Lustra

IT 496: Graduation Project Report
Product Release-1

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Introduction

The need for street lighting is more significant than ever as cities expand, and technology develops. Streetlights do more than light up our roads. They are essential for maintaining public locations' usability at night and preventing accidents [1]. Despite this, as cities get bigger, the traditional streetlights we use become less and less sustainable due to their high energy consumption. The development of the Internet of Things (IoT) has led to a drive to improve the intelligence, effectiveness, and suitability of these systems for the demands of contemporary cities.

Keeping people safe is the key to good street lighting. However, in today's world, it is also important that our infrastructure is sustainable. Selecting sustainable solutions is essential to protecting the environment. Because when compared to traditional lighting sources, connected lighting systems can lower overall energy use and carbon footprint by up to 85% while also saving money on cleanup and operation [2].

Much research has been done on smart streetlights for increased safety and energy saving [3]. These studies have shown that we can cut down on energy use while still keeping our streets safe. However, there is still a significant need to support this research field and investigate the latest technologies available for developing such systems. Therefore, developing a project on IoT Smart Street Lighting Systems remains valuable despite existing research for several reasons. First, it provides the opportunity to gain hands-on experience and acquire practical experience with cutting-edge technologies in a rapidly evolving field.

Furthermore, the project has the ability to provide advancements that are specifically designed to address local requirements or limitations. Furthermore, with the increasing adoption of smart technologies in cities around the globe, there is a need for qualified experts capable of implementing and sustaining these systems. Further advancements in energy efficiency and cost reduction in street lighting systems are still necessary, emphasizing the importance of ongoing research and development. The smart lighting industry is expected to experience significant growth, increasing from USD 13.4 billion in 2020 to USD 30.6 billion by 2025, as stated in a report by MarketsandMarkets [4]. This indicates a high demand for specialized knowledge in this field.

This project aims to contribute to developing a smart street lighting system that utilizes light infrastructure to collect geo-contextualized data for further analysis and processing. The proposed project seeks to utilize IoT sensors to optimize energy efficiency, improve lighting management, and reduce maintenance costs.

The structure of this document is as follows: Section 2 presents the problem statement, followed by the suggested solution. Section 4 provides the project vision, while section 5 presents the roadmap and shows the deliverables for each sprint. Additionally, the project objectives, scope, software and hardware tools are also provided. The last section shows the skills, roles, and responsibilities of the scrum team.

The Problem

Cities worldwide are facing significant problems with managing street lighting, showing the urgent need for smart street lighting systems. In many places, old street lighting systems waste a lot of energy. A clear example is in Los Angeles, where streetlights are left on at full brightness late at night, wasting energy and straining city budgets [5].

Similarly, the cost of maintaining regular street lighting systems is increasing. Cities like New York are dealing with higher expenses because outdated technology leads to frequent bulb replacements and repairs, partly due to inefficient management.

Also, poor street lighting makes safety problems worse. The rise in crime in poorly lit neighborhoods in New York shows how bad lighting can create unsafe areas where crime is more likely to happen, making people feel less secure [6].

These examples highlight the critical need for smart street lighting systems to address energy inefficiencies, reduce maintenance costs, provide adaptive lighting management, and enhance public safety.

The Solution

To address the inefficiencies and high maintenance costs of traditional street lighting systems, the solution involves developing a smart street lighting system designed to optimize energy usage and reduce light pollution. This system will utilize advanced technology to adjust lighting levels based on real-time conditions, thus addressing energy waste and environmental impact.

The Solution Includes developing a detailed design for the smart street lighting system, including the following:

- Integrating sensors and control mechanisms to enable adaptive lighting based on real-time data.

- Utilizing Internet of Things (IoT) sensors to monitor street activity. These sensors will provide data to adjust lighting levels dynamically according to actual needs, reducing energy consumption and minimizing waste.
- Creating a centralized platform for managing the street lighting system. This platform will facilitate real-time monitoring and adjustments, ensuring optimal lighting levels and further reducing maintenance requirements.

The main components of the proposed solution, as shown in Figure 1, are: motion sensors that are installed along the street light to detect the movement of objects; a control node that is also connected to each street light to enable the controlling functionalities; and a street light that is compatible with the required sensors and control nodes. Additionally, the control node requires an integrated communication module for data transmission. Furthermore, the website platform provides an interface for system administrators to monitor and control the lighting system.

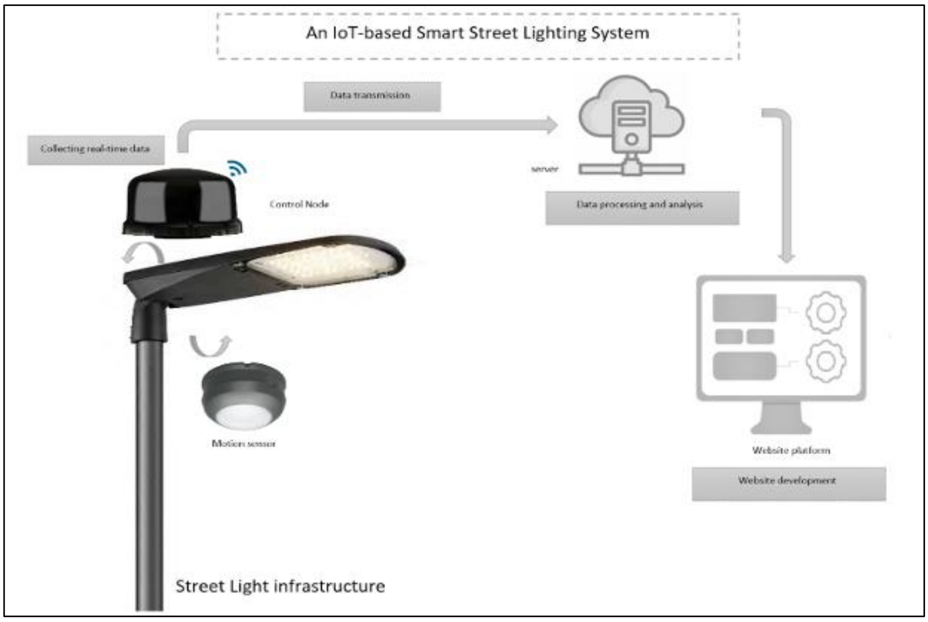

Figure 1The main components of the proposed solution.

The system will work as follows: First, the motion sensors will gather data, which the control nodes will then transmit to the server via the communication module. The server will perform the required analysis and processing, enabling the system to adjust the streetlights by sending commands to the control nodes. The administrator can access the website to view valuable insights about the current energy consumption, light status, and motion detection events.

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Product

Product Vision

For the emerging smart cities in Saudi Arabia, which aim to enhance urban infrastructure, foster sustainable economic growth, and improve citizens' quality of life through advanced technologies and data analytics, The Lustra is an IoT-powered smart street lighting system that automatically adjusts lighting based on motion detection and optimizing energy, unlike traditional street lighting systems that rely on manual operation and are less energy-efficient, our product is the first locally developed IoT smart street lighting system, delivering energy-saving solutions that support the development of smart urban environments [7].

Product Roadmap

Table 1 Product Roadmap

Sprint # 0	Start date: 1st Sep	End date: 26th Sep
• Set Up a shared GitHub repository for tracking changes and collaboration. • Create a Jira project and add a product backlog. • Write a literature review to research the project background. • Order the essential hardware/software tools • Learn basic IoT skills • Research domain and system modeling: Write user stories and their acceptance criteria.		
Sprint # 1	Start date: 29th Sep	End date: 24th Oct
• Design device configuration/ Architecture. • Create a database for data storage and management. • Develop Prototype main functions such as: 1- Motion sensos 2- Light control: ▪ Remote on/off control of streetlights. ▪ Dimming options for adjusting brightness levels.		

Sprint # 2	Start date: 28th Oct	End date: 28th Nov
• Develop remaining light control features: - Real-time monitoring for status tracking of all data acquired. • Receive alerts for faults. • Develop a data analytics feature that analyzes sensor data to provide valuable insights for optimizing lighting schedules. • Connect the interface to the database.		
Sprint # 3	Start date: TBA	End date: TBA

• Develop Monitoring and reporting of street light status features:
  • Scheduling capability for setting automatic on/off times.
  • Automatic adjustment of brightness levels based on a specific factor.
• Design the functionalities' interfaces.
• Build the dashboard interface for data visualization.
• Ensure safety communication protocols are in place for secure data handling.		

Sprint # 4	Start date: TBA	End date: TBA

• Develop more Visualization and Reporting features and their interfaces:
  - Represent the locations of the streetlights on the map.
  - Create reports on each street light information.
  - Allows administrators to control the streetlights and manage schedules
 	
• Design account management and authentication interface.
Perform a performance test and a field test.		

Objectives

1. **Product (Customer Focus - Value)**

The need to enhance urban safety and efficiency drives the development of our smart street lighting system. This system addresses the challenges of traditional street lighting by conserving energy and providing advanced features that benefit both citizens and city officials. By leveraging technology to offer real-time data and operational insights, the system aims to resolve the problems outlined in the problem section (Section 2). The users will experience reduced operational costs and improved environmental impact. Product objectives are as follows:

1.1 **Optimize Energy Consumption:** Achieve over 60% energy savings with advanced brightness controls and real-time usage monitoring [8].

1.2 **Facilitate Efficient Maintenance:** Enable faster issue detection and resolution with integrated monitoring and diagnostic tools, reducing maintenance costs and downtime.
1.3 **Support Environmental Sustainability:** Contribute to lower carbon emissions and promote eco-friendly practices by extending the lifespan of lighting fixtures and reducing energy consumption.
1.4 **Provide Real-Time Data and Insights:** Offer analytics and reporting features to manage streetlights and maintenance needs, aiding in informed decision-making.

2. **Project (Solution Focus - Plan)**

2.1 **Gather Needs:** Determine precisely what the smart street lighting system needs to do by talking to stakeholders and analyzing requirements.
2.2 **Design the System:** Create a detailed plan for how the system will work, including hardware, software, and how it will fit into the city's infrastructure.
2.3 **Build a Prototype:** Develop and test a working model of the street lighting system to ensure everything works as planned.
2.4 **Analyze Data:** Collect and study data from the prototype to fine-tune how the lights adjust and save energy.
2.5 **Create a User-Friendly Interface:** Design an easy-to-use web dashboard for city managers to control the lights.
2.6 **Test and Integrate:** Ensure the system works well with existing city systems and conduct thorough testing to iron out any issues.
2.7 **Deploy and Document:** Roll out the system in a test environment, document the process, and prepare a final report on what was achieved.

3. **Learning Objectives (Student Focus)**

3.1 **IoT Skills:** Learn how to develop and work with Internet-connected devices like smart streetlights.
3.2 **Smart City Basics:** Understand how smart technologies fit into city life and improve urban environments.
3.3 **Data and Analytics:** Discover how to use data to make smart decisions and improve system performance.
3.4 **Project Management:** Gain experience in managing a project from start to finish, including planning, organizing, solving problems, and testing.
3.5 **User Interface Design:** Learn how to design simple and effective interfaces that make technology easy for people to use.
3.6 **Sustainability:** Explore how technology can be designed to be environmentally friendly and energy efficient.
3.7 **Integration Skills:** Learn how to combine new technologies with existing systems in a seamless way.

Scope

With the trend of urbanization causing cities to become more prominent, issues naturally will arise. Proposed solutions are being discussed for the growing problems of urban infrastructure and public utilities in Saudi Arabia. The Lustra is an English web-based application developed to minimize the adverse effects of traditional streetlight lamps consuming more than needed of the country's resources; it's an innovative motion sensor street lighting control system. The IoT hardware utilized in the project is a Razo LED streetlight equipped with one CitySense Lite Zhaga motion sensor and a control node. The Ministry of Municipal and Rural Affairs and Housing administrators will be interested in our local-oriented solution.

Hardware/Software Tools and Cost

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Table 2 Hardware and Software Tools

Hardware Tools	
Name and Description	Cost
2 Citysense light Zhaga model 1B (4m ht), Company: TVLight Des: The Citysense light Zhaga model 1B is a 4-meter-tall streetlight designed for smart urban lighting. It offers energy efficiency and improved safety while complementing modern city aesthetics.	It costs EUR 69.5 each, (Ordered and expected to be delivered before sprint 1)
OpenSky Zhaga IoT (control node) 10 years Des: The OpenSky Zhaga IoT Control Node is a plug-and-play device that adds smart control to streetlights, which makes it easier to manage and more energy-efficient. It fits into standard fixtures, so it's easy to upgrade existing lights.	€89.7
RAZO-S-20-400-740-L7-ZU- LED Street light: It is a high-efficiency LED streetlight designed for outdoor lighting. It provides bright, clear illumination while using less energy compared to traditional lighting options.	It costs EUR 209, with freight costsEUR366.85. Expected to be delivered before sprint 1
Software Tools	
Name and Description	Cost
GitHub: It's a platform where programmers add their code and work together on projects	Free
Jira: A platform for software teams to manage their projects, plan sprints, assign tasks, report issues, and keep their whole development lifecycle organized in one place.	Free
OpenSky Zhaga IoT API Des: The OpenSky Zhaga IoT API allows developers to integrate smart lighting solutions using Zhaga-compliant	Free

devices. It enables real-time data access and control, enhancing energy efficiency and urban management.	
Visual Studio Des: It is a source code editor. It provides tools such as debugging, syntax highlighting, code completion, and version control support; it serves as a flexible tool for developers on various platforms.	Free
MongoDB Des: MongoDB is a flexible database that stores information in documents, making it easy to change how you organize your data. It's perfect for apps that need fast access to different types of information and can grow as your needs change	Free

Scrum Team

Skill Set Requirements

Table 3 Technical Skills Assessment and Learning Plan

Technical Skill Required	What is the current level of the team (*beginner-intermediate- advanced*) for each skill? How will the gap be bridged? *(if necessary*) Learning plan
Implementing required features using OpenSky Zhaga IoT API	Beginner, self-learning from the internet.
Cloud computing and data management	Intermediate, self-learning from the internet.
Programming languages (Python &Flutter)	Intermediate, self-learning from the internet.
Project management and documentation	Advanced
Sensor integration	Beginner, self-learning from the internet.

1.4.1.1 Learning

As a collective, we are dedicated to enhancing our knowledge for the best quality project we can make. It was through various online platforms, including Coursera and Udemy, and instructional videos on YouTube. Our focus has been on implementing back-end JavaScript frameworks, specifically Express, to establish connections with our MongoDB and utilize third-party RESTful APIs, such as Tvilight and Google Maps. We also learned to write code by implementing the front-end JavaScript framework, React. Furthermore, we have refreshed our skills in interface design using Figma. We learned to use an app called Postman to test HTTP requests and monitor server behavior.

Roles and Responsibilities

Table 4 Scrum Team

Scrum Team	
Product Owner:	D.Lamia Albraheem
Developers:	Raseel Aldawish Sarah Algarny Rawan Algarny Hend Al-Ghamdi
Scrum Master (SM):	D.Lamia Albraheem
Stakeholders:	Examiners

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Background

This chapter provides background information that is required to understand the proposed project. It highlights the shift from traditional systems to intelligent solutions, shows the significance of IoT architecture and configuration (including both real-world and emulation testing), and highlights the role of communication technologies within these systems. The remainder of this chapter is organized as follows. Section 2.1 outlines the traditional street lighting systems currently in use, while Section 2.2 discusses the IoT-based smart street lighting. Section 2.2.1 describes the IoT architecture for smart street lighting, while section 2.2.2 presents how the IoT-based Smart Street Lighting systems can be configured and implemented. Finally, section 2.2.3 explores the communication technologies utilized in these systems.

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Traditional Street Lighting Systems

Many locations still use outdated street lighting systems, such as inefficient incandescent or fluorescent lamps that must be turned on manually or using timers. These systems can't be very flexible when it comes to shifting traffic patterns or environmental conditions, and they often have large consumption of energy. Many of these lights don't have sensors, so when they're not in use, they often remain on, wasting energy and raising operating costs. Traditional street lighting systems' high energy consumption, which makes up a large portion of urban energy use, is their main drawback. If automatic control is not there, these systems run continuously at maximum brightness during times of little traffic, which drives up costs even more. Because there isn't real-time monitoring, errors or failures are frequently missed until they are manually reported, which delays repair and raises safety concerns. These difficulties underline the need for more intelligent solutions that can dynamically adjust to traffic,

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weather, and environmental factors while reducing operational costs and energy waste [9].

IoT-based Smart Street Lighting

A built sensor, controller, and communication network smart street lighting system is suggested as a solution to the problems with outdated streetlights. This advanced solution makes use of Internet of Things technologies to improve lighting based on current conditions. Through activity and movement monitoring, the system automatically modifies light levels to meet real-time requirements. The data collected by these sensors is transmitted to a central server, where it is processed and analyzed. This enables dynamic adjustment of the lighting levels, ensuring that the lights are only as bright as necessary. Such intelligent control significantly reduces energy consumption and maintenance costs while enhancing overall safety. A user-friendly web-based interface allows administrators to monitor and control the street lighting system. With the use of this platform, real-time monitoring and control are possible, giving users insight into the operational state of each light and facilitating quick resolution of any potential problems. The smart street lighting system increases public safety and reduces costs by increasing its life and maintaining ideal lighting conditions [10].

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IoT Architecture for Smart Street Lighting

The IoT architecture includes four layers: the perception layer, the network layer, the processing layer, and the application layer, as seen in Figure 2, these layers are discussed below.

1. First Layer - Perception Layer

Our smart streetlight system is equipped with advanced sensors that form the perception layer. This layer acts as the system's eyes, detecting motion and environmental changes to dynamically adjust the lighting. It enhances energy efficiency by tailoring streetlight brightness to the needs of real-time traffic [11].

2. Second Layer - Network Layer

The network layer acts as a critical communication bridge linking the perception layer to the data processing layer. It utilizes a variety of communication technologies, from short-range options like ZigBee and Bluetooth to long-range methods such as Wi-Fi and LTE, facilitating seamless data transfer. This layer is crucial for managing data efficiently and ensuring that the streetlights can be controlled effectively [11].

3. Third Layer - Data Processing Layer

The data processing layer lies at the heart of our system. This layer receives and analyzes data transmitted from the network layer, processing it through smart algorithms hosted on cloud servers. It makes intelligent decisions about streetlight operation, adjusting light brightness to save energy while considering the traffic conditions at the time [11].

4. Fourth Layer - Application Layer

A user-friendly web interface connects city Administrators to the system at the top level, or application layer. Using it, city administrators can monitor and control lighting operations, modify schedules, and gain real-time feedback. This layer unifies the system, improving city administrative capabilities and providing better data flow and communication to assist services like public safety and transportation [11].

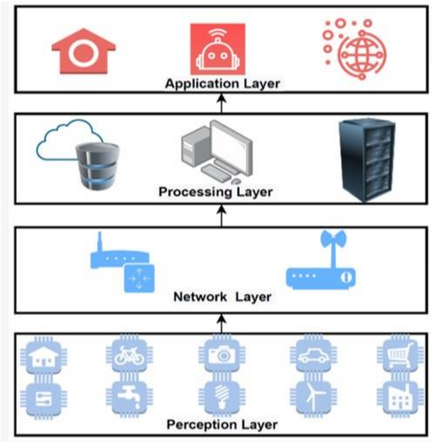

Figure 2: IoT Architecture Layers [12]

IoT Configuration for Smart Street Lighting

While the smart street lighting project provides a dynamic response to urban lighting issues, the goals extend beyond simply improving street lighting. The goal is to enhance the interaction between lighting systems and the city and its residents, leading to the need for more features and a high level of customization. One crucial step in this manner was equipping the streetlights with modern IoT components. It was best to provide the necessary tools for fully realizing the vision. While there are many standard products on the market, many lack the necessary customization options or functionality, such as effective multi-light setting management or compliance with open-source APIs. This section explores the essential elements that power intelligent streetlights *[13]*:

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• Microcontroller Units (MCUs): These are the brains of each streetlight, processing input from various sensors and making real-time decisions on light output.

• Sensors: Motion and ambient light sensors detect movement and changes in light conditions, allowing the streetlights to adjust automatically to save energy and enhance safety.
• Communication Modules: Using LTE and Wi-Fi, these modules ensure that each streetlight can communicate with the central management system for updates and monitoring without the need for local gateways.
• Power Management: Essential for maintaining the efficiency of the lights, these systems manage the power supply to each unit, ensuring optimal performance and longevity.
• Lighting Elements: LED strips and bulbs that can change color and intensity based on the data received from the sensors, providing the right light for every scenario [13].

The decision was made to build these systems from the ground up to create a customized solution. This approach allows for real-time monitoring and adjustment of every part of the streetlight network. It addresses today's lighting needs while also preparing for future smart city projects. In short, the design of IoT-enabled streetlights combines technology with city planning, resulting in a flexible lighting system that enhances urban life while ensuring safety and environmental sustainability.
The IoT-based smart street lighting system can be implemented using Real-world deployment or emulation testing. Real-world deployment of IoT-based smart street lighting systems involves implementing and testing the infrastructure in actual urban environments, utilizing existing streetlights equipped with various sensors. In contrast, emulation testing simulates these conditions using small-scale hardware components such as LEDs, Arduino boards, and sensors, allowing for controlled experimentation and troubleshooting before full-scale implementation [14]. The following subsections present the required hardware for each type.

1. Real-world testing

   Several companies offer hardware and APIs for implementing IoT-based smart street lighting systems. These solutions enable cities to modernize their infrastructure, reduce energy consumption, and improve urban lighting management. One such company that has made significant strides in this field is Tviligh. Smart outdoor lighting solutions are Tvilight's specialty. They provide a variety of modern devices that are intended to assist communities in effectively managing their street lighting infrastructure. The company offers smart streetlight controllers that allow streetlights to be remotely managed, monitored, and controlled throughout the course of a whole city [15].

   To implement a real-world IoT-based smart street lighting system, Tvilight company provides different components which includes: OpenSky Zhaga IoT, CitySense Lite Zhaga Model and RAZO streetlight that provided from their partner Vimalux [16]. These components are described in Table 5 and Figure 3.

   OpenSky Zhaga IoT:

   This control node can help intelligent lighting solutions to save 60% to 80% of energy It allows remote monitoring and real-time adjustments of light via a centralized platform. Built on open standards and APIs, it ensures compatibility with other smart city systems [17].

CitySense Lite Zhaga Model 1B:

CitySense Lite Model 1 is an innovative streetlight sensor, which works together with SkyLite Prime and OpenSky Zhaga IoT light controllers. It enables on-demand lighting by adjusting brightness based on human presence detection. When no one is nearby, the lights remain dim, conserving energy by up to 80%. Upon detecting pedestrians, cyclists, or slow- moving vehicles, the lights automatically brighten. This sensor is ideal for public parks, pedestrian pathways, bicycle paths, residential areas, and university campuses [18].

RAZO streetlight:

The VIMALUX RAZO is a modern and efficient street lighting solution designed for urban environments. It features a sleek, contemporary design that seamlessly integrates into cityscapes. The RAZO is equipped with advanced technology, including an NFC programmable DALI2 LED driver that enables sophisticated dimming and control capabilities[16].

(a) (b) (c)

Figure 3: Hardware components for Real-word deployment of IoT-based smart street lighting system [15], [16]

Table 5: The main components for implementing a real-word IoT-based smart street lighting system

Figure	Product Name	Description
3(a)	OpenSky Zhaga IoT	It offers efficient street lighting management with remote monitoring, plug-and-play installation, local cellular connectivity, and adaptive motion-based lighting [17].
3(b)	CitySense Lite Zhaga Model 1B (4m ht)	Motion sensor with various models for different installation heights and sensor coverage[19] .
3(c)	RAZO-S-20-400-740-L7-ZU LED Street Light	Sleek, efficient, and easily maintainable LED streetlight with adaptive lighting design[16].

2. Emulation testing

The main components to configure an IoT-based street lighting system using emulation testing includes different small-scale hardware such as LEDs, Arduino boards, sensors, actuator, and different wires as shown and described on Table 6 and Figure 4.

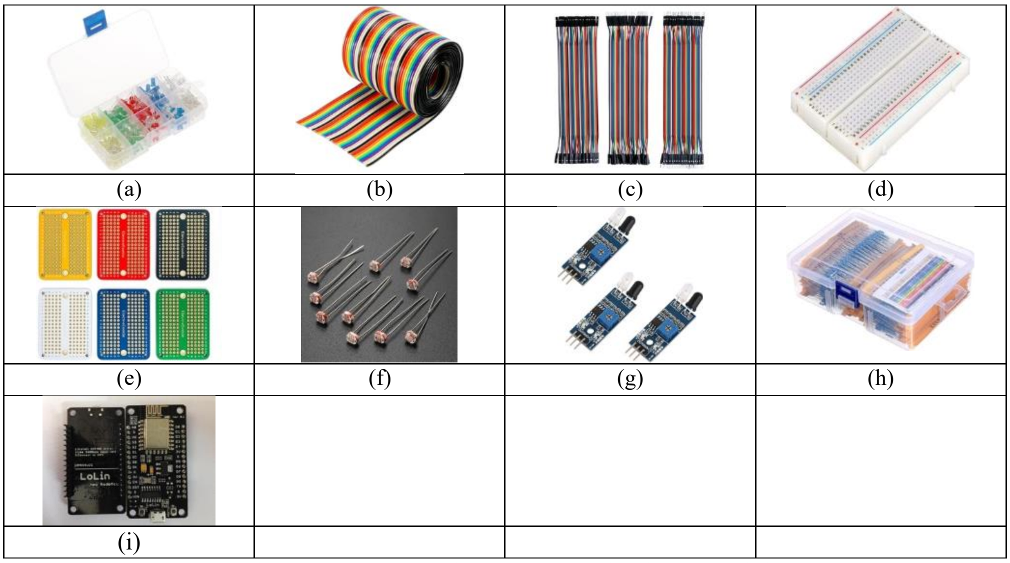

Figure 4: Hardware components for emulating testing of IoT-based smart street lighting system

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Table 6: The emulation testing components for emulating testing of IoT-based smart street lighting system

Figure	Component	Description
4(a)	5MM Light Emitting Diodes	The purpose of these LED diodes is to provide dependable circuit performance by rectifying and stabilizing current. They are long-lasting and impact-resistant since they are made of premium, sturdy materials. Since they don't release any UV or infrared radiation when operating at low voltage, they provide increased safety. These diodes are well-suited for usage in traffic signals, household appliances, electronics, and lighting systems. They are arranged in a kit box for easier access and storage [20].
4(b)	Rainbow 40P IDC Ribbon Cable, 1.27mm, 1m	This 40P jumper wire ribbon flat cable is 1 meter long and color-coded for easy identification and separation. Featuring varied specifications within one kit, it is perfect for creating neat, organized connections in your projects. Ideal for use with digital cameras, camcorders, laptops, LCD TVs, and monitors, it ensures reliable and efficient wiring for various electronic devices.
4(c)	ELEGOO 120pcs Dupont Jumper Wires Kit	This kit includes 20 cm (8-inch) jumper wires that can be easily separated for customizable assemblies. It comes with three types of jumper wires: 1 x 40-pin male-to-female, 1 x male-to-male, and 1 x female-to-female, all neatly packaged in a color box. This versatile set is perfect for a variety of wiring and prototyping needs.
4(d)	Mini 400 Points Solderless Breadboard for Arduino/Raspberry Pi	This kit includes a 300 tie-point terminal strip and two 100 tie-point distribution strips. Made from reusable ABS plastic with color-coded coordinates for easy placement, it features phosphor bronze nickel-plated spring clips for secure

		connections. Compact size: 8.2 cm x 5.5 cm x 1 cm (3.27 x 2.16 x 0.39 inches). Ideal for organized prototyping.
4(e)	ElectroCookie Mini Gold-Plated PCB (6 Pack) for Arduino	The ElectroCookie double-sided PCB features a gold-plated finish in multicolor, measuring 2" x 1.5" (50.8mm x 38.1mm) with 0.047" (1.2mm) through holes. It includes M3 (Ø3.2mm) and M2 (Ø2.2mm) mounting holes and has a 0.04" (1mm) trace width, making it ideal for various electronic projects.
4(f)	Tanzimarket 10 PCS GL5516 Photoresistor LDR	This pack of 10 GL5516 light-dependent resistors (LDRs), each 5mm in size, is dispatched within 24 hours. These photoresistors adjust conductivity based on light intensity and are ideal for use in toys, lamps, and cameras.
4(g)	RIV 3 Pcs IR Obstacle Sensor Module for Arduino	The IR infrared obstacle avoidance sensor module detects obstacles via infrared tubes, activating a green LED when reflected light is detected. It features a 3-wire interface (VCC, GND, output), operates at 3.3 to 5V, and provides a low-level digital output. The detection range is adjustable from 2cm to 80cm.
4(h)	Morelian 2600pcs 1/4W Metal Film Resistors Assortment Kit	This resistor kit contains 2600 pieces across 130 values (1Ω to 3MΩ), with 20 pieces of each. Made from durable metal, these wirewound resistors provide high precision and stability, ideal for use in TVs, speakers, and amps.
4(i)	HiLetgo ESP8266 NodeMCU CP2102 Development Board (1PC)	The ESP8266 is a highly integrated chip designed for modern connectivity, offering a complete networking solution that can host applications or offload tasks from other processors.

Communication Technologies for Smart Street Lighting

Effective communication technologies are essential for the seamless operation of IoT-based smart street lighting systems. These technologies enable real-time monitoring, control, and data transmission between streetlights and the central management system. Several communication protocols are commonly used in smart lighting, including:

1- Wi-Fi: Wi-Fi can be used for short-range communication, especially in smaller networks where streetlights are located close to each other or connected to a nearby Wi-Fi access point. It allows for fast data transmission but may not be ideal for large-scale citywide deployments due to limited range and higher power consumption.
2- LTE (4G/5G): Long-Term Evolution (LTE) networks provide a broader range and are ideal for citywide deployments. Technologies like LTE Cat M1 and NB-IoT offer low-power, wide-area coverage, making them suitable for connecting large networks of streetlights. These cellular networks ensure secure, reliable, and long-distance communication without the need for local gateways. The OpenSky Zhaga IoT Controller, for instance, utilizes LTE communication to allow for remote management and real-time control.

3- ZigBee is another low-power wireless communication protocol often used in smart lighting systems. It is particularly effective for mesh networks, where each streetlight acts as a node, forwarding data to the next, creating a reliable and scalable network. ZigBee's low power requirements make it a suitable choice for energy-efficient IoT lighting solutions [20].

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Literature Review

As cities grow, it's important to have energy-efficient street lighting. Traditional streetlights waste energy and money because they don't adjust to real-time conditions. Research by Avotins et al., Dizon et al., Gagliardi et al., Kabir et al., Yang et al., and Nagamani et al. shows that smart street lighting using LEDs and dynamic controls can save energy and improve safety. However, there is a need to give more attention to the best way to implement these systems. The following section reviews current studies on smart street lighting, discussing their benefits and challenges.

Research-Based

In 2021, Avotins et al. focus on increasing the energy efficiency of smart street lighting systems through the use of dynamic control techniques and LED technology. The system suggests modifying lighting settings in real time based on traffic intensity by utilizing motion detectors and dimming controllers, which results in increased energy savings. This dynamic adjustment ensures that lighting is provided only, when necessary, significantly reducing energy waste. The paper does not provide a specific implementation of the proposed control systems. It suggests a hypothetical scenario rather than an actual implementation. However, this study supports the project's focus on implementing adaptive lighting systems that respond to real-time conditions [21].

In 2021, Dizon et al. presented the implementation of an IoT-based smart street lighting system using an open-source simulator. Usually, a lot of councils stick to a traditional method when it comes to street lighting, which leads to inefficiencies as it fails to consider environmental factors like light levels and traffic patterns. The adoption of smart streetlights can improve public safety and wellbeing. It is one of the buildings that uses the most electricity, but it also puts an expense on the local government. A traditional approach to street lighting is typically adopted by the government; this has several drawbacks because it ignores environmental factors. Therefore, this paper focuses on different time-based schemes for light control. Additionally, the paper discusses and compares the energy savings for the presented schemes. The results showed that the different lighting schemes participate in different reductions in energy [22].

Moreover, Gagliardi et al. focuses on designing an affordable smart lighting system using an IoT infrastructure in which every streetlight is equipped with different sensors and actuators. The main problem lies in the high energy usage of city streetlights, which requires a solution that adjusts streetlamp intensity based on traffic and pedestrian activity, while still providing sufficient light. A smart lighting system was created to vary streetlamp brightness according to traffic and pedestrian activity. The result of the experiment shows that energy savings can be as high as 80% when compared to traditional streetlamp system. Expanding smart lighting system throughout the entire city may present difficulties, since the initial setup costs of sensors, camera's and IoT infrastructure could be expensive which will be a challenge for smaller local governments to adopt [23].

In 2020, Yang and al. proposes a very effective system for setting up, implementing and deploying smart streetlights. Streetlights along with sensors can be merged to create a platform for collecting data. Analyzing large amounts of data is an important and essential component of a smart city. The strategy uses container-based management for fast deployment and scalability, incorporates NoSQL and in-memory databases for adaptable data handling, and guarantees secure transmission with asymmetric keys and (Secure Shell protocol) SSH tunnels. Token-based

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[illegible]	Main [illegible]	Wireless technology	HW used	SW used	System Features	System implementation
[22]	[illegible] g an IoT-based smart street lighting system using open-source simulator	Not Given	None Simulated WSN (wireless sensor network) to detect traffic flow	Different Simulators for the environment: StreetlightSim Veins SUMO and ONMET++	Time-based dimming schemes, On/Off dimming scheme Adaptive lighting scheme based on traffic and motion Measuring energy consumption	SW Simulation (Virtual Simulation)
[23]	Implementing a real-world smart lighting system	Local communication: ZigBee Remote communication, between smart-phones and the web application, based on 3G/4G/ WiFi connections.	Smart Camera, Lighting Control Board, motion sensors, weather sensors, and dimming devices	A web application and mobile APP that allows remote management	Adaptive lighting control based on daily time and traffic intensity (segments level, single street) Provide streetlights GPS locations. Fault alarm. Measuring energy consumption trend. Remote video processing for vehicles motion detection, .	Real-World Deployment Testing
[24]	Implementing a Cloud management platform with edge services to manage street lighting and provide real-time data and video streams	Communication protocols to the edge node: RTMP and WebSocket)	Cloud server (VMs for scalability) RPi (sensor management) IP camera, the Arduino micro-controller, and air quality sensors, ambient sound,	Docker (Containerization), Nginx (a web server), MongoDB	Real-time video streaming and edge service handling to manage street lighting. Historical data query.	Simulating the environment using hardware such as LED, sensors, Arduino: This approach is known as "Emulation Testing

			temperature and humidity, intensity of illumination, ultraviolet, and motion sensing.			
[25]	Reducing energy consumption by 70% to 85% -Lighting that adjusts based on vehicle movement and daylight conditions.	Wireless communication through sensors, which allows the control of the number of streetlights.	Simulated sensors such as: ESP32 board, LED lights, LDRs, Ultrasonic Sensors, Real-Time Clocks (RTCs)	A simulation software for designing and testing the system. This will emulate the behavior of real-world street lighting and help optimize the design for energy efficiency.	Adaptive lighting control based on vehicle movement and daylight. Dimming based on data for energy saving under specific conditions	SW Simulation (Virtual Simulation)
[6]	To save energy, improve safety, and collect data on vehicle movement	ESP8266 module for wireless communication and data transfer.	Arduino Uno view, LDR Sensor, Wi-Fi Module, IR Sensor, LED, Buzzer, MAX232 IC.	Embedded C for programming the Arduino, Thingspeak IoT platform	Uses LDR for light sensing, IR sensors for vehicle detection, and a buzzer for alerts.	Simulating the environment using hardware such as LED, sensors, Arduino: This approach is known as "Emulation Testing

authentication is also utilized for linked services. Hence, this system can assist in meeting the requirements for data speed, minimal delay, setup, and creation of a smart city. The paper focuses more on implementing a cloud-based smart street management system and testing the platform's performance than on light control schemes [24].

In 2023, Kabir et al. centered on simulating a smart LED street lighting system, as it effectively reached its goal by reducing costs and optimizing electricity usage. Although streetlights are important and necessary to ensure safety and visibility in public places at night, they also play a significant role in energy usage. Every government around the world is committed to reducing household activity and electricity usage. An intelligent street system was put in place using LED lights that turn on when a vehicle approaches and off when no vehicles are around. The results showed that there is an ability to save energy by up to 80% compared to traditional streetlamps, and it also allows a remote monitoring system and smart management through peripheral devices [25] .

Furthermore, Nagamani and el. focus on improving energy efficiency and safety in cities by implementing a new streetlamp management system, utilizing wireless technology to cut down on energy wastage and prevent accidents. The difficulties lie in the high energy cost associated with traditional streetlight systems and the requirement for enhanced safety protocols to avoid accidents. A central server controls LED lights at night through light sensors and detects vehicles using IR sensors. The system efficiently conserves energy and enhances safety by changing light levels according to traffic flow and warning about parked vehicles. A strong WiFi connection is essential, along with routine care and possible future enhancements for solar energy and electric vehicle charging [6].

Table 5 Comparative Study of Smart Streetlight Systems Implementation

.

Discussion

The studies highlight the benefits of smart street lighting. Avotins et al. [1] suggested changing light levels based on traffic to reduce energy waste, but their study lacks practical details. The paper provides a generic framework rather than an actual implementation. However, the rest of the of the mentioned related works can be classified according to their implementation of the IoT-based smart street lighting system into three types: real-world deployment testing, software simulation or virtual simulation, and emulation testing. The real-world deployment involves implementing and testing the system in an actual environment using the real streetlights that are attached with different sensors. This method can provide the most realistic assessment of system performance, as shown in [3]. On the other hand, the software simulation using simulator tools to simulate the streetlight environment depends mainly on the quality of simulation models; however, it can be cost-effective since no hardware is needed, as shown in these studies [2] [5]. For the emulation testing [3][6], it simulates the environment using small real hardware components such as LED, Arduino, sensors, etc. This method bridges the gap between software simulation and real-world deployment testing.

To sum up, since there is a lack of studies that consider real-world deployment, this project tries to fill in the gap and provide real-world deployment testing for the IoT-based smart street lighting system. It will consider the common features such as adaptive controlling, time-based dimming, energy consumption reporting, and fault detection.

Competitive Product Analysis

After gaining insight into the study field of Smart Street Light Management Systems by reading the previous section, this section will compare our product with our current competitors in the same market. It is essential to outline the details of the items we have ordered for our project, presented in the background chapter, section 0. This will serve as a benchmark for comparison and help us gauge the position of our rung within the ladder of performance and capabilities of IoT smart streetlights. The competitors can be divided into two sections: companies that manufacture the components of the smart system, such as motion sensors and control nodes, also provide their own IoT-based smart street lighting systems. Examples include Dimonoff, Telensa, and FLASHNET. There are also companies that manufacture streetlights that are compatible with the required sensors and control nodes and partner with different smart street lighting companies. An example of this type of company is AEC Illuminazione and VIMALUX.

Dimonoff

Dimonoff was founded in 2006, and its headquarters is in Canada [26].Dimonoff offers a light control node called RME (Remote Management Endpoint), and the nodes are connected to the network by a gateway. Some control node characteristics are automatic on-and-off switching, dimming light intensity for energy consumption preservation, and detecting failures and problems [27]. Dimonoff provides an IoT management platform called SCMS (Smart City Management System), a web-based platform that increases the system's flexibility. It can view and control the Dimonoff control nodes, gateways, and third-party products implemented in the system. It can be connected to other applications due to open API [28]. The brand does not produce motion sensors; it makes sound sensors, but the control node is compatible with third-party sensors (motion, parking, noise, water level, temperature). The control node, RME (Remote Management Endpoint), has adaptive control capabilities; the system can adjust its lighting based on real-time conditions, such as sensor inputs.

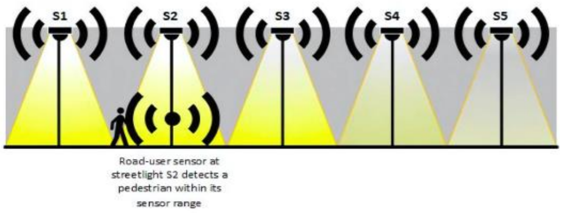

Figure 2 Adaptive lighting scheme from a pedestrian perspective [22]

Dimonoff Key features:

- Real-time monitoring provides streetlights with accurate status and energy statistics, with precision levels surpassing 0.5%[29].
- The REM control node seamlessly integrates into various environments, operating on a voltage range of 90-525 Vac and 50/60Hz, making it suitable for different regions and electrical standards globally. It is also compatible with multiple control protocols, including 0-10V (an analog dimming protocol) and DALI (Digital Addressable Lighting Interface)[29].
- SCMS's high-quality capability (Smart City Management System) is to incorporate multiple IoT sensors (parking, noise, water level, temperature) and camera inputs into a single, user-friendly interface [29].
- The Smart City Management System (SCMS) IoT platform is highly scalable and robust. It can integrate up to 1,000,000 nodes or sensors worth of data. However, the system requires 16 core CPUs, 2 TB of database, and 32 GB of RAM to operate effectively for that number of nodes [28].

Figure 3 Dimonoff System Architecture[30]

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Telensa

Telensa was founded in 2005, and its headquarters is in the UK [32]. The company has two products in the project scope: PLANet, which is Telensa's Central Management System (CMS), and second hardware is Telecell, a UNB control node. UNB (Ultra Narrowband) is a wireless technology that can transmit small amounts of data over long distances. Telensa has 5 Telecells; the one shown below is NEMA Telecell. It has an integrated antenna and NEMA (National Electrical Manufacturers Association standards) interface. This interface enables the control node to connect to any NEMA-compliant fixtures for higher compatibility with a wide range of fixtures [33]. The PLANet is flexible due to being TALQ certified, has a web interface, and can deploy multiple options: locally hosted, Telensa's proprietary cloud, and third-party cloud platform (e.g., AWS) [34].

Figure 4 NEMA Telecell [32]

Telensa Key features:

- Robustness: The control node can log activity and usually operate even if disconnected from the network [33].
- Accuracy: The metering system is very accurate because it measures energy consumption based on when the energy is used rather than simply how much is used overall, referred to as the time-of-use (TOU) model [32].

- Fault detection and monitoring: audit detailed measurements (e.g., lamp condition, mains supply, electrical data, etc.) and configure a threshold parameter to trigger alerts [33].
- Maintenance: Diagnostic information is compiled daily for ballasts, lamps, main supply, and lost connections. Monitoring reveals potential discrepancies in inventory, reducing repair times and improving inventory [34].

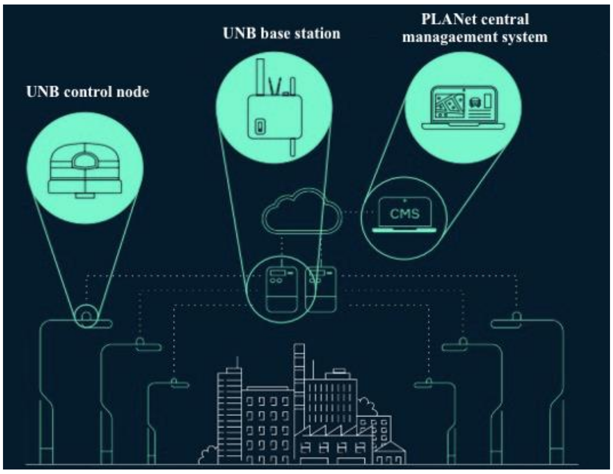

Figure 5 Telensa System Architecture [34]

FLASHNET

FLASHNET was founded in 2005 and has its headquarters in Romania. It developed a streetlight management system called inteliLIGHT[35]. InteliLIGHT has 4 types of controllers, differentiated by the type of communication technology. InteliLIGHT engineers have devised multiple mounting solutions to minimize deployment costs and ensure seamless lamp upgrades and rapid installation of lighting controllers. They utilize standardized connectors (NEMA, Zhaga) and wired (embedded, in-pole) connections. Whether employing radio or wired connections, communication technologies play a vital role in smart street lighting systems. The company offers radio frequency (LoRaWAN), a Global System for Mobile Communications (Narrow-Band IoT and LTE-M), and power line communication (LonWorks) technologies [36]. The streetlight Control software is TALQ-certified [38]. It can connect smart (motion detectors or environmental sensors) and non-smart (e.g., traffic lights, analog meters, etc.) objects to the system to allow a central hub for multiple devices for efficient deployment and management [38].

FLASHNET Key features:

- Fault detection: The controllers are equipped with real-time malfunction alerts and detailed electrical parameter monitoring, enabling the efficient detection of anomalies with reduced manual intervention [38].

- Maintenance: The controllers provide the advantage of enabling administrators to exercise greater control over inventory management, facilitating effective maintenance planning and resource allocation [38].
- CMS (central management system) software displays visual BI (Business Intelligence) reports of analyzed data provided by controllers capable of relevant analysis and trend discovery [40].

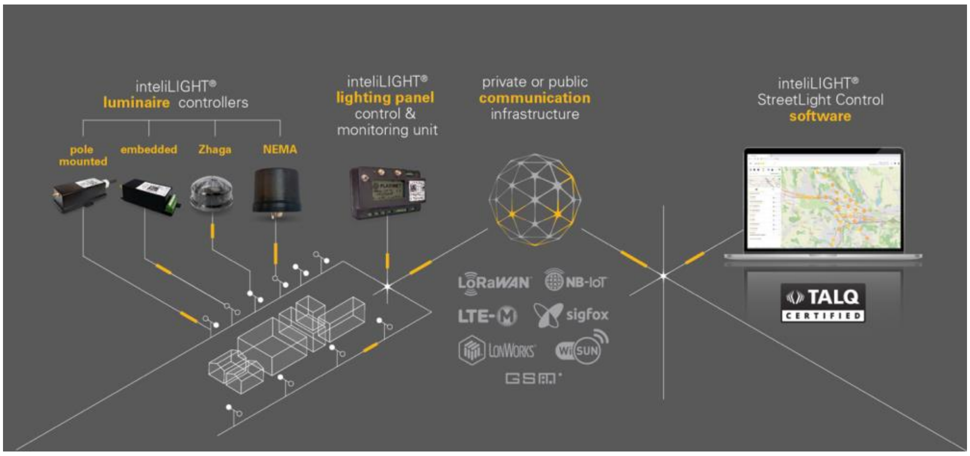

Figure 6 InteliIGHT System Architecture [37]

AEC Illuminazione

AEC Illuminazione, established in 1957, is an Italian company that competes with VIMALUX in offering smart luminaires, also known as connected luminaires [41]. Smart luminaires are equipped with interfaces to integrate IoT devices, can connect to various sensors, and comply with industry standards (e.g., DALI, D4i, Zhaga) for interoperability, allowing for centralized management system control and remote monitoring.

The company provides many light fixtures, divided into seven categories: urban, street, decorative, retrofit, floodlights, tunnel, and indoor. A light fixture similar to our objective is from the street category and is called Italo. Its design features that increase reliability and Maintenance in the product are the gasket in the upper part, rear hook, a removable optical, and gear tray compartment. The efficiency of the optical module is up to 170 lm/W [42].

AEC Illuminazione Key features

- Reliability: The power supply has two insulation layers to reduce short circuits (electrical flow taking an unintended path), open circuits (electrical path is interrupted), overheating, and overload [42].
- The operating temperature range of the Stylo luminaire is -40°C to +50°C [41].


Figure 7 ITALO luminaire [41]

Table 6 Feature Comparison between TVLIGHT and Competitor Products

Features	Similar Systems				Proposed System
	TVLIGHT	Dimonoff	Telensa	FLASHNET	
Failure detection	Yes	Yes	Yes	Yes	Yes
Require Local gateway	No	Yes	Yes	Yes	No
Web-based software	Yes	Yes	Yes	Yes	Yes
Integrated GPS Functionality	Yes	Yes	Yes	Yes	Yes
Automatic switch ON/OFF/ dimming	Yes	Yes	Yes	Yes	Yes
Energy consumption reporting	Yes	Yes	Yes	Yes	Yes
Adaptive control of street lights	Yes	Yes	No	No	Yes
Weather-proof (IP66)	Yes	Yes	Yes	Yes	Yes
Apply DALI & D4i standards	Yes	Only DALI	Only DALI	Yes	Yes
Sensor	Light, Traffic	Light, environmental, and traffic.	Light, and environmental.	Light, environmental, and traffic.	Motion
Connectivity	Edge (EGPRS), LTE CAT M1 and NB-IoT (NB2)	LoRa, NB-IoT, Digi XBee Pro.	Ultra-Narrowband (UNB), NFC, and IoT.	LoRaWaN, NB-IoT, LTE-M, and LonWorks	Edge (EGPRS), LTE CAT M1 and NB-IoT (NB2)

Dimming profile	Autonomous, astro-clock, Group/Zone dimming	Group, zone dimming.	Scheduled dimming, sensor-based, 3rd party system-based dimming	Zoning, incremental dimming, scheduled dimming	Autonomous, astro-clock, Group/Zone dimming

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we can say autonomous, time-based, Group/Zone dimming

Conclusion

It can be seen that all three companies, which are Dimonoff, Telensa, and FLASHNET do not produce their own motion or environmental sensors, unlike TVLIGHT. However, Dimonoff distinguishes itself by manufacturing environmental sensors, particularly sound sensors. All systems provide control functions that are not exclusively dependent on sensor input, including scheduled lighting, remote management and control, and energy optimization. Additionally, all systems have the capability to seamlessly integrate and utilize different types of sensors, thereby greatly enhancing the flexibility of their systems. TVLIGHT shares numerous features with its competitors, including failure detection, which is essential for efficient maintenance. They all have a web interface system that enables remote access and control. The automatic on/off light switching, and integrated GPS enhance the capabilities of all Central Management System (CMS) software. These systems are all designed to be weatherproof with an IP66 rating, providing casing protection against solid particles and liquids such as dust and water. Both TVLIGHT and FLASHNET support multiple standards, while Dimonoff and Telensa only support DALI. Moreover, Telensa's and FLASHNET's control nodes have no adaptive control ability independent of real-time feedback. The use of connectivity technologies like LoRaWAN, NB-IoT, and LTE-M is evident across various systems, signaling a move towards long-range, low-power wireless communication for managing urban lighting.

The decision to order the required devices was influenced by the availability of a gateway-free system since it simplified network architecture, resulting in easier integration with a cloud-based platform, reduced hardware costs, and faster deployment. Notably, TVLIGHT's system is the only one that does not require a local gateway to operate. Consequently, in our project, we ordered the IoT Zhaga control unit and motion sensors produced by TVLIGHT, as well as RAZO streetlights from VIMALUS, a partner of Tvilight that supplies compatible street lighting solutions. The proposed system will also incorporate the key features of well-known smart street lighting systems. These features include such things as fault detection, energy consumption, adaptive control, on/off dimming, time-based dimming, integration, and GPS functionality.

4. System Description

4.1 Methodology

The project followed Agile with 5 sprints, each lasting a month. At the beginning of each sprint, the development team planned goals to deliver a functional product by the end. Continuous improvements were made throughout the sprints based on stakeholder /supervisor feedback. Each sprint begins with the developers working on a plan to accomplish short-term goals. At the end of the sprint, they produce and test a shippable product under the guidance of a supervisor, presenting it to the scrum masters. The developers additionally held sprint review meetings with the scrum master's and signed weekly meeting notes with the supervisor using Jira software. This allowed the developers to coordinate work amongst themselves and the supervisor. The scrum team's tasks and duties are displayed in the following table.

Scrum Team	
Product Owner (PO):	Dr. Lamia Albraheem
Developers:	Raseel Aldawish Sarah Algarny Rawan Algarny Hend Al-Ghamdi
Scrum Master (SM):	Dr. Maha Al-Yahya
Stakeholders:	Examinors

The developers uploaded project code, libraries, and other resource files to GitHub as a code source that enabled teamwork and collaboration. Jira software also served as part of the development team's management tool to track the work of the developers, supervisor, and scrum master. It was also used to capture notes from weekly meetings with the supervisor and scrum master sprint reviews.

Jira: https://2024-25-sem1-gp26.atlassian.net/jira/projects?selectedProjectType=software%2Cbusiness

GitHub: https://github.com/Rawan-Algarny/2024-25_GP_26.git

4.2 Users

There is one category of users in LUSTRA smart street lighting system:

1- Admin: A well-educated and experienced decision-maker with intermediate technical knowledge. Main expertise lies in data analysis, strategic thinking, and responsibility towards high-level decision-making by monitoring and analyzing data/logs, as well as long-term planning.

4.3 Requirements Elicitation

We used interviews and questionnaires to gather requirements for further developing our system. We conducted four interviews with people connected to our project. We interviewed a deputy minister from the Ministry of Municipal and Rural Affairs, a Manager from the Lighting Maintenance Department, and a project manager who is a civil engineer. Both are employees from Riyadh Region Municipality and with an electrical engineer who graduated from KSU. Each interview consisted of 7 questions; a transcription of the interviews is presented in **خطأ! لم يتم العثور على مصدر المرجع.**. The questionnaire was distributed to employees in related sectors, encompassing the Riyadh Region Municipality, the Ministry of Energy, and Tarshid (National Energy Services Company). Regrettably, the response rate was limited to seven, and their results are presented in **خطأ! لم يتم العثور على مصدر المرجع.**.

Interview Insights

The first interview was conducted with Zamel Alshamery, Lighting Maintenance Department Manager at Riyadh Region Municipality. He indicated that the current street lighting system has different limitations, which include network connectivity, no real-time monitoring capabilities, lack of maintenance alert system, and the energy consumption data only available quarterly through electricity company reports. He also noted that the current system uses astronomical clock software for scheduling. However, there is no adaptive lighting control functionality. He said that the dimming feature can provide up to 80% energy savings at certain times since in Riyadh, we have more than 500,000 streetlights.

The second interview was conducted with Musaed Alotaibi, deputy minister at the Ministry of Municipal and Rural Affairs. He said that the main problems of the current system include energy consumption, cost challenges, administrative control of maintenance, lack of maintenance alerts system, and no real-time data. And there is no adaptive lighting control. He also suggested improving the proposed IoT-smart street lighting system by converting the street pole to a smart one and considering environmental monitoring (temperature, air pollution), fire detection (especially in industrial areas), advertisement platforms, and traffic monitoring (Saher cameras).

Furthermore, a third interview was conducted with Fahad Alburiki, civil engineer at Riyadh Region Municipality. He also confirmed that there is no remote lighting control system, but they are manually pre-setting a schedule for the street lights. The electricity usage is also hard to maintain. He also said the IoT-smart street lighting system can save costs for control and provide efficient maintenance since they are currently suffering in the street light's maintenance, which causes safety issues. In addition, the last interview was conducted with Bandar Alotaibi, an electrical engineer. He said that the remote-control feature of the suggested system is an excellent idea, and it will significantly reduce energy consumption.

Based on the conducted interviews, two primary challenges emerged: excessive energy consumption and significant maintenance difficulties. There was a strong consensus among interviewees that implementing autonomous and adaptive features would effectively address these challenges. The proposed smart street lighting system aims to enhance current infrastructure through several key features: robust network connectivity, real-time monitoring capabilities, automated maintenance alerts, energy consumption tracking, time-based dimming functionality, and adaptive control mechanisms.
While the interviews revealed the potential for expanding the infrastructure into multi-purpose smart poles, this aspect has been identified as an opportunity for future development. The interviewees' insights clearly demonstrate the urgent need and significant value of implementing the proposed smart street lighting system to address current infrastructural limitations and operational inefficiencies. The interviews referenced above are in **خطأ! لم يتم العثور على مصدر المرجع.خطأ! لم يتم العثور على مصدر المرجع.**.

Survey Insights

The survey has been sent to employees of multiple organizations related to electricity and public street lights, such as Riyadh Region Municipality, Ministry of Electricity, and Tarshid. We are truly grateful for the openness of accepting to answer a survey by strangers who contacted them through LinkedIn. The survey results of 19 responses confirmed our research direction is needed and has a credible purpose in developing our country.

Seven out of nineteen (the most chosen options) chose "not appointed" as the method of monitoring street light energy consumption. This result highlights the system's inadequacy and demonstrates how important a smart street light system is for addressing these issues within the current system. In one response, a project engineer in Tarshid didn't choose any of the choices and typed, "It's always connected to the same power supply (such as transformers), and we obtain the reading via a meter device connected to that transformer."

The employees affirmed the value of our project with the next question, as 94.7% of the related industry respondents believed that implementing a smart street light system could significantly reduce energy consumption; even the remaining percentage was uncertain about the effects.

Another question inquired in the survey about the detection system of failures and anomalies; twelve respondents believe it gets detected by scheduled maintenance, and the second most chosen answer is manual inspections. Both detection methods consume valuable time that could have been allocated towards notifying the staff and initiating the incident response process had the system possessed an alert feature akin to that of Lustra's.

The survey shows that 63.2% believe the street lights management is currently administered by specialized software. With the help of the employees, we found out the current challenges of current software; ten answered with difficulty in monitoring remote areas, and 7 chose the lack of real-time data. The challenges mentioned scan be effectively mitigated through the features offered by Lustra's smart street light system, which utilizes real-time data and network technology to collect information from distant streetlights.

The administrative features that employees believe would be most beneficial in a smart street lighting system are energy usage analytics (thirteen responses), a fault detection system (twelve responses), and automatic light control based on real-time conditions (nine responses). All these features are incorporated into the project.

Finally, every employee believed that a motion sensor automatically controlling light levels would improve energy efficiency. 57.9% believed in it, while 42.1% were undecided. This information boosted our proposal of having a motion sensor integrated into a street light. All survey questions and their results reviewed in this subsection are shown in **Error! Reference source not found.**

4.4 Architecture

The Smart Street Lighting system architecture is structured into four layers: Application Layer, Data Processing Layer, Network Layer, and Perception Layer. The Application Layer features a web interface for city administrators to monitor and control the lighting system. The Data Processing Layer utilizes cloud-based storage to manage real-time sensor data, ensuring efficient analysis of energy consumption. The Network Layer connects the cloud to the streetlights using communication technologies enabling efficient data exchange and control. The Perception Layer includes smart streetlights equipped with adaptive sensors, such as motion detectors, where sensors detect movement to adjust streetlight brightness based on real-time traffic data. The streetlights are also equipped with control nodes to manage and coordinate the lighting adjustments efficiently.

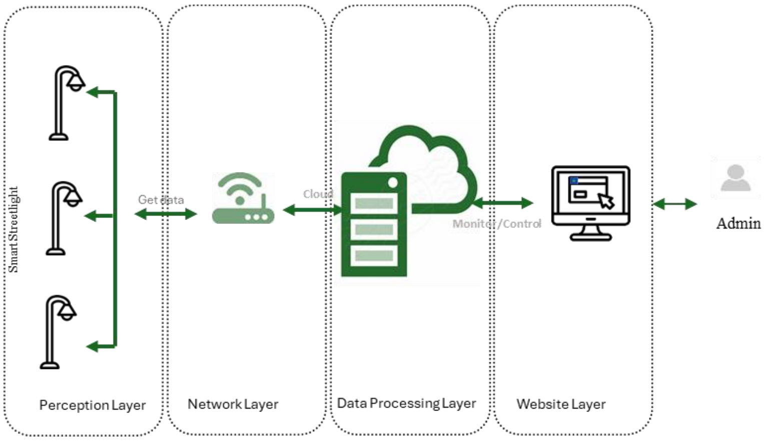

Figure 8 Architecture Diagram [11]

The system architecture emphasizes the interconnections between the layers, ensuring seamless communication and data flow. By integrating adaptive sensors, cloud processing, and efficient communication technologies, the architecture enhances real-time decision-making and responsiveness. This design supports energy efficiency, ultimately leading to smarter urban lighting solutions.

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Edit streetlight setting:
- Adjust brightness level
- set time-based dimming schedule
- set time-based on/off schedule
- (Perform on/off dimming) which is same as (Turn streetlight on/off)

Add zone
Delete zone
Edit zone setting:
- Adjust brightness level of the zone
- set time-based dimming schedule of the zone
- set time-based on/off schedule of the zone

Later during the meeting, we need to discuss extend and include relationships

4.5 Use Case Diagram

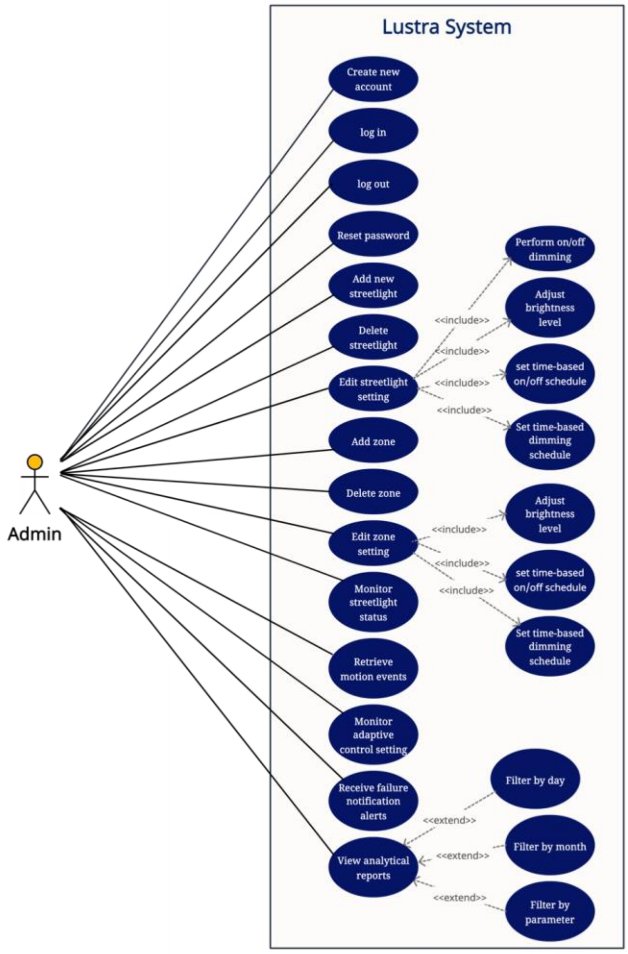

Figure 9 Use Case Diagram

5. Product Backlog

5.1 Product Backlog Table

Table 7 Functional Requirements PBIs

PBI	Size	Type	Acceptance Criteria
1. **As** an admin, **I want to** add a new streetlight to the system **so that** to remotely monitor and control it.	2	Feature	-As an admin, if I enter details for a new streetlight and confirm the adding process, the streetlight should be added to the system. -As an admin, if I try to add a streetlight that already exists, then the adding process should fail and the message "This streetlight already exists" should appear.
2. As an admin, **I want to** delete a streetlight from the system **so that** to remove malfunctioning light.	2	Feature	- As an admin, if I select a streetlight to delete, it should be removed from the system. As an admin, if I choose to delete the streetlight and do not confirm the deletion process, then the streetlight should not be deleted.
3. **As** an admin**, I want** to perform on/off dimming **so that** I can efficiently manage energy consumption.	3	Feature	-As an admin, if I choose to perform on/off, then the streetlights should be turned on/off accordingly - As an admin, the website must provide real-time feedback on the status of each streetlight, including whether it's on or off.
4. As an admin, **I want** to perform time-based	3	Feature	- As an admin, if I set a time-based dimming feature, then the

dimming **so that** that the brightness will be adjusted automatically based on time schedules.			brightness of the streetlight should be adjusted according to the specified time interval. - As an admin, the website must provide real-time feedback on the status of current brightness for each streetlight.
5. As an admin**, I want** to update a streetlight's settings **so that** I can easily review and modify the streetlight's configurations.	3	Feature	-As an admin, if I change the settings of a streetlight, the updates should be saved and reflected in the system.
6. As an admin, **I want** to view all streetlights in one page, **so that** I can easily review and modify the streetlights.	2	Feature	- As an admin, if I access the Manage Streetlights page, the streetlights' details should be displayed accurately.
7. As an admin, **I want** to schedule the streetlight's operating hours (on/off) so that I can optimize energy consumption.	3	Feature	- As an admin, if I set a schedule for the streetlight, the streetlight should be operated according to the specified hours. - As an admin, the website must provide real-time feedback on the status of each streetlight, including whether it's on or off.
8. As an admin, **I want** to adjust the brightness level of a streetlight **so that** to conserves energy.	3	Feature	- As an admin, if I adjust the R level of a streetlight, the change should be applied to streetlight immediately. - As an admin, the website must provide

			real-time feedback on the status of current brightness for each streetlight.
9. As an admin, **I want** the website to connect to a control node **so that** I manage the streetlight.	3	Feature	- As an Admin, I should be able to remotely turn streetlights on, off, and adjust the brightness levels through the website.
10. As an admin, **I want** to update a time-based dimming schedule **so that** I can easily review and modify the schedule.	3	Feature	-As an admin, if I change the settings of a time-based dimming schedule, the updates should be saved and reflected in the system.
11. As an admin, **I want to** delete a time-based dimming schedule from the system **so that** to remove unwanted time-based dimming schedule			- As an admin, if I select a schedule to delete, it should be removed from the system. -As an admin, if I choose to delete a schedule and do not confirm the deletion process, then the schedule should not be deleted.
12. As an admin, **I want** to update a control profile setting **so that** I can easily review and modify the settings.	3	Feature	-As an admin, if I change the control profile settings, the updates should be saved and reflected in the system.
13. As an admin, **I want to** delete a control profile setting from the system **so that** to remove an unwanted control profile setting.			- As an admin, if I select a control profile setting to delete, it should be removed from the system. -As an admin, if I choose to delete a control profile setting and do not confirm the deletion process, then

			the profile settings should not be deleted.
14. As an admin, I want to view the control status of streetlights on a map, represented by different colors, so that I can easily visualize and monitor the system's operational status.	3	Feature	As an Admin, I must be able to view the operational status of each streetlight on a map with different colors representing statuses (e.g., green for active, grey for inactive).
15. As an admin, **I want to** add a zone to the system **so that** to remotely monitor and control a group of streetlights.	2	Feature	-As an admin, if I enter details for a new zone and confirm the adding process, the zone should be added to the system. -As an admin, if I try to add a zone that already exists, then the adding process should fail and the message "This zone already exists" should appear
16. As an admin, **I want to** delete a zone from the system **so that** to remove malfunctioning lights.	2	Feature	- As an admin, if I select a zone to delete, it should be removed from the system. -As an admin, if I choose to delete a zone and do not confirm the deletion process, then the streetlight should not be deleted.
17. As an admin**, I want** to update the zone settings **so that** I can easily review and modify the zone's configurations.	2	Feature	-As an admin, if I change the settings of a zone, the updates should be saved and reflected in the system.
18. As an admin, **I want** to perform time-based	3	Feature	-As an admin, if I set a time-based dimming for specific zone, the

dimming for specific zones **so that** I can control the dimming for different streetlights inside the zone.			brightness of all streetlights inside this zone should be adjusted according to the specified time interval. - As an admin, the website must provide real-time feedback on the status of current brightness for each zone.
19. As an admin, I want to perform on/off dimming for a specific zone, so that I can control on/off status for groups of streetlights in different zones.	3	Feature	As an admin, if I set zoning-based on/off dimming, all streetlights inside this zone should be turned on/off accordingly - As an admin, the website must provide real-time feedback on the status of current status for each zone.
20. As an admin**, I want** to adjust the brightness level for a specific zone **so that** to control the lighting brightness of all streetlights in a specific zone.	3	Feature	- As an admin, if I adjust the brightness level of a specific zone, the change should be applied to all streetlights inside this zone immediately. - As an admin, the website must provide real-time feedback on the status of current brightness for each zone and if it will be applied to all streetlights or not.
21. As an admin, **I want** to view a streetlight located on a map **so that** I can easily	2	Feature	- As an admin, if I access the map feature, the location of the streetlight should be displayed accurately.

visualize the system's layout.			
22. As an admin, **I want** the website to connect with the motion sensor **so that** to get real-time motion data.	3	Feature	- As an admin, if the website connects to the motion sensor, then I can receive real-time motion data displayed on the website interface.
23. As an admin**, I want** to monitor the adaptive control of a streetlight, **so that** I can ensure that the streetlights are adjusted automatically based on the motion sensor.	3	Feature	- As an admin, if depending on the motion events, the streetlight brightness should be adjusted automatically based on predefined settings.
24. As an admin, **I want** to receive failure notification alerts **so that** to improve the maintenance process.	2	Feature	- As an admin, the system must receive real-time alert, whenever a failure is detected.
25. As an admin, **I want to** monitor the status of a streetlight (functioning/malfunctioning) **so that** I can identify and address issues.	2	Feature	As an Admin, I must be able to view the status (functioning/malfunctioning) of each streetlight.
26. As an admin, **I want** to view analytical reports of electricity consumption filtered by month**, so that** I can assess energy usage.	2	Feature	As an Admin, I must be able to view electricity consumption reports filtered by month.
27. As an admin, **I want** to view analytical reports of electricity consumption filtered	3	Feature	As an Admin, I must be able to view electricity consumption reports filtered by day.

by day**, s**o **that** I can assess energy usage.			
28. As an admin, **I want** to view an analytical report of electricity consumption filtered by parameter**, so that** I can assess energy usage.	2	Feature	- As an admin, the charts should allow you to view the parameters of a streetlight usage.
29. As an admin, I want to create a new account so that I can access the system using personalized credentials.	2	Feature	- As an admin, if I create a new account then I have permission to use the system. - As an administrator, if I attempt to create an account that already exists, the creation should fail, and an error notification should be displayed.
30. As an admin, I want to log in to my account so that I can access the system with personalized credentials.	2	Feature	- As an admin if I enter my email and password correctly and click login, then I should be logged into my account. - As an admin if I enter either incorrect email or password and click login, then the login should fail with an error notification indicating that the email or password was incorrect.
31. As an admin, I want to log out of my account so that I can securely end my session.	2	Feature	- As an admin, if I click on the profile icon and click on Log out, then the data associated to my account shouldn't be accessible and a notification will appear confirming that I have logged out successfully. - As an admin, if I click on the profile icon, click on Log out and did not confirm the log

			out, then I am still logged in.
32. As an admin, I want to reset my password from the authentication page so that I can change it if I forget the current one.	2	Feature	- As an admin, if I click "Forgot password," I should receive a prompt to enter my email or username. - As an admin, if I enter valid information, I should receive a confirmation email with a reset link.

5.2 Non-Functional Requirements

Table 8 Non-Functional Requirements PBIs

PBI	Size	Type	Acceptance Criteria
1- **As** an admin, **I want** the street light to automatically increase brightness when a pedestrian is detected within 5 meters of the sensor, **so that** I can ensure immediate visibility and enhance safety in the area.	5	Feature	- **If** a pedestrian is within 5 meters of the sensor in any direction, **then** the street light will increase its brightness [42].
2- **As** an admin, **I want** to be able to complete tasks in a short amount of time in less than 1 minute **so that** I can manage street lights efficiently.	2	Feature	- **If** the time it takes for an admin to perform any task is about a minute on time-based efficiency, **then** it is considered efficient in **خطأ! لم يتم العثور على مصدر المرجع.**
3- **As** an admin, **I want** to be able to complete tasks with an average number of errors 0.7 per task **so that** I can do what I need effectively.	3	Feature	-**If** the average number of errors is 0.7 or less, **then** it is considered effective in **خطأ! لم يتم العثور على مصدر المرجع.**
4- **As** an admin, **I want** an easy and simple interface **so that** I can use the system without training and feel satisfied.	2	Feature	-**If** the System Usability Scale (SUS) score is greater than 68, **then** it is above average, and people will like it in

			خطأ! لم يتم العثور على مصدر المرجع.
5- **As** an admin, **I want** to be identified and authenticated **so that** to prevent unauthorized access to my account and privileges.	3	Feature	- **If** the system identifies and authenticates the admin, **then** it should grant them access based on their role.