Measurement Systems Project Report 1
ELEN4006

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Abstract: This report illustrates a light measurement system that is mounted onto a jungle gym designed for children in a park in Johannesburg, South Africa. Safety and visibility are paramount for children playing on a jungle gym; therefore, this design entails a measurement system that automatically switches on a light provided there is insufficient illumination. A PIN-photodiode sensor was comparatively deduced to be the optimal sensor. Combined with a high-level solution of a transimpedance amplifier, low pass filter, an ATmega328P microcontroller and a light output, a dependable system for the jungle gym was designed. This report presents the description of the light measurement system on the jungle gym, the analysis of the light input signal, the specific

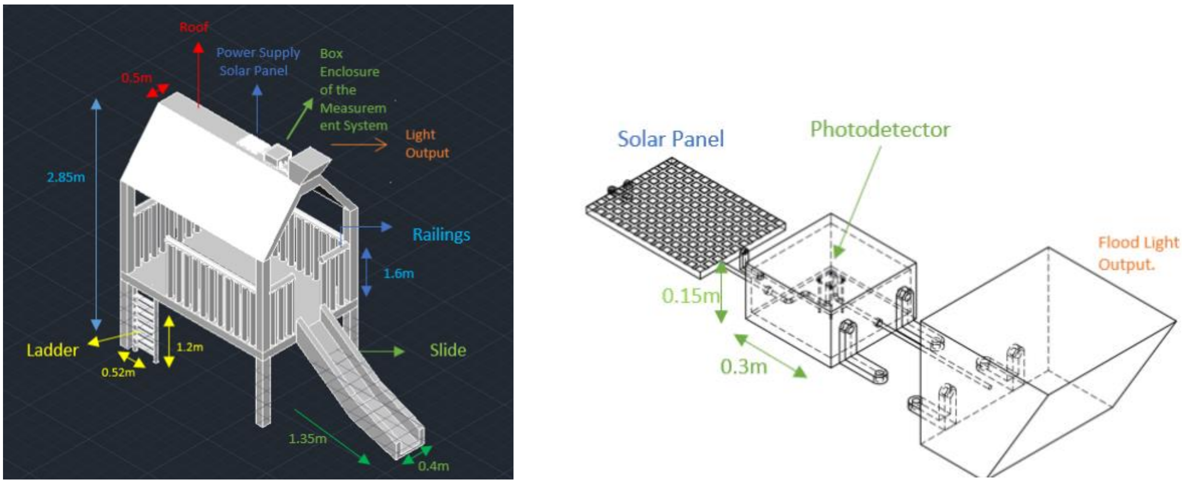
1. Introduction

This report illustrates a light measurement system that is mounted onto a jungle gym designed for children in a park in Johannesburg, South Africa. Safety and visibility are paramount for children playing on a jungle gym; therefore, this design entails a measurement system that automatically switches on a light provided there is insufficient visible illumination. A PIN-photodiode sensor has been chosen, which combined with signal conditioning and signal processing elements produces a reliable automated lighting system. This report will present the description of the light measurement system on the jungle gym, the analysis of the light input signal, the specific design requirements, existing solutions, the sensor selection, and the proposed high-level solution.

2. Description for measurement application

In order to measure light, the measurement system was placed at the highest point on the jungle gym. This ensures no interference from the children and direct exposure to the light. The jungle gym was thus customised with a flat roof, with specific focus on ensuring appropriate space for the power supply, measurement system and automated light. Nonetheless, the jungle gym was customised with an inclined roof to allow for rainfall or moisture to flow off.

Furthermore, the jungle gym was designed following the South African institute for playpark safety [1]. The ladder was specifically adapted to be a shorter height, making it easier for younger children to climb up and down without risking injury [1]. Importantly, railings were designed with sufficient height (1.6m) from all sides [1]. Similarly, the slide was custom-made smaller, with guardrails and less steep to ensure that the children slide down without falling off the side, and limiting their speed at which they descend the slide [1].



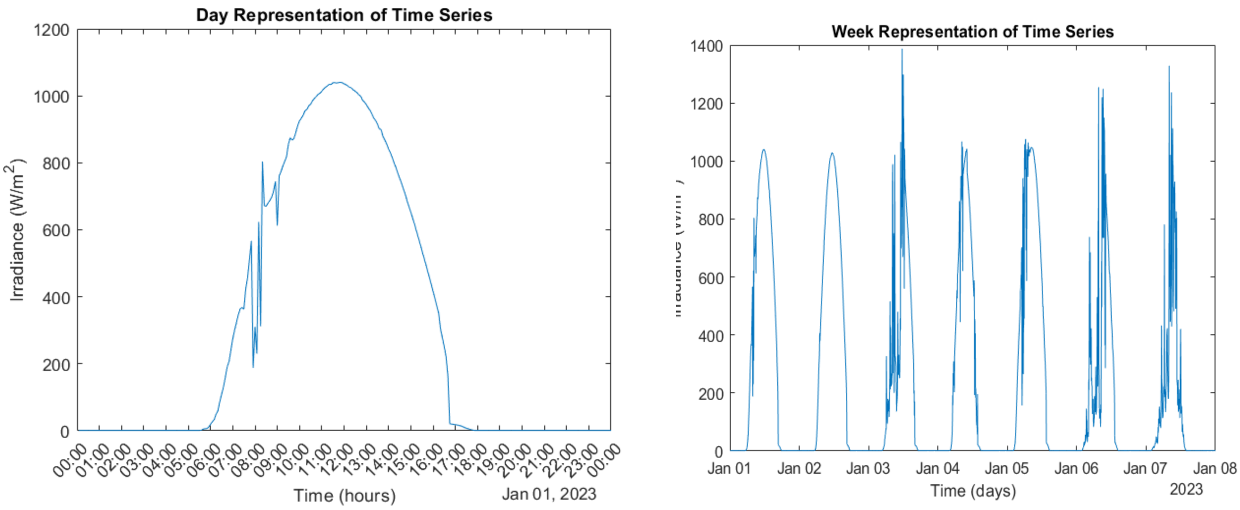
(a) *(b)*

Figure 1: Annotated Diagram of the jungle gym and annotated close-up of the measurement system with power supply and output controlled light.

The environment designed for includes temperatures ranging from -5°C to 40°C with heavy rainfall [2]. Therefore, the entirety of the measurement system was designed to be placed in a polycarbonate enclosed box with an Ingress Protection (IP) rating of IP65. Polycarbonate was selected as it provides transparency for the visible light spectrum, impact resistance, high-temperature resistance, and UV resistance [3][4][5].

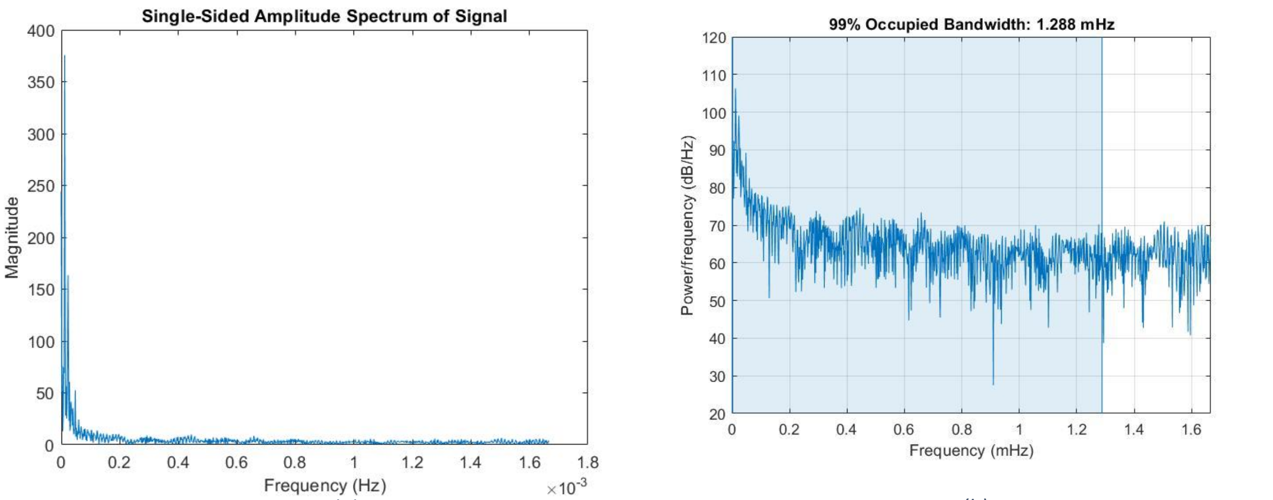
3. Analysis of measured variable

In order to model the time-series representation of visible light levels, typical days and adverse weather patterns causing sudden fluctuation in light levels were modelled. A dataset from Hawaii was utilized to model variation in the irradiance, representing the weekly rainy season of Hawaii [6] [7]. Both South Africa and Hawaii have comparatively high levels of solar radiation year-round due to their proximity to the equator and tropical environment [8]. Thereafter the Fourier transform was obtained and the precise bandwidth of 1.288mHz.



(a) (b)

Figure 2: Day representation and weekly representation of the Solar Irradiance



(a) (b)

Figure 3: Fourier Transom of Weekly Time Signal and where 99% of the Bandwidth is situated (periodogram estimate) in the power spectral density.

4. Design Specifications

Table 1: Showing the design specifications and justification.

Specifications	Value	Justification
Spectral light range (nm)	380-700	To measure visible light, a photodetector with sensitivity to the 380-700 nanometre range is required. Therefore, sensors in this study were chosen for their suitability in detecting visible light.
Solar Irradiance ($\frac{W}{m^2}$) Solar Irradiance (KLux)	0 – 1350 0- 160	The photodetector must be able to detect the Irradiance range in $\frac{W}{m^2}$. To compare the same unit for the inputs of the different sensors, Lux range was calculated [9].
Bandwidth (mHz)	5	The bandwidth ensures that the entire signal is captured with minimized aliasing and reduction in higher frequency noise.
Response Time (seconds)	100	The photodetector must be able to detect every 100 seconds whether there is a change in light intensity in order to account for adverse weather patterns.

5. Review of existing solution

Table 2 showing existing solutions and comparative components, advantages, and disadvantages.

System	Description
Solution 1: ISL29001 [10]	A light-to-digital solution that uses a photodiode to detect both visible and infrared light (IR) and has an integrated ADC that converts the light level into a 16-bit digital value, which can be read by a microcontroller through an I^2C interface. Its advantageous as it has very fast response times and high level of sensitivity. However, it requires complex circuitry and is susceptible to IR distortions.
Solution 2: LDR and Comparator [11]	A specific implementation of a light-controlled switch circuit that includes a light dependant resistor (LDR), a comparator IC (LM393), and a potentiometer for adjusting the sensitivity of the circuit. It is advantageous as it is relatively cheaper and easy to implement. Nonetheless, it has limited sensitivity, requires external components, has a relatively slow response time, and requires calibration.
Solution 3: TEMT6000 Light Sensor [12]	The phototransistor and fixed resistor of the TEMT6000 is built with a voltage divider that varies output with different light intensity. The advantages include high sensitivity, low power consumption and small size. The disadvantages are sensitivity to temperature fluctuation and distortion in very high and low irradiance levels.

6. Proposed high-level solution

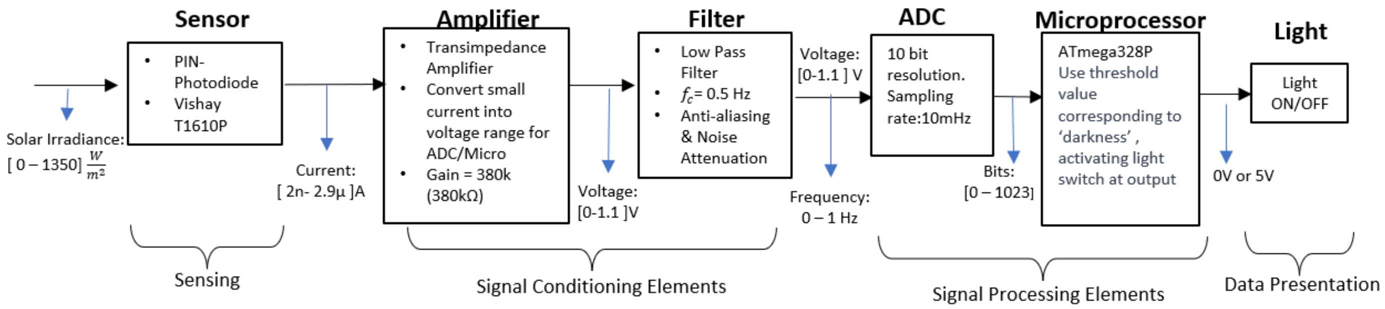


Figure 4 showing high level solution with each input range.

7. Sensor selection

Table 3 showing the specifications used to select the appropriate sensor.

	Light Dependant Resistor [13]	**Phototransistor** [14]	**Photodiode** [15]	**PIN-Photodiode** [16]
Spectral Range (nm)	400-700	390 - 700	400- 900	390 - 800
Input Illuminance [9] (KLux)	0- 164.7	0 - 100	0 – 164.7	0 -164.7
Output Range	27 KΩ- 2 MΩ; V_{cc}=5V 2.5μA -185 μA	0.1 μA – 520 μA	5nA- 6.3μA	2 nA – 2.9 μA
Operating Temperature (ºC)	-30 to 75	-40 to 85	-40 - 100	-40 to 100
Response Time	60ms	0.11ms	200µs	100ns
Sensitivity [17]	15.38 $\frac{\text{nA}}{\text{Lux}}$; V_{cc}=5V	5.199 $\frac{\text{nA}}{\text{Lux}}$	0.038 $\frac{\text{nA}}{\text{Lux}}$	0.0177 $\frac{\text{nA}}{\text{Lux}}$
Gain (k Ω) [18]	6	2.1	175	380
Linearity	Non-Linear	Linear	Linear	Linear
Lead Time [19]	14 weeks	22 weeks	12 Weeks	24 weeks
Price (ZAR) [19]	23.86	9.54	33,76	13.02
RoHs [19]	Non-Compliant	Compliant	Compliant	Compliant

The LDR was disqualified due to the 6.25% of the visible light spectrum lacking, non-linearity, higher price comparatively and non-compliance with RoHS. Thereafter, the photodiode's price was evidently an outlier. Furthermore, the photodiode has 6.25% of the visible light spectrum lacking despite having the fastest lead time and greater sensitivity. Finally, comparing the discrepancies between the PIN-photodiode and the phototransistor, the phototransistor output range requires less amplification and is 36% cheaper. However, the phototransistor's lux range was limited to where it behaves linearly, proving to be a disadvantage when considering adverse weather patterns. Additionally, the PIN-photodiode provides greater sensitivity, responding to more sharp changes. Ultimately, the price difference was deemed irrelevant given the overall price of the system. Therefore, the PIN-photodiode was selected as the optimal sensor element for this specific application.

8. Summary and conclusion

Ultimately, a realistic and safe jungle gym was customized. A PIN-photodiode sensor was comparatively deduced to be the optimal sensor for the system. Combined with a high-level design of a transimpedance amplifier, low pass filter, an ATmega328P microcontroller and a light output, a practical and dependable system for the jungle gym was designed.

References:

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Appendix A:

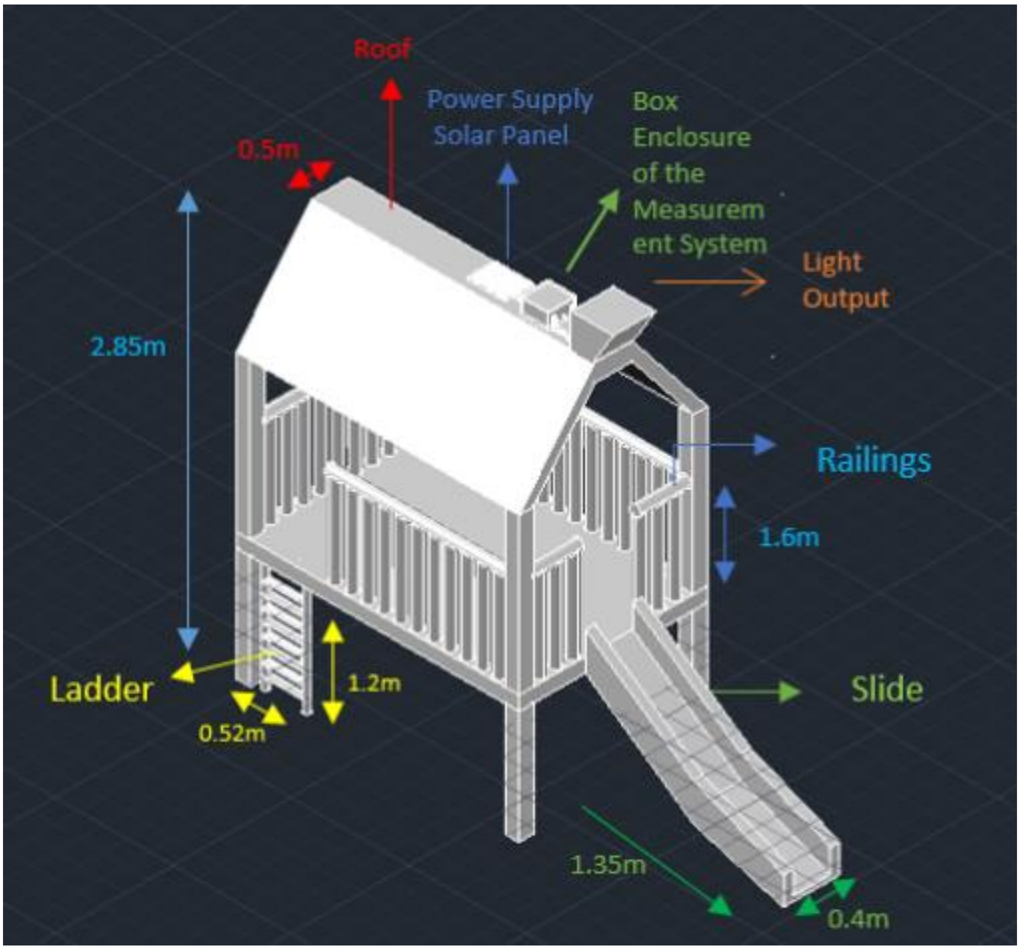

Figure 5: Annotated Diagram of the Customised Jungle Gym

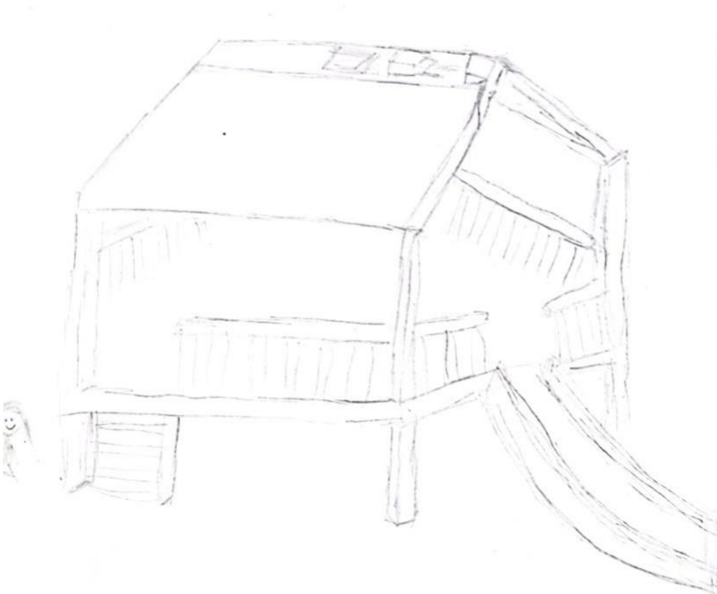

Figure 6: Rough Sketch of the customized jungle gym.

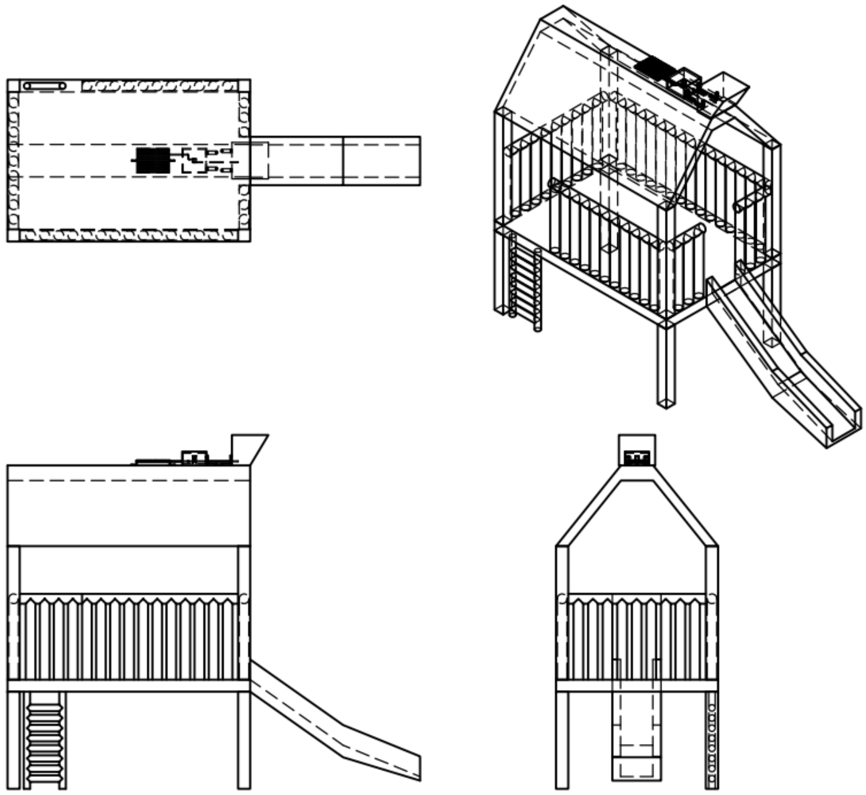

Figure 7: CAD Schematic of different angles of the customized jungle gym

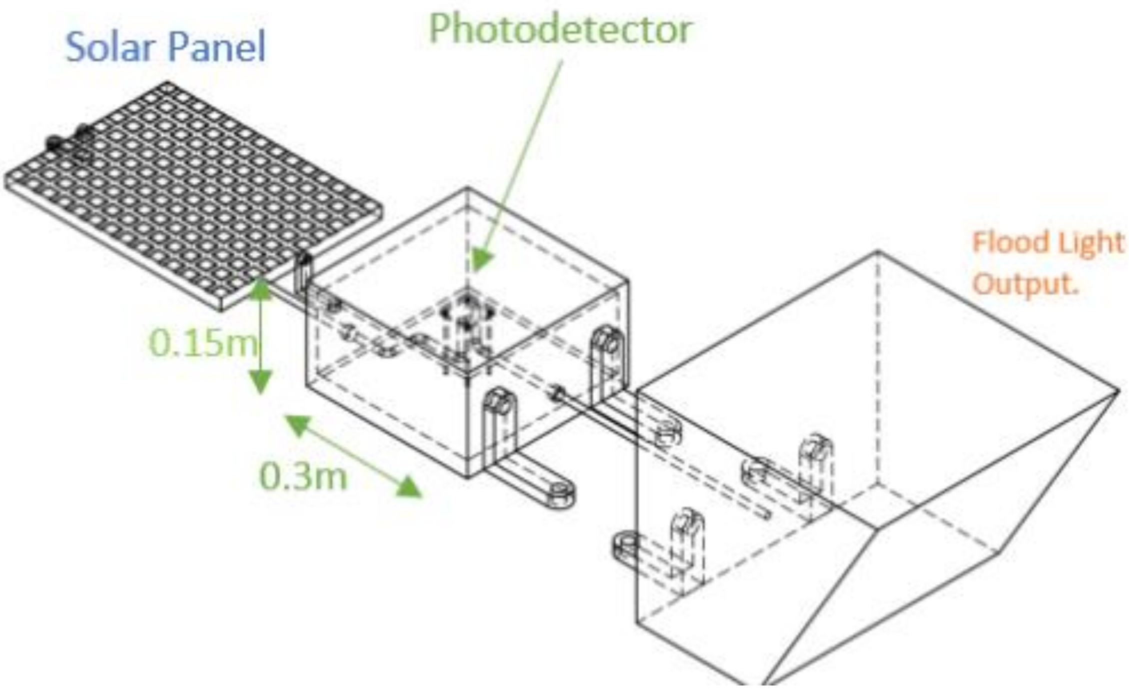

Figure 8: Annotated close-up of the measurement system with power supply and output controlled light.

Table 4: Parts List and Building Materials

Part	Quantity	Length	Width	Height	Radius
Wooden pillar	4	0.15m	0.15m	1.2m	
Wooden pillar	4	0.15m	0.15m	1.65m	
Wooden poles (Railings)	41			1m	0.06m
Wooden poles (Structure)	2			1.7m	0.06m
Ladder	1	0.52m	0.8m	1.2m	
Wooden poles	8			0.44m	0.04m
Wooden poles	8			1.2m	0.04m
Wooden plank (Floor)	1	3m	2m	0.15m	
Wooden plank (Roof)	2	3m	1.28m	0.15m	
Wooden plank (Roof)	1	3m	0.5m	0.15m	
Steel Screws (Lap Joint)	80-100	50mm	10mm		5mm
Steel Bolts (Lap Joints)	40	50mm			5mm
Solar panel	1	0.3m	0.4m	0.03m	
Box for Measurement System	1	0.3m	0.3m	0.15m	
Light	1	0.45m	0.45m	0.375m	
Brackets (solar panel)	2	0.145m	0.130m	0.01m	5mm bolt
Screws (solar bracket)	2	5 mm	50mm	135mm	5mm
Bolts(solar bracket)	2	9mm			5mm
Screws(light and box bracket)	8	5mm	35mm	100mm	2mm
Bolts(light and box bracket)	8	9mm			2mm
Brackets (light and box)	4	0.06m	0.06m	0.01m	2mm bolts