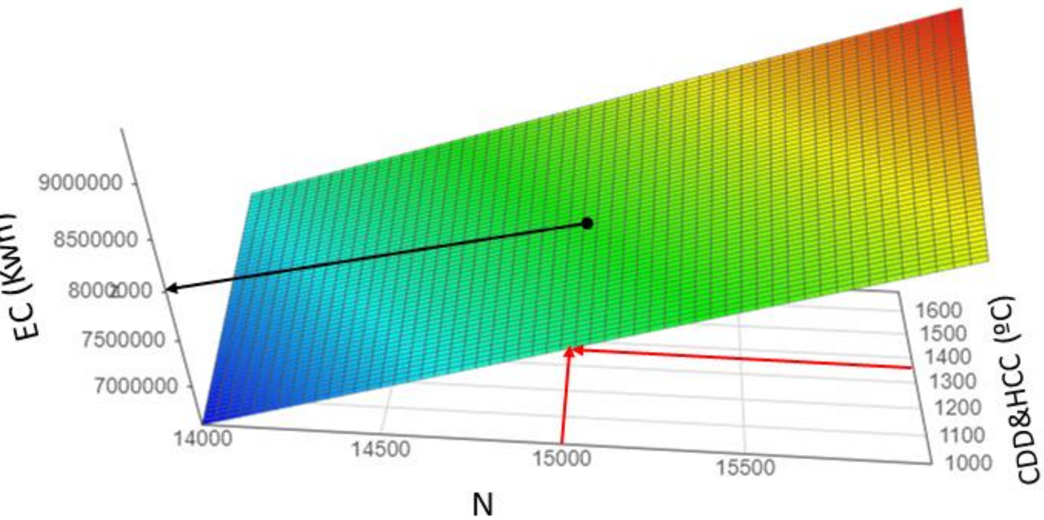


**Figure 11.** Energy consumption (EC) model obtained for the explicative variables: N (number of occupants) and CDD and HCC (°C).

### 3.5. Conclusions

Gathering high resolution outdoor temperature data during the last eight years with half an hour time frame was important for this case of study because it provided the opportunity to calculate cooling and heating degree-days. The weather factor is the most significant variable in this case study, which means that the university administration will achieve better results in term of reducing end user costs by investing in the efficiency of the HVAC system and then improving the thermal performance of the campus buildings. It has been found that research buildings consume four times more energy than teaching or administration buildings. In addition, behavioral changing programs are recommended, especially in cases like ours, where the properties are open to the public and the managers are challenged to lead the users toward sustainable actions—for instance, starting a program that aims to share information about the evolution and the gains of EC with the students and staff which could be useful to raise awareness about the continuous increase of energy use inside the campus. A similar experiment was executed in dormitory residences, and the results show that the group of residents who received real-time data feedback were more effective in energy conservation gains. The buildings from our portfolio that scored a higher energy intensity should consider installing solar panels on their roofs. Additionally, setting up systems like occupancy sensors for automatic lighting will increase efficiency. Nonetheless, energy conservation measures should not affect the indoor quality; for this reason, we must be able to reduce EC while retaining indoor quality.

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# CHAPTER IV

## Impact of the Covid-19 Pandemic on the Energy Use at the University of Almeria (Spain)

# Impact of the Covid-19 Pandemic on the Energy Use at the University of Almeria (Spain)


### 4.0 Abstract

Covid-19 pandemic has caused chaos in many sectors and industries, in the energy sector the demand has fallen drastically during the first quarter of 2020, the University of Almeria campus has also declined the energy consumption in 2020, through this study we aim to measure the impact of closing the campus on the energy use of its different facilities. We build our analysis based upon the dataset collected during the year 2020 and previous years, patterns evolution through time allows us to better understand the energy performance of each facility during this exceptional year, we have rearranged the university buildings into categories, and all the categories reduced their electricity consumption share in comparison with the previous year of 2019, furthermore, the portfolio of categories presented a wide range of ratios that varies from 56% to 98%, the library category was found to be the most influenced and the research category was found to the least influenced, this open questions like why some facilities were influenced more than others? What can we do to reduce the energy use, even more, when the facilities are closed? The university buildings present diverse structures that reveal different energy performance, which explain why the impact of such event (Covid-19 pandemic) is not necessarily relevant to have equivalent variations. Nevertheless, some management deficiencies have been detected, and some energy savings measures are proposed to achieve a minimum waste of energy.


**Keywords:** Energy consumption; Covid-19; Energy savings; Energy performance; University buildings

### 4.1. Introduction

The international energy market has known different fluctuations inflicted by the Covid-19 pandemic situation in 2020, energy demand and oil prices plummeted in early March of 2020 due to the Covid-19 outbreak throughout the globe when governments were urged to ban travel on the national and international level [1]. The lock-down of businesses and commerce has decelerated world trade, which caused a global recession in 2020, the world gross domestic product (GDP) shrunk by 4.4% [2]. On the other hand, global electricity demand fell by 5%, which led to a positive impact on the environment, and much cleaner air quality was reported on most pollutant cities, and satellite imagery had shown that urban heat island had been reduced in several metropolitan areas [3]. Moreover, schools and universities were closed in most countries, therefore, the educational system had to adapt to this situation and online learning through video conferences had been adopted widely [4]. As a result, the energy use in buildings destined for education has decreased, in the USA the energy consumption in buildings has declined by less than 10% while gasoline and jet fuel have drastically fallen by 30% and 50% respectively from March to June of 2020 [5]. Furthermore, the data collected in more than 30 countries have shown that the fall of electricity consumption in public, industrial and commercial buildings was resisted by an increase in residential buildings, which went up to 27% higher across as more people had to work and study from home [3]. The severity degree of lockdowns and its duration are the main factors that affect the energy demand, for instance in one month of confinement the energy demand decreases by 20% on average and reduces by 1.5% on a yearly basis [3]. Nevertheless, as most countries started to soften confinement measures, during June the electricity demands were 10% lower than the same month of 2019, and then it went down in July to 5% lower than the level of the same month of the previous year, with the weather corrected, in the following countries (Great Britain, India, Spain, France)

[6]. In EU countries the electricity demand started to recover levels close to the ones reached in 2019 during August, afterward the demand steadily decreased in the following months as the restriction's measures were implemented once again [6]. However, the end of the year was marked by energy demand levels that surpassed the ones in the previous year after a weather adjustment [6]. As for the economies that depend majorly on the industry such as China, where factories have been able to maintain their industrial activity by following the preventive and safety protocols that were recommended by the special authorities [7]. Thus, confinement measures had a less significant effect on the overall energy demand, since the industry sector alone accounts for more than 60% against 10% for services of the country's total consumption [7]. While the impact was much heavier in the USA where the industry sector accounts for only 20%, and the services account for 40%, as for Europe the impact was even greater since the services sector plays a fundamental role in its economy [8].

The global electricity supply dropped by 2.6% in the first quarter of 2020 than the same period in 2019 [9]. While electricity generation from renewable sources increased by 3%, this jump is mainly due to new investments in wind-solar photovoltaic power over the past year [10]. This increase came by and large at the cost of gas and coal through those two sources still generate roughly around 60% of the global electricity supply [11]. The share of electricity generated by nuclear power has also declined by 3% because fewer reactors were operational in the first quarter of 2020 [12]. Although the fossil fuel industry fell by only 2.8% in generating electricity, its market has known unusual fluctuations such as a negative price of oil in the US market, other markets switched from gas to coal because of cheap prices [11, 13, 3]. As a result, the coal-fired power fell by 8% in comparison with the first quarter of 2019 [3].

Even though the decline of the world electricity demand in 2020 has caused the reduction in $CO_2$ and greenhouse emissions, and was responsible for improving the quality of air and water, but we are still far from reaching the Paris climate change agreement goals [14,15]. Moreover, this economic crisis threatens to delay investments for clean energy, the unemployment rate grew to unprecedented levels and many families lost their income, this only makes it even harder for households to beneficiate from reliable and affordable energy, which exacerbates the issue of energy poverty [5]. The Spanish ministry for the Ecological Transition and the Demographic Challenge (MITECO) initiated measures to ensure electricity, water, and gas supplies in the residential sector, this action came as an emergency response to the lockdown that have been imposed in early march of 2020. The Spanish government implemented regulations to suspend temporarily the jurisdictions that allows disconnecting the electricity supply for non-payment, until the end of emergency state, then it proposed the partial payment as a solution to pay off the bills in an extended period of time for households that were mostly affected by the outbreak, these jurisdictions are applied on the residential sector and only on the first property. Among other support measures, the Spanish government put on hold any upward update of the domestic electricity and gas prices by supporting the default tariff during the emergency state [16]. The renewal of their social tariff deadlines had been delayed the and enlarged the number of households eligible for the electricity social tariff, the beneficiary list included also the self-employed that had to stop their activity or saw their income shrank by more than 75% [16].

The International Energy Agency has been urging nations for actions to save the enormous energy loss due to inefficiency [17]. Energy savings in buildings are usually perceived mainly from thermal insulation and indoor lighting standing point, except that energy efficiency is about all the operating component of a building, furthermore there are important amount of savings that could be made in other areas such as plug load and occupant behavior [18], In USA the electricity consumption of plug and process loads (PPLs) is responsible for 33% of commercial building and the consumption of HVAC system is not included in this ratio since it is integrated in a centralized system [19], the percentage of the plug load is expected to grow in the future since our buildings use more electrical equipment, in 2011 the Department of Energy's National Renewable Energy Laboratory

(NREL) has implemented an energy-saving program with an national strategy for commercial building in order to reduce the energy consumption without affecting the functionality of their facilities, and they were able to reduce the electricity consumption by over 30% of the plug load ratio[20].

Investing in energy efficiency programs and energy management in buildings is crucial in universities to promote sustainability and raise awareness among the academic community about our carbon footprint [21]. University campuses use energy in a different way than residential buildings, and their consumption pattern is more complicated since it depends on many different factors, such as physical characteristics of the facilities, occupancy rate, heating, ventilation and air cooling (HVAC), indoor lighting, outdoor temperature, number of computers, laboratory materials, and plug loads [22, 23]. It was estimated that plug loads are responsible for 32% of the total energy use of Stanford University's campus in a study case that included 220 buildings that evaluate around 50 GWh in yearly electricity consumption [24]. In addition, electric lighting accounts for 20% to 30% of the electricity consumption in office buildings and consumes on average about 14% of energy in the schools of the U.S.A [25, 26].

This study case will measure the impact of the Covid-19 pandemic on the energy consumption of the University campus, during the period of lockdown. In a previous study, we were able to prove that the weather factor affects the total energy consumption of the campus more than the occupancy rate factor [27], the confinement situation gives us the opportunity to evaluate the energy performance of the university campus when there is practically no human activity. Furthermore, analyzing the data during this period will allow us to understand the dynamics of the electricity consumption inside the campus and how can we minimize energy loss, many types of equipment remained operational during the lock-down, like laboratory materials, fridge, ultra-freezers that maintain low temperatures as -80 °C, security systems as sensors and cameras, and other equipment such as vending machines, exterior lighting, and internet and telecommunications equipment.

## 4.2. Materials and Methods

The University of Almeria campus accounts for 33 buildings and spreads on a surface of 170.000 m², the campus is responsible for average electricity consumption of approximately 8 million kWh each year.

The dataset is composed of the total energy consumption on a monthly basis in the period of 2011–2020 (Table 1), Energy consumption on monthly basis in 2020 of every building according to their categories (Table 2). Energy consumption on annual basis according to the buildings and its category (Table 3).

The period studied is this paper is the year 2020 which could be divided into three parts the first one is the pre-outbreak period, the second one starting from March until August when the occupancy rate at the campus was almost 0%, and the third part is when only 50% of the staff and researcher students were allowed the access the campus facilities.

**Table 1.** Monthly evolution in energy consumption of the university campus per year

| Campus Monthly EC (kWh) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Month/Year** | **2011** | **2012** | **2013** | **2014** | **2015** | **2016** | **2017** | **2018** | **2019** | **2020** |
| **January** | 722,623 | 717,867 | 706,880 | 708,499 | 765,785 | 702,918 | 773,539 | 770,454 | 776,306 | 768,904 |
| **February** | 689,088 | 746,940 | 672,895 | 657,712 | 737,049 | 693,787 | 652,036 | 725,147 | 684,468 | 681,448 |
| **March** | 729,218 | 685,622 | 681,843 | 689,979 | 728,747 | 666,108 | 706,072 | 716,676 | 682,224 | 576,683 |
| **April** | 573,686 | 571,444 | 630,393 | 597,792 | 640,762 | 644,299 | 580,052 | 680,127 | 607,203 | 416,742 |
| **May** | 700,648 | 687,262 | 644,661 | 667,437 | 717,944 | 672,034 | 713,215 | 730,265 | 737,216 | 450,385 |
| **June** | 762,909 | 765,368 | 656,218 | 696,597 | 798,527 | 761,444 | 936,273 | 740,233 | 730,448 | 519,453 |
| **July** | 737,705 | 724,290 | 707,900 | 703,602 | 877,181 | 776,462 | 801,608 | 704,690 | 788,081 | 705,993 |
| **August** | 550,274 | 527,979 | 487,813 | 513,183 | 597,359 | 545,341 | 617,208 | 608,966 | 576,199 | 549,028 |
| **September** | 760,301 | 6933 | 731,827 | 753,425 | 785,407 | 837,467 | 821,574 | 645,724 | 816,350 | 666,382 |
| **October** | 693,375 | 654,832 | 727,983 | 710,872 | 721,047 | 742,409 | 780,345 | 699,640 | 764,269 | 634,500 |
| **November** | 640,273 | 632,938 | 647,683 | 671,644 | 623,533 | 685,437 | 705,548 | 757,993 | 699,365 | 589,695 |
| **December** | 621,586 | 629,833 | 627,630 | 683,565 | 616,653 | 645,593 | 6918,18 | 872,744 | 661,745 | 584,675 |

**Table 2.** Energy consumption on monthly basis in 2020 of every building according to its category.

| Structure Category | Building Notation | EC(kWh) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | January | February | March | April | May | June | July | August | September | October | November | December |
| Administration Office | 1 | 15,513.00 | 14,207.60 | 11,061.30 | 10,785.70 | 18,578.20 | 22,494.00 | 26,905.60 | 17,793.60 | 24,893.5 | 21,040.00 | 17,817.50 | 15,892.80 |
| | 2 | 32,071.30 | 28,783.50 | 27,108.40 | 22,713.60 | 26,539.00 | 26,233.10 | 34,051.90 | 14,122.50 | 30,042.4 | 26,563.10 | 24,425.00 | 21,251.90 |
| | 18 | 5,840.70 | 5,062.30 | 5,163.50 | 4,402.00 | 5,258.70 | 5,234.70 | 5,604.70 | 3,480.00 | 61,26.3 | 5,443.50 | 5,142.90 | 4,247.90 |
| | 19 | 25,104.80 | 25,112.50 | 23,555.60 | 13,312.20 | 16,240.70 | 21,120.90 | 26,483.00 | 6,714.40 | 25,522.9 | 22,617.50 | 21,123.70 | 23,170.90 |
| | 20 | 5,995.70 | 5,755.00 | 5,442.80 | 4,560.90 | 4,952.50 | 4,427.90 | 4,599.30 | 2,178.50 | 4,427.5 | 3,619.20 | 3,687.80 | 3,308.40 |
| | 21 | 9,166.50 | 7,499.50 | 7,212.10 | 5,895.40 | 6,475.80 | 6,016.40 | 6,545.20 | 2,331.80 | 6,976 | 7,071.70 | 7,009.20 | 5,972.00 |
| | 8 | 15,021.70 | 13,602.40 | 11,353.80 | 9,328.30 | 9,187.60 | 8,631.80 | 11,880.00 | 2,568.50 | 10,301.6 | 8,761.10 | 8,739.00 | 8,441.20 |
| Teaching and Seminary Room | 3 | 20,717.60 | 21,665.20 | 17,524.80 | 11,203.80 | 12,367.50 | 15,839.7 | 19,739.50 | 19,166.20 | 21,948.6 | 29,668.40 | 19,664.30 | 15,949.20 |
| | 23 | 15,173.50 | 13,073.20 | 10,527.90 | 8,323.70 | 9,161.50 | 10,291.8 | 14,760.60 | 12,463.80 | 13,278.6 | 12,487.90 | 12,699.60 | 12,139.20 |
| | 12 | 15,384.90 | 12,819.30 | 8,268.80 | 4,012.80 | 4,628.20 | 4,691.8 | 4,487.40 | 3,866.10 | 4,520.8 | 8,206.80 | 5,377.50 | 4,169.60 |
| | 5 | 12,218.00 | 11,163.80 | 7,544.50 | 2,058.40 | 2,478.60 | 3,081 | 5,392.60 | 4,492.80 | 4,053.2 | 8,416.10 | 4,544.20 | 2,592.20 |
| | 15 | 11,656.30 | 10,946.40 | 6,880.70 | 1,726.10 | 1,991.30 | 2,819.7 | 6,292.90 | 2,340.40 | 4,115.5 | 9,300.10 | 5,868.90 | 3,426.70 |
| | 4 | 734.30 | 937.90 | 506.20 | 127.10 | 129.60 | 177 | 139.70 | 135.00 | 734.5 | 879.30 | 669.50 | 561.00 |
| | 11 | 3,367.80 | 2,653.00 | 2,692.90 | 2,180.30 | 2,295.40 | 2,094.9 | 2,591.90 | 2,117.50 | 2,352.6 | 2,875.30 | 2,880.20 | 2,615.90 |
| Research Building | 9 | 17,186.50 | 15,221.50 | 12,664.70 | 9,514.40 | 10,321.40 | 11,549.6 | 15,618.40 | 14,503.70 | 16,249.6 | 15,515.50 | 10,526.20 | 17,079.60 |
| | 30 | 72,688.40 | 69,386.60 | 73,735.50 | 69,867.90 | 74,131.80 | 73,851.9 | 75,587.90 | 73,197.50 | 70,410.9 | 73,430.80 | 72,935.50 | 74,235.20 |
| | 28 | 36,671.40 | 31,161.70 | 23,791.40 | 17,159.70 | 21,044.00 | 24,415.4 | 40,093.20 | 25,034.60 | 29,321.4 | 25,161.40 | 28,067.80 | 29,084.40 |
| | 29 | 57,178.70 | 58,173.40 | 62,339.10 | 54,599.00 | 60,793.50 | 64,173.3 | 75,002.00 | 61,692.90 | 53,543.7 | 50,239.70 | 55,223.10 | 45,242.30 |
| | 16 | 18,895.40 | 17,545.60 | 17,359.00 | 15,808.30 | 17,281.90 | 17,449.4 | 22,069.80 | 21,134.00 | 18,377.8 | 16,399.30 | 15,428.30 | 15,553.20 |
| | 31 | 18,501.10 | 16,496.00 | 10,768.10 | 4,938.50 | 6,992.50 | 16,836.3 | 21,635.00 | 7,605.20 | 18,135.5 | 16,646.50 | 14,416.40 | 12,632.70 |
| | 24 | 47,451.80 | 43,088.80 | 47,648.90 | 43,917.00 | 49,106.60 | 51,407.6 | 57,599.00 | 43,820.80 | 56,465.7 | 53,811.50 | 51,356.60 | 50,985.80 |
| | 13 | 64,815.10 | 59,686.70 | 48,958.30 | 37,050.60 | 41,733.90 | 54,277.7 | 72,961.00 | 59,137.80 | 60,154.2 | 50,546.30 | 51,314.50 | 53,166.20 |
| Library | 26 | 82,203.40 | 56,936.30 | 34,094.40 | 12,450.80 | 12,147.60 | 23610.4 | 61,082.50 | 19,951.00 | 77,694.9 | 47,935.40 | 38,894.80 | 48,547.80 |
| Sports Facilities | 10 | 5,237.10 | 5,201.70 | 5,554.50 | 4,721.80 | 5,453.40 | 4,421.80 | 3,367.00 | 1,734.80 | 4,470.5 | 6,869.90 | 6,104.70 | 5,095.90 |
| | 7 | 26,880.80 | 27,641.70 | 29,684.00 | 27,615.10 | 30,635.40 | 29,217.00 | 32,554.10 | 6,277.80 | 30,127.5 | 30,694.80 | 27,590.50 | 21,154.00 |
| | 17 | 4,154.40 | 3,722.20 | 3,869.30 | 2,237.70 | 1,897.60 | 1,592.40 | 1,105.30 | 587.60 | 1,749.5 | 3,507.90 | 3,979.50 | 2,914.30 |
| Restaurant Building | 33 | 9,183.60 | 7,873.50 | 8,795.50 | 7,997.00 | 9,664.50 | 11,067.90 | 11,697.50 | 10,502.10 | 11,314.1 | 9,751.50 | 8,245.50 | 9,292.80 |
| | 6 | 7,015.10 | 5,700.50 | 6,671.70 | 5,529.00 | 8,754.30 | 5,288.30 | 3,476.70 | 822.40 | 6,168.2 | 8,332.00 | 7,427.50 | 4,594.00 |

**Table 3.** Energy consumption on annual basis according to buildings and its category.

| Space Category | Building | EC(kWh) | |
|---|---|---|---|
| | | 2019 | 2020 |
| Administration Office | 1 | 216,983 | 190,689 |
| | 2 | 313,906 | 224,364 |
| | 18 | 61,008 | 46,567 |
| | 19 | 250,080 | 146,965 |
| | 20 | 52,956 | 33,439 |
| | 21 | 78,172 | 51,630 |
| | 8 | 117,817 | 59,227 |
| Teaching & Seminary Room | 3 | 293,292 | 225,455 |
| | 5 | 132,495 | 68,036 |
| | 15 | 122,736 | 67,365 |
| | 12 | 145,368 | 80,434 |
| | 4 | 13,263 | 5,732 |
| | 23 | 156,442 | 144,382 |
| | 27 | 299,717 | 241,767 |
| | 11 | 40,024 | 30,718 |
| Research Building | 9 | 183,607 | 165,952 |
| | 30 | 856,387 | 873,460 |
| | 28 | 340,777 | 331,007 |
| | 29 | 754,707 | 698,201 |
| | 16 | 225,731 | 213,302 |
| | 31 | 184,537 | 165,604 |
| | 24 | 503,052 | 596,661 |
| | 13 | 699,642 | 653,803 |
| Library Building | 26 | 927,397 | 515,550 |
| Sports Facilities | 10 | 58,234 | 47,041 |
| | 7 | 320,073 | 256,653 |
| | 17 | 31,318 | 15,522 |
| Restaurant Buildings | 33 | 115,386 | 72,393 |
| | 6 | 69,780 | 33,709 |


**Figure 1 .** Different locals of the administration category.

Administration buildings (Figure 1) compromise facilities like offices, meeting rooms, seminar rooms, lecture halls, these facilities host theoretical and practical training. Although the majority of research buildings were empty during an important period of 2020, nevertheless this category barely changed its consumption value to reach the equivalent of 98% from its share of electricity consumption in 2019.

Building (1) University presidency is a four-floor building with a gross floor area of 5880 m², this facility is composed of offices, meeting rooms, seminar rooms, and lecture halls. Buildings (2) Central Administrative Services is a two-floor building with a gross floor area of 11430 m², this facility is composed of offices and computer rooms, classrooms, cafeteria restaurants. Building (18) Department of Entrepreneurial and Economical Science is a three-floor building that has a gross floor area of 2620 m², this facility is composed of offices, seminar rooms, classrooms, computer rooms. Building (19) Department of Human and Social Science is a three floors building with surfaces of 8290 m², this facility is composed of offices, classrooms, seminar rooms, and computer rooms. Building (20) Department of Juridical and Law Science is a three floors building with a gross floor area of 2450 m², it is composed of offices, classrooms, seminar rooms. Building (21) Department of

Education is a two-floor building with a surface of 4605 m², it is composed of seminary rooms, teaching and computer rooms, and solar energy workshops. Building (8) Central building Cafeteria is a three-floor building with a gross floor area of 3994 m², this facility is composed of main offices, and Cafeteria.


**Figure 2 .** Different buildings of the teaching and seminary category.

Teaching and seminary room compromise facilities like classroom locals, lecture theatre, computer rooms, and these facilities usually contain a high number of occupants. Although the teaching and seminary rooms were empty during the large part of 2020, this category consumed the equivalent of 72% of its share of electricity consumption in 2019. Building (4) is a seminar building that is composed of one big lecture hall that spreads on a surface of 1002 m², events such as conferences, seminaries, and ceremonies are frequently hosted in this facility.

Buildings (5) (15) (3) are teaching facilities composed of three floors with respective surfaces of 5612 m², 4118 m², 5585 m², these buildings are mainly composed of classrooms and few computer rooms.

Building (12) is a teaching and seminary building, it contains lecture halls, teaching, and computer rooms, and this facility hosts different events from conferences to seminaries and information technology training. Building (23) is the Center for Neuropsychological

Evaluation and Rehabilitation (CERNEP), with a surface of 6605 m², it is composed of many facilities such as classrooms, rooms for practical medical exercising, and this center hosts different events from conferences to practical training and theoretical classes.

Building (27) is the Scientific and Technical Mathematics III, with a surface of 8618 m², it is composed of seminary rooms, teaching, and computer rooms, and this facility hosts different events from seminaries, theoretical classes, and information technology training.


**Figure 3 .** Different buildings of the research and laboratory category.

Research buildings compromise facilities like classroom locals, seminary rooms, computer rooms, laboratories, these facilities host theoretical and practical training. Although the majority of research buildings were empty during an important period of 2020, nevertheless this category barely changed its consumption value to reach the equivalent of 98% from its share of electricity consumption in 2019. Building (9) School of Engineering is a three-floor building that has a gross floor area of 5487 m², this facility is composed of diverse engineering fields laboratories, offices, computer rooms, classrooms, seminar rooms. Buildings (30) Center of Information and Communications Technologies Services is a three-floor building that has a gross floor area of 4301 m², this facility is composed of offices and computer rooms, information technology workshop. Building (16) Superior Council of Scientific Research is a three-floor building that has a gross floor area of 2100 m², this facility is composed of offices, seminary rooms, and hydrology and geology-related laboratories. Building (28) Scientific-Technical and chemistry is a three floors building with surfaces of 4828 m², this facility is composed of chemistry laboratories, classrooms, seminar rooms, and computer rooms. Building (29) Center of research is a three floors building with a gross floor area of 4975 m², it is composed of laboratories, and offices. Building (31) Center of Solar Energy Research is a two-floor building with a surface of 1072 m², it is composed of seminary rooms, teaching and computer rooms, and solar energy workshops. Building (24) Technical and Science is a three-floor building with a gross floor area of 3089 m², this facility is composed of seminary rooms, computer rooms and teaching rooms, laboratories, and offices. Building (13) Technical and Science II is a three-floor building with a gross floor area of 12341 m², this facility is composed of seminary rooms, computer rooms and teaching rooms, laboratories, and offices.


**Figure 4**. Different locals of the Library building.

Library Building is (26) the University and has a gross floor area of 16194 m², its facilities include different structures such as study rooms, computer rooms, meeting rooms, staff offices, and common spaces.

**Figure 5**. Different locals of the restaurant category.

Restaurant buildings provide services for the staff, students, and visitors. Building (6) is the official university restaurant, it is a one-floor facility with a gross floor area of 1280 m². Building (33) is a private bar-restaurant, it is a one-floor facility with a gross floor area of 1190 m², and these facilities are composed of kitchens, halls, terraces, toilets.


**Figure 6**. Infrastructure of the Sports facilities.

Sports facilities, the building (7) is an athletic swimming pool facility, (17) facility includes a football stadium with athletic running track and another a smaller football stadium and six tennis and paddle playing fields. Building (10) is a multi-sports hall that includes a gym, futsal, locker rooms, and showers.

### 4.3. Results

Figure 7 represents a histogram graphic that summarizes the evolution of the total electricity consumption on an annual basis from 2011 to 2020. The overall energy consumption has been varying in the range of [7.15 GWh, 8.8 GWh] and it represents a gap of 10 % between the minimum and the maximum value recorded. Furthermore, the year 2020 has known an unusual contraction due to the Covid-19 pandemic that hit Spain in the first months of 2020, this value is the lowest during the last ten years.

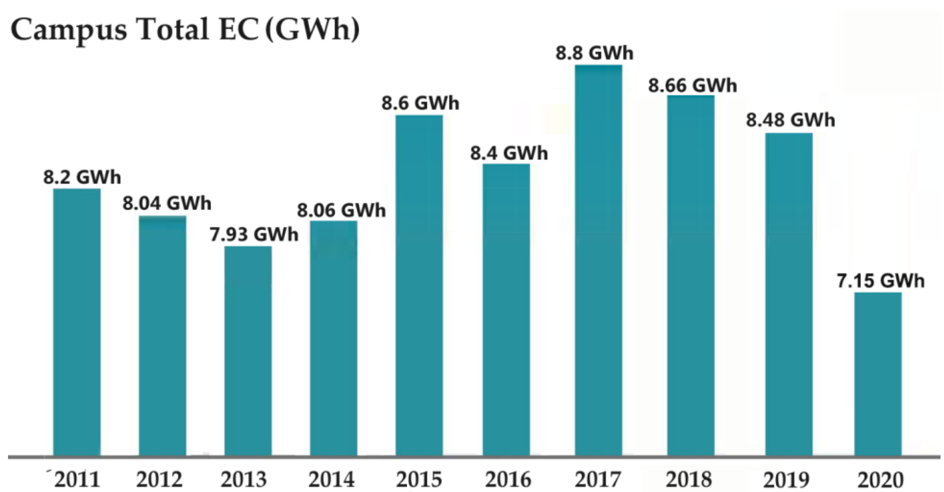


**Figure 7.** Campus annual consumption during 2011 - 2020.

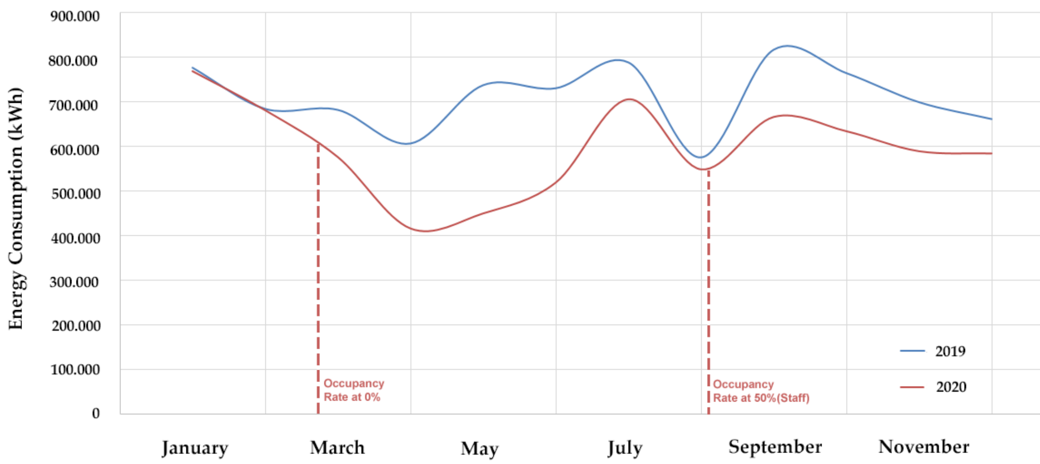


**Figure 8.** Patterns of monthly energy consumption of the University (2019–2020).

Figure 8 illustrates the campus energy consumption on monthly basis, during the first two months (January and February) both patterns of 2019 and 2020 were identical until the month of March that witnessed the Covid-19 outbreak in Spain, then the 2020 pattern had been evolving below the levels of the previous year, it has decreased sharply and simultaneously with the lockdown of the University in April. The gap begun to narrow in August, this month is a summer break, and the number of occupants is at the lowest point for each year, and then the gap between the two graphics started to widen once again but not as much as the period of the 0% occupant.

As Figure 9 illustrates research and laboratory category has reduced its electricity consumption by 2% from 2019 to 2020, this means that the occupancy rate is uncorrelated with the EC of this category. Library buildings have witnessed a significant decrease by 44%, which means that the presence of students and staff plays a key role in EC of this category. Teaching and seminary room electricity consumption share went down by 28% during the period studied, Sports facilities reduced their EC by 22%. Restaurant building's share of electricity consumption shrank by 42%. Administration and offices also have known a reduction of 31% in their share of the campus total EC. The EC gap in the same category between 2019 and 2020 varies from 2% to 44%, this disparity shows how much electricity consumption could be different from one category to another. These ratios don't reflect the manager's level of expectation, since they are far from being as low as the occupancy rate, especially in categories like teaching and seminary, research, and sports. To find more persuasive reasons, we aim to go further to study the patterns of buildings within each category.

Administration buildings compromise facilities like offices, meeting rooms, seminar rooms, lecture halls, these facilities host theoretical and practical training. Although the majority of research buildings were empty during an important period of 2020, nevertheless this category barely changed its consumption value to reach the equivalent of 98% from its share of electricity consumption in 2019.

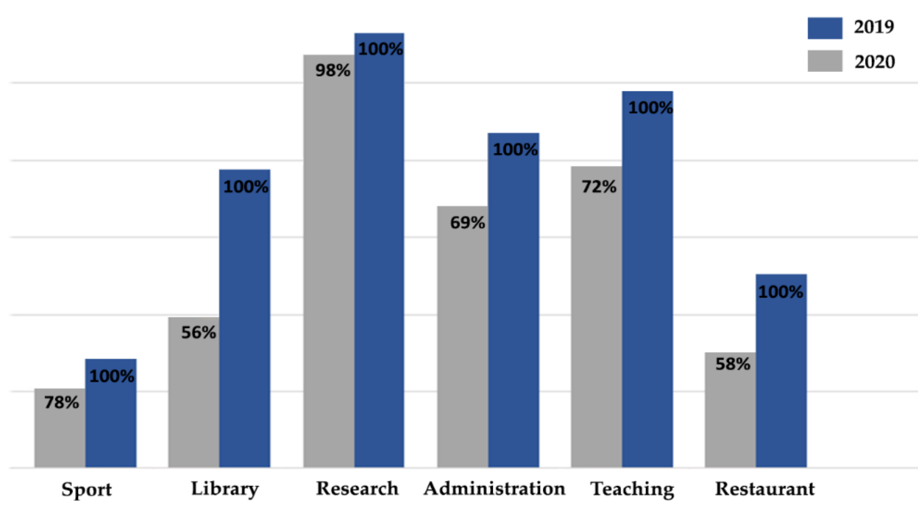


**Figure 9.** Energy consumption evolution by building category (2019–2020).

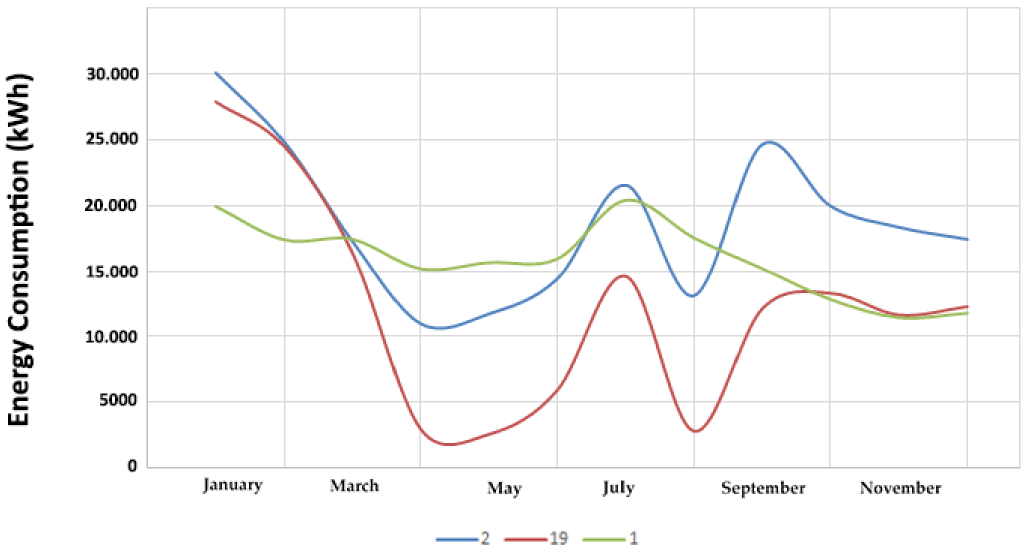


**Figure 10.** Energy consumption evolution of administration buildings.

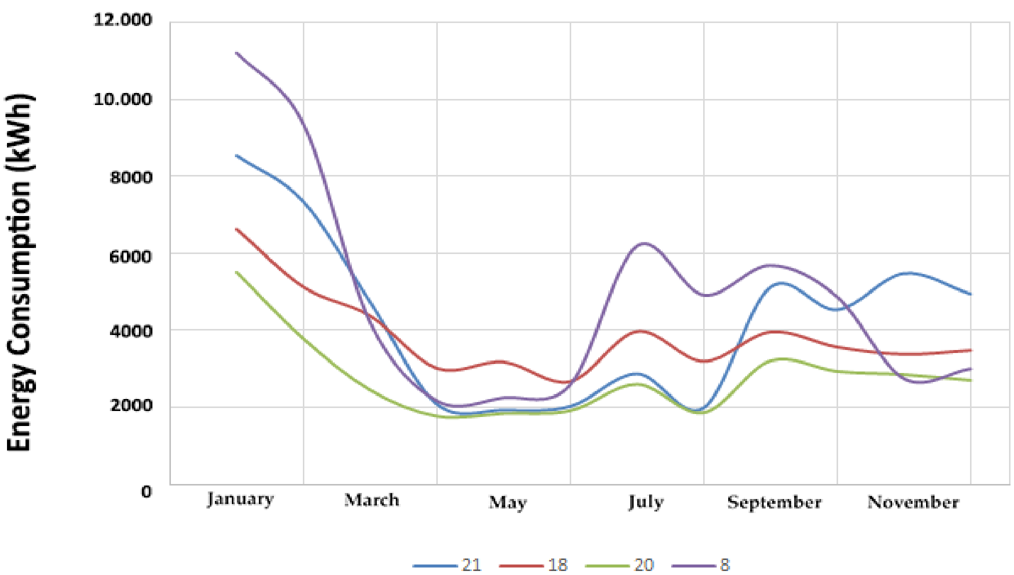


**Figure 11**. Energy consumption evolution of administration buildings.

Figures 10 and 11 showcase administration facilities have generally the same evolution through time, during the period from January to April, the administration facilities fell by a wide range of ratios that varies from [14%, 89%], however, this gap was driven by only one building (1) since all the rest of the buildings fell by levels under the 50%, moreover, the majority of the buildings have known their maximum value during the same month of January, which is a period before the outbreak happened in Spain, and five out seven buildings have had their minimum in the two months of April and May the three following. Then all of the buildings increased their consumption during June and July, then they decreased in the summer break during August, and then once the campus opened its door in September the consumption went up again showing that there is a clear correlation between the occupancy rate and the electricity consumption in this category.

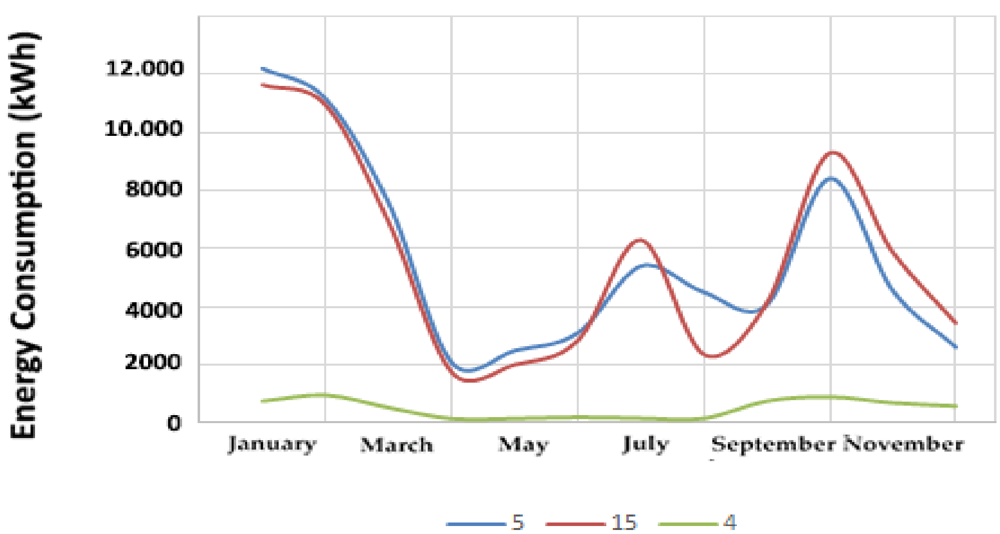


**Figure 12.** Energy consumption evolution of teaching buildings.

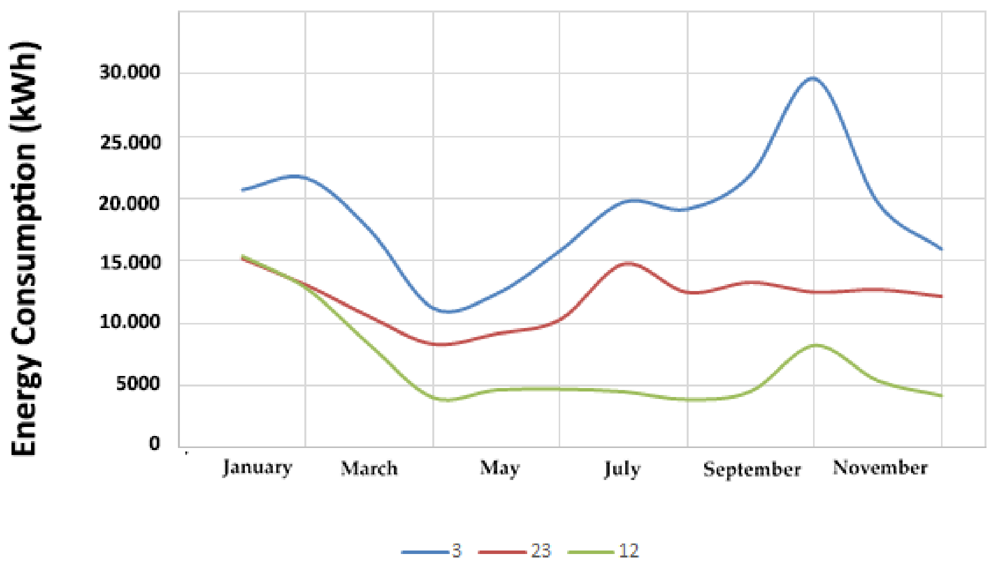


**Figure 13.** Energy consumption evolution of teaching buildings.

Figures 12 and 13 illustrate monthly energy consumption patterns of teaching facilities during 2020, the first one shows that buildings (5) and (15), have almost the same behavior during the year of pandemic, and also we can clearly notice the correlation with the lockdown measures and the electricity consumption, during April the energy consumption of the two buildings plummeted respectively to levels of 17% and 15%, compared by the level of the first month of January, buildings (5) and (15) began to steadily rise for in June and July when few facilities were reopened as measures started to ease after the first wave of the pandemic, then they decreased in August, however, they started to surge once again to reach a peak in October, before it started to decline once again in November as the second wave hit the country. Building (4) energy consumption has declined by levels around 83% from January to April, and it wasn't until September when it has slightly gone up to get close to the levels of pre-confinement, this facility overall electricity consumption has declined by 58% to be the most influenced building in this category during 2020.

Building (23) declined its consumption by 45% during the first confinement (January to April), it slightly increased in May, then it started to rise once again to peak in July, then remained relatively constant after September as its locals knew few practice activities with a limited number of researchers and students, Building (3) have similar pattern evolution to (15) and (5) except for the difference in October peak level, which in the case of the building (3) the level has surpassed the EC levels pre-confinement period. This raises the question of how can a facility consume more energy when its occupancy rate is lower than 50 %.

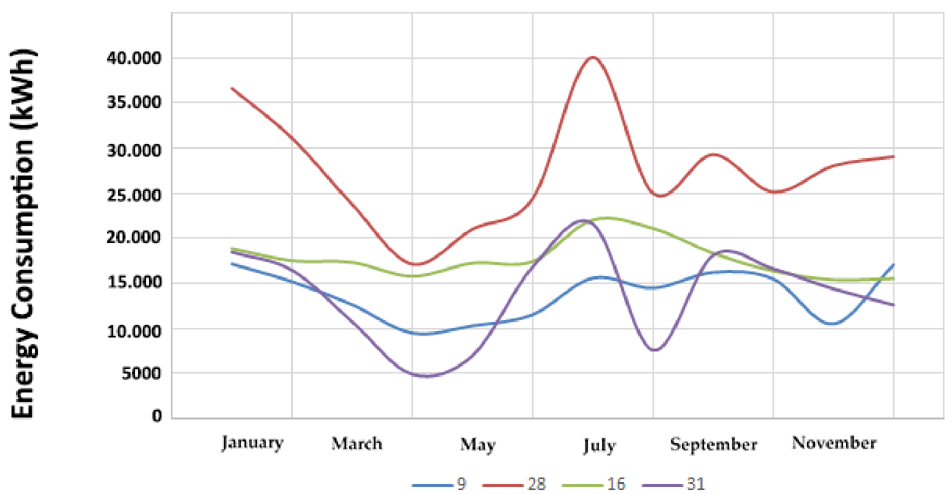


**Figure 14.** Energy consumption evolution of research buildings.

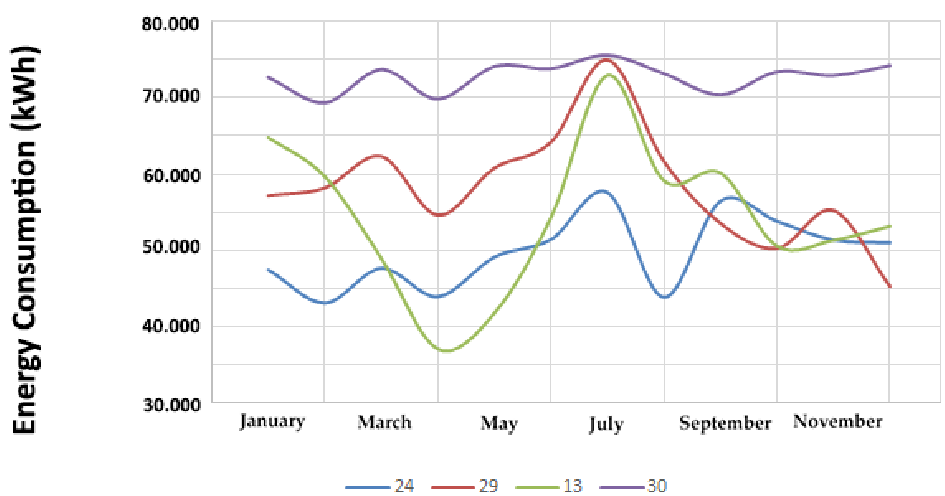


**Figure 15.** Energy consumption evolution of research buildings.

Figures 14 and 15 illustrate monthly energy consumption patterns of research buildings, research and laboratory category only fell by 2% in 2020, however, some of the buildings were affected by closing the campus during the outbreak period and others weren't. Building (13) who had higher consumption than buildings (29) and (24) during January fell in March and April to record a lower value than both buildings, moreover, five out of eight buildings dropped to reach their minimum value during April, which was the following month of the lockdown. However, all the buildings seem to have their maximum value in July except building (9), and all of these peaks happen to be during a period of a very limited occupancy rate. The data shows (see table 3) that the research and laboratory category was the least affected by the pandemic situation in 2020, the two buildings (30) (24) even consumed more electricity than the previous year, furthermore, those two facilities have the lowest fluctuations among the research category, their gap ratios between the maximum and the minimum consumption on monthly basis are respectively 9% and 25% during 2020, showing that unlike most facilities they kept a high and steady level of their EC. The electricity consumption of buildings (13) and (28) dropped respectively from January to April by 43% and 53%. However, buildings (9) (31) are the most affected by the lockdown in this category, and their consumption on annual basis fell respectively by 10% and 11% between 2019 and 2020 (see table 3).

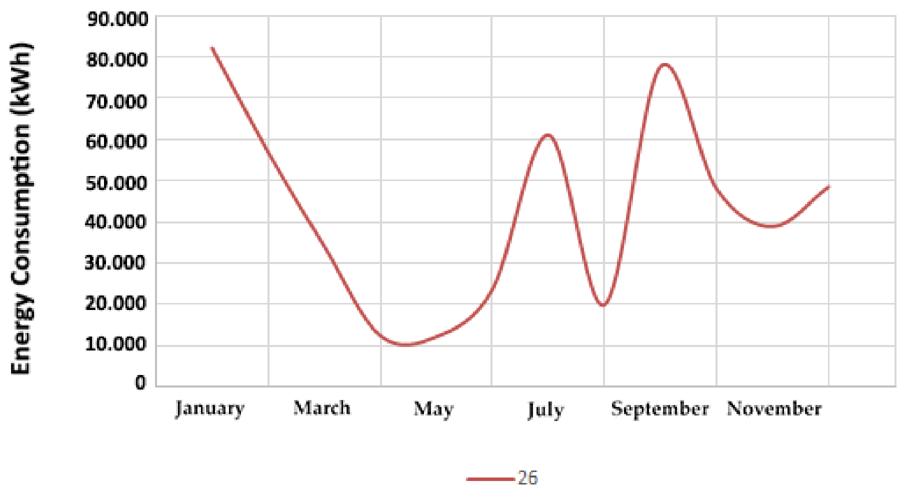


**Figure 16**. Energy consumption evolution of Library building.

As Figure 19 showcase, building (26) has known large fluctuations during 2020, during the period January-April of 2020, the library facilities fell by 85% and then increased in June and July to reach the first spike of 74% from the post-outbreak era of level, then its consumption dropped significantly during the summer break in August to get back in September to reach a second spike of 95% which is the closest level to the pre-outbreak era in 2020.

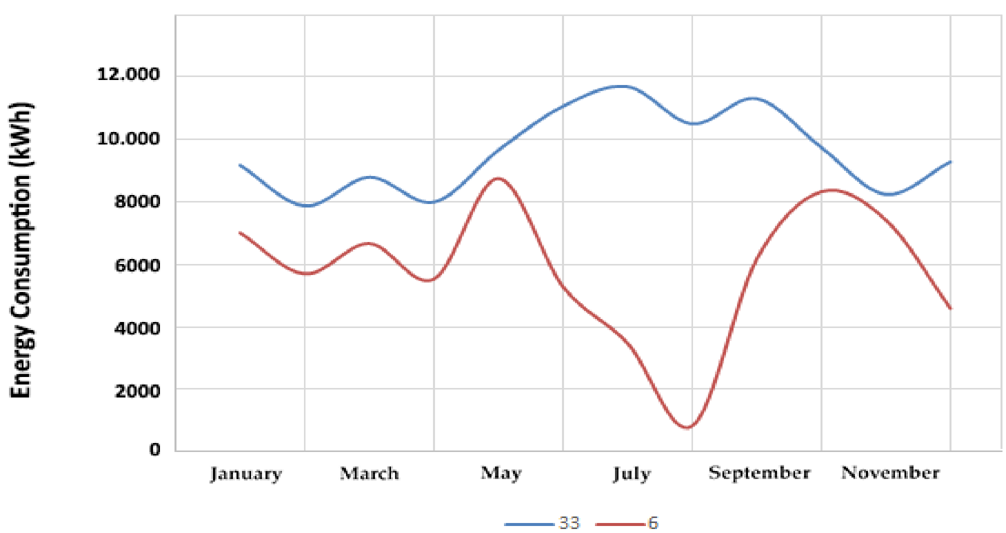


**Figure 17**. Energy consumption evolution of restaurant buildings.

The restaurant category is one of the most affected by the pandemic and its electricity consumption dropped by 42% (see Figure 17). As Figure 15 illustrates, the monthly consumption evolution of both facilities is similar until the month of May, but then it seems that the two patterns seem to take different paths. Buildings (33) and (6) respectively drop their share by 13% and 21% in comparison with the previous year during the period January-April. Then building (6) has known a spike in May due to reopening then fell during the summer break, after that it started to grow again with the beginning of the new academic year, this facility has seen its consumption share shrank by 62%. Although building (33) restaurant and it has witnessed a significant decrease on an annual basis by 47%.

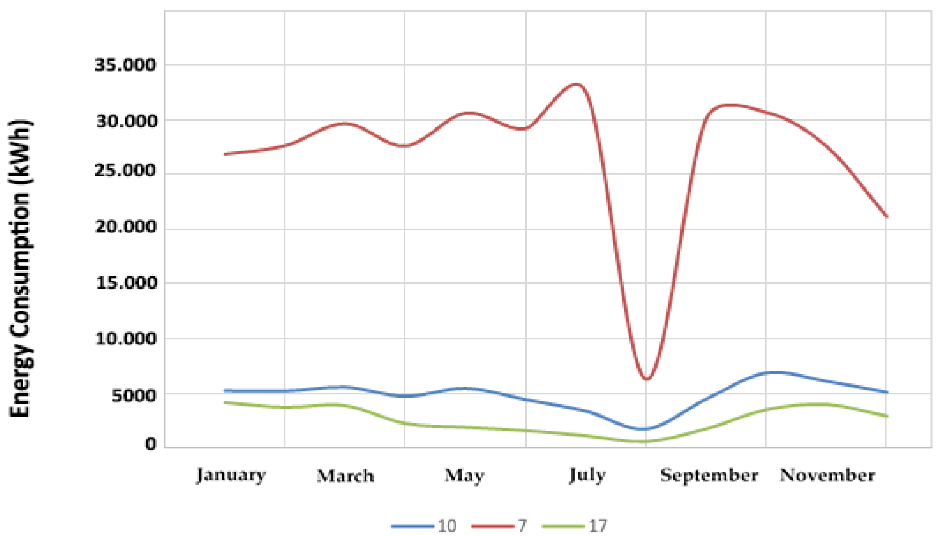


**Figure 18**. Energy consumption evolution of Sports facilities.

The two structures (10) (17) of the sports facility category have relatively the same energy consumption behavior through time as Figure 18 showcase, during the period January-April of 2020, both facilities fell respectively by 46% and 10%, and it wasn't until August when the consumption dropped significantly to reach respectively levels of 14% and 33%, after that both facilities continued to increase their energy consumption as the campus opened for the new academic year, overall the facilities (10) and (17) decreased their consumption on annual basis respectively to levels of 50% and 81% in comparison with the previous year.

The building (7) has slightly increased its consumption in the period January-Avril of 2020, which means that it consumed more during a full month of confinement than the first month of the year when the facility was operating at full capacity, the facility kept its consumption at a steady pace during May to July, then it plummets in August to reach 23% from its share of the first month of the year.

### 4.4. Discussion

The campus overall energy consumption has dropped by 1.3 million kWh in the year 2020 due to the Covid-19 outbreak, this level of consumption is the lowest recorded in the last ten years. The research and laboratory is the only category that preserved its high consumption rate with an annual loss of only 2%, this goes back to the particularity of the research buildings that include different types of laboratories with heavy plug load materials that remain operating regardless of the occupancy rate. Despite the fact that this category shrank on the macro-scale, but on the micro-scale, two buildings (30) and (24) have risen their consumption share during a year of a limited occupancy, building (30) the data processing center of the university, this facility is managed by a private entity, it has optimal conditions for this type of infrastructure, both for electricity supply (double electrical connections, uninterruptible power supply system), air conditioning (conditions of adequate refrigeration) and for security (fingerprint and/or card access control, video surveillance cameras, fire and early response systems). This building provides services like hosting servers, so the large part of the operation of this facility does not rely on the presence of occupants, moreover, during 2020 the demand on the hosting service increased since many services and businesses had to go online because of the pandemic, which explains it's high and steady energy consumption. Building (24) have also risen its consumption during 2020, because this facility operates mainly for research purposes that covers diverse fields such as information technology, food science, bio-technology and chemistry, and this research facility include equipment with heavy plug load, and it was operating during the confinement due to the importance of their projects.

The buildings within the teaching and seminary portfolio had a significant fall in energy consumption amid the outbreak except for two buildings (3) and (23), and the reason behind this resistance is due to the special infrastructure of the building (3) that includes an underground tank that collects the used water in the campus, and this structure uses a water pumping system to clear it out. During this period building (23) was going through an expansion project which requires the use of electricity by the construction company, we have noticed that construction activities were allowed to operate during the first weeks of lockdown, and also the construction sector was one of the first sectors to get back to operation as the confinement measures started to ease.

The administration and offices category recorded a wide gap of ratios in the second month of the outbreak, this gap was mainly driven by building (1), which is the university presidency, where all the management decisions are centralized. This facility includes the security office that manages all the camera recordings inside the campus, and this office stays in operation during the entire year, furthermore this facility remained operational at a minimum level during the lockdown because of the crucial role that it plays in overseeing the whole institution.

The facility (7) energy consumption pattern do not correlate with the occupant's activity (see Figure 17), sports facilities did not receive any students during the first three months of the covid-19 pandemic, and yet the building (7) kept a high and steady level until the month of August. Managers could have made an important gain by switching off the heating system of the swimming amid the outbreak.

Building (10) shrank only by 20% in comparison with the previous year despite being unoccupied for three months and having a limited number of occupants during the rest of the year. The gym materials remained plugged in during the closing period, which represents an additional waste of energy that could have been avoided.

Restaurant buildings (33) and (6) tend to diverge at some point (see Figure 15), unlike building (6) who tank by the summer break, building (33) has risen its level because it’s a private entity that stays in operation during the summer, it has also kept its activity during the lockdown as restaurants were allowed the delivery services.

Library energy consumption is mainly influenced when its locals are open for users, the energy consumption pattern (see Figure 17) have a correlation with the occupant activity, it fell by 85 % during the first lockdown and the summer break.

### 4.5. Conclusion

The situation of closing the campus facilities during the Covid-19 outbreak Influenced the overall energy consumption of the campus, however, the impact magnitude varies from one category to another, and even some facilities among the same category represented a disparity, and based on the data that we collected, we shine the light through this conducted study on how the energy performance may be different from one structure to another.

All the categories decreased their consumption value, nevertheless, the research category is the least influenced by the outbreak situation, this is due to the nature of how laboratory facilities operate, these facilities include equipment with heavy electricity load such as ultra-freezer, incubator, hosting servers equipment, and Graphic processing units for a supercomputer, and most of these equipment remains operational even during times when the campus is closed because they are part of ongoing projects.

The library is one the most categories impacted by closing down during the outbreak, and this is due to the operating nature of this facility, it offers desk light and to every student, electric outlets to plug their own devices (computer, phone), besides the centralized air conditioning in common reading rooms and areas, and of these appliances were shut down which drove-down the electricity consumption.

Efficient management could help reduce energy consumption by an important margin. Promoting energy-saving habits like unplugging unused appliances could reach 10% in some cases [28, 29]. In our case, simple decisions like turning off water heating systems in sports facilities, and unplugging all the computers and other unused appliances such as vending machines during the first confinement could have made even higher energy savings in 2020.

## 4.5. References


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# CHAPTER V
# Conclusions

## 5.1. Conclusion

This bibliometric approach can meaningfully contribute to the ongoing manual review of BIM. Conference papers are the main source of scientific publications, followed by scientific article and reviews. Experts and researchers mostly contribute to expanding BIM literature through these channels, and the rest are published through book chapters, conference reviews and article publications. The scientific contribution in this study refers to 4307 articles associated with BIM, where only 6.4% of these articles related are to BIM in universities and 46% is published in just three countries, which are the USA, UK, and China. The bibliographic records provide users with necessary data about the affiliation of different articles. Furthermore, four out of sixteen universities are present for both of the research topics BIM and BIM in universities. Georgia Institute of Technology and Pennsylvania State University are the leaders in this emerging area of research. It is also observed that the countries that made the usage of BIM mandatory in the regulation of construction are the ones which have the most interest in researching and developing this concept. The five clusters obtained in BIM research are those of the cycle in which all phases related to the construction industry are found: construction management, documentation and analysis, architecture and design, construction / fabrication, and operation and maintenance (related to energy or sustainability). However, the clusters of the last phases such as demolition and renovation are not present, which indicates a field that still needs to be developed and researched. With regard to the evolution of research, it has been observed how information technologies have been integrated with IoT. Finally, a key factor in the implementation of the BIM is its inclusion in the curriculum of technical careers related to construction such as civil engineering or architecture. Therefore, in order to remain up to date and meaningful, education in construction needs to take advantage of the opportunities and overcome the challenges presented by BIM. This bibliometric analysis provides a general overview of the subject in order to concentrate on the strategies that are still relevant and to open up promising new lines of research. This work opens new perspectives for the use of the BIM in universities, which has been found to be less extensively covered than BIM at a global level.

## 5.2. Conclusion

Gathering high resolution outdoor temperature data during the last eight years with half an hour time frame was important for this case of study because it provided the opportunity to calculate cooling and heating degree-days. The weather factor is the most significant variable in this case study, which means that the university administration will achieve better results in term of reducing end user costs by investing in the efficiency of the HVAC system and then improving the thermal performance of the campus buildings. It has been found that research buildings consume four times more energy than teaching or administration buildings. In addition, behavioral changing programs are recommended, especially in cases like ours, where the properties are open to the public and the managers are challenged to lead the users toward sustainable actions—for instance, starting a program that aims to share information about the evolution and the gains of EC with the students and staff which could be useful to raise awareness about the continuous increase of energy use inside the campus. A similar experiment was executed in dormitory residences, and the results show that the group of residents who received real-time data feedback were more effective in energy conservation gains. The buildings from our portfolio that scored a higher energy intensity should consider installing solar panels on their roofs. Additionally, setting up systems like occupancy sensors for automatic lighting will increase efficiency. Nonetheless, energy conservation measures should not affect the indoor quality; for this reason, we must be able to reduce EC while retaining indoor quality.

## 5.3. Conclusion

The situation of closing the campus facilities during the Covid-19 outbreak Influenced the overall energy consumption of the campus, however, the impact magnitude varies from one category to another, and even some facilities among the same category represented a disparity, and based on the data that we collected, we shine the light through this conducted study on how the energy performance may be different from one structure to another.

All the categories decreased their consumption value, nevertheless, the research category is the least influenced by the outbreak situation, this is due to the nature of how laboratory facilities operate, these facilities include equipment with heavy electricity load such as ultra-freezer, incubator, hosting servers equipment, and Graphic processing units for a supercomputer, and most of these equipment remains operational even during times when the campus is closed because they are part of ongoing projects.

The library is one the most categories impacted by closing down during the outbreak, and this is due to the operating nature of this facility, it offers desk light and to every student, electric outlets to plug their own devices (computer, phone), besides the centralized air conditioning in common reading rooms and areas, and of these appliances were shut down which drove-down the electricity consumption.

Efficient management could help reduce energy consumption by an important margin. Promoting energy-saving habits like unplugging unused appliances could reach 10% in some cases [28, 29]. In our case, simple decisions like turning off water heating systems in sports facilities, and unplugging all the computers and other unused appliances such as vending machines during the first confinement could have made even higher energy savings in 2020.

# CHAPTER VI
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## 6. References

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# CHAPTER VII

# Scientific Contributions

# First Publication

Chihib, M., Salmerón-Manzano, E., Novas, N., & Manzano-Agugliaro, F. "Bibliometric maps of BIM and BIM in universities: A comparative analysis." *Sustainability* 11.16 (2019): 4398

*sustainability*

MDPI

*Article*

# Bibliometric Maps of BIM and BIM in Universities: A Comparative Analysis

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**Abstract:** Building Information Modeling (BIM) is increasingly important in the architecture and engineering fields, and especially in the field of sustainability through the study of energy. This study performs a bibliometric study analysis of BIM publications based on the Scopus database during the whole period from 2003 to 2018. The aim was to establish a comparison of bibliometric maps of the building information model and BIM in universities. The analyzed data included 4307 records produced by a total of 10,636 distinct authors from 314 institutions. Engineering and computer science were found to be the main scientific fields involved in BIM research. Architectural design are the central theme keywords, followed by information theory and construction industry. The final stage of the study focuses on the detection of clusters in which global research in this field is grouped. The main clusters found were those related to the BIM cycle, including construction management, documentation and analysis, architecture and design, construction/fabrication, and operation and maintenance (related to energy or sustainability). However, the clusters of the last phases such as demolition and renovation are not present, which indicates that this field suntil needs to be further developed and researched. With regard to the evolution of research, it has been observed how information technologies have been integrated over the entire spectrum of internet of things (IoT). A final key factor in the implementation of the BIM is its inclusion in the curriculum of technical careers related to areas of construction such as civil engineering or architecture.

**Keywords:** building information modeling (BIM); legal aspects; bibliometric; sustainability; clustering

## 1. Introduction

The growing requirements for establishing sophisticated buildings are making AEC (Architecture Engineering and Construction) projects more complex, while technological advances are helping the participants to collaborate more effectively during the construction process. In fact, the building information model (BIM) provides an intelligent model-based process that connects AEC professionals and helps them to design, build, and operate building infrastructure [1]. This tool allows professionals to design 3D models that incorporate data associated with physical and operational properties, which will help architects, engineers, and contractors to work on a coordinated digital model, giving everyone a better insight into how their work fits in the overall project [2]. BIM systems encourage greater cooperation between stakeholders through a unique integrated model during the design and construction stages. Adopting BIM in the construction industry will lead eventually to a better planning and preparation process by detecting conflicts between elements and improving coordination. In addition, it will help reduce time costing errors and help decision makers to increase their efficiency during the construction phase, and finally will help facilities management with future changes and renovation work.

# Second Publication

Chihib Mehdi; Salmerón-Manzano Esther and Francisco Manzano-Agugliaro. "Benchmarking energy use at University of Almeria (Spain)." *Sustainability* 12.4 (2020): 133

*sustainability*

*Article*

# Benchmarking Energy Use at University of Almeria (Spain)

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**Abstract:** Several factors impact the energy use of university campus buildings. This study aims to benchmark the energy use in universities with Mediterranean climates. The University of Almeria campus was used as a case study, and different types of buildings were analyzed. The second goal was to model the electricity consumption and determinate which parameter correlate strongly with energy use. Macro-scale energy consumption data during a period of seven years were gathered alongside cross-sectional buildings information. Eight years of daily outdoor temperature data were recorded and stored for every half hour. This dataset was eventually used to calculate heating and cooling degree-days. The weather factor was recognized as the variable with the greatest impact on campus energy consumption, and as the coefficient indicated a strong correlation, a linear regression model was established to forecast future energy use. A threshold of 8 GWh has been estimated as the energy consumption limit to be achieved despite the growth of the university. Finally, it is based on the results to inform the recommendations for decision making in order to act effectively to optimize and achieve a return on investment.

**Keywords:** benchmark; campus energy consumption; heating and cooling degree-days; energy model; occupancy rate

## 1. Introduction

Fuel constraints are a relevant issue in both industrialized and developing countries and are related to energy prices and accessibility of energy services [1]. Public buildings such as universities, schools. and hospitals are challenged to manage the exponential growth of their energy demand and transform their buildings into energy efficient ones. The design of buildings should logically be adapted to the lowest energy consumption levels, but in most cases, it is necessary to focus on existing buildings [2]. Therefore, the reduction of both energy consumption and $CO_2$ emissions from buildings is one of society's main targets today [3]. In Spain, there is a climatic classification according to the technical code of the building that contemplates these issues, which has been mandatory since 2006 [4]. Acting as models for communities, universities are supposed to provide innovative solutions through research in order to support the sustainability and reduce the carbon footprint [5]. One of the key operating aspect for universities is related to enhance students and teachers comfort levels, which may have a significant effect on their performance [6]. Visual, acoustic, and thermal comforts should not be considered as luxuries but rather as basic standard for schools [7]. However, maintaining indoor quality will eventually lead to a significant growth of electricity consumption; therefore, transforming university locals into energy efficient ones is a necessity. To ensure that these locals have optimal energy performance, researchers and professionals have developed management systems such as energy benchmarking and energy audit [8].

# Third Publication

Mehdi Chihib, Esther Samerón-Manzano, Mimoun Chourak3 Alberto-Jesus Perea-Moreno, and Francisco Manzano-Agugliaro . "Impact of the Covid-19 Pandemic on the Energy Use at the University of Almeria (Spain)".

*Sustainability* (Under review)

sustainability

MDPI

Article

# Impact of the Covid-19 Pandemic on the Energy Use at the University of Almeria (Spain)

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**Abstract:** Covid-19 pandemic has caused chaos in many sectors and industries, in the energy sector the demand has fallen drastically during the first quarter of 2020, the University of Almeria campus has also declined the energy consumption in 2020, through this study we aim to measure the impact of closing the campus on the energy use of its different facilities. We build our analysis based upon the dataset collected during the year 2020 and previous years, patterns evolution through time allows us to better understand the energy performance of each facility during this exceptional year, we have rearranged the university buildings into categories, and all the categories reduced their electricity consumption share in comparison with the previous year of 2019, furthermore, the portfolio of categories presented a wide range of ratios that varies from 56% to 98%, the library category was found to be the most influenced and the research category was found to the least influenced, this open questions like why some facilities were influenced more than others? What can we do to reduce the energy use, even more, when the facilities are closed? The university buildings present diverse structures that reveal different energy performance, which explain why the impact of such event (Covid-19 pandemic) is not necessarily relevant to have equivalent variations. Nevertheless, some management deficiencies have been detected, and some energy savings measures are proposed to achieve a minimum waste of energy.

**Keywords:** Energy consumption; Covid-19; Energy savings; Energy performance; University buildings

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## 1. Introduction

The international energy market has known different fluctuations inflicted by the Covid-19 pandemic situation in 2020, energy demand and oil prices plummeted in early march of 2020 due to the Covid-19 outbreak throughout the globe when governments were urged to ban travel on the national and international level [1]. The lock-down of businesses and commerce has decelerated world trade, which caused a global recession in 2020, the world gross domestic product (GDP) shrunk by 4.4% [2]. On the other hand, global electricity demand fell by 5%, which led to a positive impact on the environment,