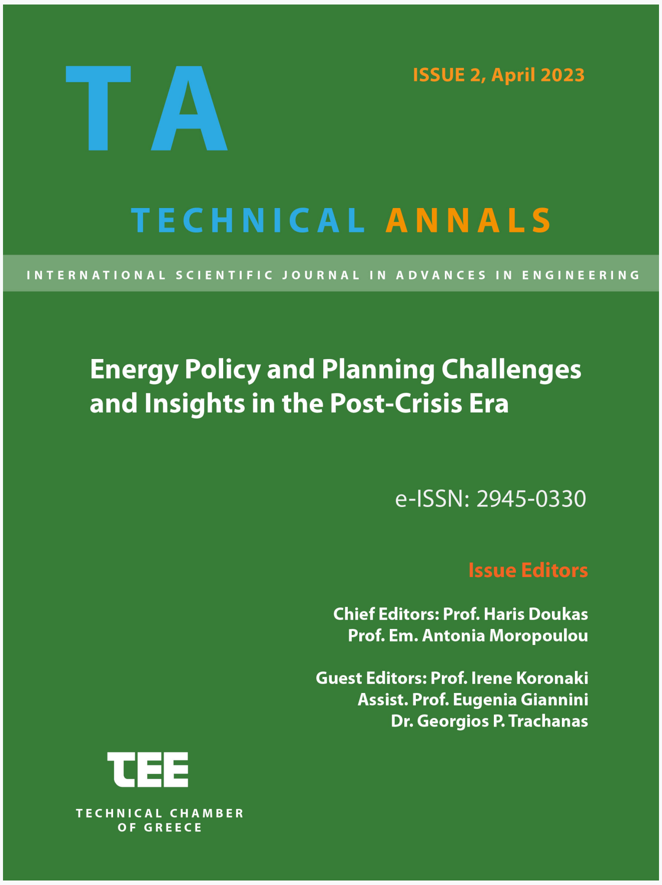
Technical Annals

Vol 1, No 2 (2023)

Technical Annals



Personalized Services for Smart Grids in the framework of Society 5.0: A Smart University Campus Case Study

Dimitris Mourtzis, John Angelopoulos, Nikos Panopoulos

doi: 10.12681/ta.34199

Personalized Services for Smart Grids in the framework of Society 5.0: A Smart University Campus Case Study

Dimitris Mourtzis[1][0000-0002-7923-7363], John Angelopoulos[1][0000-0003-1191-4935], Nikos Panopoulos [0000-0003-3829-8247]

[1]Laboratory for Manufacturing Systems and Automation, Department of Mechanical Engineering and Aeronautics, University of Patras, Rio Patras, 26504, Greece
mourtzis@lms.mech.upatras.gr

Abstract. The evolution of the power grid towards a Smart Grid is a crucial aspect of the transformation of society towards the so-called Society 5.0, where human-centered technology is the key to addressing social challenges. This paper proposes a personalized service approach for Smart Grids within the Society 5.0 framework, which aims to provide personalized energy management services to consumers through advanced sensing technologies, intelligent algorithms, and social and contextual data. Furthermore, the paper highlights the potential of personalized services in the Smart Grid context and their relevance in the Society 5.0 framework and proposes an architecture for the design and deployment of personalized energy management services in other Smart Grid contexts. In this approach, end-users play an active role in the design and deployment of personalized energy management services. The proposed methodology is tested and evaluated in a Smart University Campus case study. The results indicate an improvement in energy management and a reduction in energy consumption.

Keywords: Smart Grid, Society 5.0, Personalization, Smart Campus, Digital Twin

1 Introduction

As the Industry 4.0 manufacturing paradigm has reached the plateau of productivity [1], the industrial and manufacturing landscape is shifting towards the implementation of Society 5.0 [2,3], a concept developed by the Japanese government [4,5]. This concept requires a comprehensive digital transformation across various sectors, including energy [6]. Smart grids, an intelligent electricity distribution network, play a critical role in optimizing energy generation, transmission, and consumption [7]. With the increase in renewable energy sources, the integration of electric vehicles, and the emergence of new technologies, smart grids have become more complex, requiring innovative solutions to manage them efficiently [8].

According to [9], during 2021, the smart grid market reached a value of $43.1 billion on a global scale. According to projections, the smart grid industry is expected to reach $103.4 billion by 2026, reflecting a Compound Annual Growth Rate (CAGR) of 19.1% during the period of 2021 to 2026. The World Economic Forum (WEF) report [10]

highlights the increasing demand for renewable energy sources, government initiatives for smart grid implementation, and technological advancements in the energy sector as key factors driving market growth.
Personalized services [11] in smart grids are essential to optimize energy consumption at the individual level, improving energy efficiency and reducing costs [12]. According to a study by McKinsey& Company, personalized services in the energy sector can reduce household energy consumption by up to 15% [13]. Therefore, the implementation of personalized services in smart grids is crucial to achieve the objectives of Society 5.0 and to address the growing demand for energy efficiency, cost-effectiveness, and sustainability [14]. The contribution of this manuscript is focused on the design and development of a smart grid framework, which is applied to a university campus [15, 16]. The aim is to achieve electrical energy democratization [17] in the public infrastructure domain, and to design and develop the Digital Twin (DT) of Product Service System (PSS) Smart Grid (SG) Platform.
The remainder of the manuscript is structured as follows. In Section 2, the most pertinent literature is investigated towards the next generation of industry, i.e. Industry 5.0. Then, in Section 3, the architecture of a smart grid for a university campus is presented and discussed. In Section 4, the implementation of the proposed study is presented. In Section 5, results are presented. Finally, the manuscript is concluded in Section 6 along with the provision of future research steps.

2 Literature Review

2.1 From Energy 1.0 to Energy 4.0 and beyond

The concept of Energy 4.0, which falls under the umbrella of Industry 4.0, refers to the digital transformation of the energy industry. It is important to define Energy 4.0 in detail as it is closely linked to its evolution, Energy 5.0. This concept covers various aspects of the energy sector, including energy generation, distribution, storage, and marketing. The reason for this is that the physical world is changing rapidly with issues such as intermittent renewables, nuclear power, and new transmission and distribution grids, among others. Additionally, changes in the commercial energy landscape, such as unbundling, trading, and new product offerings, are also driving the need for Energy 4.0. The growth in the collection and flow of large datasets is also a critical factor in this transformation [18].
In Figure 1 the correlation between energy and the different industrial revolutions throughout history is illustrated. The first industrial revolution is chronologically placed in the late 18th century, introducing mechanized production as a replacement for manual labor. Approximately a century later, the second industrial revolution was sparked by the widespread adoption of electricity in industrial processes and the establishment of global electrical grids. During the third industrial revolution the integration of automation and computers to further enhance production optimization was prioritized. Presently, the fourth industrial revolution, also known as Industry 4.0, capitalizes on smart and interconnected systems to boost flexibility and productivity. This interconnectedness among machines, systems, and devices within and between industrial sites has

resulted in heightened intelligence. By leveraging the shared characteristics of sustainable energy transition and Industry 4.0, the path towards Industry 5.0 can be paved, achieving a sustainable energy transition [19].

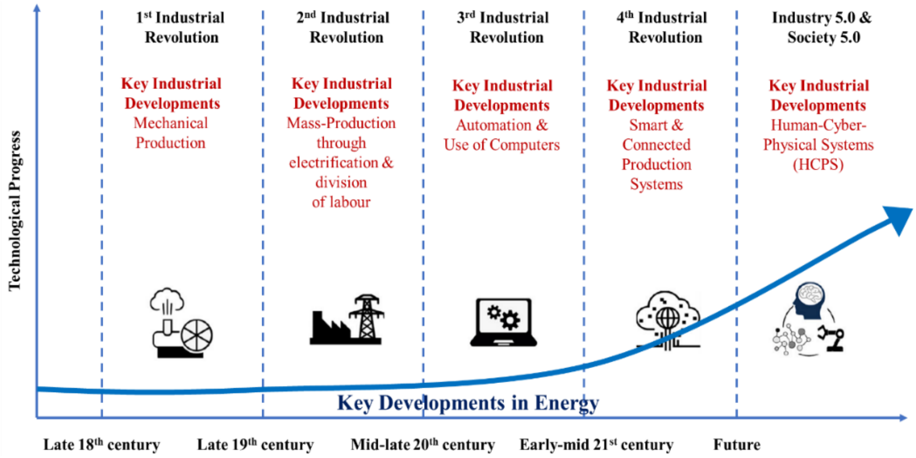


Fig. 1. Energy development milestones in correspondence to the Industrial Revolutions [20].

2.2 Smart Grids (SGs)

Up to now, energy production has primarily relied on burning fossil fuels and following a centralized system of transmitting and distributing energy in one direction [21]. During the transmission phase, electrical energy is transferred from power plants to consumers through substations with the utilization of electric cables. However, this process lacks sufficient i) real-time feedback, and ii) monitoring mechanisms. Due to the limited data flow and the sharp rise in energy demand, blackouts may occur frequently, posing a significant risk to human life [22]. Therefore, the current grid requires modernization [23]. The Smart Grid (SG) is an electrical distribution system that employs state-of-the-art digital technology to facilitate bidirectional communication between stakeholders. By constantly monitoring, analyzing, and controlling the flow of electricity, valuable information can be gleaned to create a more intelligent, adaptable, and dependable grid capable of forecasting energy demand and costs. As cited in [24], it is projected that by 2023, around 65% of electricity companies will have allocated investments towards advanced digital technologies, facilitating the introduction of innovative smart services. The SG incorporates several important features to achieve its goals. These include [25]:

1. Energy demand response support, which aims to reduce costs by providing advice on device usage during peak demand periods when prices are higher.
2. Efficient load handling to decrease the duration of peak hours and improve stability.
3. Decentralized energy production, which enables individuals or third-party stakeholders to contribute to the power grid using renewable energy sources.

By integrating smart meters, producers, and consumers, the Smart grid offers new characteristics and possibilities that aim to provide sustainable, economical, and efficient energy supply [26]. The model encourages consumers to become "prosumers" by contributing to the grid through energy production, sharing, or selling. As a result, consumers become an essential part of the grid's functionality and can optimize their energy decisions based on their energy demand. Prosumers generate energy from renewable sources, such as PV arrays or wind turbines, and share it with other consumers on the grid. The grid follows bidirectional data and energy flow between stakeholders, which can provide valuable information for optimizing the grid's function and energy distribution [27,28].

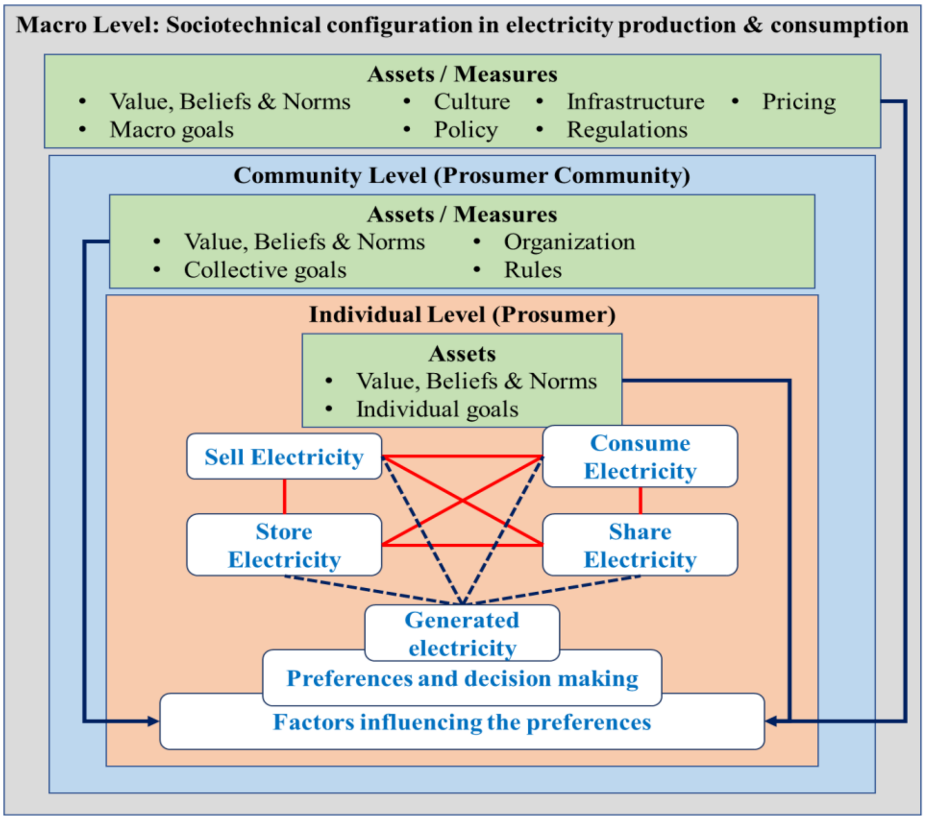


Fig. 2. Prosumers uses of energy [29].

Figure 2 demonstrates the key features of the prosumer profile. Prosumers are distinct from regular consumers because they are viewed as an upgraded version of them and offer substantial benefits for managing their energy and the overall power grid. As a result, Table 1 highlights the primary distinctions between these two energy client profiles, clarifying why prosumers can establish the foundation for the implementation of intelligent grids.

Table 1. Comparison of Consumer energy profile versus Prosumer.

Consumer	**Prosumer**
Consumes energy	Consumes, produces, shares, stores, sells energy
Has access to static data	Has access to dynamic data, better informed
Deploys non-renewable energy sources	Deploys renewable energy sources
Physical presence for device use	Remote use of device, flexible
Vulnerable to blackouts	Safer against blackouts
Not many possibilities for electricity cost management	Can manage electricity cost with better insight
Does not protect the environment	Protects the environment

2.3 Smart Grid Technologies

Smart grid technologies refer to advanced systems that integrate information and communication technologies (ICT) with power grids, enabling real-time monitoring, control, and automation of energy delivery. These technologies facilitate bidirectional communication between electricity suppliers and consumers, allowing for dynamic energy management and consumption optimization. Smart grid technologies incorporate various components, such as smart meters, sensors, advanced communication networks, and data analytics tools. They help utilities to better manage power distribution, reduce energy wastage, and improve grid reliability and resiliency. Furthermore, smart grids can accommodate distributed renewable energy sources and electric vehicles, paving the way for a more sustainable and efficient energy future [30].

2.4 Cybersecurity and Blockchain in Smart Grids

With the increasing digitization of the energy sector, ensuring the cybersecurity of smart grids has become critical. Smart grids are highly interconnected, and any breach in their security could have severe consequences, including blackouts and power disruptions. Blockchain technology offers a promising solution to enhance the cybersecurity of smart grids. Blockchain, with its decentralized architecture, provides a secure and transparent system for data storage and sharing. By implementing blockchain in smart grids, utilities can ensure the integrity of the data, prevent cyber-attacks, and protect consumer privacy. Blockchain can also facilitate secure peer-to-peer energy transactions, enabling consumers to trade energy directly with one another [31]. However, the implementation of blockchain in smart grids faces several challenges, including interoperability, scalability, and regulatory issues. Addressing these challenges is crucial

for the successful integration of blockchain into smart grids and enhancing their cybersecurity [32].
The Society 5.0 framework envisages the Smart Campus as a digitally advanced and interconnected system that uses cutting-edge technology to elevate the quality of education, research, and campus life [33]. As the Smart Campus operates through interconnected devices and data exchange, it is crucial to ensure the security and privacy of personal information and campus assets through cybersecurity and blockchain [34]. By implementing measures such as access controls, identity management, and threat detection systems, cybersecurity can prevent malicious attacks and data breaches in the Smart Campus. Furthermore, blockchain can establish a transparent and secure platform for managing and sharing data across different departments and stakeholders in the Smart Campus [35]. This will enhance data integrity and accountability while enabling peer-to-peer transactions, smart contracts, and other decentralized applications that can improve the efficiency and effectiveness of Smart Campus operations [36]. Summarizing, incorporating cybersecurity and blockchain into the Smart Campus is crucial for realizing the Society 5.0 framework's full potential, creating a secure, sustainable, and prosperous future for all.

3 Methodology and System Architecture

The growing energy demand and need for new solutions have led universities like Birmingham City University [37] and University of Glasgow [38] to invest millions of dollars to transform into smart, self-sustainable campuses. By reducing energy costs and CO2 emissions, these universities can serve as micro cities to test new ideas and promote a healthy, clean, and economic environment to students. Implementing sustainable practices in universities not only protects the environment and minimizes energy costs, but also promotes impact consciousness and education of future generations. However, creating a smart university requires consideration of multiple parameters, and a detailed recording of data is necessary to cover every level of the system. The proposed system includes smart buildings equipped with IoT devices, sensors, and actuators that interact with the digital world, enabling intelligent prediction and decision making. The system aims to optimize energy distribution by detecting and studying several parameters that affect building efficiency, such as air conditioning units, boilers, LED lights, and gas sensors. A large volume of data is created, which needs to be transferred and aggregated to the management center through communication protocols and cloud servers for processing and analysis using the digital twin.

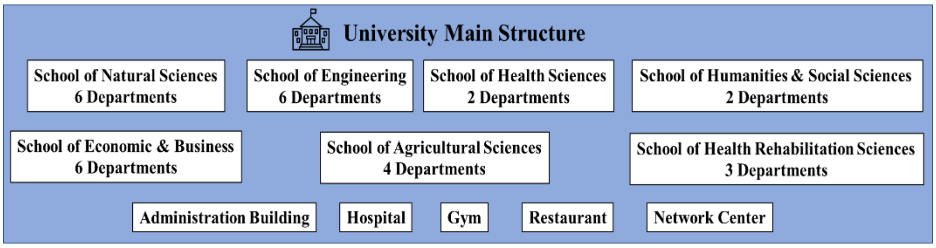


Fig. 3. University Campus Main Structure.

Table 2. University Campus Buildings for Monitoring

Building	Description
A	Administration Building
B	Hospital
C	Conference Center
D	Network center
E	Restaurant
F	Student Residence Hall
G	School of Engineering – Department 1
H	School of Engineering – Department 2
I	School of Engineering – Department 3
J	School of Engineering – Department 4
K	Gym

3.1 Cloud Platform

This paper focuses on designing and developing a Smart Grid system based on a Digital Twin implementation to optimize energy profiles for customers. A fundamental and primary element of the Smart Grid system involves establishing a customizable Digital Twin (DT) framework, which is used i) for the representation of critical elements, and ii) for facilitating the integration of new customers into the electrical energy distribution network. The implementation of the framework is based on the development of a Cloud platform that offers a range of services, including customer registration, energy consumption monitoring, and power plant creation/editing capabilities among others. Users are divided into three categories: Energy Providers, Customers, and System Administrators, each with specific roles and responsibilities. The Energy Providers user group is responsible for managing critical parameters within the Smart Grid to prevent overloading and to facilitate the temporary disabling of specific areas for maintenance purposes. The Customer's group is further classified into sub-categories such as Industrial, Professional, Office, Domestic, Organization, and Roads to prioritize energy consumption. For instance, hospitals are prioritized to ensure uninterrupted power supply. In conclusion, the System Administrator user group plays a vital role in the establishment of a smooth connection between the Cloud platform and the Smart Grid. Further to that, they also ensure that the Digital Twin model is constantly up to date when changes occur, such as when new users are added, or existing ones are removed. The platform offers customers a monitoring panel for the visualization of their real-time energy profile. In the current study the significance of implementing Digital Twin technology in Smart Grid systems is investigated, as it empowers energy consumers to further optimize their energy consumption in alignment with the overall demand of the electricity network. Consequently, this implementation leads to a more sustainable and efficient energy distribution system.

3.2 Data Acquisition and Monitoring Device

To ensure the effective implementation of the proposed system architecture and the seamless integration of the physical system(s) with the Digital Twin, it is essential to incorporate monitoring equipment for capturing relevant parameters. This entails the installation of a set of Data Acquisition devices. The modules within each device are categorized as discussed earlier. The Smart Grid nodes commonly employ sensing equipment for measuring the following: i) Light intensity, ii) micro-climate temperature, iii) micro-climate humidity, iv) current draw, and v) motion within the buildings. Some key characteristics of the sensors utilized through the nodes of the smart grid are summarized as follows [39]:

- **Light sensors** used in a smart grid must be accurate, reliable, and able to detect a range of light levels. They should have a fast response time, low power consumption, and be able to communicate wirelessly. Additionally, they should be resistant to environmental factors such as temperature, humidity, and dust.
- **Temperature sensors** used in a smart grid should be accurate and reliable, with a fast response time and low power consumption. They must be able to measure a wide range of temperatures and be resistant to environmental factors such as humidity and dust. Additionally, they should be able to communicate wirelessly and have a long battery life.
- **Humidity sensors** for a smart grid need to measure the amount of water vapor in the air accurately. They should have a wide measurement range, high accuracy, low power consumption, and be able to communicate wirelessly. They must also be robust and reliable, able to withstand harsh environments and have a long lifespan.
- **Current draw sensors** for a smart grid must be capable of measuring both AC and DC currents, with high accuracy and resolution. They must also be able to operate over a wide temperature range and have low power consumption. The sensors must be reliable and able to provide real-time data to the control systems for load balancing and demand response purposes.
- **Current motion sensors** for a smart grid must be able to detect movement in electrical current flow and provide accurate and timely data for monitoring and control purposes. They should have high sensitivity, fast response time, low power consumption, and the ability to operate in harsh environments. The sensors must also be compatible with communication protocols used in the smart grid and have sufficient data storage capacity for logging current readings over extended periods.

3.3 Digital Twin

The primary objective of the Digital Twin (DT) module is to facilitate the near real-time monitoring of the buildings (refer to Figure 3 and Table 2) within the Smart Grid, allowing for the simulation of power generation and distribution. Additionally, the DT plays a crucial role in minimizing unnecessary power consumption by aiding in the modeling process and utilizing data collected from the individual sensing devices mentioned earlier.

One important parameter calculated by the DT is the Indoor Environmental Quality (IEQ) [41]. The IEQ is a comprehensive metric that encompasses Visual Comfort (VC), Thermal Comfort (TC), and Indoor Air Quality (IAQ). In this approach, the IEQ is measured on a scale from 0 to 100, with 100 representing "optimal quality". Calculating the IEQ requires the fusion of information from various sensors [42].

Another aspect of the DT pertains to the road network connecting the buildings within the campus. By implementing an intelligent algorithm that takes into account factors such as time of day, environmental lighting, and traffic measurements, the lighting system can be automatically adjusted to provide the minimum required illumination [43]. However, to establish a reliable and continuous communication with the physical system, it is crucial to employ an appropriate communication framework, which is discussed in the next Section.

3.4 Communication framework

The communication framework serves as a vital component within the Smart Grid infrastructure. Its seamless and uninterrupted operation is crucial to ensure the continuous functionality of the Smart Grid system. To facilitate data acquisition, a Wireless Sensor Network (WSN) is implemented. The WSN follows a star topology, allowing for a single local network coordinator (Master) and multiple sensing nodes (Slave) to coexist. Each sensing node is equipped with sensors, a central data-gathering board, and an RF/Bluetooth antenna for wireless connectivity to the network coordinator. Figure 4 provides a visual representation of the star topology. The network coordinator is responsible for collecting data from the connected sensing nodes and organizing it into a structured file format, such as XML. The data files are transmitted back to the Cloud Database, where the identity of the network coordinator and WSN is included with each XML file to ensure proper classification of the data from each node.

Therefore, based on the above mentioned, in order to develop a digital twin for a smart grid requires the installation of smart sensors both inside and outside a university building to collect data about the building's energy usage and performance. Therefore, the following steps were followed in order to install the appropriate sensors (i.e., Motion sensor, Temperature and Humidity sensor, and Photoresistor - Fig. 5):

1. **Selection of Points for Installation:** Before installing any sensors, conduct a thorough site survey to identify the areas where the sensors will be installed. This will help you determine the optimal locations for sensors, the number of sensors required, and the type of sensors needed.

2. **Sensors Selection:** There are many types of sensors available for monitoring energy usage and building performance, such as temperature sensors, occupancy sensors, light sensors, and energy meters. Choose the appropriate sensors based on the data you need to collect and the areas you want to monitor.
3. **Sensor Installation:** Once you have identified the optimal locations for the sensors, install them. This may require running wires and cables, drilling holes, and mounting the sensors in the appropriate locations. Make sure to follow the manufacturer's instructions for installation and wiring.
4. **Connect the sensors to the network:** Once the sensors are installed, they need to be connected to the network so that they can send data to the digital twin. This can be done using Wi-Fi or Ethernet cables, depending on the type of sensors and the network infrastructure.
5. **Sensor Configuration:** Each sensor will need to be configured to send data to the digital twin. This may require setting up IP addresses, configuring data transmission rates, and setting up authentication and encryption protocols to ensure data security.
6. **Digital Twin Configuration:** Once the sensors are installed and configured, set up the digital twin to receive data from the sensors. This may require setting up a cloud-based platform or an on-premises server to collect, store, and analyze the data.
7. **Data Monitoring**: Once the sensors are sending data to the digital twin, monitor and analyze the data to identify patterns and trends in energy usage and building performance. Use this information to optimize energy usage and improve the building's performance.

The Information and Communication Technologies used for the implementation of the proposed system are explained in a detailed manner in Section 4 and Section 5.

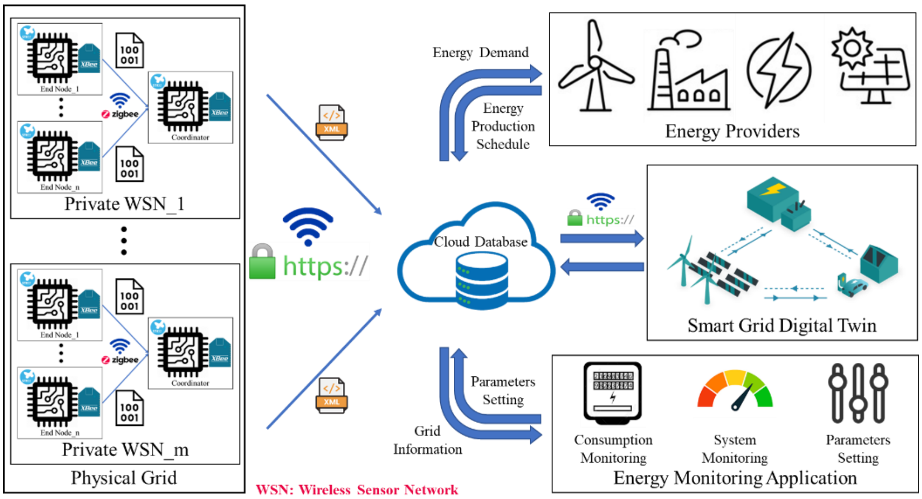


Fig. 4. Architecture of the proposed system (Developed by Authors).

4 System Implementation

The implementation of the proposed method is based on the integration of a multi-sensing device for acquiring environmental data from each of the buildings involved in the smart grid. These parameters involve the indoor environment conditions as well as the logging of the electrical energy consumption, so that they can be processed from the corresponding DT and consequently to provide suggestions of the optimization of electrical energy utilization. In simple terms, a sensor is an input device that detects physical events by modifying its electrical properties and converting them into measurable analog or digital signals with the assistance of a Micro Controller Unit (MCU). This allows human operators to observe, read, save, and further process the data in order to optimize the system. Sensors can be classified into various categories based on their working principles, including the need for an external signal, detection method, conversion method, and output signal type.

The first category distinguishes sensors as active or passive, depending on whether they require an external signal to function. Active sensors rely on a signal, while passive sensors generate an output response without external excitation. Sensors can also be classified as electric, chemical, or radioactive based on the detection method. The third classification is based on the conversion phenomena, such as thermoelectric or photoelectric conversions. Lastly, sensors can be categorized as analog or digital, where analog sensors produce continuous analog signals and digital sensors produce binary signals.

For instance, a Light Dependent Resistor (LDR) photoresistor, which is affordable and has a simple structure, is used for luminosity measurement. It is made of semiconductor materials that exhibit changes in electrical conductivity when exposed to light (photons), disrupting the material's electrical stability. This disruption creates an electric signal that can be captured by the system, although sometimes an amplifier is required to transmit the data to a computer. The resistance capacity of this sensor decreases whenever a light beam falls on the LDR cell and increases whenever no light source is present. The minimum response time is approximately 55 milliseconds for sensing any light change and approximately 45milliseconds are required in order to transmit the measured signal to the microcontroller. Furthermore, some extra characteristics are the high sensitivity, fast respond time and low-cost, making sensors reliable and more accessible to companies and users to build advanced automated systems based on them. In Figure 5, the sensors used for the implementation of the functional prototype are illustrated.

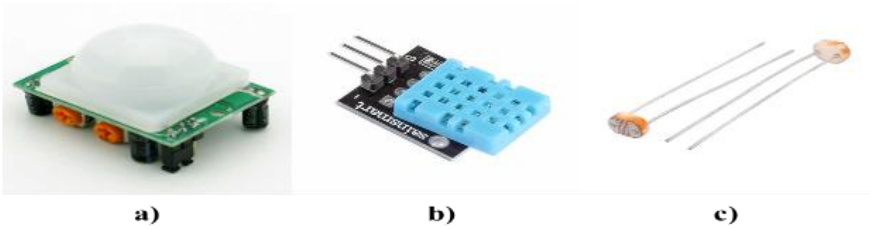


Fig. 5. (a) Motion sensor, (b) Temperature and Humidity sensor, and (c) Photoresistor.

In the current research temperature, humidity and luminosity are taken into consideration as parameters (see Table 3), for the representation of the indoor environment conditions in order to facilitate the representation of the physical environment to the digital twin.

Table 3. Environmental monitoring parameters and their measurement methods.

Variable	Parameters	Measurement
T1	Air temperature (°C)	Temperature sensor
H1	Humidity (%)	Humidity sensor
L1	Luminosity (Lux)	Photoresistor

Specifically, in Table 3 information on the variables, units, and detection sensors associated with each parameter are provided. The variables for internal parameters are represented by two symbols, a letter followed by the number 1, while external parameters are denoted by a letter and the number 2. The units used in the table are degrees Celsius (°C) for temperature, percentage (%) for humidity, and lux for luminosity, which is equivalent to one lumen per square meter.
For temperature and humidity detection, the DHT11 sensor is utilized, which is capable of measuring both variables. This sensor incorporates a resistive-type humidity measurement component and a negative temperature coefficient (NTC) thermistor. The NTC thermistor exhibits a decrease in resistance as the temperature increases, leading to an increase in conduction electrons due to the thermal effect. Additionally, an 8-bit microcontroller is employed to output the values as serial data, making the system function as a temperature and humidity module. Table 4 presents the characteristics of the DHT11 module, while Table 5 provides the technical specifications of the light-dependent resistor (LDR) used for luminosity measurements.

Table 4.DHT11 characteristics.

Technical Specification	Value Range
Temperature measurement range	0°C to 50°C
Humidity measurement range	20% to 90%
Temperature accuracy	±2°C
Humidity accuracy	±5%
Operating voltage	3V to 5.5V
Operating current	0.3mA (measuring) 60uA (standby)

Technical Specification	Value Range
Output	Serial data
Resolution	8-bit
Response Time	6sec to 30sec

Table 5.LDR Photoresistor characteristics.

Technical Specification	Value Range
Operating temperature range	-25°C to 75°C
Voltage peak	100V
Current	5mA
Power dissipation at 25°C	50mW
Cell resistance	20kOhm to 100kOhm
Dark resistance	20MOhm
Rise time	45ms
Fall time	55ms
Spectral response	550nm

Having precise knowledge of the internal conditions within each building and comparing them with the real-time external weather conditions is crucial for gaining valuable insights into the system's efficiency. By integrating this data into the Digital Twin (DT), advanced analytic methods and algorithms can be employed to optimize the University's operations. This includes evaluating and controlling the Heating, Ventilation, and Air Conditioning (HVAC) system to ensure it is performing optimally. Additionally, assessing the electricity cost is essential to evaluate the entire system, while considering all the gathered data.

To establish a remote monitoring system, the data needs to be transferred to servers or the cloud via the Internet for storage and aggregation. Wi-Fi modules, which are cost-effective system-on-a-chip devices, provide a complete Wi-Fi networking solution in a single chip. These modules come with integrated antennas and other components, such as CPUs, facilitating easy and fast connection and operation. Moreover, Wi-Fi network modules support software tools and communication protocols, enabling connectivity with Arduino for remote data exchange and system management.

To enable the Wi-Fi connection between the local network and the data acquisition device, the ESP8266 ESP-01 Wi-Fi module is utilized in this research. This module is designed for mobile platforms with restricted space and power, offering extensive Wi-Fi capabilities while being cost-effective and occupying minimal space. It integrates various components, including an antenna, power amplifier, low-noise receive amplifier, filters, power management modules, and internal SRAM. It can be easily integrated with sensors and other devices through its GPIO pins, allowing for versatility according to user requirements. During programming, specific characteristics and access codes related to the Wi-Fi module and network, such as module type, baud rate, Wi-Fi key, and ID, need to be defined to establish a stable and reliable data flow.

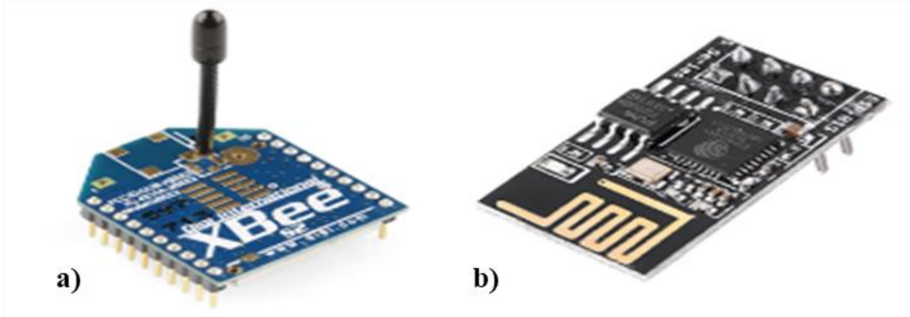


Fig. 6. (a) XBee RF module, (b) ESP8266 WiFi module.

5 Case Study

5.1 Data Acquisition Device

The system architecture implementation revolves around the development of the Data Acquisition (DAQ) device, which is considered a fundamental technology and forms the basis of the entire system. The developed DAQ device is responsible for detecting the physical environmental conditions and transmitting the data to designated servers via Wi-Fi. This enables the creation of real-time data charts, representing the precise environment, which can be further analyzed and used for predicting energy consumption throughout the day.

The DAQ device comprises both hardware and software components that work together synergistically. These components will be presented and explained in detail below. The combination of these components offers limitless possibilities, catering to a wide range of applications, as numerous detection methods and sensors are available to meet the specific needs and goals of the user.

Our customized data acquisition device is specifically programmed to measure temperature, humidity, and luminosity within the selected buildings of the university. This is achieved by connecting the appropriate equipment to the chosen microcontroller. Detailed information regarding the components and circuitry of the device can be found in Table 6, and a visual representation of the prototype is provided in Figure 7.

Table 6. Data Acquisition device parts.

Parts	**Description**
Arduino UNO R3	Microcontroller
DHT 11 (3 pins)	Humidity (%) and temperature(°C) sensor
Photoresistor	Luminosity sensor (LDR)
ESP 8266 ESP-01 module	Wi-Fi microchip
Resistances	1kOhm, 10kOhm
Male/ Female Wires	Connect and complete the circuit

Power Supply regulator	Converts power supply from 5V to 3.3V

The microcontroller utilized in this device is the Arduino Uno R3, which is reliable for the entire data acquisition system. The device detects environmental conditions through DHT11 and LDR photoresistor, connected to a breadboard with wires and resistors. The resistors are selected based on Ohm's law and are necessary for the circuit to function properly. DHT11 already has an integrated resistor, so an additional one is not required. For data transfer, ESP8266 module is utilized, which is a Wi-Fi micro-chip that establishes a connection with the WLAN and subsequently WAN through the necessary TCP/IP communication protocol suite stack. Additionally, a power supply regulator is incorporated as the ESP8266 module requires a 3.3V input to operate effectively. This regulator supplies the necessary voltage along with a greater amount of current than Arduino's 3.3V supply pin, which can cause functionality problems. The device functions by taking input from the sensors and outputting data to servers. The microcontroller, programmed using the Arduino IDE, transforms the sensor data into valuable information. Figure 7 illustrates the connection of external sensors. Furthermore, traditional circuitry components like resistors and capacitors have been added to ensure accurate sensor measurements and correct operation of the DAQ device. A 10kOhm resistor is connected to the photoresistor, and the ESP8266 module has a 1kOhm resistor. Each external sensor requires three pin connections to the MCU. The sensors are powered using a 3.3V to 5V DC voltage (red for positive and black for negative/ground pins). An extra wire (blue) is linked to an Arduino analog or digital input/output pin. Three digital pins (6 to 8) and a single analog pin are used in the current setup. The DHT11 sensor is connected to digital pin number 8, the ESP8266 module to pins 6 and 7, and the LDR photoresistor to analog pin A0. The power supply regulator is set to 3.3 volts on one side of the breadboard to guarantee the secure operation of the ESP module and 5 volts on the other side for better sensor efficiency and stability. This provides two different power supply voltages simultaneously, making the device more versatile. Furthermore, using an external power supply makes it easier to use the Wi-Fi module. The on-board 3.3V pin provides low amperage compared to the prototype's requirements, which can cause system instability and prevent communication with the cloud server.

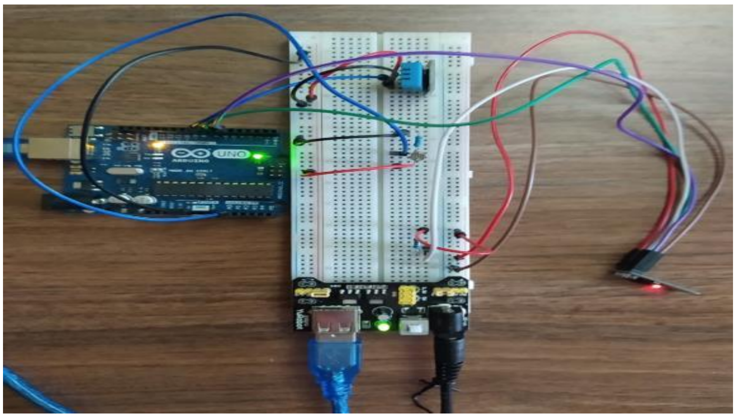


Fig. 7. Data Acquisition device prototype.

The connectivity of the sensors is straightforward but connecting the ESP module to the breadboard and Arduino is a bit more complicated due to the many pins involved. In addition to the ground and power supply connections, the Arduino's RX and TX pins must be correctly connected to the corresponding pins on the ESP module to enable bidirectional communication and constant data exchange between the two. However, not all of the ESP module's pins are necessary, and some, such as the reset pin, can be left unconnected. The system can also be reset using the reset button on the Arduino.
For this study, various sample rates for the data acquisition device were tested, ranging from 30 seconds to 5 minutes. It was found that the building conditions did not change rapidly, so a 5-minute sample rate was selected for more accurate detection of environmental changes. The code script developed for the device stores temperature and humidity as "float" data types and luminosity as "int" data type, each taking up 4 bytes per sample sent to the cloud server platform. This results in 12 bytes being sent every 5 minutes and 144 bytes every hour, well within the limit of ThingSpeak, which can receive messages up to 3000 bytes. The device has been tested with over 10,000 samples with minimal package loss due to network connection interruptions, and live and historical data can be exported for visualization and analysis.

5.2 Results and Discussion

The Graphical User Interfaces (GUI) for live monitoring of the buildings as well as an additional functionality for the setup of high consumptions periods are presented in Fig. 8.

Fig. 8. Graphical User Interfaces for Consumption monitoring and high/low consumption period setup.

Live visualizations of physical conditions within a building can be used in various ways to optimize energy functions. Correlated data plots, such as those presented in Figure 9, can help in better understanding and comparison between variables. For instance, humidity and temperature data can be presented in a single plot to easily observe their relationship, which in this case is inversely proportional.

Comparing live outdoor and indoor conditions can provide valuable insights into the performance of the HVAC system and insulation status, which can inform maintenance and repair activities. For instance, the temperature difference between the inside and outside environments should be around 10°C when the HVAC system is operating. If this threshold is surpassed, a warning message with an adjustment suggestion can be sent to prevent the air-conditioning system from overperforming and reducing its efficiency, thus increasing the overall electricity cost. Regularly detecting high humidity and temperature problems could lead to a more efficient maintenance plan, such as upgrading the equipment or insulation.

Access to the consumed kilowatts of each building is crucial for evaluating the system's economic aspect, which can be obtained from the relevant department. This enables stakeholders to evaluate any future operation, equipment, or shift while considering its economic impact.

The system has the potential for additional enhancements through the integration of smart equipment or actuators, which facilitate near real-time interaction to minimize energy consumption and promote environmental preservation. An illustrative example is the utilization of motion or LDR sensors to automatically control LED lights, resulting in reduced energy usage and cost. To demonstrate this functionality, a small LED light was connected to the prototype of the data acquisition device and programmed to activate automatically when the lux value dropped below 100, indicating a dark and overcast day.

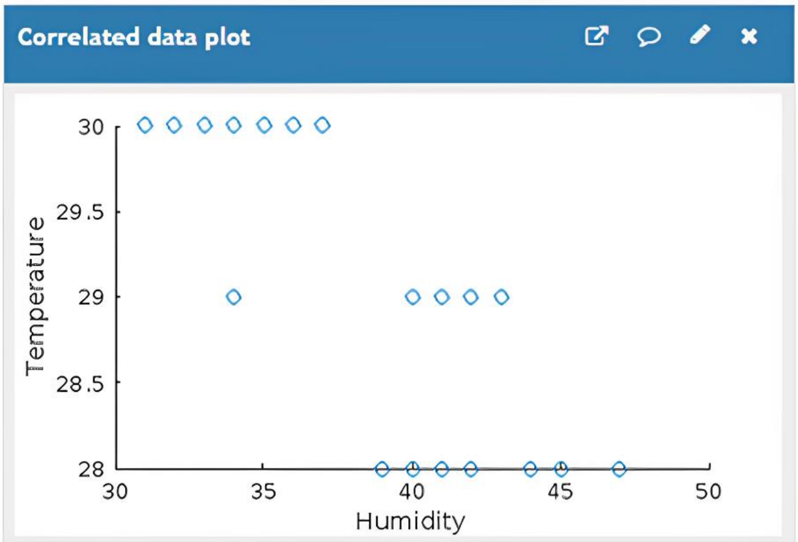


Fig. 9. Live data depicting the correlation between Temperature and Humidity.

6 Conclusions and Outlook

In this study beyond the bibliographic investigation regarding the energy democratization, a smart grid framework has been proposed and applied in a university campus. Ultimately, the purpose of the presented research work is to lay the foundations for transforming traditional consumers (including organizations such as universities), in becoming prosumers. Finally, on the basis of demand response (DR), the key challenges and opportunities for future development have been extracted and presented in Figure 10. Decentralized aggregation markets or peer-to-peer trading may be the future, but they have mainly been tested in small-scale projects and their lasting value remains uncertain. New technologies, like blockchain, increase the possibilities of implementing local and retail market mechanisms, making consumer objectives more attractive. This section outlines future trends and outlooks for DR policies for prosumers. It covers barriers that decisionmakers must overcome and opportunities and recommendations. Figure 10 shows areas for research and possible barriers and opportunities for different market players. The section discusses parameters for analyzing barriers and opportunities at four levels and provides an overview of DR programs and optimization techniques.

Similarly, in Figure 10, the domain for the democratization of energy is presented. Upon further examination of the figure, the four sub-domains can be utilized in order to highlight the key areas providing fertile ground for future research, namely i) prosumer, ii) aggregation and community, iii) market regulation, and iv) independent system operator.

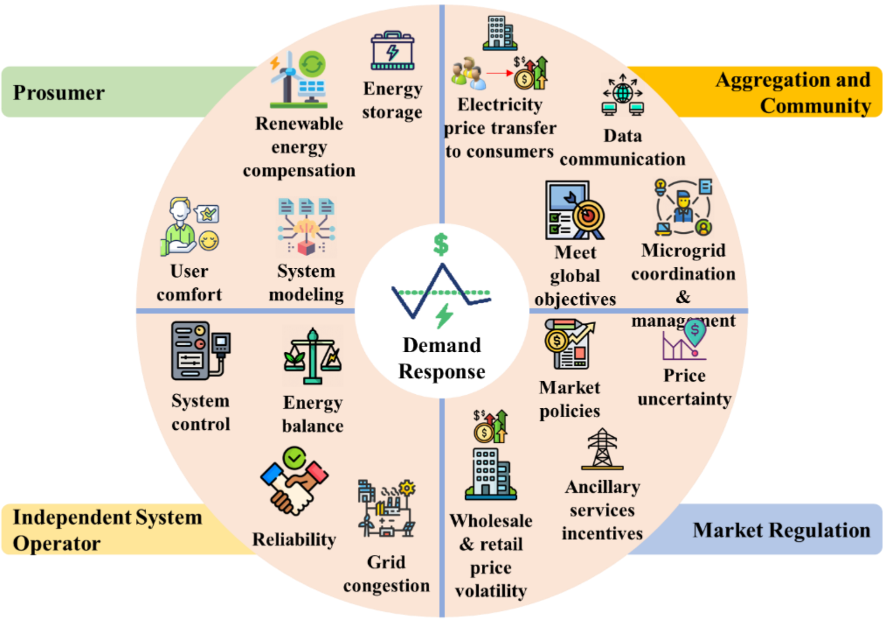


Fig. 10. Overview of key challenges and opportunities in the democratized electric energy market [44].

Prosumer: Prosumers can generate electricity and participate in the market. To overcome barriers, opportunities include using Battery Energy Storage Systems (BESS) and DR programs, developing intelligent technologies for real-time monitoring and implementing Home Energy Management Systems (HEMS), and improving mathematical models of electrical appliances.

Aggregation and Community: Current research has identified aggregators coordinating with community energy markets, but more attention is needed to create business and asset management models using DR programs and optimization, assess feasibility of migrating to participate in community electricity markets, and develop hardware and software with advanced algorithms for DR integration and optimization.

Market Regulation: To improve market regulation, more research is needed to investigate the relationship between DR programs, prosumer optimization models, and market regulation. Key considerations include utilizing DR as ancillary services, evaluating the impact of DR on price regulation, investigating legal issues related to selling surplus energy, and developing public policies to balance markets. Mathematical formulations can aid in pilot project construction, market modeling studies, and evaluation of opportunities for aggregating agents. Different business models may be applied depending on the region, and small-scale users have an incentive to engage in DR programs where allowed.

References

1. Bassi, L.: Industry 4.0: Hope, hype or revolution? 2017 IEEE 3rd International Forum on1 Research and Technologies for Society and Industry (RTSI), Modena, Italy, 1-6, 2017.
2. Mourtzis, D., Angelopoulos, J., Panopoulos, N.: A Literature Review of the Challenges and Opportunities of the Transition from Industry 4.0 to Society 5.0. Energies 15(17), 6276. (2022)
3. Huang, S., Wang, B., Li, X., Zheng, P., Mourtzis, D. and Wang, L. Industry 5.0 and Society 5.0—Comparison, complementation and co-evolution. Journal of manufacturing systems, 64, 424-428 (2022)
4. Fukuyama, M.: Society 5.0: Aiming for a new human-centered society. Japan Spotlight, 27(5), 47-50 (2018)
5. Keindaren: Opening the doors to Society 5.0. Availablet at: https://www.keidanren.or.jp/en/policy/2022/032_proposal.html
6. Mourtzis, D., Angelopoulos, J. and Panopoulos, N.: A collaborative approach on energy-based offered services: energy 4.0 ecosystems. Procedia CIRP, 104,1638-1643 (2021)
7. Fang, X., Misra, S., Xue, G., & Yang, D. Smart grid—The new and improved power grid: A survey. IEEE communications surveys & tutorials, 14(4), 944-980 (2011)
8. Gellings, C. W. The smart grid: enabling energy efficiency and demand response. CRC press (2009)
9. Smart Grid Market. Markets and Markets (2023). Available at: https://www.marketsandmarkets.com/Market-Reports/smart-grid-market-208777577.html?gclid=CjwKCAjwrdmhBhBBEiwA4Hx5gzwC6cB1Ab-vSJ5HxMtH9rSZ7O13dSLOjH9wD3AikO6ur4YbSj_2AvRoCgPUQAvD_BwE
10. Evans, S.: Renewables will be world’s top electricity source within three years, IEA data reveals. World Economic Forum (2023). Available at: https://www.weforum.org/agenda/2023/02/renewables-world-top-electricity-source-data/
11. Mourtzis, D.: (Book). Design and operation of production networks for mass personalization in the era of cloud technology, 1 – 393 (2022).
12. Bhattacharjee, A., Badsha, S., & Sengupta, S. Personalized privacy preservation for smart grid. IN 2021 IEEE INTERNATIONAL SMART CITIES CONFERENCE (ISC2)1-7). IEEE.
13. McKinsey.: Transforming advanced manufacturing through Industry 4.0 (2022). Available at: https://www.mckinsey.com/capabilities/operations/our-insights/transforming-advanced-manufacturing-through-industry-4-0
14. Mourtzis, D., Angelopoulos, J. and Panopoulos, N. Smart Grids as product-service systems in the framework of energy 5.0-a state-of-the-art review. Green Manufacturing Open, 1(1), 5 (2022).
15. Mourtzis, D., Angelopoulos, J. and Panopoulos, N., 2022. Development of a PSS for smart grid energy distribution optimization based on digital twin. Procedia CIRP, 107, pp.1138-1143.
16. Tzemos, Th., 2022. Development of a smart grid digital twin for energy distribution optimization : a PSS approach
17. Szulecki, K.: Conceptualizing energy democracy. Environmental Politics, 27(1), 21-41 (2021)
18. Ghobakhloo, M., Fathi, M.: Industry 4.0 and opportunities for energy sustainability. Journal of Cleaner Production, 295, 126427 (2021)

19. Leng, J., Sha, W., Wang, B., Zheng, P., Zhuang, C., Liu, Q., Wuest, T., Mourtzis, D. and Wang, L.: Industry 5.0: Prospect and retrospect. Journal of Manufacturing Systems, 65, 279-295 (2022)
20. Mourtzis D.: Towards the 5th industrial revolution: a literature review and a framework for process optimization based on big data analytics and semantics. Journal of Machine Engineering, 21 (2021)
21. Polymeneas, E., A. Rubin, and H. Tai.: Modernizing the investment approach for electric grids. McKinsey Company Available at: https://www. mckinsey. com/industries/electricpower-and-natural-gas/our-insights/modernizing-the-investment-approach-for-electric-grids (2020).
22. Chen, Z., Amani, AM., Yu, X., Jalili, M.: Control and Optimisation of Power Grids Using Smart Meter Data: A Review. Sensors 23(4):2118 (2023).
23. National Conference of State Legislatures, Anderson, G., Cleveland, M. and Shea, D.: Modernizing the Electric Grid: State Role and Policy Options. National Conference of State Legislatures (2019)
24. Ormazabal, M., Vanessa. S/, Rogerio. P.L, Jaca. C.: Circular Economy in Spanish SMEs: Challenges and opportunities. Journal for Cleaner Production 185:157-167 (2018)
25. Personal, E., Guerrero, J. I., Garcia, A., Pena, M., & Leon, C. Key performance indicators: A useful tool to assess Smart Grid goals. Energy, 76, 976-988 (2014)
26. Zafar, R., Mahmood, A., Razzaq, S., Ali, W., Naeem, U. and Shehzad, K.: Prosumer based energy management and sharing in smart grid. Renewable and Sustainable Energy Reviews, 82, 1675-1684 (2018)
27. Picciariello, A., Vergara, C., Reneses, J., Frías, P., &Söder, L. Electricity distribution tariffs and distributed generation: Quantifying cross-subsidies from consumers to prosumers. Utilities Policy, 37, 23-33 (2015)
28. Mourtzis, D., Boli, N., Xanthakis, E. and Alexopoulos, K.: Energy trade market effect on production scheduling: an Industrial Product-Service System (IPSS) approach. International Journal of Computer Integrated Manufacturing, 34(1), 76-94 (2021)
29. Hertig, Y., and Teufel, S.: Prosumer involvement in smart grids: the relevance of energy prosumer behavior. In 35th International Conference on Organizational Science Development, Portorož, 30-41 (2016)
30. Ekanayake, J. B., Jenkins, N., Liyanage, K. M., Wu, J., & Yokoyama, A. Smart grid: technology and applications. John Wiley & Sons (2012)
31. Mourtzis, D., Angelopoulos, J., Panopoulos, N. Blockchain Integration in the Era of Industrial Metaverse. Applied Sciences. 13(3):1353 (2023)
32. Zhuang, P., Zamir, T., & Liang, H. Blockchain for cybersecurity in smart grid: A comprehensive survey. IEEE Transactions on Industrial Informatics, 17(1), 3-19 (2020)
33. Carayannis, E. G., Morawska-Jancelewicz, J.: The futures of Europe: Society 5.0 and Industry 5.0 as driving forces of future universities. Journal of the Knowledge Economy, 1-27 (2022)
34. Alkhammash, M., Beloff, N., White, M.: An internet of things and blockchain based smart campus architecture. In Intelligent Computing: Proceedings of the 2020 Computing Conference, 2, 67-486 (2020). Springer International Publishing
35. Villegas-Ch, W., Palacios-Pacheco, X., Román-Cañizares, M. Integration of IoT and Blockchain to in the Processes of a University Campus. Sustainability, 12(12), 4970 (2020)
36. Fernández-Caramés, T. M., Fraga-Lamas, P.: Towards next generation teaching, learning, and context-aware applications for higher education: A review on blockchain, IoT, fog and edge computing enabled smart campuses and universities. Applied Sciences, 9(21), 4479 (2019)

37. University of Birmingham.: Delivering the world's Smartest Campus (2023). Available at: https://www.birmingham.ac.uk/university/building/smart-campus/index.aspx
38. University of Glascow.: Smart Campus Digital Masterplan (2019). Available at: https://www.gla.ac.uk/media/Media_702108_smxx.pdf
39. Gungor, V. C., Lu, B., & Hancke, G. P. Opportunities and challenges of wireless sensor networks in smart grid. IEEE transactions on industrial electronics, 57(10), 3557-3564 (2010).
40. Heinzerling, D., Schiavon, S., Webster, T., &Arens, E.: Indoor environmental quality assessment models: A literature review and a proposed weighting and classification scheme. Building and environment, 70, 210-222 (2013).
41. Parkinson, T., Parkinson, A., de Dear, R.: Continuous IEQ monitoring system: Context and development. Building and Environment, 149, 15-25 (2019)
42. Zaballos, A., Briones, A., Massa, A., Centelles, P., Caballero, V.: A Smart Campus' Digital Twin for Sustainable Comfort Monitoring. Sustainability 12(21):9196 (2020)
43. Mourtzis, D.: Simulation in the design and operation of manufacturing systems: state of the art and new trends, International Journal of Production Research, 58:7, 1927-1949 (2020)
44. Silva, W.N., Henrique, L.F., Silva, A.D.C., Dias, B.H., Soares, T.A.: Market models and optimization techniques to support the decision-making on demand response for prosumers. Electric Power Systems Research 210, 108059 (2022)