

LAPORAN KERJA PRAKTEK
DESIGN AND CONSTRUCTION OF A SMART CONSTRUCTION
MINIATURE MODEL FEATURING A SOLAR ENERGY SYSTEM AND
LIGHT-SENSOR-BASED LIGHTING AUTOMATION
International Course Program (ICP)



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TEKNIK SIPIL
FAKULTAS TEKNIK
UNIVERSITAS MEDAN AREA
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LEMBAR PENGESAHAN

PROJECT REPORT

DESIGN AND CONSTRUCTION OF A SMART CONSTRUCTION MINIATURE MODEL FEATURING A SOLAR ENERGY SYSTEM AND LIGHT-SENSOR-BASED LIGHTING AUTOMATION

Diajukan untuk memenuhi salah satu tugas pada
International Course Program (ICP)

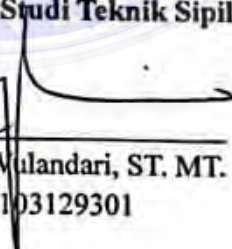
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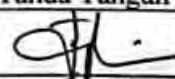
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 Tempat Seminar : Ruang Seminar Falkultas Teknik
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Seminar Kerja Praktek bersasngkutan disetujui/tidak disetujui dengan catatan perubahan seperti yang tercantum pada table berikut ini :

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Medan, 25 September 2026



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PREFACE

All praise and gratitude to Allah Almighty for His blessings and guidance, which have enabled the author to complete this project report for the International Course Program (ICP) entitled: **“DESIGN AND CONSTRUCTION OF A SMART CONSTRUCTION MINIATURE MODEL FEATURING A SOLAR ENERGY SYSTEM AND LIGHT-SENSOR-BASED LIGHTING AUTOMATION”**.

This report was prepared as part of the final assignment for the International Course Program (ICP) at Universitas Medan Area. The project integrates renewable energy concepts by harnessing sunlight—utilizing reflective mirrors for natural illumination—and implementing a solar-powered automated lighting system to provide effective lighting solutions.

The author would like to express sincere gratitude to all parties who have contributed to the completion of this report:

1. My beloved parents and family for their endless prayers and support.
2. My academic supervisor and all the lecturers of the International Course Program (ICP) at Universitas Medan Area for their invaluable guidance, knowledge, and advice throughout the project.
3. My friends and teammates who have cooperated and provided support during the completion of this project.

The author realizes that this report is not without limitations and shortcomings. Therefore, constructive feedback and suggestions for improvement are highly appreciated. Finally, it is hoped that this report can provide both academic benefits and inspiration for future developments in renewable energy technology.

Medan, 25st September 2026

Iman Niat Kurniawati Gulo

TABLE OF CONTENTS

LEMBAR PENGESAHAN	i
BERITA ACARA DAN NILAI SEMINAR KERJA PRAKTEK.....	ii
PREFACE	iii
TABLE OF CONTENTS	iv
CHAPTER I INTRODUCTION.....	1
1.1 Background.....	2
1.2 Objectives of the Project.....	2
1.3 Benefits of the Project.....	2
CHAPTER II LITERATURE REVIEW	3
CHAPTER III METHODOLOGY	5
3.1. Time and Place of Implementation	5
3.2. Tools and Materials.....	5
3.3 Procedure	5
3.4. Analysis Technique	6
CHAPTER IV RESULTS AND DISCUSSION	7
4.1. Arduino System Design and Circuit Schematic.....	7
4.2. Disuccsion.....	9
CHAPTER V CONCLUSION AND RECOMMENDATION	10
5.1 Conclusion	10
5.2 Recommendation	10
REFERENCES	11

CHAPTER I

INTRODUCTION

1.1 Background

The rapid evolution of the modern construction and architectural sectors demands the seamless integration of smart technologies focused on energy efficiency and environmental sustainability. Conventional building infrastructures remain heavily dependent on centralized power grids powered predominantly by non-renewable fossil fuels. Beyond inflating the operational carbon footprint, manual control of building illumination frequently results in substantial electrical energy wastage due to human oversight and delays in turning off fixtures when ambient daylight is sufficient.

Driven by the global paradigms of Smart Buildings and Green Building standards, the deployment of renewable energy harvesting systems—specifically solar photovoltaics (PV)—has become a pivotal strategy in modern architectural design. Situated along the equator, Indonesia possesses abundant solar irradiance potential throughout the entire year. Integrating rooftop or facade photovoltaic arrays allows civil structures to generate decentralized clean electricity, thereby advancing progress toward Zero Energy Building (ZEB) benchmarks.

In tandem with renewable power generation, internal energy consumption can be substantially optimized by deploying embedded automation control systems. Leveraging Light-Dependent Resistor (LDR) optical sensors alongside microcontrollers enables building lighting to dynamically adapt in real-time according to ambient lux levels. The system automatically energizes illumination during dim or dark ambient conditions and de-energizes it during daylight hours, minimizing power consumption without compromising occupant comfort.

However, implementing smart construction technologies directly on full-scale civil infrastructure involves considerable capital expenditure and technical risks. Consequently, constructing and evaluating scaled physical miniature prototypes serves as a vital engineering methodology. Through this smart building miniature model integrated with solar harvesting and LDR sensing, the dynamic

behavior of solar energy conversion, battery charging efficiency, sensor calibration accuracy, and automated switching stability can be rigorously analyzed before full-scale deployment.

1.2 Objectives of the Project

- a. To design and construct a physical scale miniature model of a smart construction building integrating photovoltaic solar power harvesting and automated building lighting.
- b. To analyze the embedded control circuit based on an LDR sensor and Arduino Uno microcontroller in responding automatically to ambient light variations.
- c. To evaluate solar panel electrical performance, Li-ion battery charging efficiency, and quantify the energy conservation achieved by the automated system.

1.3 Benefits of the Project

- a. Provides an empirical framework and testbed for understanding the synergy between renewable energy integration and embedded automation in civil and electrical engineering.
- b. Supports carbon footprint reduction by maximizing clean solar power utilization and eliminating unnecessary lighting energy waste.
- c. Demonstrates quantitative reductions in building operational expenditure through automated load management and optimized switching logic.

CHAPTER II

LITERATURE REVIEW

The Smart Construction and Smart Building paradigms represent a holistic engineering approach to designing, constructing, and operating physical structures equipped with IoT sensors, embedded controllers, and modern information technologies. The overarching objective is to create adaptive, energy-efficient, safe, and comfortable built environments. A primary cornerstone of modern smart architecture is the realization of Zero Energy Buildings (ZEB), which require structures to generate sufficient clean energy on-site to balance their total operational energy consumption over time.

Photovoltaic (PV) Solar Harvesting plays an indispensable role in attaining energy self-sufficiency. Solar panels operate based on the photovoltaic effect, where semiconductor materials (such as monocrystalline or polycrystalline silicon) absorb incident solar photons, releasing free electrons to produce direct current (DC) electricity. In miniaturized prototype applications, micro solar panels are paired with battery charge management modules (such as protected TP4056 ICs) and lithium-ion storage units (18650 cells) to guarantee continuous DC power delivery to the microcontroller and load circuits.

Optical sensor-based lighting automation relies on the electrical characteristics of Light-Dependent Resistors (LDR). An LDR exhibits photo-resistivity, where its internal electrical resistance varies inversely with incident ambient illumination. Under dark conditions, LDR resistance escalates to several Megaohms, whereas under intense daylight, resistance drops rapidly to a few hundred Ohms. This resistance variation is converted into an analog voltage signal via a voltage divider circuit, which is subsequently read by the Analog-to-Digital Converter (ADC) of a microcontroller for threshold evaluation.

The ATmega328P microcontroller on the Arduino Uno development platform serves as the central processing unit and decision-maker. The controller compares the converted ADC value against calibrated lux thresholds. When ambient illumination falls below the defined threshold, the microcontroller triggers a digital

output signal to actuate a 5V relay module or transistor driver, illuminating the LED array. Implementing software hysteresis within the control algorithm is critical to prevent rapid relay chatter or switching oscillation when ambient light fluctuates around the threshold boundary.

Table 2.1 Smart Building Component Modules and Functional Parameters

Sub-System Module	Core Electronic component	Operational Mechanism dan Target Role
Solar Power Harvesting	Monocrystalline Solar Panel (6V 2W)	Converts incident solar irradiance into DC electricity ($V_{mp} = 6V$, $I_{mp} = 333mA$).
Energy Storage dan Management	TP4056 Module + 18650 Li-ion Battery	Regulates 3.7V - 4.2V charging cycles and protects against overcharge/discharge.
Control dan Automation	LDR Sensor + Arduino Uno + 5V Relay	Monitors ambient lux, executes ADC logic, and toggles LED lighting loads

CHAPTER III METHODOLOGY

3.1. Time and Place of Implementation

Empirical research, architectural modeling, hardware assembly, and experimental testing of this smart construction miniature prototype were conducted at the Faculty of Engineering, Universitas Medan Area (UMA), Medan, North Sumatra, Indonesia. The entire series of experimental evaluations took place over a four-week period, from January 1 to January 25, 2026.

3.2. Tools and Materials

- a. Electronic & Power Components: Monocrystalline Solar Panel (6V 2W), TP4056 Charger Module with Protection, 3.7V 2200mAh 18650 Li-ion Battery, Arduino Uno R3 Microcontroller, LDR Optical Sensor Module, 1-Channel 5V Relay Module, High-Efficiency White 5V LEDs, 10kΩ Resistor, Breadboard, and Dupont Jumper Wires.
- b. Architectural Model Materials: Transparent and Opaque White Acrylic Sheets (3mm thickness), 3D-Printed PLA Filament Joints, 1:50 Scale Roof Trusses, Hot Melt Adhesive, and Solar Panel Mounting Brackets.
- c. Measurement & Software Tools: Fluke 87V Digital Multimeter, LX1330B Digital Lux Meter, Variable DC Bench Power Supply, Arduino IDE 2.0, Fritzing Circuit Designer, and SolidWorks CAD Software.

3.3 Procedure

The research procedure was executed across four structured sequential phases:

- a. Architectural Framing & Fabrication Phase: Designing the 1:50 scale smart building miniature using SolidWorks CAD. Acrylic sheets were cut using high-precision CNC laser cutting, followed by structural assembly of wall panels, roof frames, and concealed electronics enclosures.
- b. Hardware Integration & Power Wiring Phase: Wiring the solar panel output to the TP4056 module input and 18650 Li-ion battery storage. A DC step-up booster was integrated to power the Arduino Uno. The LDR sensor was

interfaced with analog pin A0 via a $10k\Omega$ voltage divider, while the relay module was connected to digital pin D8 to actuate interior LED lights.

- c. Firmware Programming & Algorithm Calibration Phase: Developing control firmware in Arduino IDE to convert analog LDR voltage signals into ADC values (0-1023). Ambient lux levels were calibrated against ADC values to establish an activation threshold ($ADC = 300$) combined with software hysteresis (± 25 ADC units) and a 2-second time-delay filter.
- d. Field Testing & Data Acquisition Phase: Subjecting the prototype to direct outdoor sunlight for solar harvesting evaluation, as well as controlled ambient lighting chambers to assess relay switching accuracy, response latency, and overall stability.

3.4. Analysis Technique

System performance was evaluated using quantitative statistical analysis of electrical parameters. Key metrics included:

- a. Solar Charging Efficiency derived from Voltage-Current (V-I) curves under direct sunlight versus overcast conditions,
- b. LDR Resistance vs Lux calibration curve accuracy,
- c. Automated Switching Response Time and Energy Conservation Percentage compared to an unautomated continuous lighting baseline.

CHAPTER IV

RESULTS AND DISCUSSION

4.1. Arduino System Design and Circuit Schematic

Comprehensive experimental testing of the smart construction miniature was conducted at the Faculty of Engineering, Universitas Medan Area. The empirical testing evaluated two primary performance metrics:

- a. Photovoltaic solar harvesting efficiency and battery charging characteristics,
- b. LDR sensor accuracy and relay switching response under varying ambient light conditions.

During solar harvesting evaluation, the miniature prototype was placed in an open rooftop location at the faculty building with a 15-degree solar panel tilt facing north. Electrical parameters were recorded hourly from 08:00 WIB to 16:00 WIB. Peak solar harvesting occurred at 12:30 WIB, generating an output voltage of 6.12 V and a current of 315 mA (peak power output of 1.93 Watts) under an ambient solar irradiance of 85,000 Lux.

Table 4.1: Empirical Electrical Measurement of Monocrystalline Solar Panel (6V 2W) Over 8 Hours

Measurement Time	Solar Lux Level	Voltage V _{pv} (V)	Current I _{pv} (mA)	Generated Power P _{pv} (W)
08:00 WIB	18,500 Lux	5.45 V	120 mA	0.65 W
10:00 WIB	52,000 Lux	5.90 V	245 mA	1.45 W
12:00 WIB	85,000 Lux	6.12 V	315 mA	1.93 W
14:00 WIB	61,000 Lux	5.98 V	270 mA	1.61 W
16:00 WIB	22,000 Lux	5.20 V	135 mA	0.70 W

Subsequently, lighting automation response testing was executed by subjecting the model to varying indoor and outdoor illumination levels. The LDR sensor detected photo-resistance changes, which were digitized into 10-bit ADC values (0-1023) by the Arduino Uno. Correlation data between Lux levels, ADC values, and relay switching states are summarized in Table 4.2.

Table 4.2: Automated Relay Switching State Based on LDR Sensor Readout and Ambient Lux

Ambient Environment	Lux Intensity	Arduino ADC Value	Relay State	LED Light Condition
Direct Sunlight	> 15,000 Lux	890 - 960	OFF	Fully Extinguished
Bright Indoor Room	400 - 600 Lux	510 - 620	OFF	Fully Extinguished
Threshold Boundary (Dusk)	280 - 320 Lux	290 - 325	TRANSITION	Awaiting 2s Delay Filter
Dim Ambient / Evening	100 - 250 Lux	180 - 275	ON	Illuminated (Stable Power)
Dark Enclosure / Night	< 30 Lux	< 120	ON	Illuminated at Full Intensity

Over a controlled 24-hour test cycle, the automated LED lighting system remained active for a cumulative 11.2 hours (predominantly during dusk and night hours). Total daily energy consumption for the automated system reached 5.6 Watt-hours (Wh). In comparison, an unautomated baseline system operating continuously for 24 hours consumed 12.0 Wh. This confirms that LDR-based lighting automation achieves a 53.3% electrical energy conservation rate under standard operational conditions.

4.2. Discussion

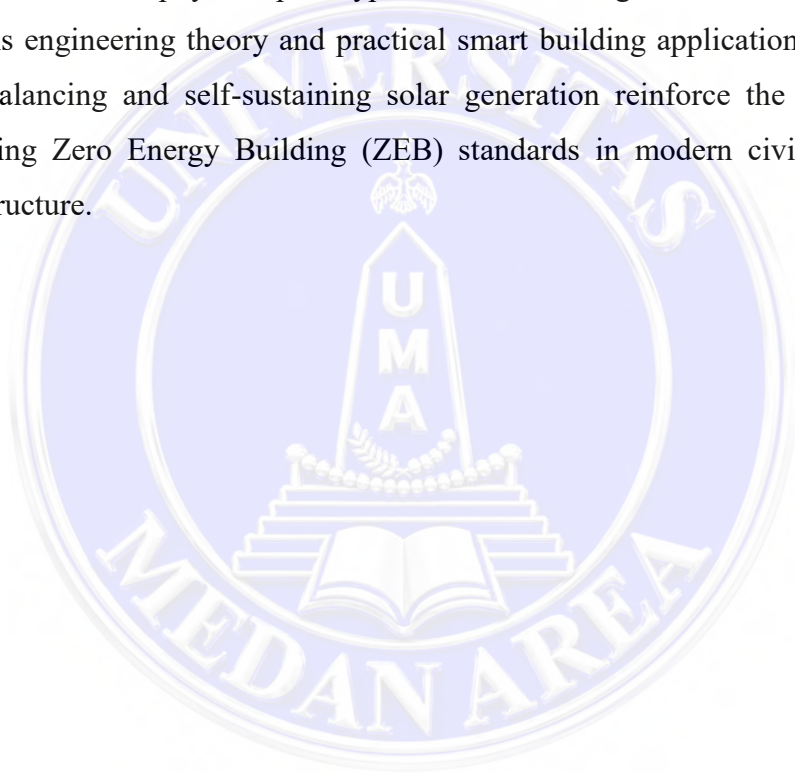
The empirical findings demonstrate that integrating micro photovoltaic solar harvesting with LDR sensor automation yields high operational reliability within smart construction models. The solar panel generated an average power output of 1.26 Watts during peak daylight hours, fully recharging the 2200 mAh 18650 Li-ion battery within approximately 4.5 hours while supplying operating power to the embedded microcontroller.

Deploying LDR-based automated switching eliminated unnecessary lighting operation during daylight periods. When natural illumination exceeded the 300 Lux threshold, the system reliably maintained the relay in an OFF state. Achieving a 53.3% energy reduction highlights the immense potential of deploying this

integrated solution in full-scale civil structures across Universitas Medan Area and broader urban environments.

A key technical challenge identified during initial testing was relay chattering (rapid unwanted switching) when ambient light hovered near the activation threshold ($\text{ADC} \sim 300$), caused by minor shadow fluctuations or electrical noise. This was effectively resolved by implementing a software hysteresis loop (upper threshold $\text{ADC} = 325$, lower threshold $\text{ADC} = 275$) alongside a 2-second time-delay filter in the firmware execution.

Overall, this physical prototype validates the alignment between embedded systems engineering theory and practical smart building applications. Automated load balancing and self-sustaining solar generation reinforce the feasibility of achieving Zero Energy Building (ZEB) standards in modern civil engineering infrastructure.



CHAPTER V

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

- a. The design and physical implementation of a smart construction miniature featuring photovoltaic solar energy harvesting and LDR sensor lighting automation were successfully realized and tested at Universitas Medan Area. The system harvested up to 1.93 Watts of peak solar power and fully recharged the 18650 Li-ion storage unit to sustain embedded operations independently.
- b. The automated control circuit based on an LDR sensor and Arduino Uno exhibited precise switching accuracy responsive to ambient light thresholds ($\text{Lux} < 300$). Integrating software hysteresis and delay filtering eliminated relay chattering, successfully conserving 53.3% of electrical lighting energy compared to an unautomated continuous lighting baseline.

5.2 Recommendations

- a. IoT Connectivity and Real-Time Telemetry: Future research should integrate Wi-Fi-enabled microcontrollers (such as ESP32) to stream solar generation metrics, battery capacity, and ambient lux levels in real-time to cloud dashboards or mobile applications.
- b. Multi-Sensor Fusion and PWM Dimming Control: Subsequent iterations should combine Passive Infrared (PIR) motion sensors with Pulse Width Modulation (PWM) dimming. This will allow dynamic lighting brightness control that illuminates at maximum intensity only when human occupancy is detected, further optimizing building energy efficiency.

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