Solentic Energy

March 27, 2017

Steve Whitmore
School of Engineering Science
Simon Fraser University
Burnaby, British Columbia
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RE: ENSC 405W Design Specifications – SolarPath™: Multi-sourced Renewable Energy System

Dear Dr. Whitmore,

Attached is a design specification document regarding the SolarPath™ renewable energy system from Solentic Energy. Our intentions are to research, design and build a renewable energy tile which will generate electricity through solar and mechanical methods. Both methods will work synchronously in order to charge a connectable battery bank.

The purpose of the design specification is to give insight on the specific implementation of SolarPath™. These specifications outline the design for the physical aspects of the SolarPath™ module and subsystems, as well as details about the circuitry for the electrical processes performed by the product. This document will be used by our team as a reference during the design, construction and testing of SolarPath™.

Solentic Energy is comprised of five passionate engineering science students: Destiny Hsu, Imran Kanji, Klein Gomes, Nolan Magee and Jin Xiong. If you should have any questions or concerns relating to our requirements specification, please do not hesitate to email our principle contact, Klein Gomes, at kleing@sfu.ca.

Sincerely,

Destiny Hsu
CEO
Solentic Energy

SolarPath™

by

Solentic Energy

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ABSTRACT

With climate change being an ever-present concern, the need and the market for renewable energy investments has grown more than ever. The Global Trends for Renewable Energy 2016, stated about 2015; "Investments reached nearly $286 billion, more than six times more than in 2004, and, for the first time, more than half of all added power generation capacity came from renewables." [1]

SolarPath™ is an energy generating tile developed by Solentic Energy, combining both solar energy and kinetic energy from footsteps, with an outlet to charge an external battery bank or other loads such as streetlamps. The energy tile is modular and interconnects to other SolarPath™ modules, with the intent to be tiled as sidewalks and other walkways. The design requirements for the SolarPath™ system will be outlined in this document, divided into the physical and electrical system aspects

The physical system specifications will outline the requirements for the structure of the overall product and parts, focusing on the mechanical aspects of the chassis design, impact and weather protection for the upper solar subsystem, weight considerations and movement for the lower kinetic subsystem, as well as details regarding the selected materials, dimensions and design plan for the modular tiles.

The electrical system specifications describe the charging circuits for both the solar and kinetic outputs, additional circuitry needed in order to maintain a constant charge from the motor, and details regarding circuitry to interconnect multiple tiles to a the main power outlet.

Throughout the design process, considerations will be made in regards to sustainability and safety for the product users, and justifications for selected materials or processes will be provided which will demonstrate how SolarPath™ will meet these requirements. Additional information regarding the product's user interface, as well as the final testing plan, will be provided in the appendix.

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GLOSSARY

AC	- Alternating Current; an AC motor provides alternating positive and negative voltage
CSA	- Canadian Standards Association
DC	- Direct Current; a DC motor provides a constant voltage
IEEE	- Institution of Electrical and Electronics Engineers
LED	- Light Emitting Diode
MC4 Connector	- Multi-contact 4 mm connecting pin connector; a single-contact electrical connector, used to link solar panels together [2]
PV	- Photovoltaic; describes a product that uses the photovoltaic effect, capturing and converting photon energy (light) into electrical energy (voltage) [3] [4]
Rectifier	- An electrical component designed to allow only one-way flow of electrons, used primarily to convert AC to DC current [5]
RoHS	- Restriction of Hazardous Substances
RPM	- Revolutions per minute
STC	- Standard Test Conditions for solar panel power ratings [6]

1.0 INTRODUCTION

The price of solar is now cheaper than burning fossil fuels in many world markets, with economists predicting costs lower than fossil fuels across all world markets by 2024 [7]. Solar energy is cheap, plentiful, and most importantly, it is renewable. With the effects of climate change being more pronounced as our dependence on fossil fuels increases, it is now paramount that we find alternative solutions to our energy demands.

Solentic Energy's SolarPath™ is part of the solution. Combining both solar cells and kinetic motion to provide energy to nearby buildings and to help reduce our dependence on fossil fuels. By harnessing multiple methods of energy generation, SolarPath™ can produce more energy throughout the day, even if the sun's not shining. This gives SolarPath™ a unique advantage over competitive products – some of which only generate electricity using a single method.

SolarPath™ uses kinetic energy as a complementary method of generating energy. The primary area of installation would be busy sidewalks and pathways, with the product's modular design allowing SolarPath™ to be tiled together into suitably-sized areas for use. Sidewalks located in sunny high traffic areas, such as beaches and parks, would be ideal due to adequate sunlight and a large amount of foot traffic throughout the day.

Figure 1: Example of pedestrians using sidewalk and streets in downtown Vancouver [8]

In this document, the design specifications going towards the construction of a SolarPath™ module will be laid out, detailing the materials, parts and processes behind each of the system's functions. At the end of each section a table will be presented to outline the design specifications pertinent to each prototype level, as well as referencing which requirements and functional specifications each design choice fulfills.

1.1 SCOPE

This document will cover the design specifications that need to be met in order for the successful completion of Solentic Energy's SolarPath™. The requirements for the physical and electrical aspects of each subsystem will be provided, with materials and devices selected based upon the functional and requirement specifications for SolarPath™. Considerations for product function and safe usage will be explained for each component, and will serve as guidelines for the final product's testing and operation.

1.2 INTENDED AUDIENCE

This requirements document is intended to be used by employees of Solentic Energy as a reference in the design and construction of SolarPath™. The mechanical and electrical engineers can use this document to refer back to design requirements and testing specifications. The project managers can use this document to view specified timelines, targeted completion dates and overall progress of the SolarPath™ project.

2.0 SYSTEM OVERVIEW

2.1 TOP LEVEL DESIGN

SolarPath™ consists of two integrated subsystems to simultaneously provide a walking surface for pedestrians and energy generation. These two subsystems include one that captures solar energy and another that captures the kinetic energy from pedestrians' footsteps. The walkable surfaces of individual tiles will be seamlessly linked together and provide charge for an external battery source.

The following two figures conceptualize how the completed tile design will appear from the top and side-profile perspectives, respectively. Only the corner springs were maintained in order to better show the internals of the product; the full product design includes eight springs at both the corners and edge centers for stability. Visible are fundamental components from both the solar and kinetic energy subsystems; the transparent protective surface, the solar panel, springs and generator, magnetic connection contacts, and the chassis for the upper and lower halves of the system. The support springs and safety stopping pillar heights are exaggerated to better show inner details.

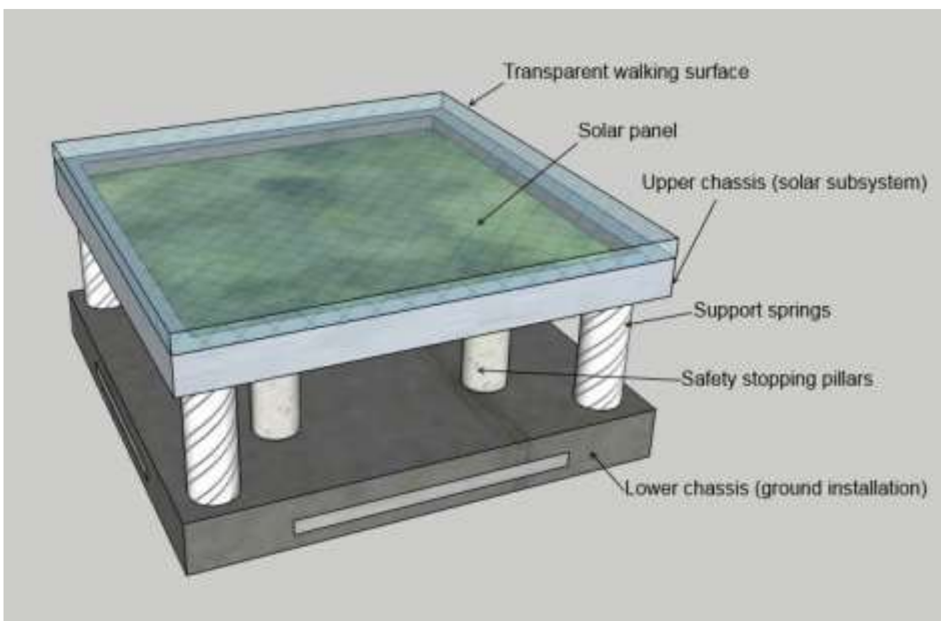


Figure 2: SolarPath™ system diagram top view, detailing upper solar subsystem spring-supported structure

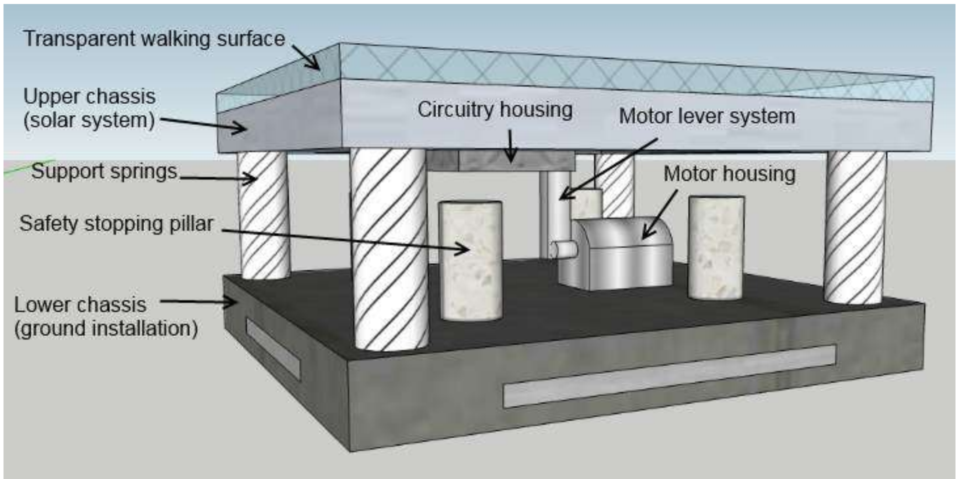


Figure 3: SolarPath™ system diagram side view, detailing the kinetic subsystem components, circuitry housing, motor and gear systems, as well as additional support structure detail

For the electrical output of the system, SolarPath™ is designed to be interconnected via a system of rails placed after installation of the tile units, in order to connect their various outputs into a single, unified outlet for battery bank charging. The tiles will be installed such that they physically interconnect on any of their four sides, while electrically each tie will have a dedicated positive and negative output linking them in parallel with one another. The full SolarPath™ system setup, including the output rails, is shown conceptually in the following figure (a top-down view with the upper solar layer removed for better visibility);

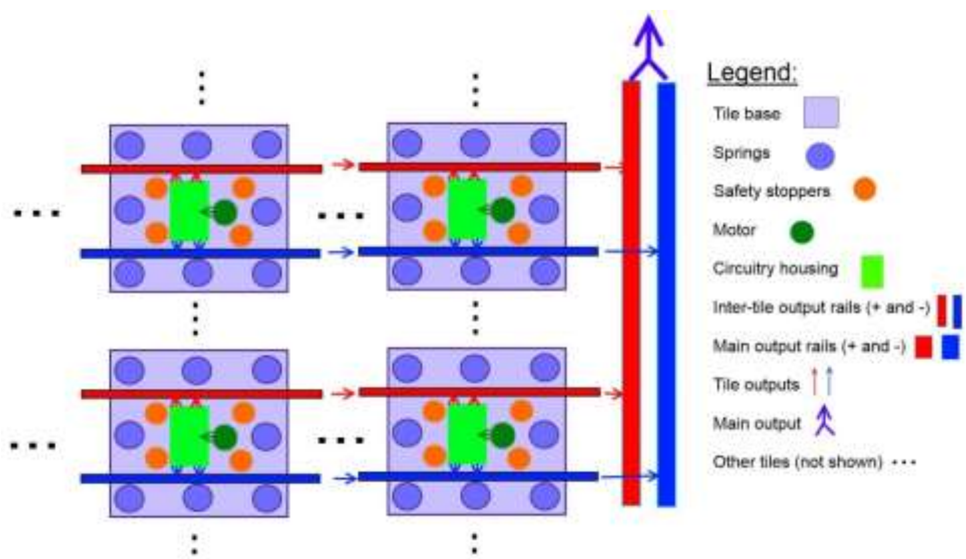


Figure 4: Full SolarPath™ system setup, showing the tiles placed in a grid pattern interlaced with positive and negative output rails

A conceptual cross-sectional view of the tile is provided below, detailing the view looking inwards at the negative side of the tile, showing the negative outputs and rails alongside the physical components;

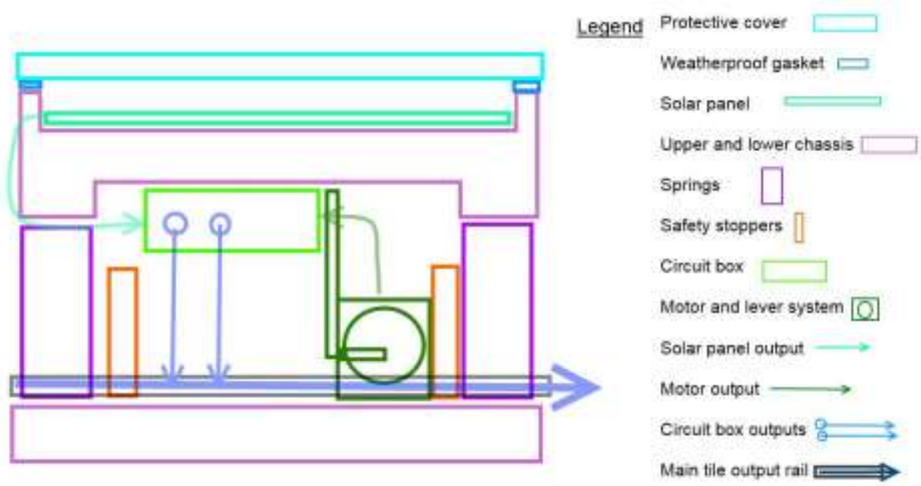


Figure 5: Conceptual cross-sectional view of tile, detailing negative electrical outputs alongside the physical structure

The following flowchart illustrates the process of the solar energy and kinetic energy harnessing subsystems, working in parallel and independently of one another, as well as a high-level concept of the subsystem and overall SolarPath™ modularity, demonstrating how multiple systems will be interconnected to charge an external battery bank.

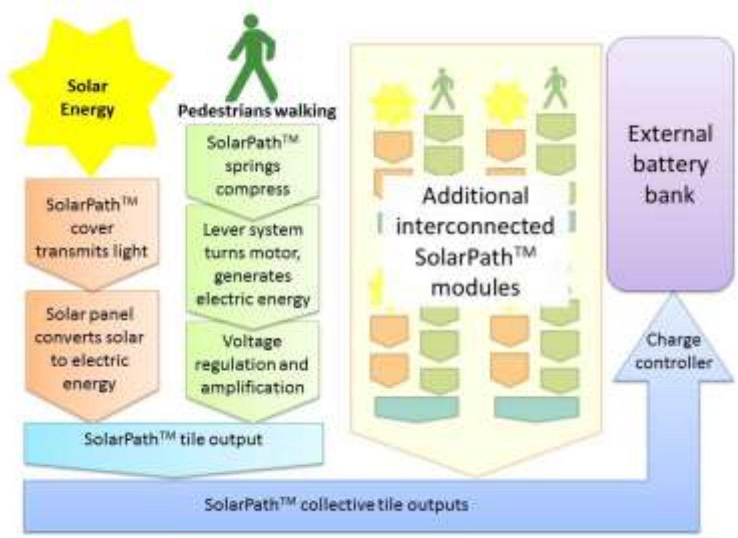


Figure 6: High-level flowchart illustrating energy flow through subsystems and overall module connections

2.2 PROTOTYPES

Our development process will include four prototypes: Proof-of-Concept, Alpha, Beta, and Gamma, constructed over staggered stages. This will allow for the gradual integration of features and step-by-step testing of the SolarPath™ system, allowing for any necessary refinements or changes to the design in order to ensure highest quality product performance. These stages, their projected completion date, overall implemented features and testing focus are all tabulated below;

Table 1: Prototyping schedule, dates, features and testing

Prototype	Completion Date	Implemented Features	Testing
Proof-of Concept	April 10, 2017	• Simple chassis (wood) • Solar energy generation • Kinetic energy generation • Charging a simple battery	• Electrical testing, charging capacity and measurements
Alpha	May 30, 2017	• Construct metal chassis • Attach protective covering	• Durability testing, repeated walking • Weight capacity
Beta	June 30, 2017	• Module connectivity - linking two tiles physically and electrically	• Connectivity testing, electrical flow • Continued durability testing • Weatherproofing test, water
Gamma	August 8, 2017	• Final chassis construction • Final weatherproofing • Circuit finalization and weatherproofing	• Weatherproofing test, water resistance

Similar tables will be presented throughout the document, further detailing each design choice's implementation through each prototype stage alongside requirement and functionality criteria fulfillment, referencing the numbers found in our Requirements and Functional Specifications document.

3.0 HARDWARE DESIGN

The hardware components and design of SolarPath™ refer to all of the components and processes which ensure the physical integrity of the product. As its intended use is for an outdoor pathway, the system must be constructed to endure temperature extremes, weather conditions, and continued physical duress from pedestrian traffic. According to the requirements and functional specifications, SolarPath's™ intended operational conditions are stated in Table 2 below;

Table 2: Values for operational ranges and physical properties of system

Operational Temperature:	-10°C to 80°C (14°F to 176°F)
Weight Capacity:	181 kg (400 lb)
Estimated Life Cycle:	Approx. 10 years
Dimensions:	Approx. 12 cm x 60 cm x 60 cm (1'x2'x2')

These ranges were selected after analysis of solar panel temperature efficiency [9] [10] [11] [12] [13] [14], average yearly weather patterns in Vancouver, BC [15], average weight of a person and a wheelchair in North America [16] [17], the lifespan of a solar panel along with estimated mechanical wear under pedestrian traffic [18] [19] and the standard size for a North American sidewalk tile [20]. For detailed derivations and analysis, please refer to the Requirements and Functional Specifications document.

3.1 UPPER SOLAR LAYER

The components of SolarPath's™ solar energy subsystem include the protective cover and gasket, the solar panel, and the overall chassis to house the panel and hold the transparent surface in place, highlighted in the conceptual cross-section diagram below;

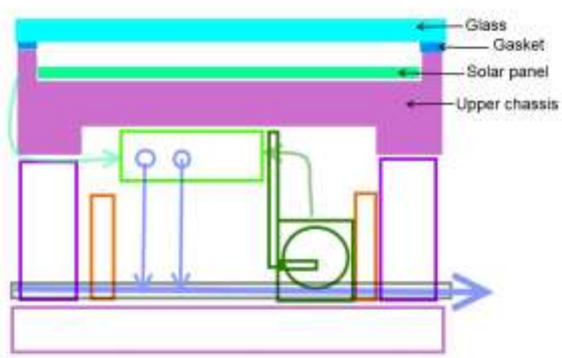


Figure 7: Conceptual cross-sectional diagram, highlighting the physical components of the upper solar energy subsystem

For the subsystem to meet the operational requirements, the selected materials are a monocrystalline silicone solar panel, glass sheet for the protective cover, silicon foam for the sealing gasket, and galvanized steel for the chassis.

3.1.1 SOLAR PANEL

The solar panel selected for SolarPath™, as well as its physical properties, are shown in Figure 8 and Table 3 below;

Figure 8: 55.5 cm x 53.5 cm x 0.3cm, 12V, 50W semi-flexible monocrystalline solar panel [21]

Table 3: Physical properties of solar panel [21]

Material	Monocrystalline silicon
Dimensions	55.5 cm x 53.5 cm x 0.3cm (22" x 22" x 0.12")
Operational temperature	-40°C to +85°C
Cell efficiency	22%
Lifespan	25 years
Weight	~100 g (0.22 lb)
Other	Waterproof, semi-flexible

As can be seen, the dimensions and operational temperature match those required in SolarPath's™ operational specifications of Table 2, with the waterproof nature meaning that the panel itself is also protected from weather conditions should the protective cover or gasket sealant fail during operation. In addition, it is very thin, lightweight, and semi-flexible, so that the panel itself does not put the lower system under additional duress from its own mass, thickness, or rigidity.

The choice of monocrystalline silicon was made due to the high-quality of the material, as they are single-ingot high-grade silicon crystals of the highest purity. This leads to the highest efficiency of all solar panels (15-20%), very space-efficient systems, the longest lifespan (25 years), and the best low-light performance of solar panels while maintaining high performances even in high-temperature environments, allowing the highest energy output during the product's operation. [22]

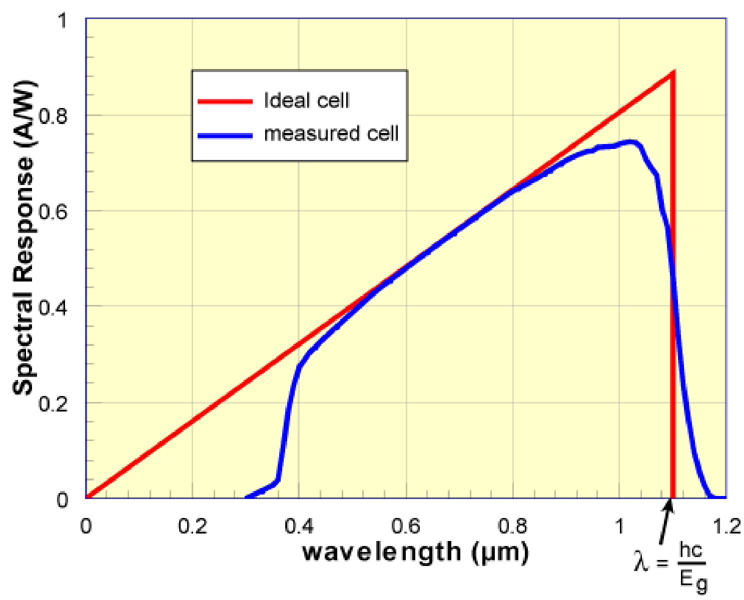
The outline for the solar panel implementation across each prototype is tabulated below;

Table 4: Solar panel implementation plan and criteria

Prototype	Features implemented	Requirement/functionality fulfilled		
Proof-of-Concept	12V, 50W semi-flexible monocrystalline solar panel installed into system	[SR-1 A] [SR-7 B] [SR-9-10 B] [SR-12 B] [SR-25 A] [SR-27 C]	[PD-28 A] [PD-31 A] [PD-31-34 B]	[ES-43-53 B]
Alpha				
Beta				
Gamma				

3.1.2 GLASS SHEET

For a solar panel to function optimally, it requires a response of about 1 μm wavelength under glass;



Graph 1: Spectral response of ideal and experimental solar cells to varying wavelengths of light [23]

Therefore, a transparent material of comparable refractive index is required. For SolarPath™, the surface must also be able to withstand constant walking pressure and abrasion. Two options were compared in regards to these criteria; tempered glass and polycarbonate sheets, both of which are transparent mediums which have high impact resistance and strength. Some key properties are presented in Table 5 below;

Table 5: Comparison of various physical properties of toughened (tempered) glass and polycarbonate [24] [25]

	Toughened (Tempered) Glass	Polycarbonate
Refractive index	1.50 [23]	1.52 [26]
Light transmission	80-90%	Max 88% (yellows under UV light) [27]
Density	2.4 g/cm^3	1.2–1.4 g/cm^3
Impact/pressure resistance	Minimum 4 times that of glass 65 MPa (9,400 psi) [28]	250 times that of glass [29] 35 kJ/m^2 [30]
HDT (Heat deflection temperature)	N/A	130 to 140 °C (270 to 280 °F) [31]
Maximum strength to weight ratio	75 kN-m/kg	110 kN-m/kg
Flexibility	Very low	High
Weather resistance	All (wind, rain, snow, temperature extremes) [32]	All (wind, rain, snow, temperature extremes) [33]
Chemical resistance	Resistant to acids and alkali [34]	Resistant to gasoline and acids [29], very susceptible to alkali and solvents [33]
Surface quality	More scratch resistant than glass [35]	Scratches and mars readily, cannot be restored with polishing [29] [30] [33]

Polycarbonate is one of the strongest and most weather-resistant plastic construction materials in the general market, with its high strength for its light weight and good thermal resistance being its main draws [29]. However, its key downsides of UV yellowing, flexibility and ease of surface marring make it unsuitable for use as SolarPath's^{TM} top protective surface, which requires a sturdy and clear material throughout its lifespan. [29] [30] [33] In addition, the manufacture of polycarbonate is very hazardous to workers and not environmentally sound, using very high temperatures, phosgene, and chlorine, which goes against Solentic Energy's standards and practices. [33]

Tempered glass maintains the clarity, weather and chemical resistance of regular clear glass, while also becoming strengthened against impact, no longer breaking under stress until above 65 MPa or 9400 psi. [35] In comparison, the capacity for a system used to measure the pressure for cars and trucks driving overtop is 4.1 MPa or 600 psi, meaning that the glass could potentially withstand automotive traffic if used alone. [36] Additionally, in order to make a suitable walkway, the glass can be treated with anti-slip surfaces; small dots can be sand-blasted across the glass to provide traction without sacrificing a large portion of the surface clarity. [37]

The outline for the protective cover implementation across each prototype is tabulated below;

Table 6: Protective cover implementation plan and criteria

Prototype	Features implemented	Requirement/functionality fulfilled		
Proof-of-concept	Basic removable wooden cover for compression testing	[SR-2 A] [SR-8 A]		
Alpha	Glass cover obtained	[SR-7 B] [SR-10-12 A] [SR-22-23 A] [SR-25-27 A]		[ES-48-53 B]
Beta				
Gamma				

3.1.3 SOLAR SUPPORT STRUCTURE - SILICON FOAM AND GALVANIZED STEEL

To house the solar energy subsystem, the structure must be made to be fully exposed to weather conditions and temperature extremes, as well as be able to continue to support the weight of pedestrians.

In order to ensure the weatherproofing of the solar panel chamber itself, a thin gasket of silicon foam will be placed between the glass and the chassis housing to seal out wind and water. An image and some properties of closed-cell silicon foam are shown below;

Figure 9: Some examples of silicon foam gaskets [38]

Table 7: Physical properties of general closed-cell silicon foam [38] [39] [40]

Temperature range	-67°F to 392°F (-55°C to 200°C)
Physical properties	Elastomeric, excellent compression set resistance, variable thickness and firmness for different applications
Sealant properties	Water and dust sealing
Environmental resistance	Oxygen, ozone, and UV light resistant
Other resistance	Thermal, chemical, electrical and aging resistant

With its versatile physical properties, ensuring the foam can be tailored to the correct size and thickness required, along with its superior environmental resilience, silicon foam is an excellent fit to weatherproof all exposed sections of SolarPath™.

For the chassis material itself, the body must be constructed of a durable and non-corrosive material that can be used in outdoor construction. The material to fulfill these requirements was selected to be galvanized steel, image and properties (compared against aluminum and stainless steel) are shown below;

Figure 10: Sheet of galvanized steel [41]

Table 8: Comparison of properties of aluminum, stainless steel, and galvanized steel [42] [43]

	Aluminum	Stainless steel	Galvanized steel
Cost	Lowest	Highest	Medium
Strength/Malleability	High malleability	High strength	High strength
Corrosion resistance	Absolute (never corrodes)	Medium (corrodes in extreme weather and stress conditions) [44]	High (corrodes only after decades of environmental use) [45]
Density [46]	2712 kg/m^3	7480 - 8000 kg/m^3	7850 kg/m^3
Thermal conductivity [47]	118 BTU/(hr·ft·°F)	17 BTU/(hr·ft·°F)	17 BTU/(hr·ft·°F)

Though aluminum is the most corrosion-resistant, its low density leads to high malleability and easy heat transfer, which will potentially lead to the product warping and overheating when under constant stress and sunlight. Steel is the stronger metal, but requires treatment to prevent corrosion. While stainless steel resists corrosion, it is not meant for constant use under extreme weather conditions, whereas galvanized steel, used commonly in construction, is made to withstand such conditions for many years, averaging up to 70 years in damp environments. [44]

The outline for the solar support structure implementation across each prototype is tabulated below;

Table 9: Solar support structure implementation plan and criteria

Prototype	Features implemented	Requirement/functionality fulfilled		
Proof-of-concept	Basic wooden chassis to house solar panel	[SR-2 A] [SR-8 A] [SR-12 B]		
Alpha **Beta**	First design of metal chassis and initial gasket installed for glass panel	[SR-7 B] [SR-16 B]		
Gamma	Final chassis design and final gasket implemented to seal solar panel system	[SR-9-10 B] [SR-21-27 B]		[ES-44 C] [ES-48-53 B]

3.2 LOWER KINETIC LAYER

The components of SolarPath's™ kinetic energy subsystem include the motor and lever system, the support springs and safety stoppers, as well as the lower casing for ground installation. These features are highlighted in the conceptual cross-section diagram below;

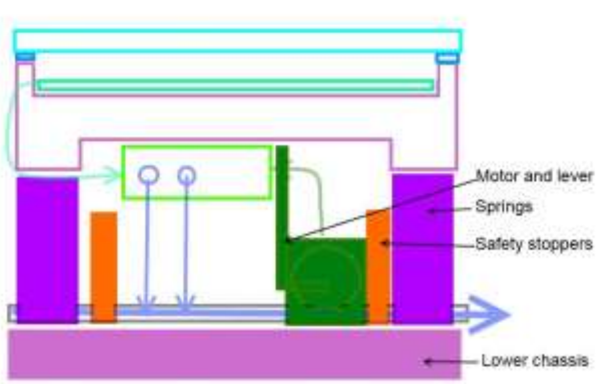


Figure 11: Conceptual cross-sectional diagram, highlighting the physical components of the lower kinetic energy subsystem

For the subsystem to meet the operational requirements, the selected materials are a Wind DC generator dynamo, heavy-duty die springs, CPVC tubes, galvanized steel, post spikes, steel strips and bolts, and silicon foam for weatherproofing inter-component casings.

3.2.1 MOTORS AND LEVER SYSTEM

In order to capture the kinetic energy as electric energy, the system requires a small motor which can fit beneath the upper solar subsystem layer while still allowing for room for circuitry and a system for turning the motor itself. The following DC motor was selected, its dimensions listed in the figure and table below;

Figure 12: Dimensions of the wind-driven DC generator dynamo, given in mm [48]

Table 10: Physical properties of the wind-driven DC generator dynamo [48]

Length:	130 mm
Motor diameter:	35 mm
Shaft length:	22 mm
Shaft diameter:	8 mm
Material:	Plastic, iron
Weight:	400g

The motor itself will be positioned laterally so that the shaft will be parallel to the ground, allowing roughly 8-10 cm of space beneath the tile so that the top layer can displace up to 2 cm without hitting the implement. It will be mounted by bolting into a weatherproof container at the floor of the chassis, slightly elevated to avoid any collected water that could arise. The shaft will be extended out of the container in order to allow rotation and the non-rotational base sealed with silicon foam as described in 3.1.3 Solar Support structure - Silicon Foam and Galvanized Steel.

An example of the weatherproofing cover for the shaft side of the motor is shown below;

Figure 13: Weatherproof 4"x2.75"x2" outlet box [49]

In order to drive the motor using the vertical motion of the tile, a lever system is employed to translate vertical tile compression into rotational motion. The system consists of a rod attached through the motor shaft, connected with a free-sliding bolt to a flat steel rod with a small horizontal window cut out near the bottom, creating some allowances for shear movement of the rigid bodies. A conceptual diagram is shown below, with dimensions and angles calculated via simple trigonometry;

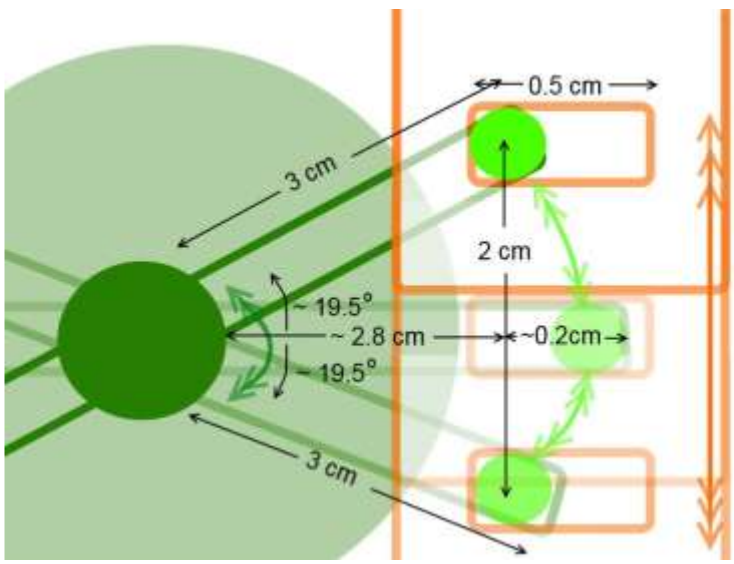


Figure 14: Conceptual diagram of motor and lever system with dimensions. Features shown are the motor (in green), steel rod (in orange) and connecting bolt (in pale green)

This system will allow for approximately 41° of rotation of the motor shaft in both directions from the 2 cm depression allowed by the tile, which in turn will create the torque to generate the output voltage of the motor.

The outline for the motor and lever system implementation across each prototype is tabulated below;

Table 11: Motor and lever system implementation plan and criteria

Prototype	Features implemented	Requirement/functionality fulfilled		
Proof-of-concept	DC motor installed with prototype lever system	[SR-1 A] [SR-16 B]	[PD-28 A] [PD-35-37 A] [PD-39 A]	
Alpha	Lever system improved and finalized, preliminary weatherproof container created for motor housing	[SR-20 A]	[PD-38 B]	
Beta				
Gamma	Final motor housing and lever system installation	[SR-9-10 B] [SR-21 B] [SR-24-27 B]	[PD-30 B]	[ES-43-46 A] [ES-48-53 B]

3.2.2 SPRINGS AND SAFETY SUPPORTS

Due to the motor requiring vertical movement to generate power, the springs were selected to be able to compress 1-2 cm even with the minimum load of a single, average-massed person (80.7 kg or 177.913 lb) [16]. In mechanics, two or more springs are said to be in series when they are connected end-to-end, and in parallel when they are connected side-by-side; in both cases, so as to act as a single spring. In the product's system, eight springs are to be used to support a single structure, thus reflecting the 'parallel' spring configuration as shown below;

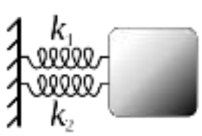


Figure 15: Springs in parallel configuration [50]

The relevant formulas for the parallel-spring situation, as well as its derivation, are shown below;

Quantity	In Parallel
Equivalent spring constant	$k_{eq} = k_1 + k_2$
Equivalent compliance	$\frac{1}{c_{eq}} = \frac{1}{c_1} + \frac{1}{c_2}$
Deflection (elongation)	$x_{eq} = x_1 = x_2$
Force	$F_{eq} = F_1 + F_2$
Stored energy	$E_{eq} = E_1 + E_2$

Figure 16: Spring and force equations for parallel configuration [50]

Equivalent Spring Constant (Parallel) [hide]

Both springs are touching the block in this case, and whatever distance spring 1 is compressed has to be the same amount spring 2 is compressed.

The force on the block is then:

$$\begin{aligned} F_b &= F_1 + F_2 \\ &= -k_1 x - k_2 x \end{aligned}$$

So the force on the block is

$$F_b = -(k_1 + k_2)x.$$

Which is why we can define the equivalent spring constant as

$$k_{eq} = k_1 + k_2.$$

Figure 17: Derivation of the equivalent spring constant for parallel configuration [50]

Hooke's Law is used to relate the force acting on a spring with its displacement from equilibrium and the inherent spring constant k:

Hooke's Law:

Force:

$$F_x = -k(x - x_0)$$

Spring Force Constant:

$$k = \frac{F_x}{x - x_0}$$

Distance from Equilibrium:

$$x = x_0 - \frac{F_x}{k}$$

Spring Equilibrium Position:

$$x_0 = \frac{F_x}{k} + x$$

where,
F_x = Force,
k = Spring Force Constant,
x = Distance from Equilibrium,
x_0 = Spring Equilibrium Position.

Figure 18: Hooke's Law for force, spring constant, distance from equilibrium and equilibrium position [50]

We desire the spring to be at 10 cm (0.1 m) length when depressed from force of platform and pedestrian and have set dx from a footstep to be 2 cm (0.02 m). The spring should therefore be 12 cm (0.12 m) long. This is equivalent to 4.72 inches.

The force from a walker/runner is approximately 1000-2000 N (based on an average of 70-80 kg mass). Using Hooke's Law and the parallel spring theorem (treating all eight as a single spring), these constraints dictate a K_{eq} of 50,000-100,000 N/m or kg/s^2. [51] [52]

Divided by 8 identical springs - K1, K2, K3, K4, K5, K6, K7, K8 = 6,250-12,500 N/m or kg/s^2. This is equivalent to approximately 35.69-71.38 lb/inch.

Using this range of K constants, a spring was selected to lie within this range and have a reasonably wide diameter versus height, shown below;

Figure 19: 1/2" OD x 9/32" ID x 3-1/2" OAL Red Medium-Heavy Duty Die Spring [53]

Table 12: Physical properties of the Raymond® Heavy-Duty Die Spring [53]

Inner Diameter	9/32"
Length	3-1/2"
Material	Chrome Silicon
Outer Diameter	1/2"
Rating	4.0 lb per 1/10"
Style	Medium Heavy Duty
Type	Raymond® Die Spring
Product Weight	0.046 lbs

This spring has the proper K-value with the widest dimeter to the shortest length in order to allow for better stability. As well, the chrome silicon allows for a maximum temperature tolerance of 245°C. [54]

For the safety supports, CPVC tubes were selected, due to sharing PVC's strong and rigid structure and resistance to most acids and bases, but also having a higher operating temperature of 82°C degrees as opposed to 60°C. [55] They also come in a wide variety of diameters and thicknesses and can be easily cut and worked to the required height. [56] One example with PVC cutters and a ½" pipe are shown below;

Figure 20: CPVC/PVC tubing cutter and 1/2" CPVC tubing [56]

The outline for the springs and safety support system implementation across each prototype is tabulated below;

Table 13: Spring and safety support implementation plan and criteria

Prototype	Features implemented	Requirement/functionality fulfilled		
Proof-of-concept	Springs temporarily mounted in prototype chassis for weight and compression testing, temporary stoppers made of either plastic or wood	[SR-8 A] [SR-13-16 B]	[PD-28 A]	
Alpha	Final springs and safety stoppers installed into new metal chassis	[SR-25 A]	[PD-38 B]	[ES-46 A] [ES-48-53 B]
Beta				
Gamma				

3.2.3 LOWER SUPPORT STRUCTURE

As with the upper chassis, the lower support structure will need to be of a weather-durable material that is non-corrosive, sturdy and with a long lifespan. These criteria are nearly identical to those of the upper chassis; therefore galvanized steel was selected as the chassis material, based upon the analysis performed in 3.1.3 Solar Support structure - Silicon Foam and Galvanized Steel.

For physical interconnection between tiles, the chassis is designed to be able to bolted together adjacent tiles on any of the four edges via galvanized steel strips, bolts and screws. An example of a two-by-two interconnection of tiles is shown below, simplified to show only the lower chassis, spring, and connection placements;

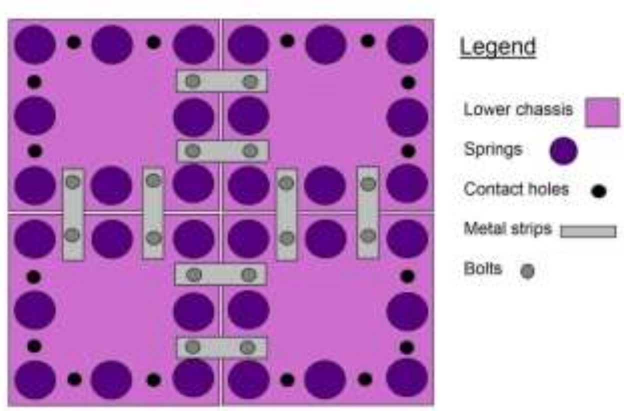


Figure 21: Conceptual diagram of physical connections between tiles, demonstrated on a 2x2 tile layout

The two bolted sections along each tile's edge will help ensure that the tiles are secure against one-another, and solely bolting the bottom chassis together ensures that each module's upper chassis will be able to compress freely and independently of one another.

To fully secure the system, the modules will be mounted into the ground via four post spikes, attached to the bottom of each corner of the lower chassis. Some examples of post spikes are shown below;

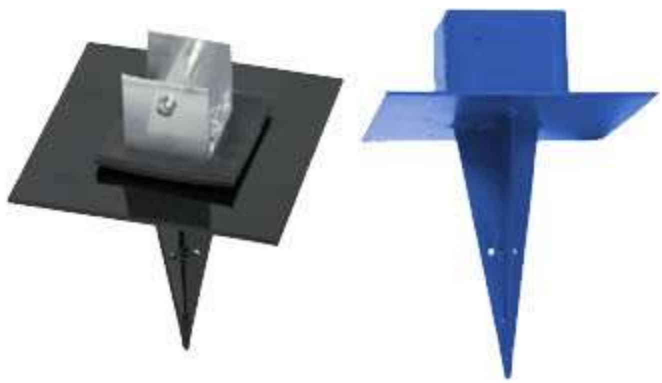


Figure 22: Two examples of type G post spikes with plates [57]

These spikes are zinc-plated to prevent rust and corrosion, have long lifespans suitable for use with either wood or metal ground installations, extremely durable, and environmentally friendly. [57] After they are attached to the chassis, each SolarPath™ tile can then simply be pressed firmly into the ground to secure, and can be moved or relocated if needed as well, making installation simple and easy for customer use.

The outline for the lower support structure implementation across each prototype is tabulated below;

Table 14: Lower support structure implementation plan and criteria

Prototype	Features implemented	Requirement/functionality fulfilled		
Proof-of-concept	Simple chassis made of wood, no interconnects or spikes	[SR-2 A] [SR-12 B]		
Alpha	Chassis constructed out of metal	[SR-7-10 B] [SR-16 B]		
Beta	Connection holes drilled for steel bolts and plates	[SR-4 A] [SR-17-18 A]		
Gamma	Post spikes attached to bottom of chassis for ground installation	[SR-5 A] [SR-19 B] [SR-25-27 B]		[ES-44 C] [ES-48-53 B]

4.0 ELECTRICAL DESIGN

SolarPath™ is designed to provide charge for a 12 V battery bank, based upon the typical capacity of a lead-acid battery. A lead-acid battery was selected as the target charging load, as unlike lithium-ion batteries it can withstand continuous charging and discharging from zero capacity. [58] In order to accomplish this requirement, SolarPath™ is designed with two energy subsystems working in parallel in each tile module, a solar and a kinetic energy system, and overall parallelization of a network of individual tile modules as well, as shown in Figure 4 and Figure 6 under 2.1 Top Level Design. The electrical components that will be described in this section are highlighted in the conceptual cross-sectional diagram below;

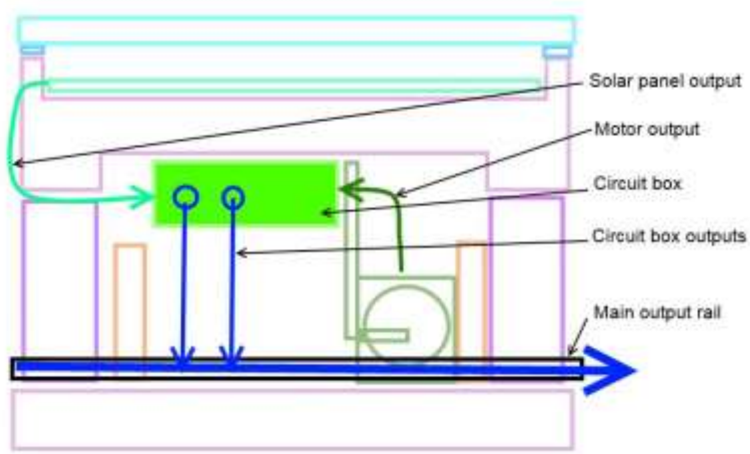


Figure 23: Conceptual cross-sectional diagram with electrical components highlighted (negative outputs shown, positive outputs on other side of tile)

These specifications will present three main groups of the electrical components; the solar output, the kinetic output, and the interconnection rails and main output.

4.1 SOLAR OUTPUT

The goal of the solar subsystem is to provide a minimum of 12 V in parallel with the kinetic system. The electrical properties of the selected solar panel from

3.1.1 Solar panel are tabulated below;

Table 15: Electrical properties of solar panel [21]

Voltage	12 V
Power	50 W
Current	4.2 A
Cell efficiency	22%
STC	1000 W/m 2h
MC4 Connecting Line	96 cm
MC4 Connector	2 pcs

As can be seen, this solar panel meets the requirements for a 12 V output, and will do so with the parameters listed above. The output of each solar panel is to be sent via MC4 connector and line, shown below;

Figure 24: MC4 connectors for PV systems, male (right) and female (left) [59]

These connecting cables are UV and weather-protected with a plug-and-socket design, in order to lock firmly and seal out water damage. [59] A positive and negative MC4 output is equipped with each solar panel, which will be lead down to the circuit box on the undercarriage of the upper chassis and attached to output leads for the interconnection rails.

The outline for the solar subsystem electrical implementation across each prototype is tabulated below;

Table 16: Solar subsystem electrical implementation plan and criteria

Prototype	Features implemented	Requirement/functionality fulfilled		
Proof-of-concept	Solar panel outputs directly to charge controller	[SR-1 A] [SR-3 A] [SR-7 B]	[PD-28-34 A]	
Alpha				
Beta	Solar panel output connected through circuit box and connects to output rail	[SR-4 A] [SR-9 B] [SR-20-21 B] [SR 25-28 C]		[ES-43-53 A]
Gamma				

4.2 KINETIC OUTPUT

The electrical properties of the selected DC wind-powered motor (selected in 3.2.1 Motors and Lever System) are shown below;

Table 17: Electrical properties of wind-powered DC motor [48]

Motor output voltage:	5V-24V
Maximum output current exceeds:	1500 mA
Maximum load voltage:	40 V
Maximum load power:	20 watts

Although the maximum output voltage of the motor reaches 24 V, this is dependent on the speed of rotation of the motor shaft. With the vertical movement of the tile limited to 2 cm and dampened slightly by the springs, the motor's output will be at the lower range (5 V), found via experimental testing. In addition, as the tile compresses and returns to its original height, the motor will be generating voltage in alternating directions, due to the internal armature being driven in opposing directions and inducing opposing currents from the forwards and backwards rotation. [60]

In order to maintain a DC output of 12 V from the selected motor, an additional circuit is required to first convert the AC output to DC, amplify the output voltage to a minimum of 12 V, as well as prevent back charging of the motor. The parts required to perform these functions are a bridge rectifier, followed by a DC to DC step-up module, and finally a diode rectifier.

4.2.1 BRIDGE RECTIFIER

A bridge rectifier, or full wave diode bridge rectifier, is comprised of four diodes placed in a loop, each of which acting as a switch prior to only allow positive voltage to pass. [5] [61] An illustration of the setup and the positive and negative half-cycle current flows are shown in the following figures;

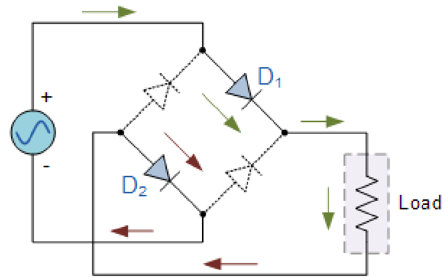


Figure 25: Full wave diode bridge rectifier, positive half-cycle [61]

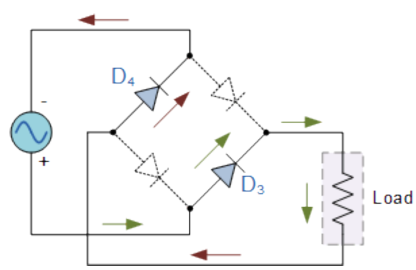


Figure 26: Full wave diode bridge rectifier, negative half-cycle [61]

This configuration often includes a smoothing capacitor in parallel with the output, which aids in reducing the amount of "ripple" (voltage drop) the DC load experiences between the positive and negative phases of the charging source. [61] The final configuration, along with the resultant output waveform, is shown below;

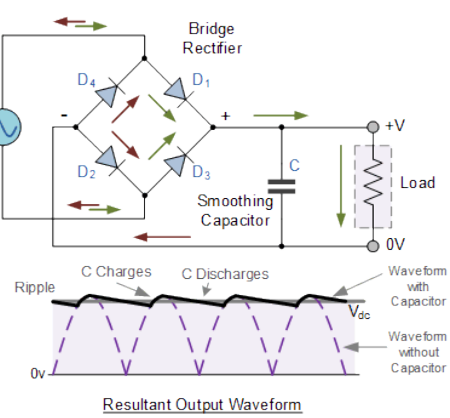


Figure 27: Full wave diode bridge rectifier with smoothing capacitor and resultant output waveform [61]

The RS604 bridge rectifier, selected to fulfill the circuit requirements, is shown in Figure 28, along with its maximum ratings and electrical characteristics in Figure 29;

Figure 28: RS604 bridge rectifier [62]

MAXIMUM RATINGS AND ELECTRICAL CHARACTERISTICS

Rating 25˚C ambient temperature uniess otherwies specified.
Single phase half wave, 60Hz, resistive or inductive load.
For capacitive load, derate current by 20%.

TYPE NUMBER		RS601	RS602	RS603	RS604	RS605	RS606	RS607	UNITS
Maximum Recurrent Peak Reverse Voltage		50	100	200	400	600	800	1000	V
Maximum RMS Voltage		35	70	140	280	420	560	700	V
Maximum DC Blocking Voltage		50	100	200	400	600	800	1000	V
Maximum Average Forward Rectified Current .375"(9.5mm) Lead Length at Tc=50℃					6.0				A
Peak Forward Surge Current, 8.3 ms single half sine-wave superimposed on rated load (JEDEC method)					250				A
Maximum Forward Voltage Drop per Bridge Element at 6.0A D.C.					1.0				V
Maximum DC Reverse Current	Ta=25℃				10				µA
at Rated DC Blocking Voltage	Ta=100℃				200				µA
Operating Temperature Range, T_J					-65 — +125				˚C
Storage Temperature Range, T_{STG}					-65 — +150				˚C

Figure 29: Maximum ratings and electrical characteristics for the RS604 bridge rectifier [63]

This rectifier is rated up to 400V with an operational temperature range well within those of the SolarPath^{TM} system, making it a good fit for the product's circuit.

4.2.2 DC-DC STEP-UP CONVERTER MODULE

The LM2587 step-up DC-DC converter module is shown in Figure 30, with its specifications listed in Table 18 below;

Figure 30: LM2587 step-up DC-DC converter module [64]

Table 18: LM2587 specifications [64]

Nature of the module:	Non-isolated boost (Boost)
Rectification:	Non-synchronous rectification
Input voltage:	3V - 30V
Output voltage:	4V - 35V
Output current:	5A (maximum), load current: 15mA
Transfer efficiency:	92% (maximum)
Switching frequency:	100KHz
Output ripple:	50mV (maximum)
Load regulation:	±0.5%
Voltage regulation:	±0.5%
Operating temperature:	-40°C to +85°C
Dimension:	48 x 23 x 14mm (L x W x H)
Power:	15W (no radiator), 20W (with radiator)

This model of step-up converter allows for input voltages as small as 3V to be amplified up to 35V, and is easily tunable to meet SolarPath's™ specifications, with some typical outputs shown below;

Table 19: Sample of typical outputs for LM2587

Input	Output
5V	12V / 1.2A
5V	24V / 0.6A
7.4V	12V / 2A
7.4V	19V / 1.2A
7.4V	24V / 0.9A
12V	19V / 2A
12V	24V / 1.5A

The LM2587 was also selected for the high maximum transfer efficient of 92%, its minimal output ripple as low as 50 mV, as well as small size and low power for minimal heat production, allowing it to be safely and readily integrated into SolarPath's™ electrical system.

4.2.3 DIODE RECTIFIER

A diode rectifier's purpose is to restrict current flow in one direction only. [5] In the case of our product, with the outputs all linked in parallel and the motors producing only sporadic output, a rectifier must be put in place to prevent the solar panel or adjacent tile outputs from running the motor. The 1N5402 diode rectifier is shown along with its electrical properties in Figure 31 and Table 20 below;

Figure 31: 1N5402 diode rectifier [65]

Table 20: Specifications of 1N5402 diode rectifier [66]

Voltage - Forward (vf) (max) @ If	1.2V @ 3A
Current - Average Rectified (io)	3A
Diode Type	Standard
Capacitance @ Vr, F	30pF @ 4V, 1MHz
Package / Case	DO-201AD, Axial
Configuration	Single
Forward Voltage Drop	1.2 V
Max Surge Current	200 A
Power Dissipation	6.25 W
Maximum Operating Temperature	+ 150 C
Lead Free Status / RoHS Status	Lead free / RoHS Compliant
Voltage - Dc Reverse (vr) (max)	200V
Current - Reverse Leakage @ Vr	5µA @ 200V
Speed	Standard Recovery >500ns, > 200mA (Io)
Mounting Type	Through Hole
Product	Standard Recovery Rectifier
Reverse Voltage	200 V
Forward Continuous Current	3 A @ Ta=75C
Reverse Current Ir	5 uA
Mounting Style	Through Hole
Minimum Operating Temperature	- 55 C
Reverse Recovery Time (trr)	-

This diode allows outputs of 1.2V/3A and above to pass through, while preventing any backflow up to 200V, while also lying within the product's operational temperature range and being lead free and RoHS compliant, making it a good choice to integrate with our product.

4.2.4 CIRCUIT BOX

The final kinetic output circuit will be housed within a circuit box attached to the undercarriage of the upper solar energy chassis. This is designed to keep the electrical components away from any potential water collection on the bottom of the lower chassis, while also allowing the box to be vented along its sides for better heat dissipation. A temporary circuit box with the assembled kinetic output circuit is shown in the figures below;

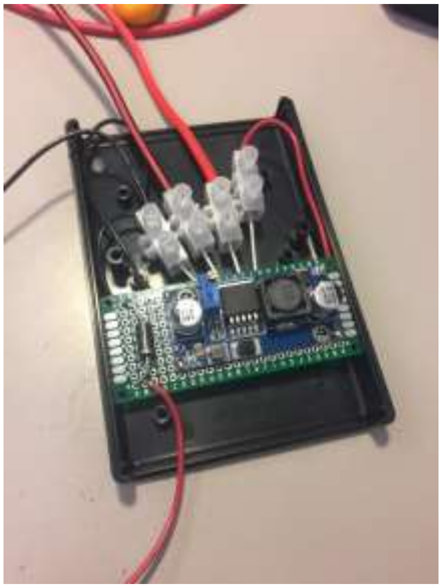


Figure 32: Kinetic output circuit, showing the diode (left), DC-DC step-up module (right) and bridge rectifier leads (top), resting in a temporary circuit box

Figure 33: Closed temporary circuit box with vents along bottom of box and output leads out of sides

In the final model of SolarPath™ , the vents will be moved from the bottom to the sides of the box between the leads, due to the bottom being the most likely part to touch any water collected in the system. The input leads from the motor and the output leads to the intermediary rails will be waterproofed with silicon foam, while any additional heatsinks required may be attached to the bottom surface for further heat dissipation.

The outline for the kinetic subsystem electrical implementation across each prototype is tabulated below;

Table 21: Kinetic subsystem electrical implementation plan and criteria

Prototype	Features implemented	Requirement/functionality fulfilled		
Proof-of-concept	Motor and intermediary circuit implemented in temporary circuit box	[SR-1-3 A]	[PD-28-29 A] [PD-35-39 A]	
Alpha	Circuit box weatherproofed and attached to undercarriage of upper chassis	[SR-4 A] [SR-9 B]	[PD-31 A]	
Beta	Outputs of circuit box weatherproofed and connected to main output rail	[SR-20-21 B] [SR-25-27 C]	[PD-30 B]	[ES-43-53 A]
Gamma				

4.3 TILE INTERCONNECTION RAILS AND MAIN OUTPUT

As shown in Figure 4 and Figure 6, the tiles will be electrically connected in parallel with one-another via external output rails, carrying the positive and negative outputs along opposing sides of rows of tile modules to a single output rail for battery bank charging. This parallel connection of the solar and kinetic outputs, along with the outputs of neighbouring tiles, will allow for scalability of the overall system; as more tiles are added to the pathway area, the output voltage will remain a consistent 12 V, instead of becoming cumulative as it would with a series system connection (shown in Figure 34). [67]

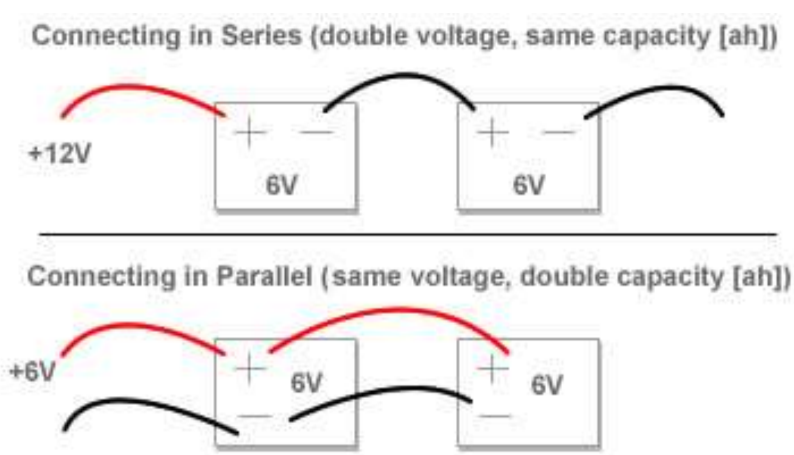


Figure 34: Comparison of a simple series connection versus a simple parallel connection [67]

The rails themselves are copper wire enclosed in weatherproofed, colour-coded PVC pipes (red for positive and blue for negative), fitted between the compression springs and safety stoppers along opposite edges of each tile. Copper wiring was selected for its excellent electrical conductivity and corrosion resistance, allowing high conduction along long rails even in outdoor environments. It is also easily joined and ductile while maintaining its strength, as well as being non-magnetic and recyclable, making it suitable to be used in the conduction rails in SolarPath™ sidewalks without worry of bending issues or magnetic interference in its vicinity. [68]

Along the rail, there will be outlets equipped with MC4 connectors for the solar panel outputs, as well as weatherproofed single-pin outlets for the kinetic system outputs, an example shown below;

Figure 35: Esky Mall weatherproofed electrical wire connection plug components; one-way male and female housing (top), cable seals (bottom left) and male and female terminals (bottom right) [69]

Currently, the rails are meant to be sized prior to installation of the SolarPath™ system, with each rail's length determined by the number of tiles to be placed and connected in a given area, but future designs will allow for modular rail portions for each tile that can link together like a segmented pipe.

The outline for the tile interconnection and main output rail implementation across each prototype is tabulated below;

Table 22: Tile interconnection and main output rail implementation plan and criteria

Prototype	Features implemented	Requirement/functionality fulfilled		
Proof-of-concept	Basic outputs from solar and kinetic directly to charge controller and battery	[SR-1 A] [SR-3 A]	[PD-28 A]	
Alpha				
Beta	Interconnection and main output rails installed into system	[SR-4 A] [SR-9 B] [SR-20-12 B] [SR-25-27 C]	[PD-29-31 A] [PD-40-42 A]	[ES-43-53 A]
Gamma				

5.0 SUSTAINABILITY AND SAFETY

At Solentic Energy, we are dedicated to creating a product which produces a sustainable source of power. Therefore, we also endeavor to work towards making SolarPath™ itself a sustainable and safe device throughout the entirety of its lifespan and beyond.

Our ideal vision for SolarPath's™ lifecycle would be that of the cradle to cradle design, wherein every stage of the product's life would be developed to be as environmentally sound as possible, making use of recycled materials, responsible and renewable manufacturing methods, and be ultimately recyclable with minimal waste. [70] To approach this ideal, we will work through multiple design stages to construct with as many recycled materials as possible, while also developing a sound structure with a long lifespan in order to maximize product use and minimize part replacement.

As stated under our Requirements and Functional Specifications - Engineering Standards, our requirements for SolarPath™ include following the guidelines for designing for sustainability in CSA's Z762-95 [71] as well as life cycle assessment in CAN/CSA-ISO 14040-06 [72], driving our development stages to focus on sustainability. The estimated lifespan for a completed product will be approximately 10 years, in order to maximize material use and minimize repair costs and waste from over-frequent replacement, as well as being reparable after installation. The kinetic subsystem were also streamlined, from an original plan of four to eight motors in series, to a single motor and intermediary circuit for 12V output, reducing the amount of both mechanical and electrical components per tile, simplifying repairs and maintenance. This will allow for reuse of the solar subsystem between expended modules, and aid in minimizing waste from motor repairs and replacements. In addition, for the product to be deemed acceptable, we require all materials used to be lead-free and RoHS compliant [73], allowing long-term use in outdoor conditions without polluting the installation area via harmful or corrosive matter. Finally, the ultimate disposal of SolarPath™ after the end of its lifespan will be compliant to the guidelines outlined in CSA's SPE-890-15, detailing best practices for managing end-of-life materials. [74]

Due to its intended use as a public pedestrian pathway, we demand additional requirements for SolarPath™ to be deemed safe and reliable for all users. By complying with the CAN/CSA and IEE guidelines for electrical installations, we ensure that our product's electronic components will remain operational and secure under all weather conditions to which it shall be subjected. All electrical components are designed to either be stored away from weather conditions such as wind or rain, or sealed with weatherproof materials such as silicon foam. In addition, the main circuitry of the system will be housed away from water and vented at the sides to aid in heat dissipation.

In order to assure the safety of pedestrians, we have added in the stipulations that the walking surface be a secure, non-slip and sturdy platform. Tempered glass was ultimately chosen despite potential for obstructive spider-web patterns when cracked, sacrificing some usability if the product in order to reduce risk of large glass shards upon breaking, which would compromise user safety. Compression of the product is also minimized to no more than 2 cm, with permanent safety stoppers to prevent any further compression. This is to minimize any risks of balance-loss for pedestrians, or difficulty in passage for wheelchairs and other wheeled devices on uneven surfaces, as well as the stoppers preventing sudden, spontaneous compression should the springs happen to fail. As for safety regarding our product's construction, we have outlined the need for materials that will not rust or corrode over long-term, outdoor use, and which are free from hazardous substances that could pollute or cause harm to either users or maintenance workers. This was brought into consideration for the choice in non-corrosive alloys such as galvanized steel or copper, as well as electrical components being rated lead-free and RoHS compliant for all modules.

6.0 CONCLUSION

Solentic Energy's SolarPath™ is a product designed to discretely and unobtrusively generate energy from renewable methods. It will be best applied in sunny and high foot traffic areas including sidewalks near beaches, parks and campuses. Harvesting energy from busy sidewalks using solar a kinetic energy can be used to power streetlights stored in batteries or sent straight to the grid. Fossil fuels are a problem since it is an energy source that takes millions of years to produce while nuclear is very expensive and has dangerous by products. We need a green energy and long lasting solution. Novel and renewable energy products like SolarPath™ will help contribute to our much needed green energy future.

This document covered the system overview, prototype schedule, hardware and electrical design, and safety standards for SolarPath™. The UI interface and test plan documentation are also included in the specification appendix.

Our project will consist of four prototypes: proof of concept, alpha, beta and gamma prototypes. Each successive prototype will improve upon build quality by using more robust production-ready materials including alloys and glass. The physical components of the system will be housed in two galvanized steel chassis, an upper for the solar layer and a lower for the kinetic layer. For the solar panel layer, the covering will be constructed of tempered glass sealed with silicon foam, with a 50W 12V monocrystalline silicon solar panel to collect solar energy. The lower kinetic layer will house a wind-driven DC generator dynamo in a weatherproof box at the bottom, while a lever system will attach to the upper layer to drive its rotation. Heavy-duty die springs and CPVC pipes will support the structure and control the compression, while bolts and steel panels will interconnect panels and post spike will keep the tiles secured into the ground.

The electrical components, both within the tile (solar and kinetic systems) and between tiles will be placed in parallel, linked with interconnecting output rails of copper wire with MC4 and weatherproof single-pin outlets. The solar panel output is rated at 12V, and the output of the motor is raised to 12V through a RS604 bridge rectifier, LM2587 step-up DC-DC converter module, and a 1N5402 diode rectifier to prevent back charging.

Each component and design choice was selected in order to comply with CSA and IEEE guidelines for sustainability and safety, ensuring a high quality and environmentally-sound product that is safe for all users.

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APPENDIX A - UI INTERFACE AND DESIGN

Solentic Energy's SolarPath™ is a modular dual-sourced energy-capturing system, designed to be installed by municipalities as sidewalks. As such, the intended users for the system will be two-fold; the installers of the tiled pathways and the pedestrians who frequent them. This appendix outlines the product's considerations and constraints for UI Interface and Design with respect to both user groups.

A.1 DISCOVERABILITY

SolarPath™ is developed in a four-staged prototype plan, allowing intermediary testing and design revisions along each progressive step as summarized in Table 1. In-house testing of the physical and electrical components will be performed during the proof-of-concept and alpha prototype stages, while upon reaching the beta and gamma stages, user groups will be surveyed for the ease of use and usability of the product. For the initial stages of testing, the system will undergo basic acceptance tests (e.g. weight and balance) as well as stress-tests (e.g. continuous compression, weather testing) in order to deem the product suitable for public use.

During the alpha prototype stage, where designing the tile interconnections and installation portions is the main focus, users such as construction workers and electricians will be given samples of the tiles and asked to attempt installing them in a sample of ground, as well as hooking the system to a battery bank. They will be observed during the process as well as surveyed afterwards regarding any problems or difficulties the product design posed for installation.

Once the product reaches its gamma prototype stage, randomly selected pedestrians will be asked to walk along small sections of SolarPath™ walkways, as well as specifically targets use groups, including bicyclists, strollers, and mechanical an electrical wheelchair users. These testers will be observed and surveyed to obtain information regarding the comfort and ease of use of the pathway.

A.2 FEEDBACK

Due to the tiered production design, receiving and integrating feedback from testers will be simpler to apply to the final product. As outlined in discoverability, use groups will be both observed and surveyed during testing stages of the pathway at separate prototype stages, allowing for reworking of the design at each stage, or regressing back in design stages in order to address user concerns.

In addition, once the product is in production and in use as city sidewalks, feedback from the municipalities regarding energy output, as well as potential complaints from pedestrians, will continued to be accepted and worked into developing improved models of the SolarPath™ system.

A.3 CONCEPTUAL MODELS

From the initial concept of solar and kinetic energy in a sidewalk tile, conceptual models were developed to illustrate the basic fulfillment of these requirements. Figure 2 and Figure 3 show two views of a 3D conceptual model built to satisfy the desired functionality of each individual tile module, and focus on the pedestrian's usability regarding a sturdy walking surface with minimal depression.

Afterwards, basic conceptual installation designs and cross-sections were created to symbolically simulate the electrical installation network and physical interconnections of the tiles. Figure 4 demonstrates a full grid setup of a SolarPath™ walkway with the interconnection output rails, while Figure 5 is a wire cross-section of an individual module, this time also outlining the electrical outputs and connections. Figure 21 is another full grid setup, but now detailing how the tiles will physically interconnect instead of electrically.

A.4 AFFORDANCES

The current model of SolarPath™ is designed to output 12V from both the solar and kinetic subsystems, allowing the charging of a 12V battery bank. The product does not come equipped with a full charge controller, therefore the user is required to connect the system to a battery bank equipped with a charge controller for proper use.

Due to the interconnection rails being manufactured separately from the tile modules, users purchasing the system for installation will first need to provide an area plan of where the pathway will be installed, in order for the correct lengths of rails to be supplied. This will be corrected in future models of the device, where each tile module will come equipped with in-built interconnection rails that can easily snap together.

In addition, due to the polarized nature of the tiles, modules will need to be installed such that they are in parallel with one another, in spite of being able to physically connect on all sides; all of the 'positive' sides must align in each row, as well as the 'negative' sides, as shown in Figure 4, in order for the electrical outputs to be installed correctly. Currently, the system will need to be installed into soft ground, i.e. before sidewalks are placed, due to both the height of the system and the post spikes in the bottom requiring earth instead of concrete. As well, due to the current design of the tiles being square, SolarPath™ will need to be installed in square or rectangular areas with a minimum of hills and dips for best usability.

For operation, SolarPath™ is designed to be able to be used outdoors in most environmental conditions, however specific ranges are restricted to those outlined in Table 2; use outside of these ranges is not guaranteed by the company. The solar surface is also not equipped with any self-cleaning mechanism, therefore the tile surfaces will need to be cleared of collected dirt and debris on a regular basis.

A.5 SIGNIFIERS

The current model is not equipped with any in-built signifiers for the installation use group to know if the module is working. A user will need to check the outputs with a watt meter or charge controller in order to determine exact functionality of the tile. However, for future modules, a small series of LEDs will be provided along the edge of each module which will indicate whether each subsystem (solar and kinetic) is outputting the required 12V, with a simple green for 'yes', yellow for 'standby', and red for 'broken'. Also, several obvious signs of breakage are also available; if the tile no longer compresses, or does not decompress, the spring systems have failed and need replacement. If the glass surface is cracked or broken it will also need replacement.

During installation, in order to ensure proper electrical and physical installation, the interconnection rails are colour-coded with red and blue options for positive and negative, corresponding to red and blue safety stoppers in the tile itself. The installer will need to simply line up the red rails with the red stoppers and similarly with the blue to ensure proper postie and negative contacts. For the solar and kinetic outputs, each has its own specific connector; MC4 and single-pin respectively. One will not fit within the other, and will therefore only join with the corresponding connector in the rail.

For the pedestrian user, its installation in a normal sidewalk path will serve to indicate that it is meant to be walked upon, whereas the glass surface and visible solar panel beneath will serve as signifiers that this is not a typical sidewalk, as well as alerting users to be more attentive to what they are walking upon.

A.6 MAPPINGS

As stated under signifiers and affordances, red rails and stoppers are mapped to positive electrical outputs, while blue rails and stoppers are mapped to their negative equivalents. There are no further mappings required for the pedestrian use group, as the entire tile will have simply one function only, as a pathway.

A.7 CONSTRAINTS

The system is designed so that the lower portion will be equipped with spikes, therefore not making it sensible or feasible to install upside-down. With the placement of the physical tile interconnections lining up in a grid-like pattern, the tiles must be placed side-by-side in order to properly install together. In addition, even if the user does not install the tiles to match the parallel configuration, the rails will not connect properly to the opposing outlet (red to blue), therefore not permitting the user to install the tiles the wrong electrical direction. Also, the outlets for solar panels (MC4 connectors) and the motor (single-pin connectors) are incompatible with one another, preventing a user from connecting a soar panel output to a motor output, or to a motor input, or vice-versa.

APPENDIX B - TEST PLAN

B.1 PHYSICAL TESTING

The physical tests encompass those that verify the strength of the overall chassis of the tile, as well as its robustness over time and under various conditions. These tests are mostly qualitative, and will consist of the staff and potential users physically stepping on the system to test the weight, continually stepping or using a machine for continued use, physically attempting to break any interconnection or ground installations, and placing in weather conditions to observe usability afterwards. The final test criteria are outlined below;

Table 23: Physical test plan

Test	Results	Comments
Physical		
Weight capacity: Must handle a minimum of 80 kg without breaking over multiple trials	☐ Pass ☐ Fail	
Interconnection: Must be able to be connected to sample piece and not dislodge/remain firmly connected	☐ Pass ☐ Fail	
Installation into ground: Must be able to install into ground and has minimal shift/wiggle after installation	☐ Pass ☐ Fail	
Weatherproofing: Must be able to leave physical structure outdoors for minimum one day in rain and still function	☐ Pass ☐ Fail	

B.2 ELECTRICAL TESTING

The electrical tests are to ensure proper functioning of the tile at every stage of the charging process, from the individual outputs, to the interconnection output, to the main. Each step of the process will be tested for their output to a 12V lead-acid battery and charge controller, with exact parameters measured using a DMM and watt meter. The final electrical testing criteria are outlined below;

Table 24: Electrical test plan

Test	Results	Comments
Electrical		
Solar output: Must have minimum 12 V output	☐ Pass ☐Fail	
Kinetic output: Must have minimum 12 V output	☐ Pass ☐Fail	
Tile interconnection output: Must scale when additional tiles are connected together and not break circuit	☐ Pass ☐Fail	
Main output: Must be able to recharge a 12 V lead-acid battery	☐ Pass ☐Fail	

B.3 SAFETY TESTING

The final tests are to ensure the safe use of the product in outdoor, all-weather use by average pedestrians. These will be mostly qualitative once more, and will be enacted by subjecting the system to the final product's outdoor conditions and evaluating the quality of use afterwards. The final criteria are outlined below;

Table 25: Safety test plan

Test	Results	Comments
Safety		
Waterproof: Must have physical structure be able to operate minimally after one day in the rain and no water collection in electrical containers	☐ Pass ☐ Fail	
Slip-proof surface: Must be able to run shoe across surface and not slide	☐ Pass ☐ Fail	
Heat dissipation: Must have internal circuits not malfunction due to heat after minimum one day continued use	☐ Pass ☐ Fail	
Shock hazards: Must comply with standards for electrical safety (have all electrical components sealed in wires/containers, no exposed shock hazards to user)	☐ Pass ☐ Fail	