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Sustainable Design Protocol in BIM Environments: Case Study of 3D Virtual Models of a Building in Seville (Spain) Based on BREEAM Method

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Abstract: One of the key problems facing the construction industry concerns the requirement to integrate sustainability criteria that effectively reduce the environmental impact throughout the lifecycles of buildings. For this, it is necessary to use digital tools with the capacity to evaluate the environmental performance of the different solutions proposed through the design process. In this context, the objective of this study was to establish a protocol of sustainable standards defined by the Building Research Establishment Environmental Assessment Method (BREEAM), employing building information modeling (BIM) technology to simplify the integration of these indicators in the initial phases of the design process. This study focuses on a case study associated with the use of BIM technology and the BREEAM method. The results of the analysis enable us to define which of the BREEAM indicators can be integrated into and evaluated in BIM environments in the initial phase of the design process and to identify the environmental improvements and economic costs associated with these indicators. This study concludes that the indicators associated with the geometric and spatial definition of the building are the most influential in improving sustainability in the initial design phase, without requiring significant economic investment. In turn, these are easy parameters to evaluate using BIM, reducing design times compared to the use of traditional tools; this facilitates their involvement in the design phase and enables them to have a real impact on improving the environmental conditions of the final construction.

Keywords: building information modeling; lifecycle analysis; BREEAM; sustainable design; 3D virtual models; construction industry

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1. Introduction

In light of the current context of climate change and the global energy crisis, it seems necessary to invest in the development of measures that guarantee sustainability and reduce the environmental impact of any activity linked to the development of human life [1]. One of the sectors that is clearly affected by this problem is the construction industry. Numerous initiatives aimed at achieving these objectives have been proposed in recent years, such as the obligation to comply with a certain level of energy demands and emissions associated with energy certification [2]. However, the effective results provided by these mechanisms do not meet the required needs.

Part of the problem is that these assessments are usually completed once buildings have been fully designed. Therefore, there are few opportunities to introduce design changes to improve environmental performance, and these changes generally only have an impact on energy-related areas [3]. In addition, these changes are usually associated with additional construction costs. Therefore, it is important to use design tools that integrate information associated with the environmental performance of the defined elements, in order to evaluate their behaviors under sustainability criteria from the initial stages of the process [4]. This paper focuses on building information modeling (BIM) technology, which is aimed at the development of three-dimensional virtual models with the ability to manage geometric, constructive, and material information, costs, maintenance, and energy performance [5].

Based on the use of this tool, it is important to consider sustainability criteria that go beyond energy efficiency [6]. Currently, buildings are only required to meet a minimum level of energy demands and CO_2 emissions. However, the calculation of the environmental impact of a building throughout its lifecycle is influenced by many other indicators that contribute to improving sustainability [7]. In this regard, the international seals of sustainable quality have emerged as internationally recognized standards of sustainable indicators in buildings. Thus, compliance with the criteria adopted by these labels helps to mitigate the environmental impact of the lifecycles of buildings on the environment [8], providing a credible label for the energy status of buildings and stimulating demand by creating value for sustainable buildings.

The problem is that numerous indicators are implicated in the fulfillment of the criteria adopted by these labels, which complicates the process. Therefore, evaluations are usually carried out by specialized managers, which entails increased costs and the extension of deadlines associated with the process of designing and constructing a building. To address this problem, this study aims to define a simplified indicator protocol associated with compliance with these green seals, which can be integrated in a simple way into the development of BIM virtual models in the initial phases of the design process. Using this protocol, it will be possible to evaluate the behaviors of these parameters in the design phase, test different solutions, and opt for the most appropriate ones, obtaining a positive result in terms of the environmental impact of the final construction.

Current Energy Assessment Mechanisms and Sustainable Standards According to Green Seals

As a first step to achieving this objective, many sustainable regulations and policies have been defined in different regions. Although the environmental impact assessment and lifecycle of a building involve various parameters [9], the first aspect that has been regulated is the energy efficiency of buildings. The purpose of these mechanisms is to analyze the energy situation of the current building stock and define parameters to quantify the energy improvements that can be implemented to reduce the energy demands and dependence on sources derived from oil, as well as CO_2 emissions [10]. This involves analyzing three key elements: the building envelope and its energetic behavior [11]; the consumption of energy from facilities and equipment; and the use of renewable energies.

The combined study of these aspects results in a value for the energy demands required by the building to maintain comfortable conditions, and a value of CO_2 emissions associated with the maintenance of these conditions [12]. Both values are represented through a scale that classifies the building using letters A to H, with A being the value signifying the lowest demand and the lowest CO_2 emissions.

The energy certification for new buildings recognized in Spain by the Ministry for Ecological Transition and Demographic Challenge is the one carried out using the Lider-Calener Unified Tool (HULC in Spanish) or the residential energy rating abbreviated method (CERMA in Spanish) [13]. Its compliance for all buildings in Spain is mandatory by regulations.

However, together with energy assessment parameters, it is necessary to incorporate indicators that influence the environmental impact of the lifecycle of the building, which implicates all the phases associated with the construction process [14]: the manufacture of materials; the transportation of materials; construction; the operation of the building; demolition; and waste management. At the same time, in addition to the criteria of the reduction in energy demands and emissions, it is necessary to incorporate parameters such as the use of durable materials; the design of flexible buildings that can adapt to changes in a simple way; the design of suitable maintenance to reduce the building's environmental impact throughout its lifetime; and ensuring the reuse and recycling of materials.

In this regard, the green quality certification seals appear to establish strategies aimed at improving sustainability conditions in buildings [15] and evaluating the presence of energy efficiency standards, the use of alternative energies, the improvement in indoor environmental quality, efficiency in water consumption, the sustainable development of free spaces, and the selection of resilient materials. Therefore, this kind of certification represents an advance with respect to the tools described above, since it affects not only the energy efficiency of buildings but also their environmental impact and the control of their lifecycles in a more complex way. Compliance with these requirements allows the building to obtain the requested quality seal, which certifies it as a green building, promoting the improvement in the environmental impact of the construction industry.

Nowadays, there are different seals with international recognition that are worth mentioning. The Leadership in Energy and Environmental Design (LEED) certification was created in 1993 by the Green Building Council of the United States and soon saw more widespread use. The main objective of this certification [16] is to promote strategies that facilitate the global improvement in the environmental impact of the construction industry [17] through the evaluation of eight criteria [18]: location and transport, sustainable sites, water efficiency, energy and atmosphere, materials and resources, indoor air quality, innovation in design, and regional priority.

Another of the existing certification seals is WELL, developed by the International Well Building Institute (IWBI), which focuses on the health and comfort of the occupants of a building. In this case, there are nine evaluated concepts: air, water, feeding, lighting, thermal comfort, sound, materials, mind, and community.

In addition, the Passivhaus certification is intended to officially recognize the qualities of low energy consumption in buildings. It has its origin in the Passivhaus Institute in Darmstadt, Germany, in the 1990s. The objective is to achieve maximum comfort for users, improve indoor air quality, and reduce energy consumption, which means reducing the energy demands of the building during its useful life [19]. To this end, the concepts taken into account by this seal are the thermal insulation method, the thermal bridge limitation, the use of high-performance carpentry, airtightness, and the use of mechanical ventilation with heat recovery. In addition to these basic criteria, other factors, such as outdoor sun protection, natural ventilation and thermal inertia, equipment and efficient lighting, and heating and cooling facilitates, are considered.

Finally, there is the Building Research Establishment Environmental Assessment Method (BREEAM), a system for evaluating sustainability in construction projects that was developed by the Building Research Establishment (BRE) in the 1990s and adapted to local Spanish standards in 2009 [20]. The BREEAM evaluation centers around ten categories, which are management, improvement in terms of health and well-being, energy efficiency, transport, saving water, materials, waste management, ecological land use, contamination, and innovation.

It should be noted that all of these seals use similar objectives and procedures to carry out their environmental assessments. The one whose general objectives are the least typical is undoubtedly Passivhaus. However, this study focuses on the standards defined by the BREEAM seal, since it presents a European and more local vision, and it is adapted to certain countries' regulations, such as Spain. For this reason, it is the seal chosen by the promoter of the building that is the object of this study, located in Seville (Spain).

2. BIM Technology and Sustainable Design: Literature Review and Reference Studies

In addition to serving as a tool for the three-dimensional representation and visualization of projects, building information modeling (BIM) technology can simulate the situation of a project [21], enabling an analysis of the possible conflicts that may arise during the construction phase of a building [22], and facilitating the management and coordination of projects [23]. BIM allows for the three-dimensional modeling of geometries (3D), associating them with additional information to turn them into virtual constructive elements, which adds a fourth dimension (4D) to the process. While computer-aided design (CAD) software requires the user to interpret different lines representing a wall, a beam, or a pillar, in BIM, the program assigns thickness or materiality to these elements, which transform that geometry into a constructive component, moving from drawing to building virtual models [24].

In this context, this technology allows all the agents involved in the development of a project to carry out their work on the same platform, facilitating coordination between disciplines from the initial phases of the design process [25]. In this way, the BIM methodology consists of developing a virtual model, adjusted to reality in terms of design (dimensions, materials), and incorporating other factors of the project, such as the work plan, the quality of materials, commissioning, human resources, and the climatic conditions of the environment. In effect, it constitutes a simulation of reality that tests and carries out all the necessary changes during the design phase before they affect the construction [26].

Therefore, in addition to its third and fourth dimensions [27], BIM is associated with a fifth dimension of cost control (5D), a sixth dimension of incidence of sustainability and energy analysis [28] (6D), and a seventh dimension of maintenance and facility management [29] (7D), which makes this platform a virtual space suitable for the integral management of a building project during the construction and post-construction phases [30]. In this context, it is of interest to relate the use of BIM virtual models to the definition of sustainable parameters integrated during the design phase of a project, in order to evaluate different solutions and foresee their environmental behaviors in the initial phases of the design.

Focusing on the analysis of reference studies that use building information modeling (BIM) technology as an instrument for lifecycle analysis in the building design phase [31], we found multiple different approaches. On the one hand, some studies point to the value of using this technology to incorporate information into a virtual model to carry out environmental assessments during the design process [32]. However, the process of exchanging the data integrated into these models to other different simulation tools presents automation problems [33], which means that it is necessary to use manual or semi-automatic methods [34] (conventional spreadsheets) to establish a relationship between the BIM model and the lifecycle assessment; this issue is noted by Tajda et al. and Carvalho et al.

Despite this initial difficulty, the advantages of using BIM for the design and evaluation of buildings are clear, not only for its use in the design phase but for the proper definition of the deconstruction of the building in a digital environment. In this way, researchers including Arghavan et al. highlight the use of this technology in the study of waste management, the use of recyclable materials, or the management of information regarding the raw materials used [35]. However, problems related to the interoperability of information also hinder the diffusion of this technology in this field [36].

To help improve the automation process, researchers such as Llatas et al. propose a systematic approach for implementing automation in an analysis of lifecycles in BIM through a harmonized data structure that enriches BIM objects [37] and the integration of new parameters into the Industry Foundation Classes (IFC) exchange format. In this way, it is possible to visualize the results of the evaluation in real-time and to identify the most beneficial solution. It is true that on many occasions during the design phase, there are many parameters that are not yet defined. Therefore, as Zhen et al. point out, it is a phase in which information, constructive knowledge, and environmental, social, and economic impacts are taken into account in general terms [38] with the help of BIM. From this initial model, through the simulation process, the design is optimized before the final definition phase of the project starts.

Researchers including Soust et al. also point to the lack of information during the initial design stage, in response to which they propose the development of a detailed data structure that supplies the indicators that are not yet defined [39]. In this way, the designer can begin to use estimated information regarding decisions not yet made and evaluate the improvements that produce changes for the parameters of interest in this phase of work, which are generally related to the structure, envelope system, and finishes of the building. In addition to these aspects, a key issue that can initially be integrated into the process of developing a BIM model is related to lighting [40], as Montiel-Santiago et al. [41] point out. In this way, it is possible not only to develop a virtual model with the ability to analyze the energy efficiency associated with the artificial lighting of a building but also to design the envelope under the parameters of efficiency in terms of natural lighting and ventilation.

On the other hand, there are studies such as that conducted by Samad et al., which advocate for the integration of BIM technology and the Internet of Things (IoT) [42] for the purpose of evaluating sustainability in construction. In this way, the BIM virtual model developed in the design phase will, in the construction and maintenance phases, take on an additional role by integrating sensors for the monitoring of building behavior [43].

All these studies show the value of integrating BIM in the analysis and evaluation of the lifecycle of a building. However, as Oludolopa et al. point out, there are still important barriers that hinder the implementation of BIM in construction projects [44]: the costs associated with the integration of this technology, the deadlines required to develop an adequate virtual model, the lack of standards for its use, and the lack of qualified personnel who can use this tool in an effective way. Regarding the lack of standards, and focusing on the sustainable quality seals mentioned above, studies such as that of Macías et al. advocate for the integration of sustainable indicators in the design of buildings [45] as a way to influence the reduction in their environmental impact during their lifecycle.

In this context, the general objective of this study is to establish a protocol of sustainable standards collected by BREEAM to be considered when starting a design process. We achieve this through the development and simulation of virtual BIM models to improve lifecycle analysis in buildings. To this end, several specific objectives are defined:

- Facilitating the introduction of sustainability standards in buildings from the initial design phases, so that they do not require subsequent changes.
- Avoiding the requirement of specialized agents at such early stages of the design process.
- The protocol allows us to establish a clear scale of values to be considered from the beginning of the design process; these affect the decision-making process and have a tangible impact on the final result.
- The information is centralized in a BIM platform capable of managing information that can be evaluated in the initial design phases.
- BIM technology helps to reduce lead times in the design process of sustainable standards versus traditional design and simulation tools.

As such, the main contribution of this study is that the sustainable design criteria introduced here will have a real impact on the design process from the initial stages, without requiring the introduction of extra agents or costs to the design process and reducing the design and simulation times. These characteristics could facilitate its dissemination in the construction sector and the substantial improvement in the environmental impact of buildings throughout their lifecycles.

3. Materials and Methods

To achieve this objective, on the one hand, a literature review was carried out to define the context in which the research is framed and previous lines of work, in terms of the mechanisms of energy analysis, environmental impact, and lifecycle analysis in buildings; the definition of green certifications in buildings; and studies that integrate the use of building information modeling (BIM) in the analysis of sustainability in the construction sector [46].

On the other hand, this study focuses on the results achieved by a real case study designed using BIM technology under the conditions of the Building Research Establishment Environmental Assessment Method (BREEAM) certificate. The selected case is a multi-family residential building of 125 homes, commercial premises, parking lots, and interior urbanization located in the east of Seville (Spain). This case study was chosen as a reference as it responds to several of our research questions: it is a project that employs BIM technology from the initial phases of the design process; the developer of the building requires compliance with the conditions defined by the BREEAM green certificate, one of the most relevant certificates in the Spanish context; it is the first residential building with this seal that follows the parameters established by the 2020 protocol in Andalusia; and the author of this study is part of the BIM design team of the project and is familiar with the work process carried out.

The design work of the project under study took place between March and December 2020. The construction phase started at that time and finished in September 2022. In parallel to the design and construction work of the building, the BREEAM seal was processed, obtaining positive certification for the design phase in February 2022 and for the post-construction phase in January 2023; the project was classified as Good, with 52.75% points. All the design and monitoring work developed was carried out using BIM technology.

Once the case study to be analyzed had been defined, we defined the work plan, as shown in Figure 1:

1. The sustainability indicators associated with compliance with the BREEAM seal were defined, focusing on those related to decision-making in the initial phase of the design process. Additionally, the standards considered in this study have to address four fundamental aspects:
    - The standards considered can be classified as geometrical/spatial parameters or material/energetic parameters.
    - The standards considered can be integrated into a virtual BIM model for evaluation in the design phase [47].
    - The standards can be evaluated directly in a BIM environment [48].
    - The standards can be evaluated through an external evaluation, to which data from BIM are transferred.
2. Once the standards used in this study were selected, we defined how each one of them should be integrated into the BIM model to be evaluated, according to the case study analyzed.
3. According to the measures adopted in the case study for each standard, the results of the BREEAM seal evaluation were presented, in order to determine the environmental performance of the designed solutions according to the score obtained, to analyze the cost associated with the measures proposed for each standard, and to assess their impact on the total work.
4. Finally, a protocol of sustainable indicators was defined, which includes a list of BREEAM standards to evaluate in the BIM environment during the initial phases of the design process, according to the results of this study. These standards are evaluated, comparing the estimated time to model and evaluate them in BIM with the time necessary to perform this task through traditional design systems (without the use of BIM).

3.1. Definition of BREEAM Method to Follow

Once the working method to be used in the study has been defined, we delve into the Building Research Establishment Environmental Assessment Method (BREEAM), certification method that serves as a reference. The methodological scheme developed to obtain this certification varies depending on the type and use of the building, distinguished by five categories: BREEAM urbanism, BREEAM housing, BREEAM new construction, BREEAM in use, and custom BREEAM, in the case of unique buildings that do not fall into the categories of new construction and housing. In the case study analyzed, we focus on the work scheme BREEAM housing. The certification process is carried out by a BREEAM-accredited advisor, and is separated into two phases:

- The design phase (FD): this leads to obtaining a provisional BREEAM classification, occurring before the start of the works but in a design phase that is sufficiently advanced to be able to carry out the evaluation (usually the project execution phase). However, in the initial phase (basic project), there are already standards that can be integrated into the design process to ensure compliance with the conditions of the seal.

- The post-construction phase (FPC): this leads to the as-built building obtaining a final BREEAM classification. This evaluation is carried out either by supplementing the evaluation carried out at the design stage or, when there has been no evaluation at the design stage, by carrying out a complete evaluation.

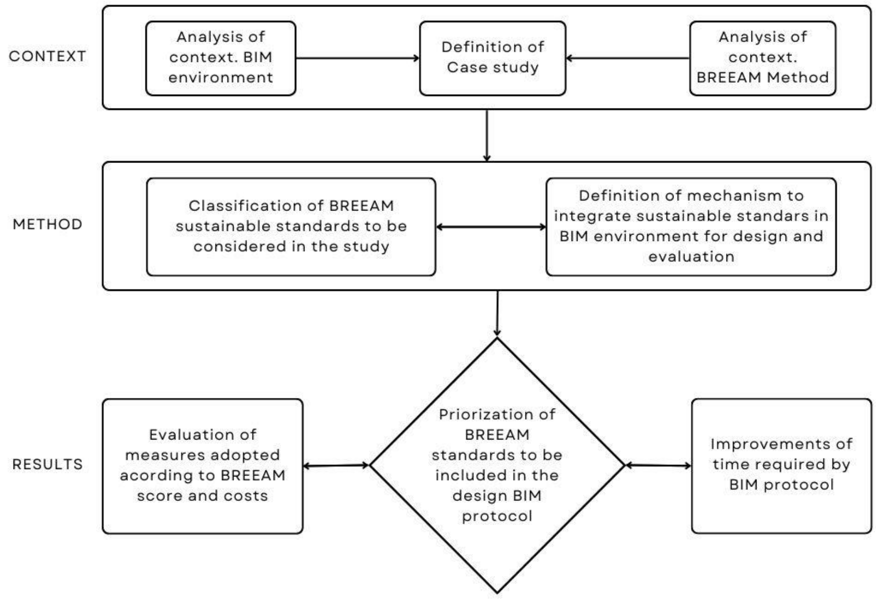

Figure 1. Flow chart of the research methodology.

Focusing on the early stages of the design phase, we describe the standards considered by the BREEAM method that are included in this study, as defined by the BREEAM work scheme [49]. Therefore, the parameters marked in green in Table 1 are those included in this study as they can be taken into account in the initial phases of the design process.

Table 1. Scheme of categories and standards defined by the BREEAM seal for compliance with sustainability conditions in a building. The standards highlighted in green are those included in this study, related to the initial phases of the design process.

Management	Health and Wellness	Energy	Transport	Water	Materials	Waste	Soil and Ecology	Contamination	Innovation
Project management	Visual comfort	Energy efficiency	Public transport	Water consumption	Shelf life of materials	Demolition Materials Management	Emplacement	Refrigerants	Innovation
Lifetime planning	Indoor air quality	Lighting	Services	Leak prevention	Responsible sourcing	Recycled aggregates	Ecological value	NOx emissions	
Responsible construction	Thermal comfort	Low-carbon installations	Alternative transport	Efficient network	Durability	Household waste management	Ecological improvement	Runoff water	
Delivery of the building	Acoustic efficiency	Efficient transport	Mobility plan		Efficiency	Climate change	Impact on biodiversity	Noises	
Post-occupancy tracking	Accessibility	Efficient equipment	Home office				Erosion control		
	Natural hazards	Drying spaces							
	Recreational spaces								
	Water quality								

- Health and wellness aspects:

One important aspect to be analyzed here is the visual comfort of the building. This includes the natural lighting strategy of rooms. Another aspect that is relevant to wellness in buildings is the indoor air quality guarantee, which is linked to the natural ventilation of rooms. Thermal and acoustic comfort conditions are also important elements for health issues. Finally, we point out the compliance with accessibility conditions, by defining the appropriate design of public access routes to buildings; and the requirement to define recreational spaces associated with the building (private outdoor spaces that meet adequate size and accessibility criteria, such as private gardens, terraces, and balconies), as well as free spaces for the use and enjoyment of the community.

- Energy aspects:

One important element of this category is the energy efficiency of the building, according to the parameters established in the current regulations. Some parameters that relate to this calculation are the design of efficient artificial lighting systems in private and common areas of the building and the use of low-carbon energy-generation sources associated with the facilities and equipment in the building to guarantee comfortable conditions, as well as the use of energy-efficient systems such as elevators and equipment. One parameter linked to the first phase of the design is the requirement to define drying spaces in homes (laundry rooms) whose dimensions are adequate for the surface area of the house.

- Transport-related aspects:

One relevant parameter for defining a sustainable protocol for the lifecycles of buildings is linked to a reduction in transport and the consumption of energy in the city. In this context, an important issue to include during the design phase is the definition of a mobility plan for the building, associated with a system of shared-use vehicles, the design of facilities for the recharging of electric cars, and locations for bicycle parking. Therefore, it is important to design houses that are compatible with the use of home offices, providing them with adequate space and facilities for the undertaking of teleworking at home. The design of coworking spaces in buildings is also valued.

- Water-related aspects:

With a lower influence in the initial phase of the design, the seal defines the importance of analyzing the conditions of water consumption that guarantee its quality, as well as the definition of efficient equipment within the water supply network.

- Aspects related to materials:

Although the selection of materials is not a specific task linked to the initial phase of the design, it is important to take into account the importance of their impacts in the lifecycle of the building in order to responsibly procure construction products during the execution of works. Therefore, the definition of materials in the design process is oriented to their durability and resilience, as well as their efficiency.

- Waste aspects:

As is the case for the parameters related to materials, waste-related aspects are not considered in the initial phase of the design. However, one specific standard to be taken into account in the design phase is the study of the domestic waste-management model for housing, defining the interior and exterior composting areas, as well as locating bins in common areas.

- Aspects related to land use and ecology:

In this section, the seal defines some aspects that are important in the initial stages of designing a building, such as the requirement to improve the ecology of the site. Therefore, green outdoor spaces are designed according to the criteria of specialists and by using native species.

3.2. Parameters and Data Considered to Develop the Work: Classification of BREEAM Standards

Once the BREEAM standards have been defined, we point out which parameters and data are taken into account to classify them to develop the work as outlined:

1. Type of standard to be integrated into BIM:

The first classification relates to whether standards are associated with geometric and spatial issues of design, or whether they relate to the choice of materials, equipment, and facilities. Each of them is characterized by:

- Standards associated with the geometry and spaces of the building: When working on the development of a virtual BIM model associated with a design phase, certain key elements affect its environmental performance. They are usually linked to aspects such as the orientation of the facades within the plot, the orientation of the different holes within the facade, and the location of these holes within the space to be naturally illuminated or ventilated.
- Standards associated with the materiality of the building: Additionally, in the initial design phase in BIM virtual environments, parameters such as the durability of materials, the selection of materials from native areas, and the use of recyclable or reusable materials or materials with insulating properties (thermal or acoustic) can be considered.
- Standards associated with the equipment and facilities in the building: The design of spaces that facilitate the optimization of the facilities and equipment in the building, as well as the definition of efficient equipment and facilities or the use of renewable energies, are important points to consider.

From this definition, we classify two types of action within the work protocol to integrate green standards from the BREEAM criteria in the initial phase of the design process: actions linked to the definition of geometry and spaces, which are defined in BIM as three-dimensional geometries, and actions linked to materials, facilities, and their efficiency, which are defined in BIM as information associated with the modeled geometry.

2. Type of standard to be evaluated:

Depending on the environment in which a standard is evaluated, it can be classified according to the following categories:

- Standards that can be analyzed directly in a BIM environment: In other words., analysis through the sunlight module of the software, in this case Allplan 2022, through simulation and automatic testing programs associated with the Industry Foundation Classes (IFC) BIM exchange format, in this case the Solibri Model Checker 2019.
- Standards that have to be analyzed in platforms external to BIM: In other words, analysis through other simulation tools. It is important to transfer the information associated with the BIM model to this software, in this case Dialux evo 9.2., for lighting simulation, or the residential energy rating abbreviated method (CERMA V.4.2.5 in Spanish)/Lider-Calener Unified Tool (HULC 2019 in Spanish) for energy efficiency simulation.

3.3. Parameters to Evaluate the Results Obtained

Once the standards were implemented in the case study, BREEAM analyzes the building to certify it. Based on this assessment, we can define the following standards:

1. Evaluation of the results provided by BREEAM

On the one hand, the BREEAM seal offers a score for each standard analyzed. The total score achieved is the sum of all standards (between 0 and 100), and these total points define the BREEAM classification of the building, according to Table 2. Since the study focuses on selected standards, a weighting of the score of these standards with respect to the total is carried out, to define the best- and worst-scored standards.

Table 2. Certification scale of the green seals of BREEAM.

Scale	Not Classified	Passed	Good	Very Good	Excellent	Exceptional
Score	Under 30 points	30–44 points	45–54 points	55–69 points	70–84 points	More than 85 points

On the other hand, the implementation of a standard in the case study analyzed has an economic cost. This study analyzes the percentage increase in the cost of each standard with respect to the total cost of the work analyzed.

2. Evaluation of the standards integrated into the defined protocol

Once the most relevant standards for this study have been selected to be part of the work protocol, they are analyzed to define the improvements introduced according to the following criteria: the estimated time to implement the standard and evaluate it in BIM, and the estimated time to implement the standard and evaluate it using traditional design methodologies.

To perform this, we define specific tasks associated with the priority standards included in the BIM model developed, in order to compare the time required for this work with the time estimated to perform it through CAD tools and manual evaluation.

4. Results

From the development of the work described above, we define the results achieved. Table 3 shows a classification of the different sustainability indicators defined by the BREEAM seal according to whether the indicator can be integrated during the initial stage of the design process; whether the type of intervention associated with the indicator affects the geometry and spaces designed in the building or the materials and system of the facilities chosen; whether the indicator can be integrated into the BIM model; whether the indicator can be evaluated in a BIM environment; and whether the indicator can be evaluated in an alternative software by transferring information from the BIM model.

4.1. Characteristics of the Standards Implemented in the Case Study Analyzed

Based on these indicators, we define the characteristics of the measures addressed in the case study that meet the requirements of BREEAM, after entering these data into the BIM model and evaluating different design alternatives according to the noted mechanisms.

Table 3. Scheme of BREEAM standards according to the categories defined by the study method.

BREEAM Sections	Indicators	Initial Stage of Design	Type of Element	BIM Integration	BIM Evaluation	Alternative Evaluation
HEALTH and WELLNESS	Visual comfort	x	Geometry	x	Sunlight module	Dialux
	Indoor air quality	x	Geometry	x	Solibri Model Checker	
	Thermal comfort	x	Geometry/Efficiency	x	Solibri Model Checker	HULC/CERMA
	Acoustic efficiency	x	Geometry/Efficiency	x	Solibri Model Checker	
	Accessibility	x	Geometry	x	Solibri Model Checker	
	Recreational spaces	x	Geometry	x	Solibri Model Checker	

Table 3. *Cont.*

BREEAM Sections	Indicators	Initial Stage of Design	Type of Element	BIM Integration	BIM Evaluation	Alternative Evaluation
ENERGY	Energy efficiency	x	Efficiency	x		HULC/CERMA
	Lighting	x	Efficiency	x	Solibri Model Checker	HULC/CERMA/Dialux
	Low-carbon installations	x	Efficiency	x		HULC/CERMA
	Efficient transport	x	Efficiency	x		HULC/CERMA
	Efficient equipment	x	Efficiency	x		HULC/CERMA
	Drying spaces	x	Geometry	x	Solibri Model Checker	
TRANSPORT	Mobility plan	x	Geometry	x	Solibri Model Checker	
	Home office	x	Geometry	x	Solibri Model Checker	
WATER	Efficient network	x	Efficiency	x	Solibri Model Checker	
MATERIALS	Durability	x	Geometry/Efficiency	x	3D Visualization	HULC/CERMA
WASTE	Household waste management	x	Geometry	x	Solibri Model Checker	
SOIL AND ECOLOGY	Ecological improvement	x	Geometry	x	Solibri Model Checker	

4.1.1. Geometrical and Spatial Design Actions

When the standard to evaluate is linked to a geometrical or spatial definition, the BIM tool facilitates the three-dimensional construction of virtual models to perform geometric analysis.

1. Analysis of visual comfort: it is important to produce an adequate design in terms of guaranteeing the natural lighting conditions of the different rooms of the building, which means selecting a suitable orientation. In addition, it is necessary to properly size the holes to ensure the adequate lighting of the rooms (10% of the useful surface area of the space to be illuminated). In this regard, the BIM tool ensures the following from the beginning of the design process:

- Including the latitude and altitude of the building in the project definition parameters.
- Incorporating three-dimensionally the adjacent elements and buildings that may affect the generation of shadows on the faces of the designed building.
- Performing sunlight analysis by testing on the virtual model the behavior of natural lighting for different times/days/months.
- Estimating, based on the surface area of the gap in relation to the surface area of the room, whether the natural lighting parameters defined by the BREEAM standard are met, in this case, evaluating whether there is a window less than 5 m away from any point of the different rooms.

The analysis of natural lighting is undertaken using the sunlight model of Allplan 2020. It can be completed with an analysis in Dialux evo 9.2., to optimize the solution designed, or with the use of the Solibri Model Checker 2019 to introduce rules about the minimum distance from the windows to the different points of a room.

2. Guarantee of indoor air quality: as in the previous case, the presence of holes in the facades of the building not only seeks to guarantee adequate natural lighting but also ensures the consequent natural ventilation of rooms. In this way, and depending on the useful surface area of each room, we establish as a quality standard that at least 5% of the total surface area of the room is an open surface; we analyze compliance through a test conducted with the virtual model, in which the position and adequate distance of these holes are also determined. The analysis was carried out using the Solibri Model Checker 2019, introducing rules that relate to the surface areas of rooms and the distance to windows in the IFC virtual model.
3. Compliance with thermal and acoustic comfort: since the BIM tool facilitates modeling of the elements that make up the envelope of the building not as drawing elements but as constructive elements, we establish in the BIM virtual model the different layers that make up the facade, roof, and elements in contact with the unheated spaces in the building. In so doing, we define the type of insulating material to be used and its thickness, which ensures that, from the initial phases of the design process, the constructive elements have adequate thickness to comply with the conditions of thermal comfort. Therefore, there is a geometrical component, as well as associated information about its energy-related behaviors. The analysis was carried out using CERMA V.4.2.5, introducing the defined specifications for isolation materials in the BIM virtual model. For parameters not defined in the early stage of the design process, a generic value is considered. In the same way, we test whether the defined constructive elements comply with the acoustic insulation standards established by the regulations.
4. Compliance with accessibility conditions: this is a requirement of the BREEAM seal that has a direct impact on the social sustainability of buildings. At the same time, it is a solution that guarantees accessibility to a building, meaning that, in the future, it will not be necessary to incorporate mechanical elements such as lifting platforms, with their associated energy expenditure, to give access to people with reduced mobility. The BIM tool allows us to test whether the different spaces associated with the evacuation route of a building comply with the minimum dimensions established by the relevant regulations, as well as ensuring the presence of adequate slopes that facilitate access to spaces at different levels. The analysis is carried out using the Solibri Model Checker 2019, by introducing rules to check the adequacy of spaces designed according to accessibility requirements.
5. Design of recreational spaces associated with the building: in the initial design phase, attention must be paid to the importance of designing free spaces within the building with adequate dimensions, whether these are community or private spaces (gardens, terraces, balconies, etc.). It is important to test the fulfillment, among other factors, of the conditions of sunlight and natural lighting in these spaces, emphasizing the importance of giving the surface areas of these spaces suitable dimensions in relation to the height of the building. The analysis of this parameter is carried out using the Solibri Model Checker 2019, introducing rules to assess the adequacy of these designed spaces.
6. Design of drying spaces: to avoid the use of mechanical drying equipment, with the consequently associated energy consumption, it is important to include spaces with natural ventilation, in which the drying of clothes can occur in residential buildings. These spaces must have adequate dimensions and be proportionate to the total size of the house and the estimated number of occupants. This analysis is carried out using the Solibri Model Checker 2019, introducing rules to assess the adequacy of these spaces in relation to the requirements of BREEAM.
7. Design of a mobility plan in the environment of the building: promoting the use of alternative means of transport to those dependent on oil is linked to the existence of space for bicycle parking, which helps promote the use of this means of transport. The analysis is carried out using the Solibri Model Checker 2019, introducing rules to

assess the adequacy of the surface area designated for bicycle parking according to the BREEAM standard.

8. Design of housing to reconcile the use of home offices: with the boom in home working experienced in recent years, this measure is proposed as a means of reducing displacement for those who undertake their professional work at home. For them, the design of spaces at home with characteristics and dimensions suitable for working is proposed. This analysis is carried out using the Solibri Model Checker 2019, introducing rules to assess the adequacy of the surface area of rooms designated for home working according to the BREEAM standard.
9. Impact of the use of materials on the lifecycle of the building: although decisions related to the use of materials do not have to be made during the initial design phase, there are issues of an aesthetic nature that are related to the appearance of certain materials that affect the final result of the design. Therefore, it is important to prioritize native materials that are linked to the area where the work is being undertaken, and which are durable, easy to maintain, and have the capacity to be reused in the future. The three-dimensional representation in the BIM virtual model enables the appearance of different material solutions to be tested so that the designers can opt for the most appropriate ones based on these parameters. Therefore, there is a geometrical component, as well as associated information about its energy-related behaviors. The visual analysis used to choose between different materials can be developed in a BIM environment (Allplan 2020 in the case study). Nevertheless, the materials' energy-related behaviors should be analyzed using CERMA V.4.2.5.
10. Study of the domestic waste-management model: in the initial phases of the design process, it is necessary to undertake the adequate forecasting of spaces. This is the case for space destined for the accumulation of waste, whether collective or individual; there should be adequate surface areas in these rooms for the separation of waste and the recycling of the same. The analysis is carried out using the Solibri Model Checker 2019, introducing rules to assess the adequacy of the defined surface area according to the BREEAM standard.
11. Improvement in the ecology of the site: when the building is associated with green outdoor open spaces, it is important to design these spaces according to sustainable criteria, encouraging the use of native species to positively influence the building's possible impact on biodiversity. The analysis of this criterion is carried out using the Solibri Model Checker 2019, introducing rules to assess the adequacy of the surface areas defined for green spaces according to the BREEAM standard.

4.1.2. Definition of Materials and Facilities According to Efficient Design Criteria

When the standard to evaluate is linked to the energy-related behavior of the element designed, BIM facilitates the integration of this information into three-dimensional elements of the virtual model. However, the evaluation of these standards should be developed through a different software.

1. Energy efficiency: it is linked to geometric and material aspects (i.e., insulation thickness defined above) or the efficiency of equipment, included in other standards. Therefore, the evaluation of this specific standard, through CERMA V.4.2.5., is linked to the development of other defined standards.
2. Lighting: as in the case of natural lighting, it is essential to define an efficient artificial lighting system. Therefore, the process of designing facilities should consider not only the installation, but also the requirement to incorporate presence detectors, energy-saving luminaires, timers, or twilight clocks in the case of outdoor lighting. The analysis is carried out using CERMA V.4.2.5., introducing the defined specifications for the artificial lighting facilities designed in the BIM virtual model.
3. Development of the design of low-carbon facilities: this is a starting condition for the development of the design of the building's different facilities. In general, it involves the use of facilities associated with the generation of renewable energy. The design of

this type of facility requires reserved spaces to be taken into account at the beginning of the building design process. The analysis of the environmental performance of this indicator is carried out using CERMA V.4.2.5., introducing the specifications defined in BIM. Moreover, the adequacy of the reserved spaces' surface areas can be analyzed using the Solibri Model Checker 2019.

4. Energy-efficient transport systems and equipment: as noted above, the choice of elevators (transport) or heating/cooling equipment is not the subject of the initial design phases. However, it is important to note that the impact of the efficiency of this equipment will be of enormous relevance in the final environmental assessment of the building. The analysis of the environmental performance of this indicator is carried out through CERMA V.4.2.5.
5. Mobility plan and alternative modes of transport associated with the building and its surroundings: associated with the search for energy production mechanisms that are not dependent on oil, the design of garages and car parks is promoted by incorporating recharging equipment for electric vehicles. The analysis of the environmental performance of this indicator is carried out through CERMA V.4.2.5.
6. Efficient water network: although this is an aspect to be checked in more advanced phases of the design (i.e., the execution of the project), it is important to start with an adequate design of water supply facilities that are in strict compliance with the current relevant regulations. Likewise, efficient equipment must be used, optimizing the flow of water consumption and the design of separative networks for wastewater and rainwater. At the same time, it is important to effectively design the building's irrigation network.

4.2. BREEAM Evaluation of the Measures Adopted; Definition of Environmental Improvements and Costs

Once the aforementioned standards were integrated into the building taken as a case study, an evaluation of the results achieved by each of these indicators according to BREEAM was carried out. We now analyze, on the one hand, the indicators that are best valued by the seal in its environmental assessment, according to the points assigned to each one by BREEAM; on the other hand, the data concerning the economic costs associated with the implementation of each of the standards in the case study analyzed are expressed as a percentage of the total investment to be made.

In this way, Table 4 collates the data from the case study analyzed.

The information related to the score assigned by BREEAM to each of the standards is analyzed. BREAM analyzes the information of the project object of the case study and assesses the environmental value of each of the standards included in its methodology. In this way, we have the score of each standard and the sum of each of the sections included in the BREEAM method. From the global analysis of the BREEAM standards in the case study, the score assigned to the standards considered by this study is determined, marked in green. These standards are those that correspond to the initial phase of the design process, which can be integrated into the BIM model, previously specified. From the score of these specific standards, the weighted score of the standards selected for this study in relation to 100% of the points assigned by BREEAM is indicated.

Table 4. Results of the BREEAM evaluation of the indicators included in the initial design phase and associated economic costs. The cells highlighted in green are those included in this study, related to the initial phases of the design process.

BREEAM Section	BREEAM Standard	BREEAM Score	Total Score by Section	Score by Section of Selected Standards	Ponderated Score to 100% of Selected Standards	Economical Investment	Total Costs by Section	Total Costs of Selected Standards by Selection	Percentage of Costs Ponderated to 100%
MANAGEMENT	Project management	1.5	5			500	2000		
	Lifetime planning	1				500			
	Responsible Construction	1.5				500			
	Delivery of the building	1				500			
	Post-occupancy tracking	0				0			
HEALTH & WELLNESS	Visual Comfort	1.5	10.5	7.5	**19**	600	18,900	18,300.00	**32**
	Indoor air quality	1.5				600			
	Thermal Comfort	1.5				5100			
	Acoustic efficiency	1				5100			
	Accessibility	1				600			
	Natural hazards	1				300			
	Recreational spaces	1				6300			
	Water quality	2				300			
ENERGY	Energy efficiency	1.5	5.5	5.5	**13**	6300	26,700	26,700.00	**46**
	Lighting	1				3900			
	Low-carbon installations	0.5				6300			
	Efficient transport	0.5				4200			
	Efficient equipment	1				4200			
	Drying spaces	1				1800			

Table 4. *Cont.*

BREEAM Section	BREEAM Standard	BREEAM Score	Total Score by Section	Score by Section of Selected Standards	Ponderated Score to 100% of Selected Standards	Economical Investment	Total Costs by Section	Total Costs of Selected Standards by Selection	Percentage of Costs Ponderated to 100%
TRANSPORT	Public transport	2	7	3	**7**	200	4900	3000.00	**5**
	Services	1				200			
	Alternative transport	1				1500			
	Mobility plan	1.5				1200			
	Home office	1.5				1800			
WATER	Water consumption	2	4.5	1.5	**4**	300	3000	1200.00	**2**
	Leak prevention	1				1500			
	Efficient network	1.5				1200			
MATERIALS	Shelf life of materials	1.5	6	1.5	**3.75**	200	4900	3000.00	**5**
	Responsible sourcing	1				200			
	Durability	1.5				3000			
	Efficiency	2				1500			
WASTE	Demolition Materials Management	1	4	1	**3**	500	3700	2400.00	**4**
	Recycled aggregates	1				300			
	Household waste management	1				2400			
	Climate change	1				500			

Table 4. *Cont.*

BREEAM Section	BREEAM Standard	BREEAM Score	Total Score by Section	Score by Section of Selected Standards	Ponderated Score to 100% of Selected Standards	Economical Investment	Total Costs by Section	Total Costs of Selected Standards by Selection	Percentage of Costs Ponderated to 100%
SOIL AND ECOLOGY	Emplacement	1	5	1.5	**3**	300	6100	3600.00	**6**
	Ecological value	1				500			
	Ecological improvement	1.5				3600			
	Impact on biodiversity	1				1200			
	Erosion control	0.5				500			
CONTAMINATION	Refrigerants	1.25	3.75			1500	2600		
	NOx emissions	1.5				600			
	Runoff water	0				0			
	Noises	1				500			
INNOVATION	Innovation	1.5	1.5			1800	1800		
TOTAL		**52.75**	**52.75**	**21.5**	**52.75**	**74,600**	**74,600**	**58,200**	**100**

Information on the cost of implementing these standards in the case study is analyzed. The total cost of the work carried out amounts to 9,270,000 euros. Of this total, a total of 74,000 euros is allocated for the implementation of the BREEAM standards in the project, around 8% of the total investment. Table 4 shows the cost assigned to each of the standards defined by BREEAM in euros, which includes not only construction costs but also project management costs. From these data, the total expenditure assigned to each BREEAM section and the expenditure of the standards taken into account in the study are indicated, as in the previous analysis. Finally, the percentage of expenditure with respect to the total 100% that is invested in each of the BREEAM sections is indicated, considering the standards included in the initial phase of the design process and that can be integrated into BIM.

According to the results shown in Table 4, according to the criteria defined in the methods section, Table 5 and Figure 2 collate the percentage of points scored by the standards selected in this study, as well as the percentage of the economic costs in relation to 100%. In addition, the relationship between the percentage of costs associated with each section and its score is included, in order to define the best- and worst-valued standards, the best being the one with the lowest cost/score ratio.

Table 5. Relationship between points scored by BREEAM sections and economic costs associated with these standards.

BREEAM Section	BREEAM Score	Percentage of Economic Costs	Relationship Percentage of Cost/Score
MANAGEMENT	-	-	-
HEALTH and WELLNESS	19%	32%	1.68
ENERGY	13%	46%	3.54
TRANSPORT	7%	5%	0.71
WATER	4%	2%	0.50
MATERIALS	3.75%	5%	1.33
WASTE	3%	4%	1.33
SOIL AND ECOLOGY	3%	6%	2.00
CONTAMINATION	-	-	-
INNOVATION	-	-	-
TOTAL	**52.75%**	**100%**	

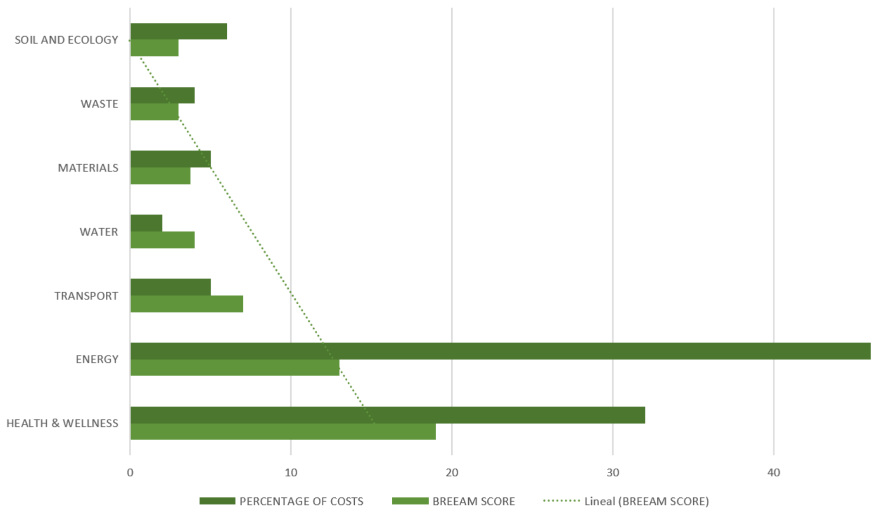

Figure 2. Graphical representation of the relationship between the score of the BREEAM evaluation and the economic cost of the actions developed to implement the BREEAM standards in this study.

Based on the results achieved after the environmental assessment of the BREEAM seal and analyzing the costs associated with the implementation of each of the indicators in the building, we make the following observations:

- The standards that are most important to the environmental improvement in the building are those linked to the health and wellness section, followed by the energy and transport indicators.
- The rest of the sections associated with the standards of the initial phases of the design process generate a moderate improvement in the environmental situation with respect to the total.
- The largest investment made to achieve these improvements pertains to energy and is closely linked to the improvement in the energy efficiency of the building, followed closely by the indicators of the health and wellness section.
- The relationship between the cost associated with each section and the improvement provided at the environmental level indicates that the most expensive investment is focused on the energy section, while transport and water are the most profitable sections.
- The health and wellness section is quite profitable since it does not require a high initial investment compared to the significant improvement it represents for the environmental status of the building.

4.3. Protocol for Defining Sustainability Standards in BIM during the Initial Phase of Design

According to the results analyzed in the study, we can state that the proposed design protocol of the BREEAM standards must prioritize the initiatives that are closely linked to spatial design criteria over the choice of materials and equipment. These issues are also usually the most important to define in the initial design process; therefore, testing sustainable solutions for the orientation of facades, the location of holes for natural lighting and ventilation, or the design of spaces to facilitate the flexibility of the building from the start of the project will make these decisions difficult to modify later on. The rest of the elements, which are mostly focused on the efficiency of the building at the energy level, are also important, but can easily be modified in later phases of the project development process.

Therefore, the sustainable BIM design protocol for the initial design phases consists of a series of prioritized standards according to their environmental and economic impact in the case study analyzed, as well as the BREEAM criteria. To define this protocol in more detail we will point out specific issues that characterize it:

- Steps:

The protocol is composed of two types of standards: on the one hand, those that we have defined as geometric and spatial, which can be integrated and evaluated directly in BIM, which makes it easy to include them in the initial phases of the design process and evaluate the proposed solutions directly. These standards will be considered a priority when applying the protocol; on the other hand, a secondary level of standards is defined, which relates to energy aspects. These aspects can be integrated into the BIM model as geometries and information, but in order to evaluate them we need additional software to export the BIM information, which makes it difficult to carry out evaluations in the early stages of the design process.

Therefore, the priority standards focus on the proper orientation of the buildings, the opening elements of their facades, and the correct dimensioning of their rooms to comply with the conditions of the flexibility of the building throughout its useful life, leaving a second phase of work for the energy checks.

- Features:

The designed protocol acts as a review list for the designer to check if he has taken into account the different standards included in it. In this way, in the initial phases of the design process, when there is greater freedom to make basic decisions about the project, the designer has a roadmap that allows him to immediately integrate sustainability standards well valued by labels such as BREEAM. At the same time, the protocol facilitates that the decision-making associated with these initial tasks can be carried out in BIM, as it can be modeled and tested in this environment.

- Time:

As noted throughout the text, the protocol is specifically designed to be used early in the design process. This means that the designer will have this review list during the first few days of work on the project. It is estimated that the priority standards defined in the protocol can be included in the BIM model and tested in this environment during the first week of work on the project.

- Potentials:

The defined protocol simplifies the work of integrating sustainable standards in the initial phases of the design process: on the one hand, because it includes issues that must be defined in the first few days of work on the project; on the other hand, because they are easy to introduce in BIM. In this way, the designer is encouraged to include sustainable standards in their projects that affect aspects linked to the useful life of their building, and not only energy aspects that are usually the easiest to include. In addition, being a simple protocol to include in BIM encourages the use of this technology and its expansion in the construction sector, since it is not necessary to have highly specialized personnel in this technology or introduce large costs or extend deadlines to develop the design work.

- Limitations:

Once the geometric and spatial standards included as priorities in the protocol have been defined, it is more complex to continue advancing with the incorporation of standards in the BIM model, mainly due to the difficulty of evaluating them outside the BIM environment. In this sense, it is necessary to deepen the knowledge of the BIM tool and facilitate the transfer of information from this environment to other software so that more BREEAM standards can be integrated into the BIM model as the design phases of the building progress.

Table 6 systematizes the standards included in the protocol, as defined throughout this study, prioritizing them as indicated. It includes aspects to consider when integrating these standards into the design and evaluation.

4.4. Testing of the Designed Protocol: Quantification of Deadlines Reductions

As a final evaluation of the proposed protocol, we analyzed the time invested in modeling and evaluating the BREEAM standards defined as a priority in the protocol in a BIM environment and in a CAD environment. In this way, we determined whether there is any quantitative benefit to implementing this working method, in addition to the qualitative improvement achieved in terms of the sustainability of the designed building. For this, different specific tasks are defined under the use of the protocol defined. Therefore, Table 7 shows these tasks to define the time used to develop and evaluate them in the BIM virtual model associated with the case study analyzed and compares it with the time estimated to perform the same task using traditional methods of design and evaluation, in this case, a CAD tool (Autocad 2020) and manual evaluation of the compliance of the requirements defined.

In this way, we can observe how BIM modeling reduces the design time and verification of compliance with the defined standards by 30%. In addition, we observe that although the distribution between the time saved is similar in the modeling and valuation work, this second one is the one that is more beneficial, assuming a saving of 17% of the estimated time compared to 13% saved in the modeling time. It is important to note that the standards analyzed are those defined as priorities in the protocol, that is, those associated with geometric and spatial aspects. Therefore, these are easy elements to model in a BIM environment and can also be evaluated in BIM. The second level of standards associated with the protocol concerns energy aspects that need an evaluation outside the BIM environment, which makes the work and evaluation times increase and approach those required to perform the work by traditional methods.

Table 6. Synthesis of sustainable standards protocol for the design of BIM virtual models. Cells in green indicate the standard analyzed, while blank cells refer to specific tasks to be performed associated with these standards.

Sustainable Standards Protocol for the Design of BIM Virtual Models	
Priority Standards to Consider	**Secondary Standards to Consider**
Geometry and Spaces	**Material, Facilities, and Equipment (Efficient)**
1. Analysis/simulation of visual comfort	**1. Energy efficiency**
Orientation of the building and its envelope (definition of facades to north/south/east/west prioritizing the orientation with greater lighting)	Linked to thermal and acoustic comfort: choice of insulating materials in facades and roofs and efficiency equipment
Dimensioning of holes for natural lighting (10% of the useful surface area of the space to be illuminated)	**2. Analysis/simulation of visual comfort**
Modeling of adjacent buildings and sunlight study (leftovers thrown on building facades and their effect on the building's natural lighting)	Efficient artificial lighting installation design: presence detector, timers
2. Indoor air quality	**3. Network design of low-carbon facilities associated with the use of renewable energies**
Dimensioning of holes in the facade depending on the surface area of the rooms to be ventilated naturally (5% of the total surface of the room)	**4. Use of efficient equipment and appliances**
3. Accessibility conditions	**5. Design of charging networks for electric vehicles**
Adequate dimensioning of accessible routes of the building for the passage of people with reduced mobility (according to mandatory accessibility regulations)	**6. Design of water supply network that guarantees its quality and responsible consumption**
4. Recreational spaces	
Design of gardens, terraces, balconies, or private patios (it will be verified that when a house has a terrace, it has an area greater than 10% of the surface area of the house)	
5. Drying spaces	
At least 5% of the total surface area of the house, with an outward ventilation area of at least 1 facade front	
6. Design of space reserved for bicycle parking	
In total, 20% of the total number of car parking spaces. A safe and accessible place will be allocated within the common areas of the building	
7. Design of spaces that facilitate the compatibility of the use of home office and coworking	
At least one secondary bedroom will have 10 m^2 of surface area and will have telephone sockets and an internet connection	
8. Forecasting of spaces for waste management	
Space destined inside the house for recycling containers, differentiating organic waste, packaging, and paper	
9. Design of sustainable green spaces that improve the impact on biodiversity	
When there are common free spaces, the presence of landscaped surfaces and vegetation will be enhanced. At least 20% of the total plot	

Table 7. Quantitative improvement in the BIM protocol defined. Evaluation of time invested in BIM compared to traditional methods (CAD). Cells in green indicate the standard analyzed, while blank cells refer to specific tasks to be performed associated with these standards and its quantification.

Evaluation of Sustainable Protocol (BIM)		
Priority Standards to Consider	**Time (Hours)**	
Specific Tasks	**BIM Method**	**CAD Method**
	Through Allplan	**Through Autocad**
Analysis/simulation of visual comfort		
Modeling of a building of 7 floors and 1500 m^2 of constructed area per floor, looking for the best orientation to optimize the natural lighting of your rooms	Modeling 3.0 h	Drawing 4.0 h
	Evaluation 0.5 h	Checking 1.0 h
Indoor air quality		
Dimensioning of windows with an area greater than 5% of the total rooms of the building described above, to meet adequate natural ventilation conditions	Modeling 0.75 h	Drawing 1.0 h
	Evaluation 0.25 h	Checking 1.0 h
Accessibility conditions		
Dimensioning of access routes to the aforementioned building complying with accessibility conditions (passage widths > 1.20 m; turning radii in corridors > 1.50 m)	Modeling 0.75 h	Drawing 1.0 h
	Evaluation 0.25 h	Checking 0.50 h
Recreational spaces		
Presence of terraces in all homes with width of 2.20 m minimum and dimension >10% of the useful surface area of the house	Modeling 0.75 h	Drawing 1.0 h
	Evaluation 0.25 h	Checking 0.50 h
Drying spaces		
Dimensioning of surface area of clotheslines >5% of the total surface area of the house	Modeling 0.75 h	Drawing 1.0 h
	Evaluation 0.25 h	Checking 0.50 h
Design of space reserved for bicycle parking		
Dimensioning of space reserved for bicycle parking with an area >20% of the area reserved for car parking	Modeling 0.30 h	Drawing 0.30 h
	Evaluation 0.20 h	Checking 0.20 h
Design of spaces that facilitate the compatibility of the use of home office and coworking		
Design of an additional bedroom per dwelling with an area >10 m^2	Modeling 0.30 h	Drawing 0.50 h
	Evaluation 0.20 h	Checking 0.50 h
Forecasting of spaces for waste management		
Dimensioning of kitchens in homes with an additional area of 1.5 m^2 for waste accumulation	Modeling 0.75 h	Drawing 0.50 h
	Evaluation 0.25 h	Checking 0.50 h

Table 7. *Cont.*

Evaluation of Sustainable Protocol (BIM)		
Priority Standards to Consider	**Time (Hours)**	
Specific Tasks	**BIM Method**	**CAD Method**
	Through Allplan	**Through Autocad**
Design of sustainable green spaces that improve the impact on biodiversity		
Common surface clearance >20% of the total plot area	Modeling 0.30 h	Drawing 0.30 h
	Evaluation 0.20 h	Checking 0.20 h
TOTAL	Modeling **7.65 h**	Drawing **9.60 h**
	Evaluation **2.35 h**	Checking **4.90 h**
	10.0 h	**14.5 h**
RATE REDUCTION		**−30%**

5. Discussion

Having defined the standards for the protocol to be integrated into the initial phases of the design process through the use of building information modeling (BIM) technology, we analyzed them, to determine the extent to which they contribute to knowledge in the field.

The environmental and energy analyses associated with the evaluation of the life-cycles of buildings are usually carried out after the end of the project phase when many geometric and spatial parameters have already been defined and it is difficult to modify them. However, defining sustainable standards in the initial phases of any design process ensures that these standards will be integrated into the final building, improving its environmental behaviors.

While several researchers have noted the value of implementing BIM in this type of process, studies such as that of Oludolapo et al. identify the important barriers that hinder the implementation of this technology in construction projects. These barriers relate to cost issues and the extension of deadlines required to develop an adequate BIM model [50], but also to the lack of standards that would enable more effective work. This study aimed to provide a definition of clearer standards that would facilitate the development of initial BIM models using sustainable criteria, in order to encourage their use and improve the integration of this technology in the sector, as well as to reduce the required time to perform it, as researchers such as Macías et al. have also suggested.

In this context, returning to a point made by other researchers such as Oludolapo et al. regarding the need for extended deadlines to develop an adequate BIM model, we must point out that the standards included in the protocol affect the initial phases of the design process, in which the definition level of the project is low, and therefore also affect the BIM model. Therefore, highly elaborate BIM models are not necessary in this phase of the project and, as the study points out, the deadlines for carrying out these first evaluations will not only not be extended but will be shorter than those estimated for traditional design and evaluation methods.

There is no doubt that, during the initial phase of the design process, many of the aspects to be taken into account when carrying out environmental assessments may not yet be defined. Therefore, as Zhen et al. pointed out in their study, generic values of energy and environmental behavior are introduced into the BIM model for these elements. Thus, the simulation carried out will estimate improvements in the parameters that are modified in this phase, keeping the others fixed. In this sense, libraries of existing BIM elements that incorporate generic information can be used [51], or, as Llatas and Soust et al. pointed out in their studies, a detailed data structure can be developed [52] that replaces decisions not yet made in the evaluation process.

Regarding the parameters analyzed in the initial phases of the design process, it has been pointed out that there are two basic categories: on the one hand, the parameters associated with geometric and spatial design; on the other hand, the parameters associated with constructive elements, equipment, and facilities that are more strongly linked to energy. The results achieved by this study suggest that the first category of parameters offers the best results in the evaluation carried out by the Building Research Establishment Environmental Assessment Method (BREEAM). Additionally, the parameters associated with energy issues (insulation of the envelope, installation of efficient equipment, etc.) offer very positive results in terms of the overall evaluation of the seal. However, the costs necessary to undertake the necessary actions to meet the conditions of the seal in terms of energy are higher than those associated with the geometric and spatial aspects.

In addition, geometric and spatial standards are the most important aspects in the initial phase of the design process, as they are the most difficult to modify in later phases. Therefore, the defined standards protocol seeks to prioritize the incorporation of geometric and spatial sustainable parameters in the initial phase of the design process since they are the most important to consider in this first step of the process. They also produce significant environmental improvements according to the BREEAM seal assessment and require low costs in relation to the environmental improvement produced. In addition, these are parameters that are entered directly into the BIM model and that can be evaluated directly in this environment, without the requirement to transfer information to other evaluation software that complicates the process.

5.1. Contribution of This Study

In this way, this study and the protocol designed focus on facilitating the integration of parameters associated with the improvement in environmental performance throughout the lifecycles of a building during the initial phases of the design process, in a simple way and employing a single tool: in this case, the BIM environment, which reduces the working time compared to traditional tools.

The protocol designed aims to prioritize a series of sustainable standards that serve as a review list for designers to incorporate into the initial design phases. In this way, during the first few days of work, these criteria will be taken into account, which at the same time can be integrated into a BIM model in a simple way, since they are geometric and spatial elements that are easy to model and evaluate in a BIM environment. In this way, for the designer, it will not be necessary to require specialized personnel to use this technology, which will not entail additional costs. At the same time, the development times of these tasks will be reduced compared to traditional methods; 30% in total, according to the test performed. This saving not only refers to the design and modeling of the building according to the standards included in the protocol but also in terms of the evaluation of these solutions in the BIM environment, which will mean the greatest time savings, 17% of the total.

Thus, in the face of more ambitious and complex methodologies, the protocol defined seeks to simplify the process, facilitating its implementation in a significant number of projects, and ensuring that these changes have a tangible impact on the environmental performance of the designed buildings.

5.2. Implications of This Study for Future Experiences

The standards included in the protocol establish a categorized list of sustainable parameters that can help other designers to integrate them into their buildings in the early stages of the project. Therefore, using BIM virtual models to evaluate these parameters enhances their impact on the final environmental behavior of the building, saving time in comparison with traditional methods of design and evaluation.

Thus, designers should focus on the appropriate definition of the orientation of the building, its facades, the dimensioning of holes, and, in general, on ensuring that an adequate forecast of spaces is generated to guarantee that, once the execution project has been developed, the building will meet the relevant green quality standards. It is important to note that the parameters taken into account by the BREEAM seal also incorporate standards associated with the sustainable use of the building throughout its useful life. These include the definition of drying spaces that minimize the use of dryers and therefore energy-intensive equipment; the definition of spaces intended for home working, which means minimizing displacements outside the building and the associated energy consumption; or the provision of the use of alternative means of transport that are not dependent on oil. These are, therefore, aspects of significant relevance to the initial phases of the design process, which will directly affect the building's lifecycle and its environmental impact throughout its useful life.

Taking this protocol of standards into account, integrating them into the initial BIM model and evaluating them in this environment will also make it easier for designers to score well in a possible BREEAM evaluation once the project has been completed, reducing the labor time invested and the cost associated with specific measures to develop these standards during the construction phase.

5.3. Limitations of This Study

The simplification of the BIM model developed can be considered a limitation of the present study. It is true that the objective of this study is to introduce standards in the initial phases of the design process, but there are many other indicators related to the environmental behavior of a building that should be incorporated into this protocol. However, because the integration of these standards into BIM is complex, or because it is not yet possible to evaluate them in this environment, it was decided not to incorporate them into the protocol, to avoid having to use other software.

It is linked to an important limitation of this technology, which has to do with the difficulty of being able to perform all the required assessments in a BIM environment. As noted in this study, different standards can be analyzed in BIM environments: in this case, the software Allplan 2020. Other standards can be analyzed using software that is linked to the Industry Foundation Classes (IFC) exchange format, in this case, the Solibri Model Checker 2019. Usually, the standards analyzed in this environment are those linked to the geometric and spatial aspects of the building. For energy assessments, for example, it is necessary to resort to other software, usually associated with compliance with the specific regulations of each region: in this case, the residential energy rating abbreviated method (CERMA V.4.2.5. in Spanish). As noted by Tajda et al. or Carvalho et al., when carrying out this exchange of information, there are still automation problems that require the use of manual or semi-automatic methods to establish a relationship between the information associated with the BIM model and the evaluation program. When we work with data associated with the initial phases of the design process, the transferred data are easier to control; however, when the evaluation is carried out on a finished building, this working method is more complex, which makes it difficult to implement the use of BIM for these processes; for example, for the evaluation of waste management, the use of recycled materials or raw materials, as Argahavan et al. point out.

Finally, we point out as a limitation of this study the fact that only one case study has been analyzed to define the protocol of sustainable standards. In part, this limitation is due to the fact that nowadays this type of methodology is not very implanted in the construction sector, which makes it difficult to find real case studies that combine the use of BIM and BREEAM analysis in Andalusia's environment. The objective of this study is to simplify these processes to make them more attractive to designers and to extend them in the sector.

However, we have tried to make up for this limitation by performing different tests of specific tasks associated with the standards defined to evaluate the protocol, among others, the time invested to perform the tasks and thus be able to compare it with that necessary to perform the tasks by traditional methods.

5.4. Future Lines of Research

Therefore, we can establish as a future line of research the requirement to simplify and automate the process of data exchange between BIM and other environmental and energy assessment software packages, so that the different standards not included in the protocol because they complicate the work to be carried out in the initial phases of the design process are incorporated. Therefore, more parameters would be included in the evaluation of BIM models in the early stages of projects without the work being more complicated to perform or requiring more time or costs to elaborate on it.

Therefore, the different criteria introduced would have a real impact on the design process from the initial phases. This improvement would facilitate the diffusion of the use of BIM for the evaluation of sustainability in the construction sector and the substantial improvement in the environmental impact of buildings throughout their lifecycles.

6. Conclusions

From analyzing the results obtained herein, we can conclude that this study establishes a protocol for the sustainability standards included in the evaluation of green seals, such as the Building Research Establishment Environmental Assessment Method (BREEAM), which can be easily integrated into the development of virtual BIM models in the initial phase of the design process.

- The standards prioritized by the protocol are those linked to the geometric and spatial definition of the building since they are the ones that have the greatest impact in the initial phase of the design process.
- They are also easy indicators to introduce into an initial BIM model, to test their behavior in this same environment.
- This protocol seeks to simplify the work of introducing sustainable parameters to a building in this initial phase and does not require additional efforts at the level of cost, deadlines, or the integration of specialized personnel. In fact, working with these initial BIM models reduces working times by 30% compared to traditional tools.
- In addition, although the time savings are similar in terms of modeling and verification tasks, the latter is more beneficial, with a time saving of 17% compared to the total.
- Taking this protocol of standards into account will facilitate designers to score well in a possible BREEAM evaluation once the project has been completed, reducing the labor time invested, and the cost associated with specific measures to develop these standards during the construction phase.

Therefore, instead of looking for more ambitious and complex methodologies, the proposed BIM protocol seeks to simplify the process of introducing sustainable standards in the initial phase of a design process. Therefore, designers are encouraged to include sustainable standards in their projects and do so using BIM methodology, as it is an advantage in terms of deadlines compared to traditional methods, in order to facilitate its implementation in the construction sector and ensure a tangible impact on the environment.

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