Solar Potential and RES Evaluation into UniTO's Digital Asset Management System for Sustainable Campus Development

Alsibai, Hashem (1); Gasbarri, Paola (2); Boscariol, Marta (2); Meschini, Silvia (2); Tagliabue, Lavinia Chiara (2); Dansero, Egidio (2); Tartaglino, Andrea (2)
1: Politecnico di Torino, Italy; 2: Università di Torino, Italy
hashem.alsibai@polito.it

Abstract. Universities are aimed at shifting towards smart and sustainable campuses, adopting digital Asset Management Systems (AMS) to improve decision-making and align with sustainable development goals (SDG). Technological and strategic organisational changes are required to provide comprehensive, easy-accessible, and updated data. The University of Turin (UniTO) represents a pivotal case due to its large and widespread asset, which has been made displayable via an AMS-app which aggregates different data, BIM, and GIS. UniTO's digital transformation is part of the digital and green transition agenda, contributing to optimising resource consumption and adopting renewable energy sources (RES) towards the decarbonization goal. The potential of the AMS to integrate and analyse energy consumption data and RES clean energy production is investigated, defining a method and related data set to estimate how to integrate photovoltaics in buildings (BiPV) and how to accurately estimate the potential solar area for BiPV installation. In the AMS such data are displayable through tailored dashboards, providing prompt insights on energy performance, and effectively identifying potential for the optimization of the interventions.

1. Background and Motivation

Asset Management (AM) of large and widespread properties such as university assets, characterised by heterogeneous constructions in building geometry, period and typology of construction, services, and users' needs, often results in complex issues to solve due to highly dynamic and variable data involved in the decision-making process. Such management complexity is also due to the need for integrated and comprehensive data, exchanged by multiple stakeholders with different granularity. Moreover, current AMS are often organised on barely accessible, fragmented and still document-based databases, resulting in incomplete information leading to ineffective decisions and slow time of reaction to daily rising problems. Thus, universities are shifting towards digital AMSs based on the principles of information management, aiming at enhancing decision-making for a better user experience, and reducing costs and wastes, as required by the SDG. Nonetheless, it is still lacking a holistic AMS able to manage information spread in several databases (Qiuchen Lu et al., 2019; Moretti et al., 2021) with accurate and scalable information timely available, in the required format, and throughout the whole asset lifecycle. An AMS with such features would be key to overcoming the previously illustrated management issues (Qian and Papadonikolaki, 2020), and university campuses represent a great opportunity to recommend and test a solution for managing large building stocks through data integration scalable and applicable to multiple public assets (e.g. schools, hospitals, social housing, etc.).

A campus can be defined as "the collection of buildings of a university or college including the land around it" (Oxford, 2022). This definition is not accurate when it comes to the context of a community or a city, particularly under the umbrella of sustainable development in response to green transition to mitigate climate change effects. A "smart campus" or "technology campus" (Den Heijer, 2011), overcame that definition, by incorporating the various built environments associated with the fields of planning, urban and regional studies, business, science, and technology. Only a handful of campuses have been thoroughly investigated from this perspective, considering them as real estate objects, investigated in strategic, financial, functional, and physical domains (Den Heijer 2011, Hoeger & Christiaanse 2007). The concept of a “smart campus” can be borrowed at the campus scale for greener and more efficient choices supported by digital tools and information technology (Chagnon-Lessard et al., 2021), providing the so-called “sustainable campus”. Even if a unique definition of smart campus or technology campus still lacks, Dong et al. 2020 identified the following six main features: context-aware, data-driven, forecasting, immersive, collaborative, and ubiquitous, highlighting the key role of data and their contextualization in providing more valuable information (Qiuchen Lu et al., 2019) for effective decisions and investments.

Similarly, sustainable communities are seen as the energetic, economic, functional, and spatial context of a city, thus a “sustainable campus” should be characterised by its environmentally conscious approach, seamlessly integrating environmental science into policies, management practices, and scholarly endeavours (Buana et al., 2018; Puspadi et al., 2016). Universities are increasingly focused on developing it (Tiyarattanachai & Hollmann, 2016), experiencing significantly higher satisfaction, a better quality of life and learning performance, increased energy conservation and efficiency (Pham et al., 2019; Baitule & Sudhakar).

For this purpose, the availability of updated and accessible data on the building and its surrounding results core, providing effective digital AMS development with complete and shared knowledge, useful for more sustainable decisions on multiple aspects such as environmental comfort, energy consumption, maintenance and efficiency measures, optimisation of space use, etc. The use of static and dynamic data, representing the basis for smart campuses, can support the execution of automated tasks improving efficiency and reducing the time of response to emergency issues. However, integrating and processing diverse data from heterogeneous sources to support asset managers is still rather challenging.

Recently, the use of BIM (Building Information Modelling) and GIS (Geographical Information System) has shown great value in providing complete knowledge about asset consistency with information available at different scales. BIM and GIS integrated into Business Intelligence (BI) tools proved to be valid in supporting university AMS (Bao et al, 2023; Qiuchen Lu et al., 2019; Moretti et al., 2021). A multi-scalable database can be provided, applying clear information management to define a framework supporting data aggregation and updating through defined standards (Zhang, Q. et al 2022).

Moving from these assumptions and with the aim of achieving a better comparison, understanding, and sharing of information by stakeholders with different backgrounds, UniTO developed a tailored AMS (Di Giuda et al., 2023). It is based on the integration of BIM and GIS into BI tools, and data on buildings, their geolocation, spaces, usage, energy consumption and occupancy flows are processed and visualised through interactive dashboards, customised for different management purposes. BI tools allow to integrate and process heterogeneous data from different sources, including BIM models and GIS-based maps, providing both geographical and detailed information about individual buildings and their components. The UniTO AMS permits to evaluate the updated state of the asset and apply the management policies through data analysis and visualisation via a Web-App, dealing with multiple topics (Di Giuda et al., 2023). A dedicated section to Energy and Sustainability, recently developed, is tackled in the paper, presenting how the AMS can be adopted to integrate and analyse data about energy consumption and solar potential to upgrade the campus towards decarbonization. In order to estimate the actual available surface area for photovoltaic panels installation to use RES green power, the energy, economic, and spatial data of the University of Turin, are collected, processed, and compared through two main methodologies, taking advantage of GIS in the former case, and BIM in the latter. Additionally, the research demonstrates the potential of the combined use of BIM, GIS and BI tools in providing immediately accessible information, easily comparable and comprehensible, facilitating the decision processes of the university directorates. Furthermore, the analysis and visualization dashboards highlights the potential for improvements and optimization, enabling more targeted and effective actions. The paper concludes discussing the results and future developments.

2. Methodological Framework

To provide an effective university energy and sustainability policy evaluation, the overall methodology focused on solar potential, buildings energy consumption and PV energy production calculation, accordingly with two different methods, exploiting GIS and BIM for providing useful data for calculation and BI tools for visualization. Specifically, the next paragraphs state how GIS and BIM have been exploited.

Then, a comparison between approaches has been conducted and presented in the results section, aiming at evaluating the most accurate prediction of yearly PV energy production on real estate assets, from the university assets owners and managers perspective.

In order to test the validity of the process, a replicable methodology is defined and applied through a pilot case study selected among UniTO's buildings, namely Palazzo degli Stemmi. This building has been chosen accordingly to its position in the city centre and its technical, regulatory and architectural peculiarity common to university's historical buildings, which cover more than 40 percent of their in-use building stock, currently subjected to national or international protection (Legislative Decree 42/2004). Palazzo degli Stemmi is a 6-floor historical building in the Turin city centre that hosts some university administrative functions, whose selection was made considering the roof characteristics, common to local historical buildings. The research considers this building as a case study to define and test the proposed methodology, aimed at identifying suitable roof areas for the installation of photovoltaic panels, considering multiple factors (technical, regulatory, and architectural).

2.1 GIS-based Calculation (Method 01)

The first approach exploits radiation data and GIS functionality for solar potential calculation. Handling vast amounts of data, particularly numerical datasets concerning solar radiation, necessitates GIS software capable of streamlining these processes. This ensures clear planning and optimal positioning of rooftop solar systems within urban neighbourhoods. Hence, according to the GIS based method, the integration of datasets is facilitated by QGIS, containing aspects regarding the average day of each month, the diffused global radiation, Linke turbidity data and the D/G (direct/global radiation) ratio. Table 1 provides the data types along with their sources.

Table 1: Data extracted from open-source platforms

Data	Source
Avg Day	Klein 1977
Diffuse to global radiation ratio - UNI 10349-1 (2016)	ENEA 2024
Linke turbidity data	SoDa (Linke Turbidity Factor,2024)
DG_ratio	Solargis 2024

To obtain the energy production values generated by PV panels, the previously created dataset is translated from pixels (raster-based) into a point-based layer, each one representing a pixel (1m x 1m). By combining the point layer with the shape layer of the city of Turin, the final map, shown in Figure 1, classifies buildings by colours to show the energy potential of each one, in the units of [kWh/m^2]. The calculation of the solar production proceeds using the Šúri correlation formula incorporating factors such as panel efficiency, surface irradiance, and available installation area (Šúri et al., 2007):

$$E = PR\ Hs\ S\ \eta \quad (2)$$

Where E is the electrical energy produced by year [kWh/year]; PR is the performance ratio, estimating the quality of a PV installation performance, independently of orientation and inclination of the panel, but including all losses dependent on the size of the system, technology used and the site (PR=0.85);.

Hs is the solar potential (cumulative annual solar radiation) [kWh/m^2/year]; S is the exposed surface of the panel [m^2]; η is the conversion efficiency of the PV panel, given by the ratio: electrical power in kW_p of the PV panel divided by the area of the panel (η=0.2), as described in the equation (3).

$$\eta = W_p/(S*I_{stc}) \quad (3)$$

In the latter, W_p is the peak power of the PV panel [kW_p]; S is exposed surface of the panel [m^2]; while I_{stc} indicates it applies to Standard Test Conditions (STC).

Figure 1: Turin Roof Solar Potential [kWh/m^2]

Fully utilising the roof surface area with solar panels presents an ideal scenario, nonetheless, practical constraints such as maintenance access limitations make it unrealistic. Therefore, as a commonly adopted procedure, this study opts to reduce the percentage of the exploitable surface

(40% of the roof surface area in this case), ensuring the feasibility evaluation, while maintaining adequate solar production values based on standard PV panel characteristics.

With the aim of validating the results of the proposed methodological framework, the output data was extracted from the selected building, and compared with the results of an alternative methodology, which focuses on a single building instead of on geographical areas. The pilot case study, Palazzo degli Stemmi, has been examined using Equation (2) to determine its potential energy production. This production will then be compared against consumption data, obtained from the Energy Office of UniTO.

2.2 BIM-based Approach Integrated through the UniTO AMS (Method 02)

In parallel with GIS-based analysis conducted on the territorial scale, a BIM-based case-study pipeline on the building scale has been developed. Aligning with the in-use methodology (Di Giuda et al., 2023), which prescribes accurate modelling and integration of mapped use-case built assets spaces in UniTO AMS, the modelling of roofs has been introduced. As-built 3D shapes of roofs have been recreated through a BIM-authoring tool, depicting heights, slopes, protruding objects and other characteristics that might affect the installation of PV panels. Additionally, fictitious roofs of minimum thickness have been modelled, representing those areas compatible with PV installation in terms of regularity and dimension of the surface. Gutters, ventilation shafts, skylights, dormers and other irregularities have been excluded from drawing the outline of the exploitable surfaces. Additionally, since all PV systems equipment shall be installed at more than 1 m from smoke and heat evacuators and from the projection of vertical fire compartmentation elements on the roof, according to Italian fire prevention laws (Ministero dell'Interno et al., 2022), a precautionary separation strip 1 m wide has been taken as drawing offset from all above-mentioned boundaries. Regional, municipal and landscape-environmental constraints prescribe architectural insertion coplanar to pitched roofs, not to alter the outline of the building and not to increase the wind action on the modules themselves. Italian guidelines (CEI 82-25, 2022) supported taking into account those relevant criteria aimed at maximising the capture of available annual solar radiation for energy purposes. Generally, the photovoltaic generator should be optimally exposed to sunlight, preferentially choosing a southern orientation. However, use-case related architectural constraints must be considered, determining sub-optimal orientation of roof pitches housing the PV generator and the shading effects of the surroundings. Energy losses due to shading on the solar surface affect the cost of the kWh produced and the payback time of the RES investment. In order to include in the evaluation intrinsic characteristics of singular 3D-modelled roof areas, project parameters have been assigned to Revit roof types, importing them as custom defined shared parameters. Such parameters manage information about: slope (in angular degree), geographical direction (from a predetermined list of terms: N, S, E, W and a combination of them), type of roof pitch (from a list of terms: e.g. inclined, flat, curved), material of the roof pitch (from a list of terms: e.g. clay tiles, concrete tiles, metal, membrane), net area. Finally, it was possible to place PV panels on the suitable pre-identified areas, resulting in a realistic count of installable modules, comparable to the gross area (in m^2) of the roof and leading to an adequate approximation of the generable power (in kW), accordingly to the efficiency of the module.

Delving into the modelled of Palazzo degli Stemmi, it could be noticed how its roof morphology, rich in dormers and dimensional constraints, limits the installation of PV panels to 1724.68 m^2 of the gross 2451.20 m^2 calculated with the BIM authoring tool as overall roof area, therefore to its 30%. For every single eligible surface, parameters could be written, as well as real-dimension panels could be placed, with a final count of 605 installable PV panels. The panel family used in Revit is respondent to high-performance market products of (LxWxH) 2120x1052x40 mm, with peak (or maximum) power of the photovoltaic module (expressed in

W_p) of the module of 465 W_p, measured under Standard Test Conditions (STC). Considering the number of PV panels, the entire roof would hold 281.325 kWp. This leads to a rough estimation of electrical energy producible by the photovoltaic system, depending on multiple criteria (CEI 82-25, 2022) listed as follows:

- the solar radiation incident on the modules surface, related to the latitude of the installation site, the reflectance of the surface in front of the photovoltaic modules, the exposure of the modules in terms of angle of inclination and angle of orientation, any shading or soiling of the photovoltaic modules;
- the outdoor temperature;
- the modules characteristics, such as peak power, temperature coefficient, etc.;
- decoupling or mismatch losses due to the system, etc.;
- the characteristics of the BOS (Balance of Systems): i.e., inverter efficiency, losses in cables and diodes.

The availability of the solar source for the installation site can be verified using the data given in UNI 10349 concerning monthly average daily values of solar radiation on the horizontal plane for each Italian province, to calculate the solar radiation received by a fixed surface however exposed and oriented using the formulas given in UNI 8477. To improve the level or accuracy of the calculation, the solar radiation data from the PVGIS solar atlas was adopted. It relies on a dynamic daily-data-based calculation, accessible from the website of the European Research Centre. Solar irradiance, which is defined as the intensity of solar electromagnetic radiation incident on a surface of unit area (IEC 60904-3, 2019), has been estimated by PVGIS tool, subsequently to the input of data provided by the 3D model of the roof (γ and α as the definition of the solar surface in relation to the sun) and the designed installable PV panels the:

- PV technology is set to crystalline silicon, according to the efficiency η of the PV panel assumed ;
- PV peak power of 281 kW_p is Installed for the entire roof;
- System losses dependent on the BOS (Balance of Systems) are set to 15% to respect Italian regulations requiring a performance ratio (PR) at least equal to 85% (Aste & Del Pero, 2010);
- Mounting position is considered as roof integrated (BiPV);
- Slope angle γ is set to 21°, representative of the most extended area of the roof,
- Azimuth angle α is set to 42° West.

Solar irradiance in PVGIS is provided by a satellite-based database (PVGIS-SARAH2) and it is referred to the year 2020, as yearly in-plane irradiation at a given angle. For the exact coordinates of the building (45.06850772724428, 7.690509915344536) and the above mentioned input data (H_s), it is estimated at 1624.03 kWh/m^2. According to the calculation, it could lead to a yearly PV energy production of 326'084.17 kWh. As a comparison, yearly PV energy production has been estimated as well using use-case hypotheses, applied to the previous illustrated formula (2), considering: PR = 0.85; H_s = 1624.03 kWh/ m^2; S = 605 panels x 2.23 m^2 = 1349.15 m^2 (which is the 55% of the total roof surface, differently from assumptions of Method 02, deriving from considering the surface of each panel as 2120x1052 mm = 2.23 m^2); η = 0.465/2.23= 0.2085 (20.85%) as defined in equation (3). Thus, recalling equation (2), E = PR Hs S η= 388’310.62 kWh and the estimated yearly PV energy production results 16% lower than the calculation provided by the PVGIS tool.

As intended by the overall AMS methodology (Di Giuda et al; 2023), the BIM model, georeferenced and integrated with its related data has been implemented into UniTO AMS-app, creating tailored dashboards for the topic of Energy and Sustainability. Their content is further explained in the following section.

3. Results and Discussion

In order to compare the results obtained from the implementation of the two methodologies described above, BI tools have been exploited, analysing data deriving from the BIM model of the case study building and about solar radiation, energy consumptions and estimated energy production levels. The calculated values with both methodologies can be visually compared into customised dashboards. The one depicted in Figure 2, in addition to giving information regarding annual building consumptions, aims to describe how monthly calculations of solar radiation, energy production and estimated percentages of energy savings given by the two methods (in blue is Method 01, exploiting GIS; in red is Method 02, exploiting BIM) follow the same trends, although differing in terms of absolute values. As an example, evaluating deltas between monthly energy production calculated with the two methods showed a difference of 12-20% during summer, while in winter it was 30-52%. Both energy production values and savings percentages per month are estimated to be higher when following Method 02.

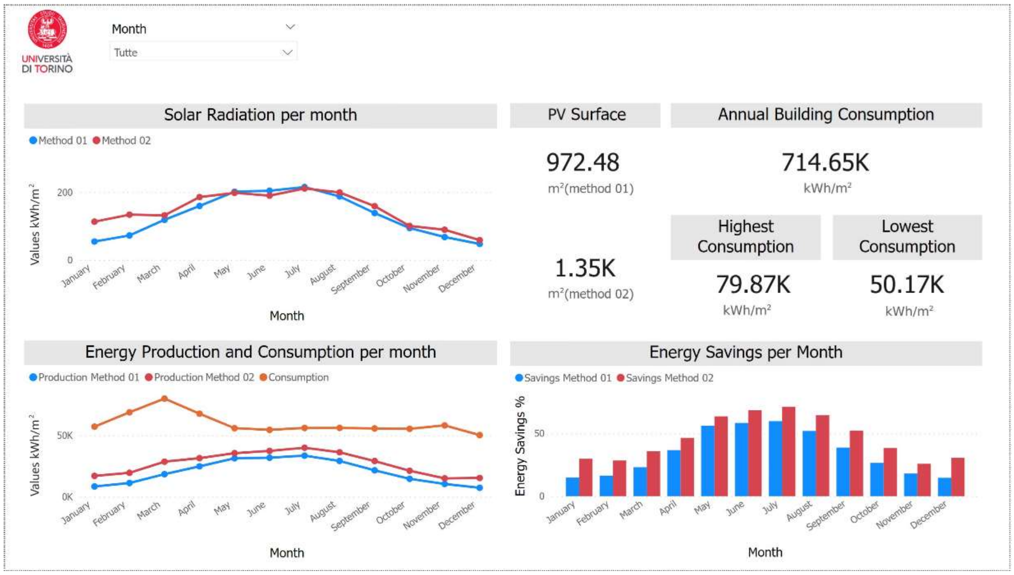

Figure 2: BI dashboard comparing the two adopted methodologies

It could also be noted how the potentially producible energy levels could only partly cover the energy demands (in orange in Figure 2 and Figure 3), supporting the managers in the evaluation of strategic and compatible alternative technological solutions. In Figure 3 the 3D BIM model is visually displayed and it also allows, via selection of singular roof pitches, the interrogation of their properties regarding the position, geometry and construction type. The dashboard tells the viewer some piece of information concerning the consistency of the building (Total Net Area, number of rooms and users), in addition to general or pitch-specific data, according to the user's selection. Accordingly to the totality of the inclined brick-tiled roof, having a surface of 2451 m^2, it can be seen that panels can be placed on a reduced portion of 1725 m^2, whereas in *Figure 2* the area deriving from the number of panels installed is shown. The latter amounts to 1350 m^2, therefore 55% of the total roof and 78% of the potentially installable areas identified. Slope and exposure information are shown per each pitch when selected. This dashboard also focuses on reporting monthly calculations of energy production and consumption deriving from the BIM-based Method 02, proving its accuracy.

PV Panels available surface	Slope	Exposure
9741.34	20.00	NE
6447.58	21.00	NO
1011.81	27.00	

Building's information

Total Net Area	Rooms	Users
15.36K m²	391	270

Roof data

Surface	PV Panels available surface	Material
2.45K m²	1.72K m²	Brick tiles
Roof type	**Slope**	**Exposure**
Inclined	- ° (DMS)	-

Energy data

Annual Building Consumption: 714.65K kWh/m²

Annual Building Production: 326.08K kWh/m²

Figure 3: BI dashboard displaying information deriving from AMS BIM-based method

The comparison indicates that the BIM methodology (Method 01)tends to predict higher and potentially more consistent solar power production values compared to the GIS methodology (Method 02). However, the suitability of each methodology may also depend on various factors such as accuracy, ease of implementation, and data availability. GIS methodology utilises open-source data to calculate roof surface area, providing a broad-scale estimation, while BIM methodology employs detailed building models, resulting in more precise calculations due to accurate dimensions of solar surfaces. Thus, BIM leans towards providing accurate results at the building scale, nevertheless, the GIS methodology demonstrates efficiency when analysing solar potential across urban areas on a broader scope. Combining both methodologies offers a comprehensive approach, leveraging the accuracy of BIM at the building level and the efficiency of GIS at the urban scale. This integrated approach empowers stakeholders to make well-informed decisions regarding solar power deployment, optimising resource allocation, and maximising energy production potential. Introducing a BIM-based approach to PV energy estimation shows potential benefits for managerial purposes, as it outlays and gathers all information needed to evaluate the feasibility of PV installation on managed built assets, from both technical and cost-effective points of view. The criteria for the executive design choices of a grid-connected photovoltaic project to be considered in the first place are related to:

- the optimization of space available for the installation and the maximization of solar radiation capture, through optimal positioning of modules and limiting systematic shading;
- the choice of components and plant configuration, in order to achieve an optimized operating efficiency of the photovoltaic system (i.e., efficiency of the PV panels, PR, BOS efficiency BiPV systems and ventilated roofs, etc.);
- the achievement of budgeted energy gains related to the production systems, facing metered energy expenditure.

4. Conclusion

The paper presents an effective methodology for energy and sustainability policy evaluation of universities, which is aimed at optimizing resource consumption by adopting RES for solar cover while considering methods to integrate photovoltaic systems and calculate the potential roof area for PV panels and related production of green energy. The overall methodology focuses on solar potential, buildings energy consumption, and potential PV energy production calculation, accordingly with two different approaches. The former exploits only GIS, the latter exploits BIM for calculation, and BI tools for visualization. The paper illustrated how both methodologies can bring significant benefits, especially when integrated with data visualization tools, facilitating information awareness and supporting decision-making processes (i.e., UniTO climate change mitigation plan). Indeed, integrating the results into BI tools provides a comprehensive knowledge effectively able to support university building asset management. The results obtained are quite satisfying in providing a methodology aimed at investigating the potential of RES adoption in university campuses and related data to be considered. The proposed method has been tested through the pilot case study of UniTO and its AMS-app, demonstrating high potential of scalability and applicability. However, in order to increasingly use accurate data, further developments will consider the application of the presented tools to a broader range of built assets, aiming at extending energy management consideration at the campus level to create energy communities. A refinement of the proposed methodological approach and parameters will be considered, to better match stakeholders' requirements, enabling optimised managerial solutions.

References

Aste, N. and Del Pero, C. (2010) Technical and economic performance analysis of large-scale ground-mounted PV plants in Italian context. Prog. Photovolt: Res. Appl., 18, pp. 371–384. doi: 10.10025/pip.984

Baitule, A.S. and Sudhakar, K. (2017) Solar Powered Green Campus: A Simulation Study. Int. J. Low-Carbon Technol., 12, pp. 400–410. doi: 10.1093/ijlct/ctx011.

Bao, Z., Hashim, K.F., Almagrabi, A.O. and Hashim, H.B. (2023) Business Intelligence Impact on Management Accounting Development given the Role of Mediation Decision Type and Environment. Information Processing & Management, 60, p. 103380. doi:10.1016/j.ipm.2023.103380

Buana, R.P., Wimala, M. and Evelina, R. (2018) Pengembangan Indikator Peran Serta Pihak Manajemen Perguruan Tinggi Dalam Penerapan Konsep Green Campus. RekaRacana J. Tek. Sipil., 4, pp. 82–93.

Clugston, R.M. and Calder, W. (1999) Critical Dimensions of Sustainability in Higher Education. In: Filho, W.L., ed. Sustainability and University Life. Vol. 5. New York: Peter Lang Scientific Publishers, pp. 82-93.

Cortese, A.D. (2005) Integrating Sustainability in the Learning Community. Facilities Manager, January/February 2005.

Den Heijer, A., De Vries, P. and De Jonge, H. (2011) Developing knowledge cities. In: Van Geenhuizen, M. and Nijkamp, P., eds. Creative knowledge cities. Edward Elgar.

Di Giuda, G.M., Accardo, D., Gasbarri, P., Meschini, S., Tagliabue, L.C. and Scomparin, L. (2023) BIM-GIS and BI Integration for Facility and Occupancy Management of University Assets: The UNITO Pilot Case. In: Capone, P. et al., eds. Proceedings e report. Florence: Firenze University Press, pp. 419–430.

Dong, Z.Y., Zhang, Y., Yip, C., Swift, S. and Beswick, K. (2020) Smart campus: Definition, framework, technologies, and services. IET Smart Cities, 2(1), pp. 43–54. doi:10.1049/iet-smc.2019.0072.

Fracastoro, G.V., Yang, Y., Coppa, G. and Simonetti, M. (2011) Atmospheric turbidity measurements in Turin: A comparison between 1975 and 2010. In: 30th ISES Biennial Solar World Congress 2011. Kassel, Germany, pp. 3545-3553.

Hoeger, K. and Christiaanse, K. (2007) Campus and the City - Urban Design for the Knowledge Society. Zürich: gta Verlag.

International Electrotechnical Commission (2019) IEC 60904-3:2019 Photovoltaic devices - Part 3: Measurement principles for terrestrial photovoltaic (PV) solar devices with reference spectral irradiance data. TC 82.

Italian National Standardization Body (2022) CEI 82-25 - Guida alla progettazione, realizzazione e gestione di sistemi di generazione fotovoltaica Parte 1: Generalità - Acronimi, Definizioni e Principali Leggi, Deliberazioni e Norme. Milano: CT 82.

Klein, S.A. (1977) Calculation of Monthly Average Insolation on Tilted Surfaces. Solar Energy, 19, p. 325.

Ministero dell'Interno, Dipartimento dei Vigili del Fuoco, del Soccorso Pubblico e della Difesa Civile, & Direzione Centrale per la Prevenzione e la Sicurezza Tecnica (2022) Testo coordinato della Nota 07 febbraio 2012 - Guida per l'installazione degli impianti FV – Edizione anno 2012.

Moretti, N., Ellul, C., Re Cecconi, F., Papapesios, N. and Dejaco, M.C. (2021) GeoBIM for built environment condition assessment supporting asset management decision making. Automation Constr., 130, p. 103859. doi:10.1016/j.autcon.2021.

Pham, T.N., Tučková, Z. and Phan, Q. (2019) Greening Human Resource Management And Employee Commitment Towards The Environment: An Interaction Model. J. Bus. Econ. Manag., 20, pp. 446–465.

Puspadi, N.A., Wimala, M.I.A., Sururi, M.R., Sipil, J.T. and Nasional, I.T. (2016) Comparison of Obstacles and Challenges in Implementing Green Campus Concepts at Itenas and Unpar. J. Reka Racana, 2, pp. 1–13.

Qiuchen Lu, V., Parlikad, A.K., Woodall, P., Ranasinghe, G.D. and Heaton, J. (2019) Developing a dynamic digital twin at a building level: Using Cambridge campus as case study. In: International conference on smart infrastructure and construction 2019 (ICSIC) driving data-informed decision-making, pp. 67–75.

Qian, X. and Papadonikolaki, E. (2021) Shifting trust in construction supply chains through blockchain technology. Engineering, Construction and Architectural Management, 28(2), pp. 584-602.

Šúri, M., Huld, T.A., Dunlop, E.D. and Ossenbrink, H.A. (2007) Potential of solar electricity generation in the European Union member states and candidate countries. Solar Energy, 81(10), pp. 1295-1305.

Solargis (n.d.) Global solar atlas. Available at: https://globalsolaratlas.info/support/faq (Accessed: March 29, 2024).

SoDa (n.d.) Linke turbidity factor. Available at: https://www.soda-pro.com/help/general-knowledge/linke-turbidity-factor (Accessed: March 29, 2024).

Tiyarattanachai, R. and Hollmann, N.M. (2016) Green Campus Initiative and Its Impacts on Quality of Life of Stakeholders in Green and Non-Green Campus Universities. Springer Plus, 5, p. 84.

Walton, J. and Matson, L. (2012) Measuring Campus Sustainability Performance: Implementing the first