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XXIII Congresso Nazionale CIRIAF

Sviluppo Sostenibile, Tutela dell'Ambiente e della Salute Umana

Approach to energy analysis using Building Information Modeling (BIM) software

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Abstract: To date, the design of low-energy buildings remains one of the main issues globally. The construction sector accounts for approximately 36% of global primary energy consumption, contributing to almost 40% of the total CO_2 emissions worldwide. However, significant energy savings can be achieved if buildings are correctly designed. Therefore, it is crucial to integrate energy efficiency issues into the entire building design process, starting from the preliminary stage. Recent innovations have allowed the construction industry to invest in cutting-edge technologies and adopt new processes. In particular, applying the Building Information Modeling (BIM) methodology has introduced important changes in the design process. BIM makes it possible to optimize construction processes, from the design phase to the management phase. It is capable of providing information regarding the architectural and structural characteristics of the building, the materials, and the construction systems used, all according to the desired level of detail. Furthermore, the possibility of exchanging information with other software makes BIM a tool with great potential. This work explores the abilities of BIM in the architectural and energy field through the modeling of a specific case study, i.e., an academic building. In particular, the model was used for solar analyses, useful for identifying the most suitable surfaces for the installation of photovoltaic modules. The results demonstrated that the energy efficiency of a building is closely linked to its orientation and construction characteristics. In fact, the most favorable surfaces for the installation of the modules resulted in the two roof pitches exposed to the South-West, with an incident solar radiation value of 903 kWh/m^2.

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Keywords: Building Information Modelling (BIM); energy efficiency; sustainable building, incident solar radiation, energy simulation.

1. Introduction

In recent years, the interest in environmental sustainability has involved the construction sector, bringing attention to the issue of energy efficiency in buildings. Currently, the building sector is the largest consumer of energy. In fact, according to statistics supplied by the European Commission (EC) Directorate General of Energy, it is responsible for 36% of energy consumption and 40% of carbon emissions worldwide [1]. One of the measures proposed by the European Commission provides that by 2030 new buildings must be zero-emissions [2, 3]. For this reason, it is important to review the way buildings are designed, introducing energy aspects already in the preliminary stages of the project. In this scenario, Building Information Modeling (BIM) helps to control different aspects of the design process, allowing the integration of energy characteristics with architectural ones. Building Information Modeling is a data-rich, object-oriented, intelligent, and parametric digital representation of the facility, which can be used to extract and analyze information to help designers make decisions and improve the process of delivering the facility [4, 5]. Preliminary thermal, daylighting, and energy modeling can be involved in the first design phase, determining the project goals and requirements (site development, building orientation, massing, and form, the initial building services, and the structure system) already in the conceptual stage. Although BIM has aroused strong interest among researchers in the past decade, the studies on its applications for the development of green buildings are not numerous [6]. Among these, Krygiel and Nies [7] summarised the overall applications of BIM during the building design process, including the orientation optimization of buildings to reduce building energy consumption, analysis of the building's massing (assess the form of the building and optimize the building envelope, such as the ratio of equivalent transparency), daylight analysis, investigation of water harvesting potential. Azhar et al. [8] analyzed the potential of BIM for environmental sustainability studies. The aim of the work of Maltese et al. [9] is to provide stakeholders with tools and procedures allowing them to extract rating protocols data from the BIM model in order to forecast the sustainability rating in every step of the design phase and of the operational life of the building. Mah et al. [10] proposed a BIM model to measure the CO_2 footprint in a house construction process and to provide recommendations for improving the construction activity schedule and to reduce associated emissions. Larsen et al. [11] proposed a new approach for analyzing the energy performance of retrofit projects using BIM and 3D laser scanning. Lagüela et al. [12] presented a hybrid method based on BIM and other information technologies to support energy rehabilitation processes ranging from energy usage diagnoses to retrofitting decision-making. Shen et al. [13] used BIM for sustainable design and project-based energy simulations.

Predicting the energy performance of a building during the operational phase is very important in order to preliminarily verify the correctness of the choices made during the design.

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This work, through the modeling of a sample building for academic use, explores the potential of BIM in the architectural and energy fields. In fact, after modeling the building, analyses of the incident solar radiation were conducted to identify the most suitable surfaces for the installation of photovoltaic modules. The contribution offered by the study is particularly relevant in a context where renewable energy sources are becoming increasingly important for reducing energy consumption. The results obtained demonstrate that BIM has a strong potential that is just waiting to be explored.

2. Materials and Methods

Although many studies have been conducted on BIM in recent years, its applications in the energy field are still very limited. Since the utility of BIM in the construction sector has been widely recognized, it is necessary to explore its potential in green buildings [6].

Solar energy deployment is gaining greater attention as a sustainable source of energy that could alleviate aspects of the current climate crisis [14]. Renewables play a crucial role in efforts to de-carbonise energy supplies and avert negative impacts associated with climate change [15]. The need for increasing the share of electric energy produced by renewable resources has pushed, over the last years, the installation of photovoltaic (PV) plants [16,17]. The introduction of photovoltaic systems in buildings offers advantages to the environment by reducing the emission of polluting particles into the air and, at the same time, allows the building's electricity consumption to be significantly reduced. The lack of awareness about the photovoltaic potential of the various building's surfaces is one of the most important obstacles to the diffusion of photovoltaic systems in the construction sector [18, 19]. There are several estimation methods to deal with this issue. These methods try to evaluate various factors such as the intensity of the solar incident, the availability of usable roof area, and the shadows cast by nearby objects [20].

The present work exploits the potential of BIM to offer a useful methodology for the preliminary design of a photovoltaic system. Through BIM modeling, detailed shading and incident solar radiation analyses were performed on a sample building for academic use.

2.1. Methodology

The aim of the contribution is to explore BIM both in the architectural and energy fields. To pursue this goal, the methodology used can be basically divided into two phases:

- the first is represented by the choice of the sample building and its modeling on a BIM software;
- the second focuses on the analysis of incident solar radiation and shading.

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3. BIM modeling: the case study of the "Solar House"

The sample building chosen for the experimentation is the Las.E.R Laboratory (Laser and Electro-optical Research in engineering metrology) of the University of L'Aquila, which hosts research activities currently focused on topics such as the study of heat transmission, the application of thermography for building energy efficiency and building energy efficiency in general [21].

The building is located in Monteluco di Roio, L'Aquila, near a wooded area characterized by a dense presence of trees. It is part of a complex of university buildings housing the Departments of Industrial Engineering, Information Economics (DIIIE) and Civil, Building-Architecture and Environmental Engineering (DICEAA) of the University of L'Aquila (Figure 1).

Figure 1. Sample building's location.



The building (Figure 2), built in the 70s, is in reinforced concrete. It consists of three floors. In detail, the basement houses the laboratories, the ground floor the maintenance company and the first floor the offices of the research group involved in the issues of energy efficiency in the construction sector. The structure is characterized by a pitched roof designed for the insertion of photovoltaic and thermal panels. Hence the nickname "Solar House". Notwithstanding the above, there are currently no roof panels. For this reason, the proposed study aims to analyze the effective predisposition of the building for the integration of a hypothetical photovoltaic system.

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Figure 2. "Solar house" boxed in red. (a) “Solar House” front. (b) “Solar House” back.



(a)

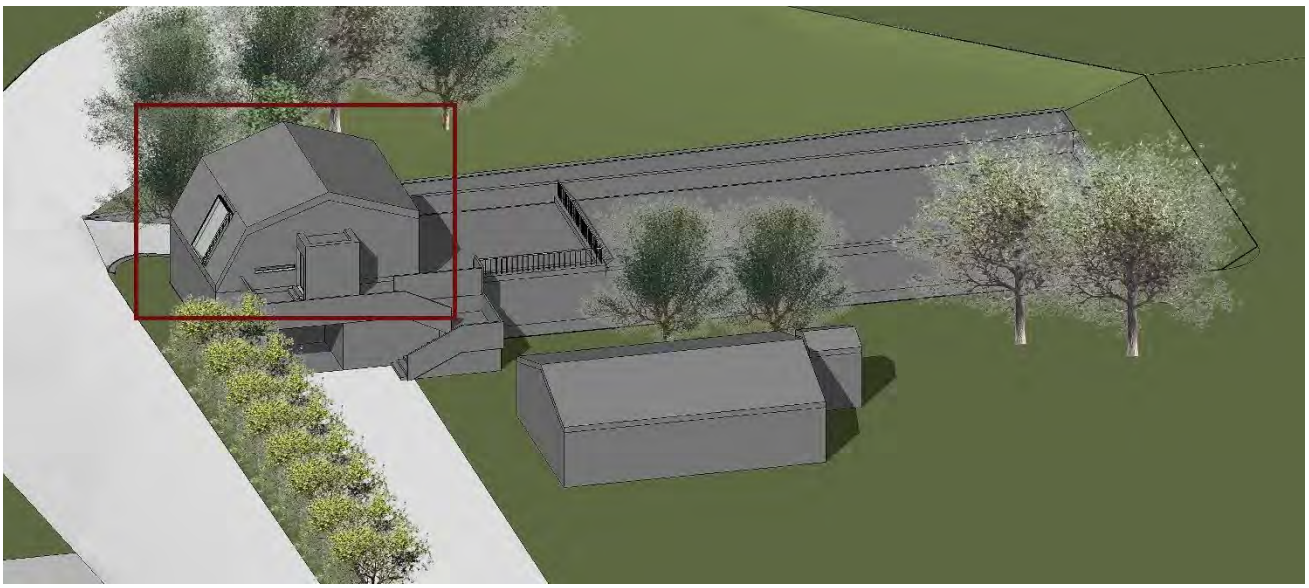


(b)

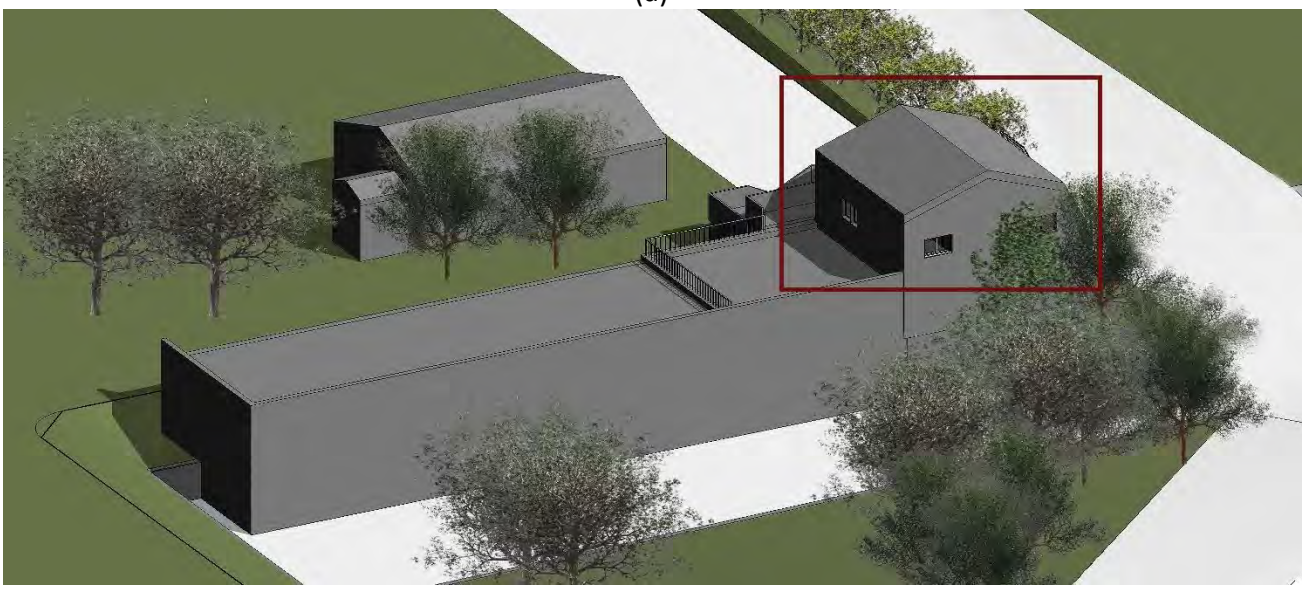
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At the basis of the design of a photovoltaic system, there must be an assessment of the feasibility of the system. For this purpose, it is necessary to carry out preliminary studies which certainly include solar analyses. The various analyses were conducted through the use of BIM software, i.e., Autodesk Revit. The building has been modeled in detail and inserted into the context in which it is located (Figure 3). Subsequently, the coordinates of the site were entered to make the simulations as realistic as possible. The analyses mainly focused on the top floor of the "Solar house", framed in red in Figure 3.

Figure 3. BIM model. (a) South-East view. (b) North-West view.



(a)



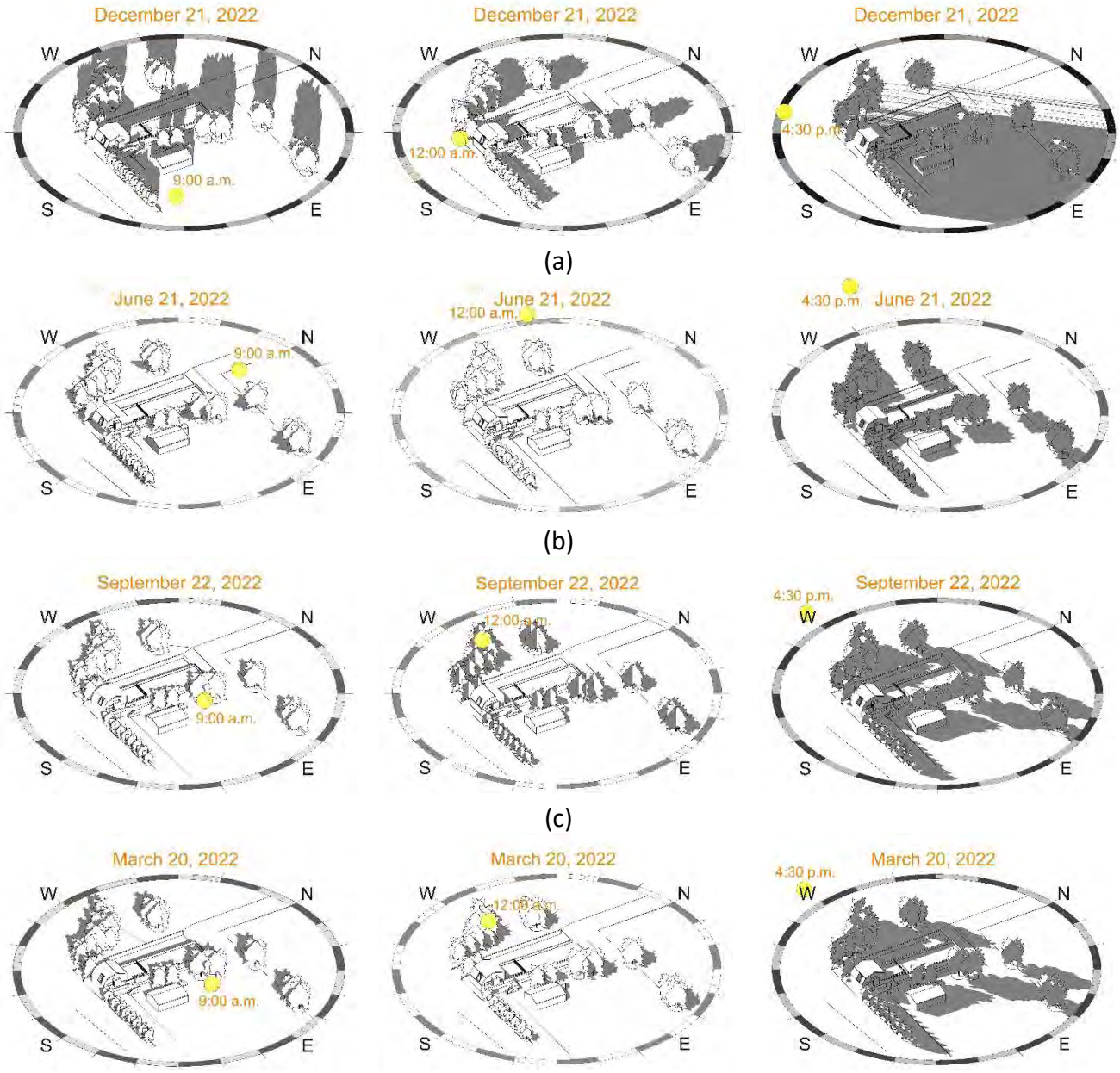
(b)

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3. Solar analyses and Results

Through a simulation of the path of the sun, the shading affecting the building was studied. In detail, the analyses were conducted in the winter and summer solstices and in the autumn and spring equinoxes in 2022. The purpose of the simulation was to identify the parts of the building most exposed to sunlight and most favorable to inserting the panels. Figure 4 shows the results obtained from the shading analysis.

Figure 4. Shading analysis. (a) Winter solstice. (b) Summer solstice. (c) Autumn equinox. (d) Spring equinox.

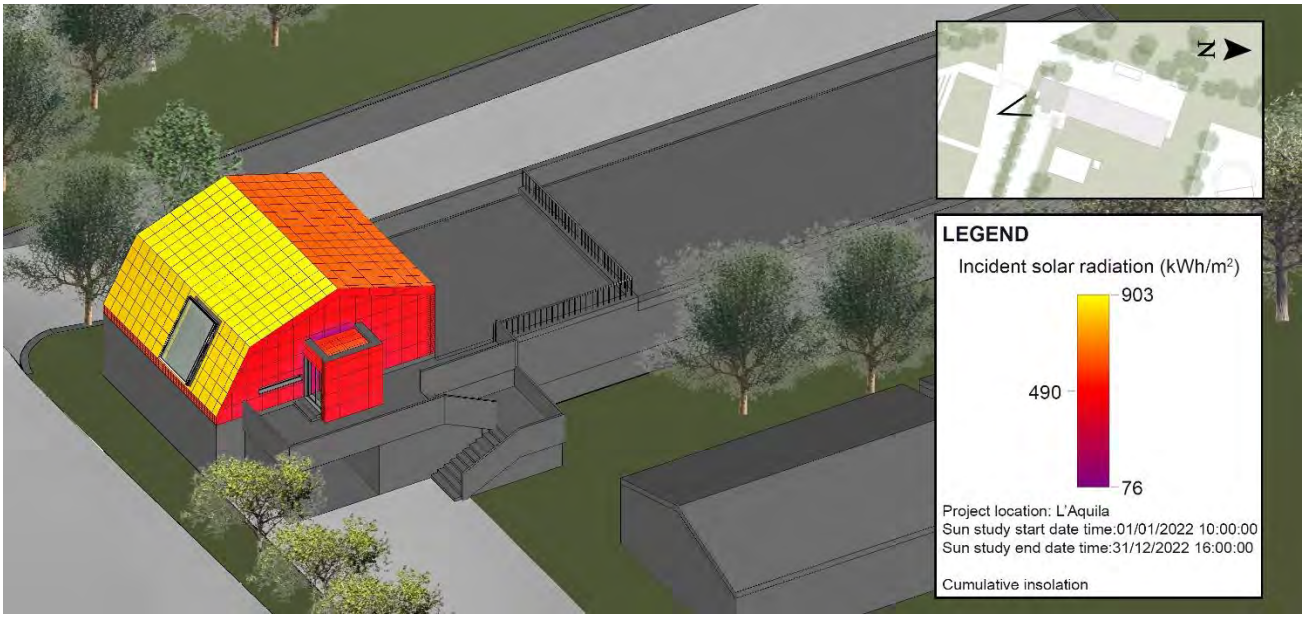


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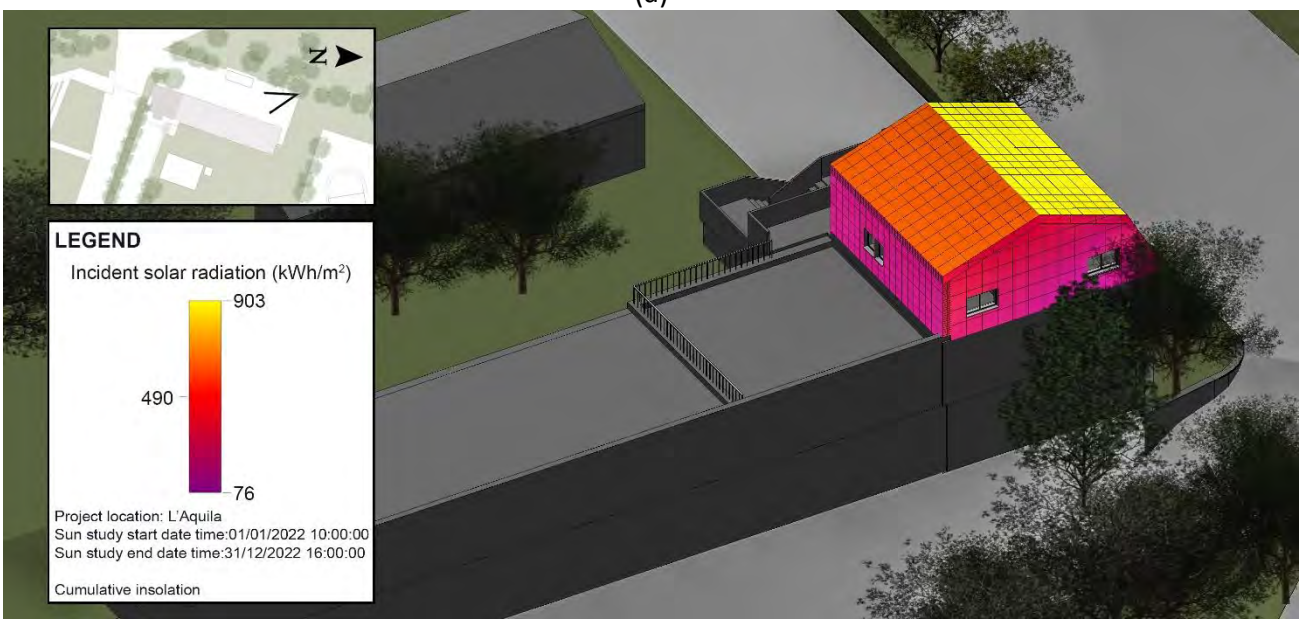
The amount of energy produced by a photovoltaic system strongly depends on the climatic conditions of the locality where it is installed. In practice, the energy potential of a certain location is expressed by means of the average annual insolation, which provides the amount of solar energy that affects an area of 1 m^2 over the course of a year.

The analysis of the incident solar radiation was performed in order to identify the more or less suitable surfaces for the installation of the photovoltaic modules, in relation to their predisposition to produce electricity. Figure 5 shows the results of the analysis of the incident solar radiation.

Figure 5. Incident solar radiation analysis. (a) South-East view. (b) North-West view.



(a)



(b)

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Thanks to the modeling of the context in which the building is located, the study was carried out very accurately, also taking into consideration the shadows caused by nearby trees and buildings.

The results obtained show a close correlation between the two analyses, from which it emerges that the most suitable surfaces for the installation of the photovoltaic system are the two slopes of the roof exposed to the South-West, with an incident solar radiation value of 903 kWh/m^2.

4. Conclusions

The construction sector is facing major challenges arising from high energy consumption. Statistics supplied by the EC are alarming and require immediate and efficient solutions.

Recent innovations have allowed the construction industry to adopt cutting-edge technologies. Among these new methodologies is BIM, which has established itself in the last two decades. Integrating graphical and non-graphical information, it enables construction stakeholders to work collaboratively for efficient project delivery throughout the lifecycle of construction projects.

The energy performance of buildings strongly depends on the local meteorological conditions and on the construction characteristics of the envelope. During the design phase, correct and detailed modeling of the building can be crucial for the identification of suitable intervention strategies for the case in question.

In this work, the potential of Autodesk Revit has been used to conduct solar analyses on an academic building. The results showed that the energy performance of a building greatly depends on its orientation and construction characteristics. In fact, the most favorable surfaces for the installation of photovoltaic panels resulted in the pitches of the roof being exposed to the South-West and not covered by any shading element. In particular, on the aforementioned surfaces, the value of incident solar radiation resulting from the analyses is 903 kWh/m^2. The study conducted demonstrates that BIM represents an excellent solution to facilitate the integration and management of information during the design phase of a building or its components, offering the opportunity to make the best use of the available design data for sustainable design and performance analysis. Furthermore, the interoperability feature of BIM makes it an extremely flexible and dynamic software. In the future, the work begun with this contribution will be able to expand by deepening the theme of interoperability between Building Information Modeling (BIM) and Building Energy Model (BEM) software, increasingly refining the design in relation to the issue of energy saving.

References

1. European Commission. Clean Energy for all Europeans Package; Publications Office of the European Union: Luxembourg, 2019.
2. Verso un settore edilizio a zero emissioni: le nuove proposte della Commissione. Available online: https://asvis.it/rubrica-europa-e-agenda-2030/1339-10917/verso-un-settore-edilizio-a-zero-emissioni-le-nuove-proposte-della-commissione (accessed on 9 March 2023).
3. Proposal for a DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on the energy performance of buildings. Available online: https://eur-lex.europa.eu/legal-

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Published by Morlacchi Editore University Press.

content/EN/TXT/?uri=COM:2021:802:FIN&qid=1639818893678 (accessed on 9 March 2023).
4. Ernstrom, B.; Hanson, D.; Hill D.; Clark, J.; Holder, M.; Turner, D.; Sundt, D.; Barton, L.; Barton, T. The contractors' guide to BIM. Associated General Contractors of America; 2006.
5. Gao, H.; Koch, C.; Wu, Y. Building information modelling based building energy modelling: A review. *Applied Energy* **2019**, *238*, 320–343.
6. Yujie, L.; Zhilei, W.; Ruidong, C.; Yongkui, L. Building Information Modeling (BIM) for green buildings: A critical review and future directions. *Automation in Construction* **2017**, *83*, 134-148.
7. Krygiel, E.; Brad, N. Green BIM: successful sustainable design with building information modeling. *John Wiley & Sons*, New Jersey, USA, 2008.
8. Azhar, S.; Brown, J.; Farooqui, R. BIM-Based Sustainability Analysis: An Evaluation of Building Performance Analysis Software. In Proceedings of the 45th ASC Annual Conference, Gainesville, FL, USA, 1–4 April 2009; Vol. 1, pp. 1–4.
9. Maltese, S.; Tagliabue, L.C.; Re Cecconi, F.; Pasini, D.; Manfren, M.; Ciribini, A.L.C.; De Angelis, E. Sustainability Assessment through Green BIM for Environmental, Social and Economic Efficiency. In Proceedings of the International High—Performance Built Environment Conference—A Sustainable Built Environment Conference 2016 Series (SBE16), Sydney, Australia, 17–18 November 2016.
10. Mah, D.; Manrique, J.D.; Yu, H.; Al-Hussein, M.; Nasseri, R. House construction CO2 footprint quantification: a BIM approach. *Construction Innovation* **2011**, *11 (2)*, 161-178.
11. Larsen, K.E.; Lattke, F.; Ott, S.; Winter, S. Surveying and digital workflow in energy performance retrofit projects using prefabricated elements. *Automation in Construction* **2011**, *20 (8)*, 999-1011.
12. Lagüela, S.; Díaz-Vilariño, L.; Martínez, J.; Armesto, J. Automatic thermographic and RGB texture of as-built BIM for energy rehabilitation purposes. *Automation in Construction* **2013**, 31, 230-240.
13. Shen, Z; Jensen, W; Wentz, T; Fischer, B. Teaching sustainable design using BIM and project-based energy simulations. *Education Sciences* **2012**, *2(3)*, 136–149.
14. Mansouri Kouhestani, F.; Byrne, J.; Johnson, D.; Spencer, L.; Hazendonk, P.; Brown, B. Evaluating solar energy technical and economic potential on rooftops in an urban setting: the city of Lethbridge, Canada. *International Journal of Energy and Environmental Engineering* **2019**, *10*, 13–32.
15. Mueller, S.; Frankl, P.; Sadamori, K. Next Generation Wind and Solar Power from Cost to Value. International Energy Agency, Paris, 2016.
16. Muttillo, M.; Nardi, I.; Stornelli, V.; de Rubeis, T.; Pasqualoni, G.; Ambrosini, D. On field infrared thermography sensing for PV system efficiency assessment: Results and comparison with electrical models. *Sensors* **2020**, *20(4)*, 1055.
17. Nardi, I.; Ambrosini, D.; de Rubeis, T.; Paoletti, D.; Muttillo, M.; Sfarra, S. Energetic performance analysis of a commercial water-based photovoltaic thermal system (PV/T) under summer conditions. IOP Conf. Series: Journal of Physics: Conf. Series 923 (2017) 012040.
18. Castellanos, S.; Sunter, D.A.; Kammen, D.M. Rooftop solar photovoltaic potential in cities: how scalable are assessment approaches? Environmental Research Letters **2017**, *12(12)*, 125005.

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Published by Morlacchi Editore University Press.

19. Strupeit, L.; Palm, A. Overcoming barriers to renewable energy diffusion: business models for customer-sited solar photovoltaics in Japan, Germany and the United States. *Journal of Cleaner Production* **2016**, *123*, 124–136.
20. Gooding, J.; Edwards, H.; Giesekam, J.; Crook, R. Solar City indicator: a methodology to predict city level PV installed capacity by combining physical capacity and socio-economic factors. *Solar Energy* **2013**, *95*, 325–335.
21. Department of Industrial and Information Engineering and EconomicsT.O.E. Thermal Sciences and Optical Engineering. Available online: https://laser.diiie.univaq.it/index.php?id=2835 (accessed on 9 March 2023).

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