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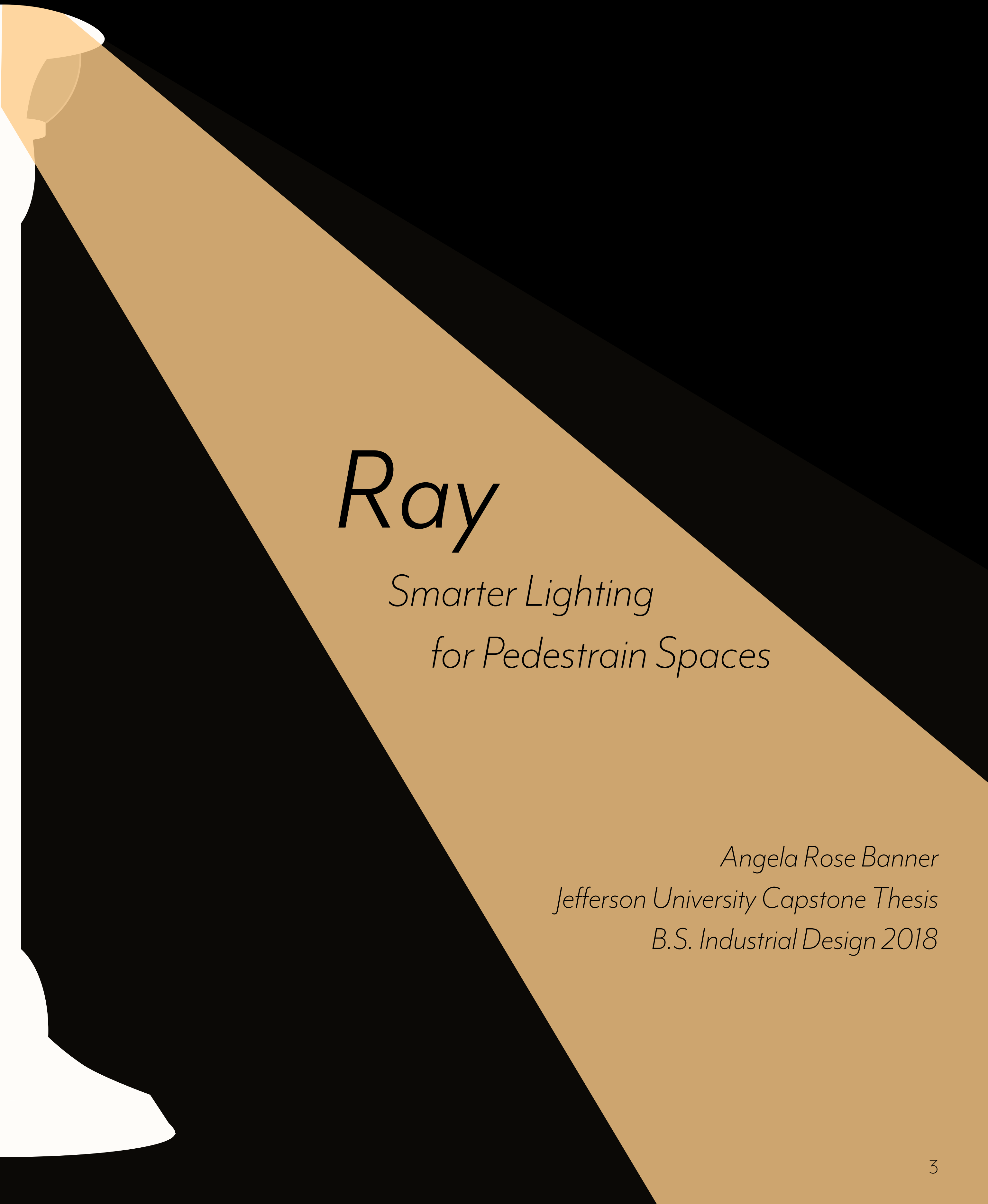
Ray

Angela Banner
Thomas Jefferson University

Industrial Design Capstone Documentation



Ray

Smarter Lighting for Pedestrain Spaces

Angela Rose Banner
Jefferson University Capstone Thesis
B.S. Industrial Design 2018

Thank You

A thesis is a lot of work over a long time - two whole semesters! I would like to thank some of the people who helped keep the momentum on this project going, without whom the final product would be so much less.

First, a huge thanks to the Industrial Design Faculty at PhilaU/Jefferson for directing my idea into a proud example of how I approach the design process.

Another thank you to The Lighting Practice, for a wonderful summer internship that taught me how to think about designing lighting as well as lumenaire design. Also for answering my questions over the spring semester, and for letting me come back. I cannot wait to give back what I have learned to such a great company.

I would also like to thank the Philadelphia IES and IALD for providing opportunities to learn from lighting experts from every field, and for coming together to review this thesis, providing critique and validation when it was most needed.

The last group I would like to thank are my friends and family, who have heard so much about this project they could present it themselves. You have inspired me to think about lighting from so many different perspectives. I hope that some of that diversity is represented through the process - it added another dimension each time you taught me something new.

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Preface

This book documents the design process of developing a lighting solution to the complex system that is public pedestrian spaces.

This project grew from an interest in interactive art installations and become a study of how to apply the same technology in a more common object: the city street, as used by people.

Why Pedestrian Spaces?

The technology developed in this project can also be applied to road lighting for vehicles, but the focus is on the pedestrian dominated public spaces. These spaces include (but are not limited to) sidewalks, parks, squares, and plazas. This makes the project about human centered design, not simply meeting code light levels.

The idea of focusing urban design on pedestrian users and not vehicle traffic is a growing movement that has generated some surprising benefits in areas used as case studies. One such movement is the use of super-blocks in Barcelona, which began as a solution for their extreme noise levels and air pollution. The superblocks have helped both those issues, but also boosted neighborhood communities, and improved sales for all of the retail within the blocks.

Lighting for Community

A city is a system that is made up of diverse, overlapping communities. This leads to understanding that the success of public design comes from the strength of the communities that the design facilitates. This makes the ideal public lighting environment one which encourages community users, such as bikers, dog walkers, and joggers, as well as one which draws attention to unwanted users.

Dynamic and Responsive Lighting

Combining the idea of lighting to encourage users in a space with interactive lighting environments lead to the questions that guide the design of Ray: Where is the line between subtle and effective interactive lighting? And what are the extended effects of such a lighting environment?

Ray is not so much a *solution* to the problem of existing public lighting, but rather a demonstration of the potential that human centered, dynamic, and responsive lighting infrastructure can bring to urban design.

Contributers and Consultants

This project could never have happened without real lighting professionals to talk to about it. These are some of the people in the network I built to navigate the opportunities and challenges of the world of lighting infrastructure. They come from all levels and backgrounds of lighting experience, but they have all helped keep my project grounded in the present needs of the lighting world.

Inga Birkenstock

Inga Birkenstock is the principal of Birkenstock Lighting Design in San Fransisco. She has 30 years experience in architectural lighting and interior design. I consulted with Inga on what features and appearances make a fixture appealing to lighting specifiers. Her recommended fixture became my starting point for research on the styles of pedestrian fixtures available and desired.

Jared Widmer

Jared is a Principal at TLP and the former IES President for the Philadelphia region. He is incredibly busy but always finds the time to be interested in this project when I want to ask for advice. He pointed my research towards the Osram Omnipoint as an example of an interior light with a similar effect. He also explained that the interior fixture was not getting far because of interior energy code, but that the concept applied to an exterior fixture could work because of the higher energy budgets.

Lillian Knoerzer

Lilly is the IALD (International Association of Lighting Designers) Regional Coordinator. She is organized the IES and IALD critique of the lighting Capstone projects when I asked if I could get a panel of experts to review my work. Lilly is also a lighting designer and project manager at TLP, with experience as a manufacturer representative and a background in interior design.

Rochelle Spahn

Rochelle is an associate at TLP, who also is an adjunct proffessor at Drexel University. She was very patient when I would ask questions about lighting design and fixture criteria, especially the advantages of direct vs indirect light sources.

Chelsae (Benewicz) Bauknecht

Chelsae is the other IALD Regional Coordinator. She is also an interior design professor at PhileU/Jefferson. She has been very enthusiastic about collaborating and sharing resources withe the Industrial design students who want to learn more about lighting from the architectural side. I learned about the existing lighting control options that are available from one of her classes I was invited to attend.

Alex Marino

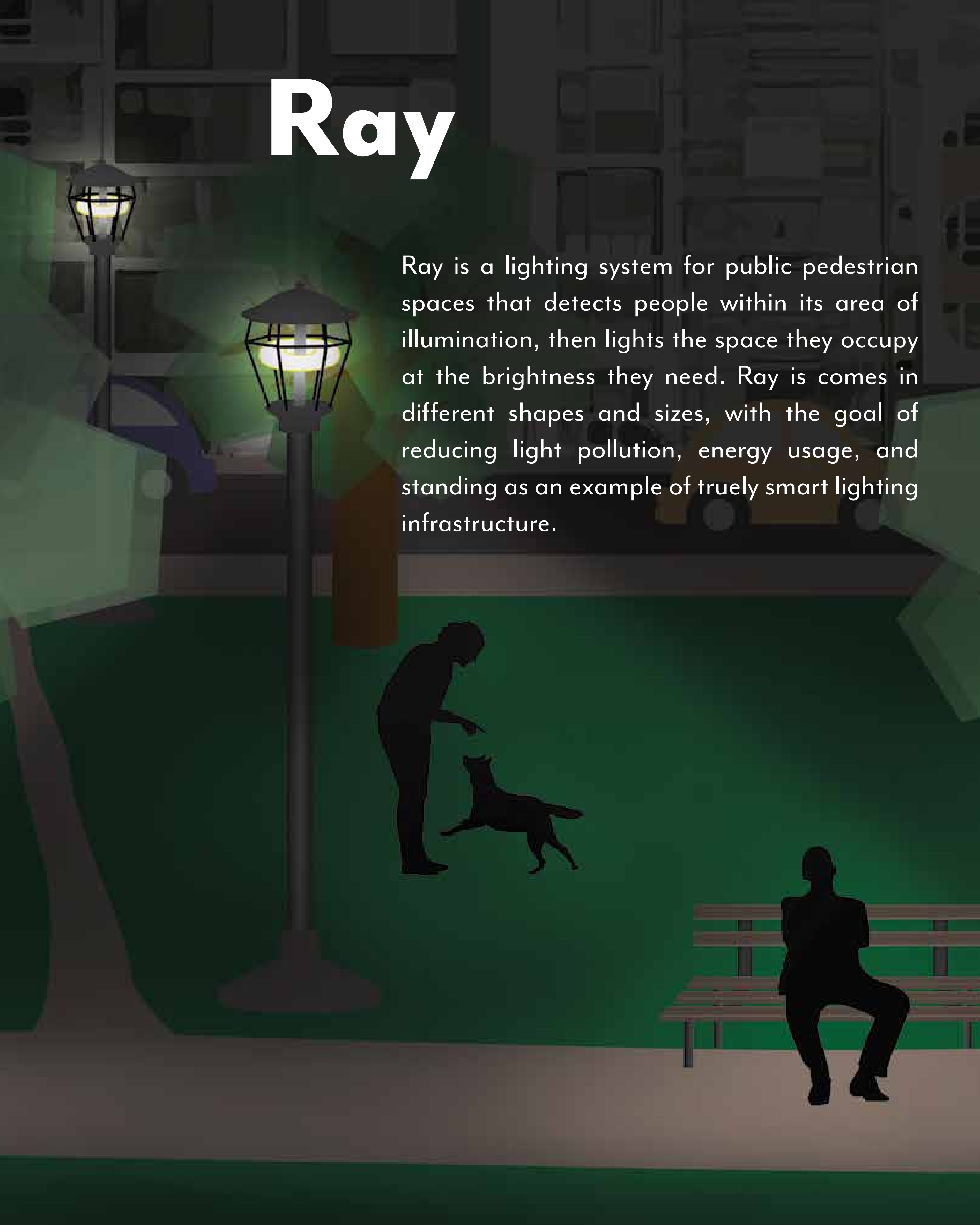
Alex is an ID classmate of mine who has much more experience with electronics. He has saved my prototypes from exploding looked and my buggy arduino code so many times, this project would not have have a single working LED diode without his advice and help.

Lyn Godley

Lyn is the lighting professor of the Industrial Design program. She is a product designer, and does art-light shows and installations. Lyn has always been able to put the project into perspective based on what is already out there, and is alwasy pushing the make the next breakthrough in lighting.

Ray

Ray is a lighting system for public pedestrian spaces that detects people within its area of illumination, then lights the space they occupy at the brightness they need. Ray is comes in different shapes and sizes, with the goal of reducing light pollution, energy usage, and standing as an example of truely smart lighting infrastructure.



Smart lighting for pedestrian spaces

Background

Why do we have public lighting?
You can't get more then a paragraph into any research on lighting without the word safety coming up. All municipal lighting is for safety at night. Safety includes car accidents, tripping on uneven ground, and detering robberies.

Everyone is invested in public lighting, but some people pay for it, other use it, and others want it. Balancing the needs of these interest groups is a key part of designing Ray.

Empty street with public lighting

London lamplighter 1930

With all this discussion of urban communities and interactive lighting, it is important to establish the purpose of public lighting.

Why We Have Public Lighting

The lighting of public spaces has been a responsibility exerted by municipal powers for centuries.

The first modern case of public lighting was a law passed by the Mayor of London in 1417 requiring all homeowners to hang a lantern outside thier front door to illuminate the street. This made the private citizens responsible for contributing to the illumination of public spaces, and the citizens responsibility is enforced by the municipality. Similar laws went into effect in other cities over the next few centuries, gradually shifting the burden of illumination onto the city, who employed lamplighters to maintain the candle-powered lumenaires.

In 1617, the city of Paris began the tradition of ringing a large bell once all the lamps in the city were lit. The bell served as an announcement that **the streets were now safe** - the first recorded direct connection between lighting and safety.

In Paris and in other cities, the idea of safe, illuminated streets was met with controversy. This is because the "safety" the lighting provided was for the wealthy upper class, not everyone. The criminal and lower classes of that time had made the streets thier own territory once the sun went down. They knew their neighborhoods well enough to navigate without the new lighting, and could go about thier private business under the cover of darkness. Some of the wealthy resented the lighting as well, because it made them recognizable when they wanted to do questionable business at night.

This demonstrates the core of why it is important to light public spaces: **Well illuminated spaces allow the people there to be observed.** With the possibility of observation comes "appropriate" behavior. Looked at the other way, individuals wih activities they do not want observed must seek out areas that are without other people, and/or very dark.

Safety is a Public Service

Based on the above, there are two general criteria for creating safety:

1. **Multiple people in the location**

2. **Doing things that can be seen by each other.**

We need light to see (other people) at night, thus safety and lighting beome tightly interlinked.

However, lighting alone cannot produce safety. **Safety requires other people.**

What makes an area safe?

Pedestrians gather on sidewalks for Halloween block party

Security lighting is about the reduction and prevention of crime.

The data on crime rates and light levels in urban areas is pretty easy to find, but it does not prove that making dangerous areas brighter reduces crime.

The most dangerous neighborhood in Chicago is lit at up to 30fc, and the increased illumination has not reduced the crime rate at all. Case studies of lighting and crime are highly contrary and do not show clear correlation and certainly not causation.

Blacking out an area will not stop crime.
Bright security lighting will not stop crime.

Some studies suggest that appropriate lighting can deter opportunistic crime:

- **It cannot be pitch black**, or there is no way to tell if crime is occuring.

- **It cannot be too bright**, or victimes are loose their night vision, and become easy targets.

And none of this matters if no person is available to witness and call the cops on any crime that may or may not be occuring.

Lighting for Security

Lighting for Safety

"Safety is an experience, not a number."

Therefore, safety can only be studied through individuals reactions to an experience. This qualitative data is very subjective, and heavily influenced by personal experience.

Lighting can make an area *feel safer*, which can include lighting that will prevent tripping on a pile of leaves, or make pedestrians visible to cars.

We get our sense of safety from a combination of factors, including:

- Line of sight (Are you visible to others?)
- Previous experience (familiarity with area)
- Other people (herd immunity)

If a crime occurs in a brightly lit parking lot, but there is no one there to see it, is the parking lot still dangerous?

"It's never really desolate," she said. "Every 100 feet I see runners and other dog walkers."
-Dianne Montague, night dog walker in Central Park

Benchmark 1

The fixture must provide a safe experience

Stakeholders in Public Lighting

Who needs it most, who uses it most, and who pays for it?

Residential townhouses

Now that it is established that public pedestrain lighting is needed, it is time to discuss who the lighting really benefits.

“Public” lighting is for everybody- or it should be, at any rate. But because this project is focused on lighting public pedestrain spaces, there are some groups of more specific stakeholders.

Residents

The people who live in the areas overlooking public spaces. They may rent or own, but all of them care if what’s outside of their windows is safe, distracting, or dangerous. Residents also have the most to worry about light pollution - if the areas outside their homes are too bright, it can affect their sleep.

Retail

Shops, resaurants, and other local small businesses depend on thier location for foot traffic. More people walking by equals more people walking in, bringing more sales. Retail, especially small local ratail, wants public lighting that attracts people to their street and makes it safe enough for them to stay.

Retail with busy sidewalk at night

Mr. Blumberg exercises at night in Central Park, NYC

Residents and Retail are the groups that are the most invested in the quality of the lighting in thier area, but they are not always the groups actually using the public areas as the sun goes down.

Leisure Groups

The groups that actually use these public spaces after dark are often residenets, but also just people passing through. Dog walkers, runners, and commuters all use pedestrain spaces like sidewalks, parks, and squares at later hours. This is because these are activities that occur outside of working hours. Most people work during the daylight hours, which pushes their other activities into the time before or after work, often when the sun is going down or not up at all. These are also the pople that make up much of the foot traffic that businesses need to attract. Because these groups use the public spaces deliberately, they choose where to be, and where not to be. This decision is based on a lot of factors, but often on how the areas "feel." These groups want to use public areas that feel pleasant and safe - both feelings that appropriate lighting can generate.

Local Authorities

The municipality that governs these public spaces is also the decision maker on how they are illuminated. They pay for the installation, maintanence, and electricity for public lighting. They enforce regulations about what level of illumination os appropriate for each area, and set times for these spaces to be open and closed. Most of this regulation is done for safety, with saving money a close second.

Lighting for Community

Together all of these groups form a single interwoven community around a public pedestrian space, whether it is a sidewalk or park. Stronger communities share these spaces and use them throughout the day. **Lighting can be a powerful tool toward making these community space usable, pleasant, and safe at night.**

Street lighting in London

Benchmark 2

The system must address the main concerns of each stakeholder group:

- **Energy cost**
- **Nusiance**
- **Safety**

Existing Products

Designing an intelligent light fixture requires 3 main pieces:

1. A Lumenaire or fixture. This is the body of the product.
2. The light source or lamp. This produces the illumination.
3. Intelligence. This is the system of sensors and controls that let the light respond to its environment.

Also included re examples of proposed smart street lighting concepts and some existing responsive lighting installations.

Outdoor Lights 101

This is the most common fixture in pedestrian spaces. It goes by many names, but its is always a light at the top of a pole. Multiple lamps can be mounted on top of a single pole for greater illumination.

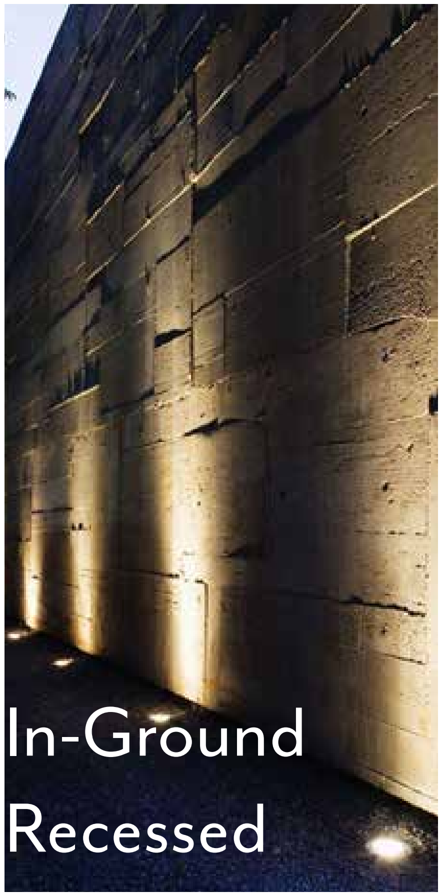
These fixtures are design for wide roads with cars. They extend over the road to get more light on the driving surface, and less on the sides. They can be very tall to cover more road with a single fixture. They are for cars, not people.

The compound pole is a road-lighting fixture on the same pole as a pedestrian area light. Typically seen in areas with a lot of pedestrians on sidewalks and lots of traffic on the roads.

Common catagories of fixture and function

The outdoor version of a sconce, wall mounted fixtures are intended for pedestrain spaces near buildings. They can replace poles along paths that run along the edge of a buildings, and draw attention to entrances.

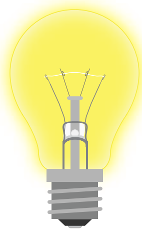
Miniature poles for people-scaled spaces. These fixtres are no more then 4 feet tall and light the ground where people walk. Short fixtures require tighter spacing, and thus more fixtures.



These lights have one limitation: they can only illuminate up from a surface instead of down onto a surface. Ground lights are used to uplight other objects in a pedestrain space like trees or walls. Looking down into them is a great way to get a face full of glare.

Lamp types used in area fixtures

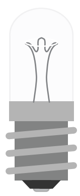
The lamp is the device that emits the light in a lumenaire. The lamping used will determine the energy effeciency, lifespan, brightness, light quality, and controls of a fixture. These are the most common lamps in area lighting, and I have rated each. The "best" lamp is the one that has the lowest energy cost and maintenance, but the highest quality light and controls. This makes LED the clear winner.



Incandescent

The oldest electric lighting. Runs electricity through a tungsten filament, which resists the energy and releases heat and light. These lamps need to be replaced regurally and use a lot of power.

Energy Cost
Maintenace
Controls
Light Quality

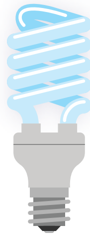


Metal Halide (HPMV)

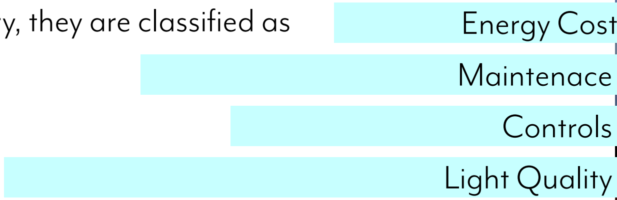
High Pressure Murcury Vapor lights produce a very bright white light, but use a lot of energy. They are most used for large highways and security in parking lots.

Energy Cost
Maintenace
Controls
Light Quality

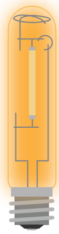
Florescent



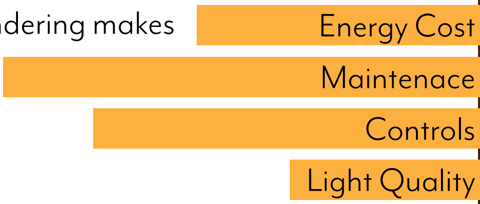
An electric current in the gas excites mercury vapor, which produces short-wave ultraviolet light that then causes a phosphor coating on the inside of the lamp to glow. The typical luminous efficacy of fluorescent lighting systems is 50–100 lumens per watt. Because they contain murcury, they are classified as hazardous waste.



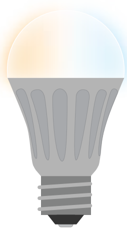
Sodium Vapor



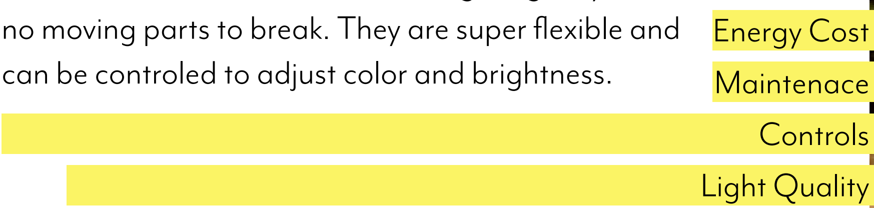
The orange street light that lights a crime scene and you cannot tell whether that puddle is water, oil, or blood. This lamp turns any scen into a black and white nior film, with negative color rendering. It was very cost effective when it was invented, and got put everywhere. The poor color rendering makes it a safety hazard, as well as the occational explosion.



LED



Light Emitting Diodes are the present and future of all lighting. The lamp is a chemically coated chip that emits light when a current is passed through in the correct dirrection. These lamps are rated for 50,000 hours minimum, and as solid state lighting they have no moving parts to break. They are super flexible and can be controled to adjust color and brightness.



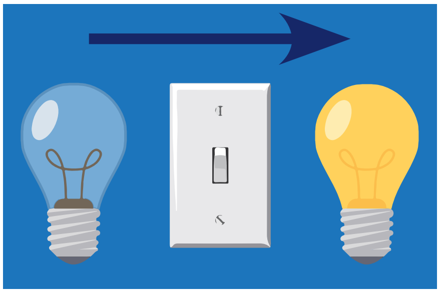
Lighting Controls

The lighting industry has reached the point where a light fixture can be almost anything and produce any type of light. The greater interest is in what we can make these lights *do* with controls.

Controls are critical because they let the lights have more settings then on and off.

- **Any time a light is using less then 100% power, energy is being saved.**
- **Any time a light is on when it does not need to be, energy is being wasted.**

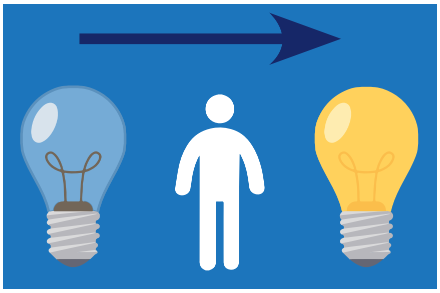
On, off and everything in between



Manual Controls

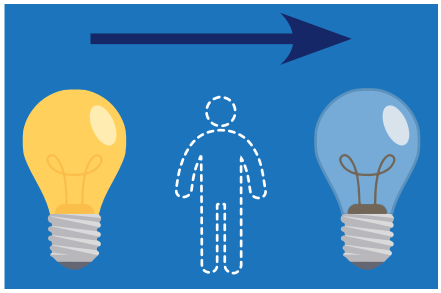
This is a switch that people have access to. It can be **on or off**. In public lighting, this means the lights are all wired back to a control panel that a municipal official can access.

This is used as an override rather than intelligence.



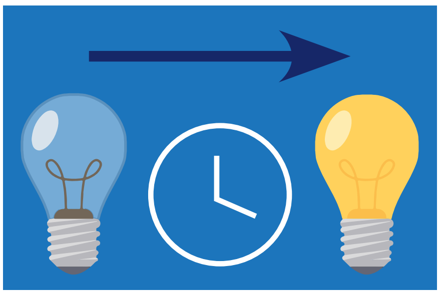
Occupency

A light controlled by an occupency sensor defaults to off. These are controls are linkd to occupancy sensors. Occupency sensors use infrared beams or microphonics to detect the **presence of people**. When there is a person, the light is turned on.



Vacency

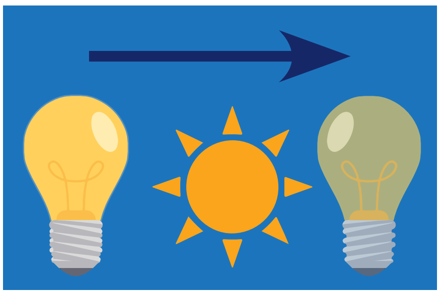
A light controled by a vacency sensor defaults to being on. These controls use infrared and microphonic sensors to determine if the space is empty. When the sensors register the **absence of people**, and the light turns off.



Scheduling

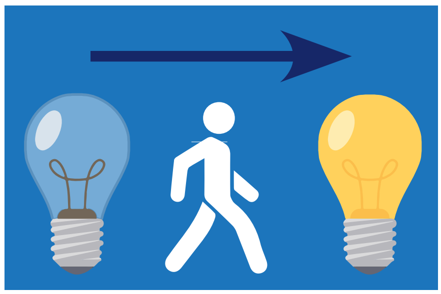
This is a **timer for the lights**. On, off, and dimming can all be set up and run on a 24 hour cycle.

An even smarter way of using scheduled controls for public lighting is to use a digital clock that can account for the time the sun sets and rises.



Daylight Harvesting

Lights controlled with daylight harvesting **respond to the level of light already in a space**. They use a photosensor to measure the illuminance on surfaces in the area. If the area is too bright, the controller will **dim the output of the light**.



Motion Activated

These controls use infrared bems to detect motion in an area. You may have them as a security light or porch light. The amount of motion required to set them off can be an issue - resolved by adding a low resolution **camera to detect the size of the motion**.

Benchmark 3

Use energy saving LED lights and automatic digital controls

Smart Lighting Examples

Sensors, controls and communication technology in your streetlights have the potential to create a grid of Internet of Things devices throughout your town. Each light pole becomes an intelligent brain cell in your smart city.

The idea of intelligent infrastructure network begining with lighting is not new. Several copanies are develping master network control systems that promise a variety of features, including:

- **Energy efficient LED lighting** system reduces carbon footprint and long term operation costs
- Operational integration with real time **data allows lighting control** as and when required
- Street disturbances and law and order system monitoring through **noise detection**, CCTV and community response
- **Traffic flow monitoring** and data generation for city planning
- **Air pollution monitoring** integrated into the lighting network
- Extension of **WiFI** services through the street light network.

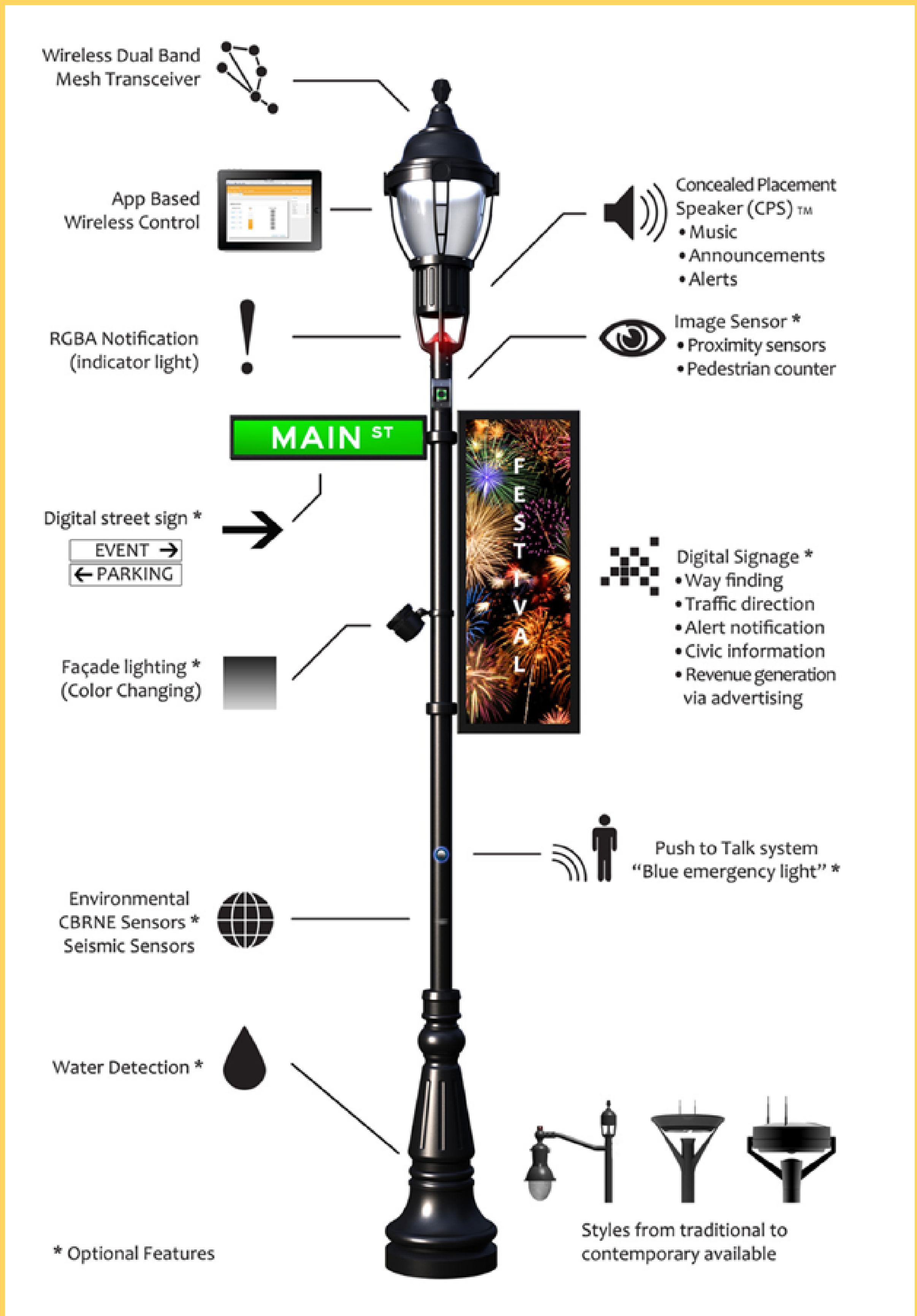
IntelliStreets Smart Light Concept

This concept has a couple of issues:

1. Privacy. These features turn each post into a passive informant on pedestrains in its area.
2. Attaching extra stuff to the fixture makes the pole more intelligent, but not the actual lighting.
3. This design is mostly gears toward collecting data on vehicles for traffic flow, noise, and air quality.

This type of fixture is gaining popularity in cities with a lot of crime and gang actitivity, such as Los Angelos and parts of Chicago. In those cases, enhancing the police fuction is more inportant than privacy to the municipality. Although the law abiding citizens who are also being monitored are not happy.

Existing products are not focused on the *individual experience* that smart lighting can provide.

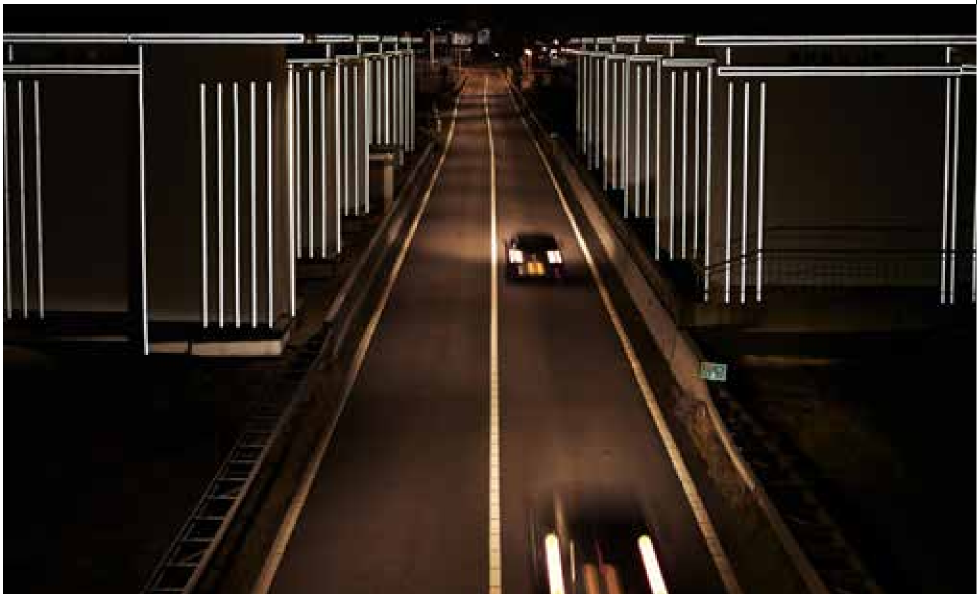

Wireless Dual Band
Mesh Transceiver
App Based
Wireless Control
RGBA Notification
(indicator light)
MAIN ST
Digital street sign *
EVENT →
← PARKING
Façade lighting *
(Color Changing)
Environmental
CBRNE Sensors *
Seismic Sensors
Water Detection *
* Optional Features
Concealed Placement
Speaker (CPS) TM
• Music
• Announcements
• Alerts
Image Sensor *
• Proximity sensors
• Pedestrian counter
FESTIVAL
Digital Signage *
• Way finding
• Traffic direction
• Alert notification
• Civic information
• Revenue generation
via advertising
Push to Talk system
"Blue emergency light" *
Styles from traditional to
contemporary available

Lighting for Experience

Interactive art installations are designed to light spaces and people to give an experience. The common experience was to light where the people are in the space.

Studio Roosegard Van Gogh Path (right). This lighting installation uses solar charging chips that are embedded in the pavement of the path to provide illumination for bikers at night. This is effective and beautiful lighting because it clearly defines the space for the bikers to use. It creates a beautiful experience of walking on swirling galaxies, and it uses no power because the chips are solar charging.

Studio Roosegarde Gates of Light (bottom) This is a lighting installation that uses no power. The designs on the floodgates are created from a super prismatic reflective material that reflets the light from car headlights a they drive across the bridge. This is interactive because the gate illuminate with the passage of people across the bridge, and darken when they leave.
This is less ideal for pedestrain areas, because people do not have headlights on them all the time. Still, a very elegent way to use an existing light source and generate a dynamic, immersive experience.



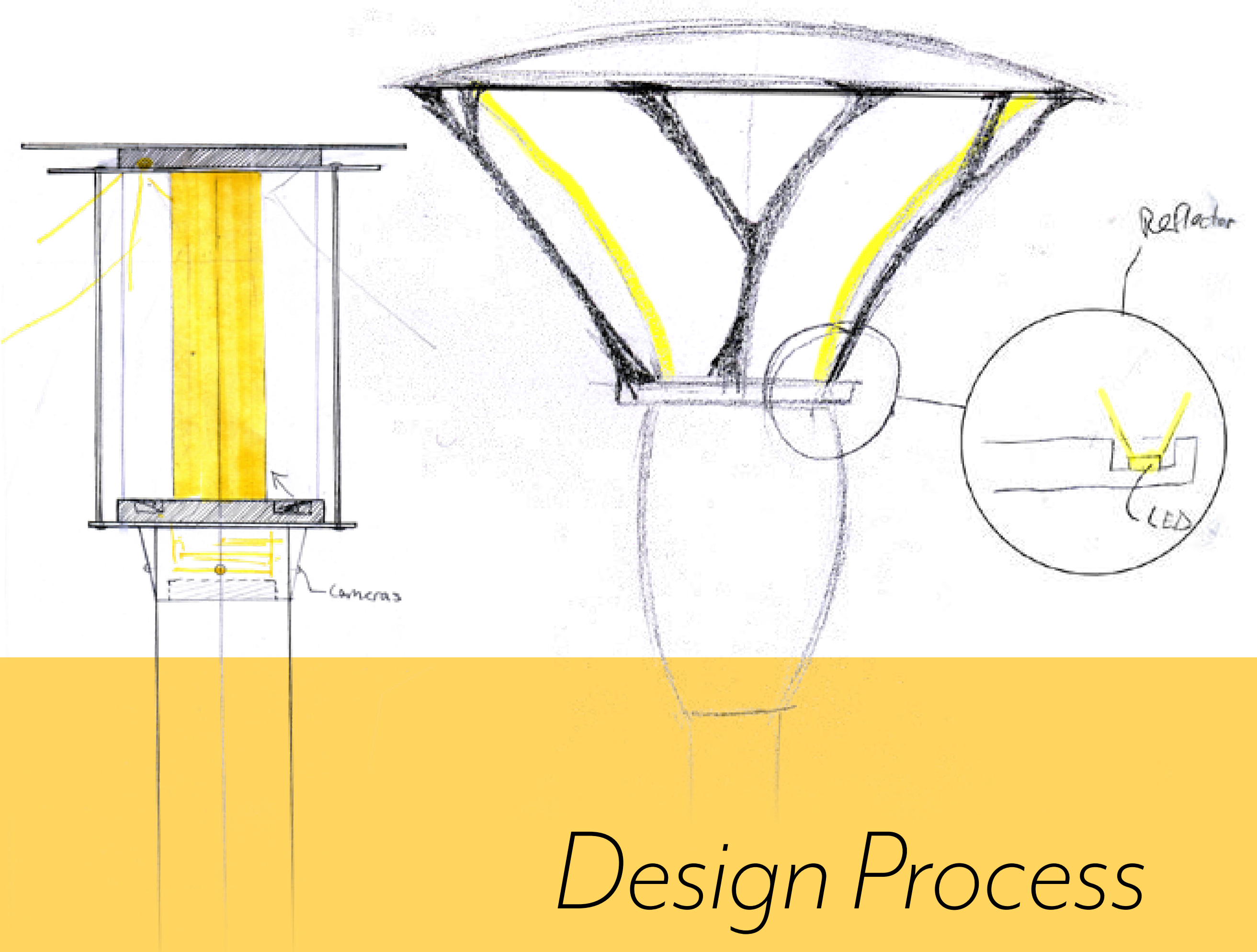
Studio Roosegarde Dune (top). This installation is a great example of interactive lighting. Each light reed has sound an motion sensors that cause it to light up when people are near. This playful effect is personal, magical, and very clever. Keeping most the the reeds off until a person walks by saves power, and lets the areas with people stand out against the darkened, empty stretches.

There is a clear difference between these installations and a street light- they are works of art, and a street light is utilitarian. However, these installations save power, make these spaces safer, and draw people to them - all things desirable in any public space. Why can't an everyday lamppost provide a similar interactive experience?

Light the space where the people are

Benchmark 4

Provide interactive lighting environment that places light at peoples’ location



Design Process

Initial Concept

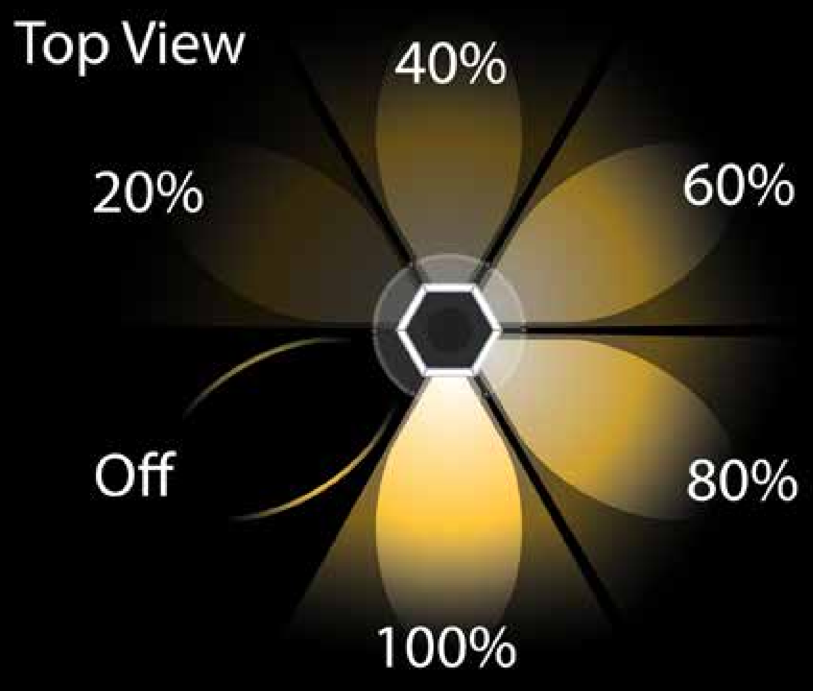
Light pole wih directional control

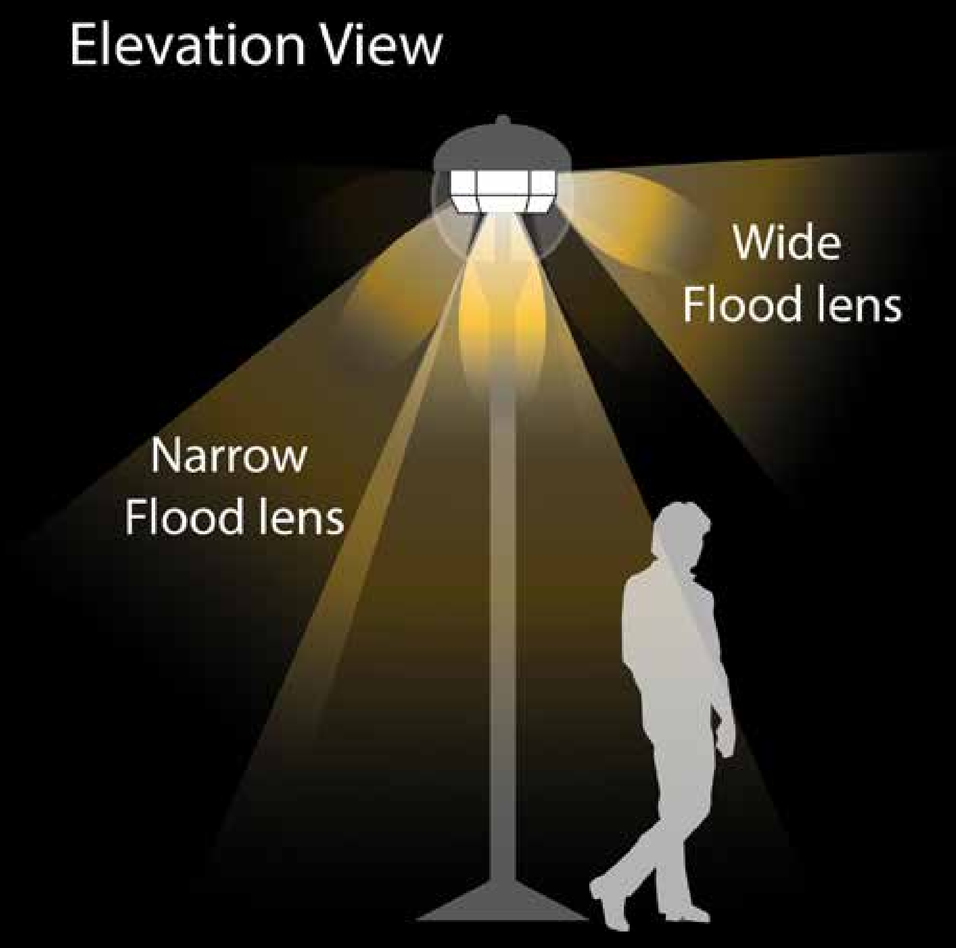
Moving forward with lighting for pedetrian spaces, I began by studying how people actually use these public areas. I identified key activitites and how the lighting should be for each activity. These activities were:

- Transit - people in pedestrain spaces that are just passing through. Commuters, joggers, and errand runners are all just going from one point to another and passing through the public space on the way.
- Relaxation - people relaxing in pedestrian spaces are not moving around much and stay in the same area for more then a minute. These are the people who use the benches, chairs, and sometimes bring blankets to sit on.
- Socializing - Groups of people use pedestrain spaces as gathering points to get together. The goal of these groups can be transit or relaxation, but because more people make more movement and take up more area, the lighting needs to change to account for groups.

The best lighting for each activity is slightly different. People in transit want light on the ground and ahead of them. People relaxing want to feel safe and and onserve their surroundings. The social people want light on faces and in a larger zone around them.

Key pedestrian activities and how each should be illuminated.





My first concept to address the different users of pedestrain spaces was a light pole or post top lumenaire. The light would come from different panels to shine in six directions all around and two types of lens for further lighting targets, and closer lighting targets. This made for a total of 12 "beams" coming from one lumenaire that could be controled independently.

That control would need to be based on something though: people in the space. This concept used a combination of microphonics (tiny microphones that detect people sounds like talking) and PIR (passive infrared motion sensing) to determine if there were people in the space and what type of lighting they would need.

Socializing creates lots of sound and motion.
Transit creates a lot of motion but not sound.
Relaxation is both quiet and still.

On the next section I began researching how these sensors worked and if they would be appropriate for a post-top lumenaire.

Detecting People

Finding the right sensors

Sonar

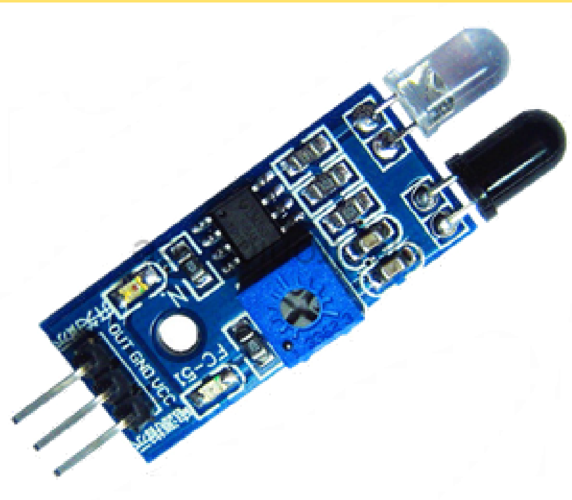
An ultrasonic speaker sends out a pulse. The pulse bounces off an onject and beck to the microphone. the amount of time it takes lets the sensor dermine the distance of the object.

Pros

- Precise distance along the line of the speaker

Cons

- Linear
- Bother wildlife
- Difficult to scale up



Passive Infrared

An IR light shines into a space. Two photosensors measure the same amount of IR bouncing off the space. An object passing through the space interupts the beam of one sensor, causing an inbalance.

Pros

- Uses lenses to vary sensor range and depth
- Detects hot bodies (wont be detecting trees)

Cons

- Not size variable (can be set of by cars and squirrels)
- Does not detect distance

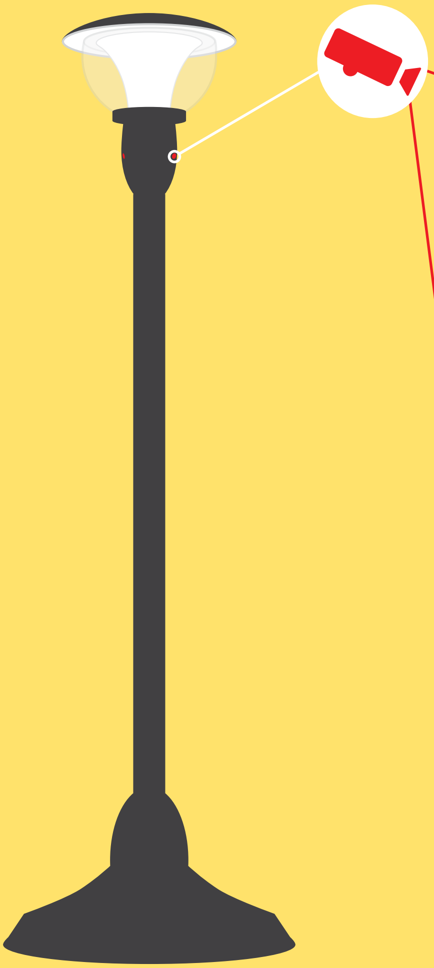
Computer Vision

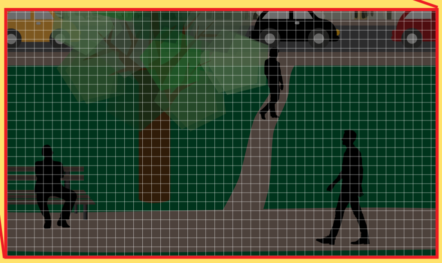
The analysis of pixel data from cameras to identify objects and people. This is how snapchat filters and automatic tagging in social media work. Groups and proportions of pixels are analyzed to determine what is there and what it means

Pros
- Only requires a camera
- Multiple types of data can be collected from it (distance, direction, patterns, predictive algorithms)

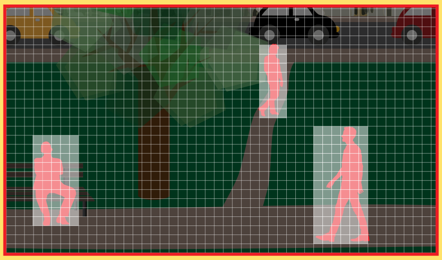
Cons
- Privacy concerns from cameras in public spaces
- Requires additional computing power for image processing

How CV Works

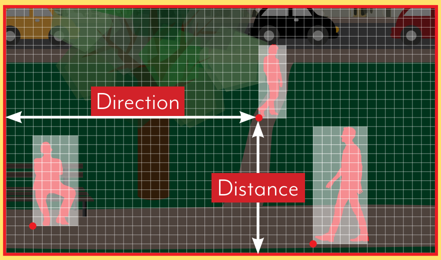




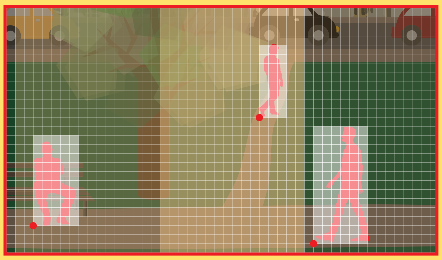
1. Low resolution infrared cameras capture the environment as an image of pixels



2. Pixels are run through a computer vision algorithm to detect people



3. The distance and direction of the people from the fixture is calculated



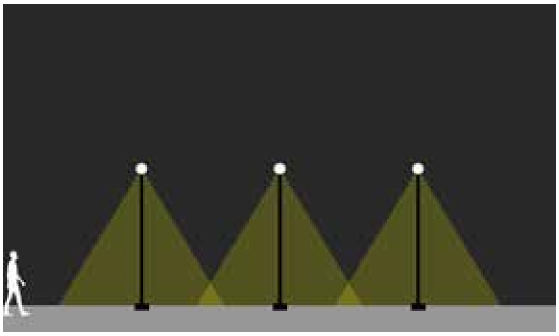
4. The fixture lights each zone with people accordingly

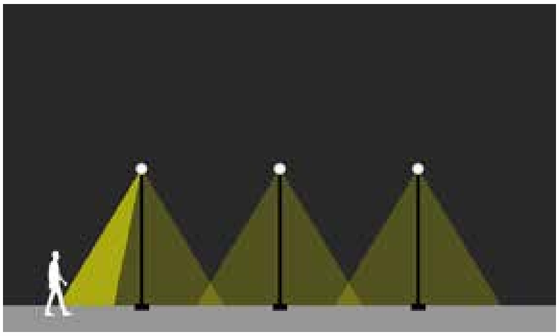
Visualizing Interaction

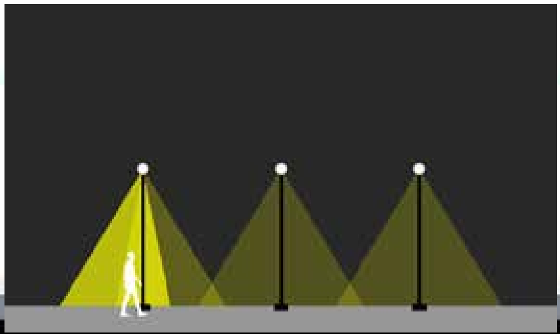
Using Processing Sketches

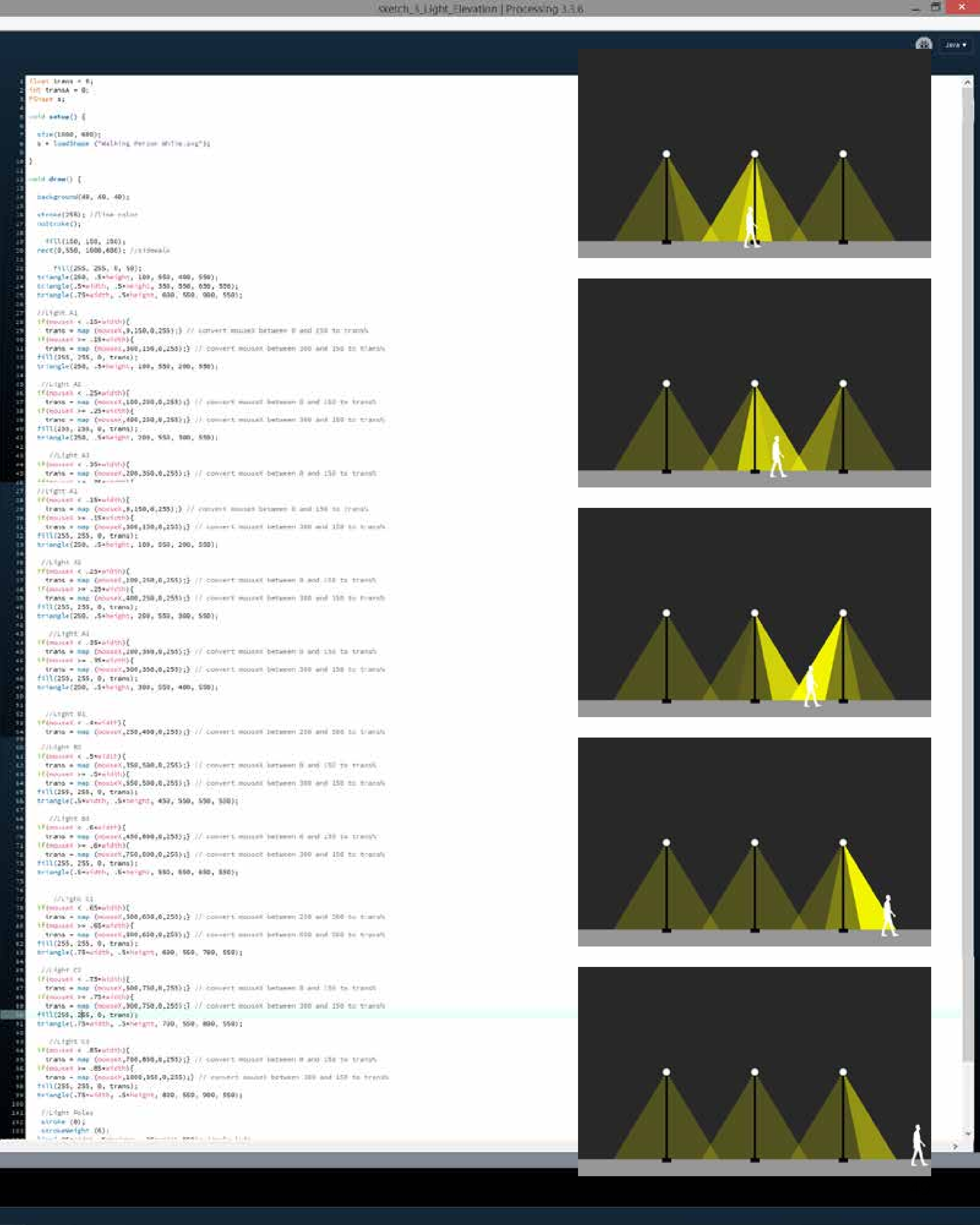
Processing is a training program for writing Java that eaches the basics of building visual interaction in code. I used it to being understanding first, how to write code, and second, how to visualize the light changing as people move through a space.

These lights are built with basic shapes and the opacity of the light-beam shapes varries depending on thr coordinates of the mouse in the processing sketch. The person is also linked to the mouse coordinates. By predetermining the “brightness” of each beam at a horizontal mouse coordinate, I could see how light and motion were related.








sketch_1_Light_Elevation | Processing 3.3.6

Sensor Prototyping with Arduino

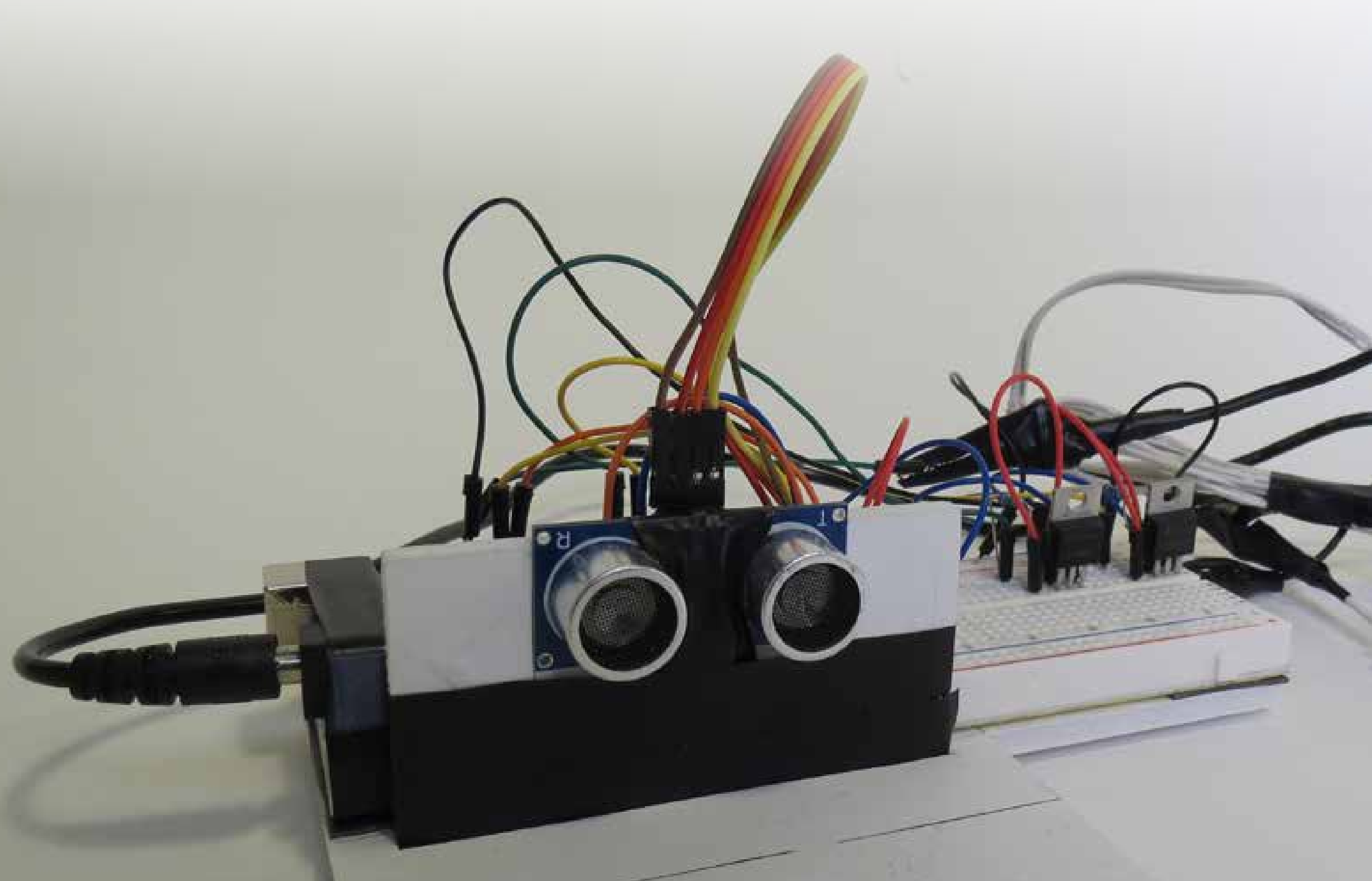
The next stage was to simulate the interaction with real lights. For this I used a setup shown below, which consisted of:

- 3 LED diodes of ifferent colors (to make differentialting them in the code easier
- Sonic distance sensor (one side is sends out a pulse, the other side recieves the "echo" of the pulse off of an object.
- A board that marked off each centimeter (each centimeter equal one foot to show scale.

This set up would simulate 3 non-directional light poles light pole along a path. It had to be along a path because the sonic sensor can only detect in a straight line. It had to use the sonic sensor because I needed an accurate (1cm = 1ft) distance.

The code was written so each LED connected to a pin on the arduino board that could use PWM (pulse with modulation.) PWM is the way to digitally simulate analog dimming by turning the light on and off faster than the human eye can detect. The ratio of time off to time on makes the light appear dimmer or brighter.

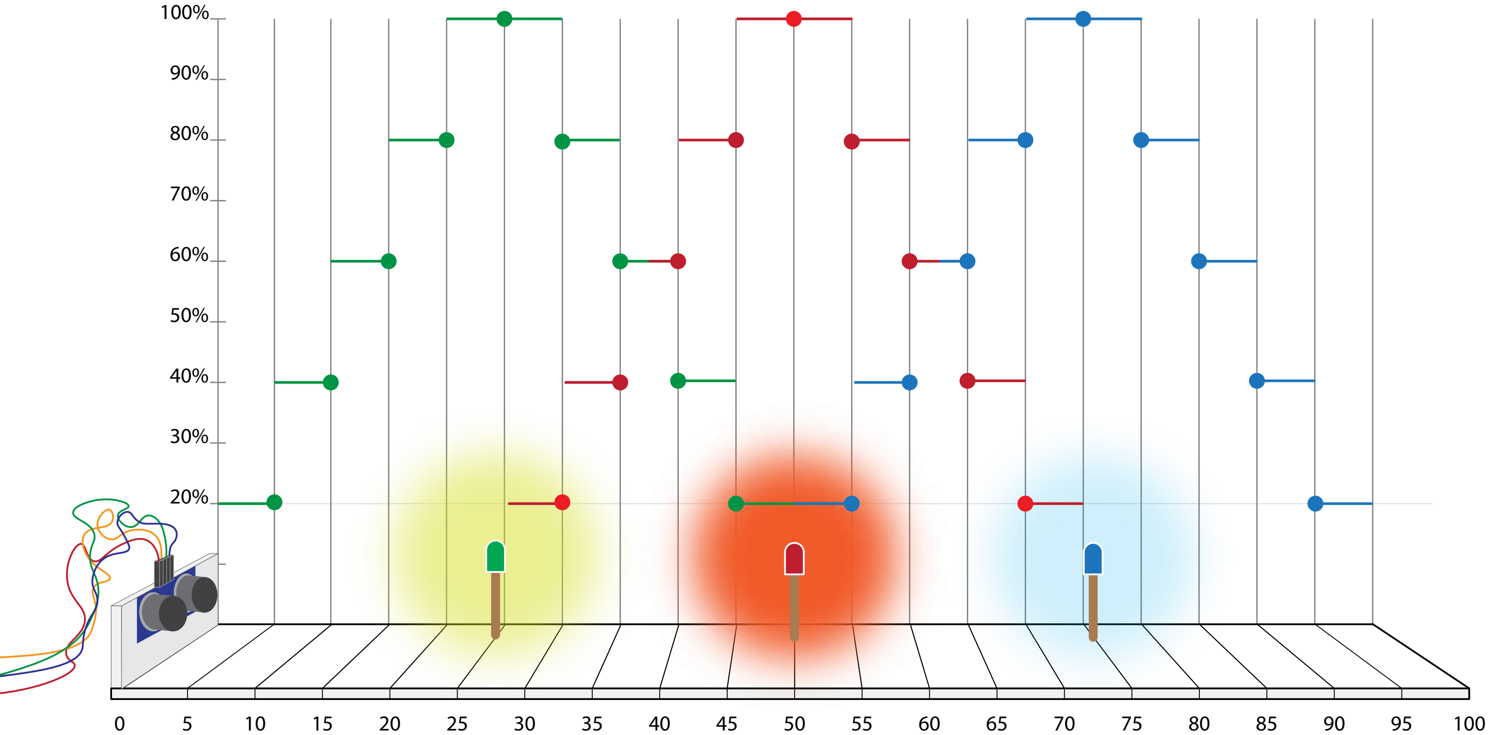
Each LED was set to a brightness determines by the distance detected by the sonic sensor. I coded in 5cm sections to make the coding go faster. Each LED was at 100% brightness when the object parallel with the diode, and at 20% when the object was at the next LED.



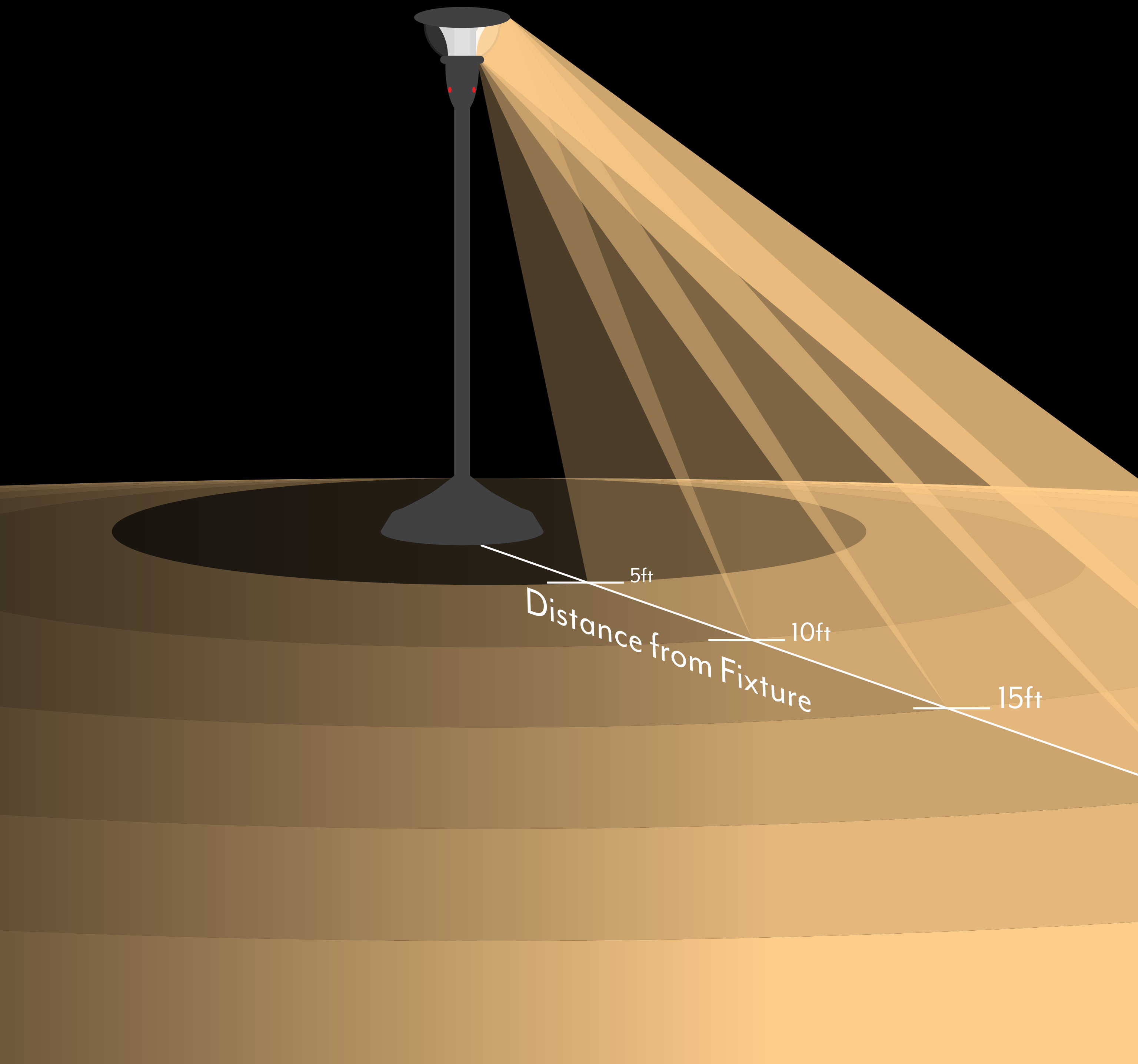
Sonic_to__3_LED_brightness.ino

```
const int echoPin = 12;
////SR04 sr04 = SR04(ECHO_PIN,TRIG_PIN);
long a;

int Y = 3;
int G = 5;

void setup() {
  pinMode(trigPin, OUTPUT);
  pinMode(echoPin, INPUT);
  pinMode (Y, OUTPUT);
  pinMode (G, OUTPUT);

   Serial.begin(9600);
   delay(10);
}

void loop() {
  digitalWrite(trigPin, LOW);
  delayMicroseconds(2);
  digitalWrite(trigPin, HIGH);
  digitalWrite(trigPin, HIGH);
  delayMicroseconds(10);
  digitalWrite(trigPin, LOW);

  int duration = pulseIn(echoPin, HIGH);
  int distance = (duration*.0343)/2;
  Serial.print("Distance: ");
  Serial.println(distance);
  delay(100);

  if (distance < 36 && distance > 0 ){
    analogWrite(Y, 255);
  }
  if (distance > 36){
    analogWrite(Y, 0);
  }

  if (distance > 36 ){
    analogWrite(G, 255);
  }
  if (distance < 36){
```

Light Levels Graph 1



Brightness and Distance

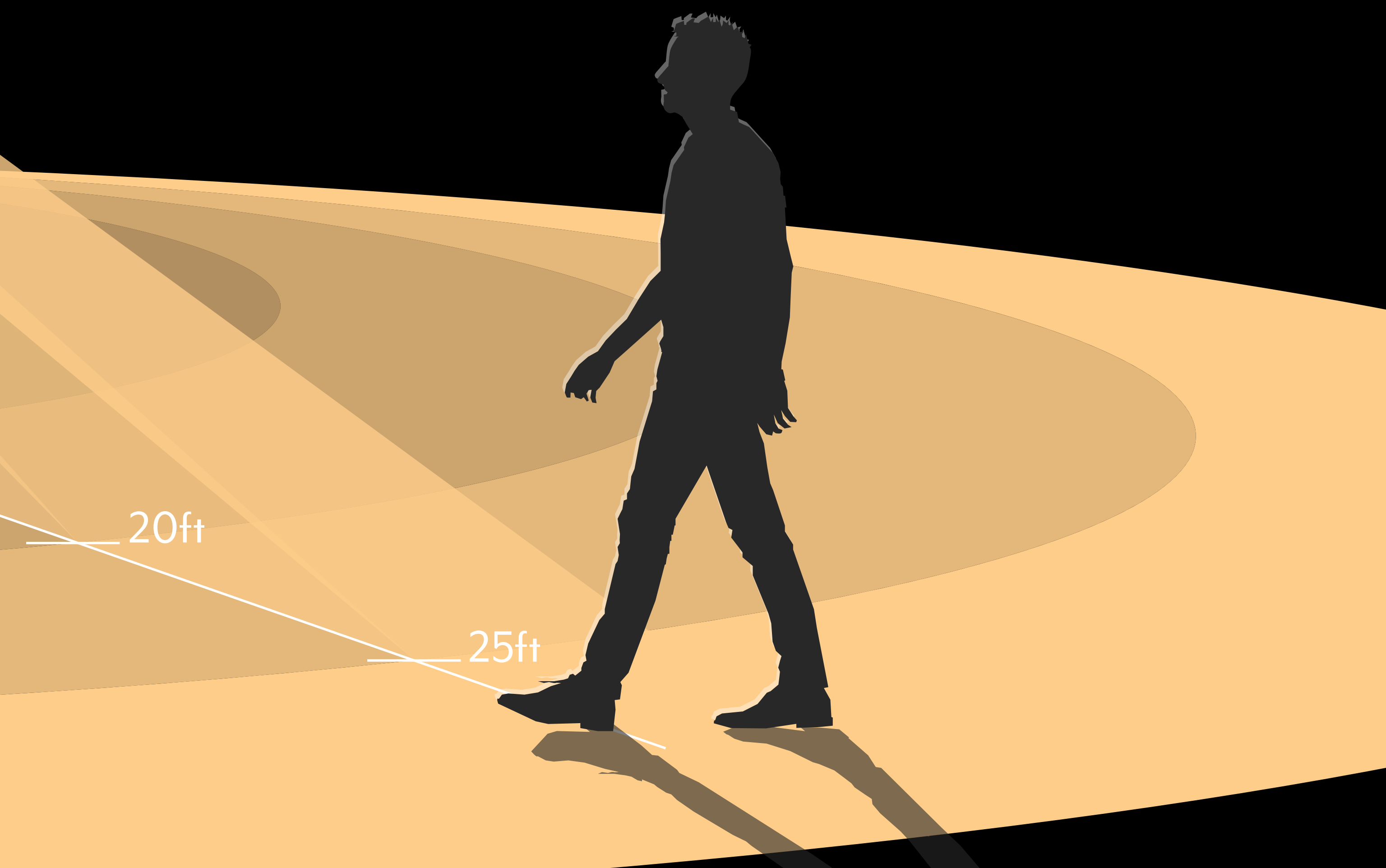


One criteria in my initial concept was that the light should very depending on the activities of the people in the space. This criteria was discarded becuase the capabilities of the sensors available cannot distinguish between the different activities, and assumes lighting needs that are not universal from person to person.

The next iteration of that design criteria - that the light should use dynamic dimming, is that the **brightness of the light should be related to the distance that a person is from the fixture.**

The first visualizations always showed the light getting brighter as the person got closer, but I realized this would be a waste of both light and energy. A normal lamp is already going to create a brighter area closer to itself, so a smart fixture would do the opposite.

The light should be brighter when aperson is further away to reach across the distance to provide igt on the ground and surroundings, then it should dim as the person approaches because the closer you are to the source, the more light is recieved. The overall effect would a constant level of illumination where the person is, regardless of the distance from the pole.



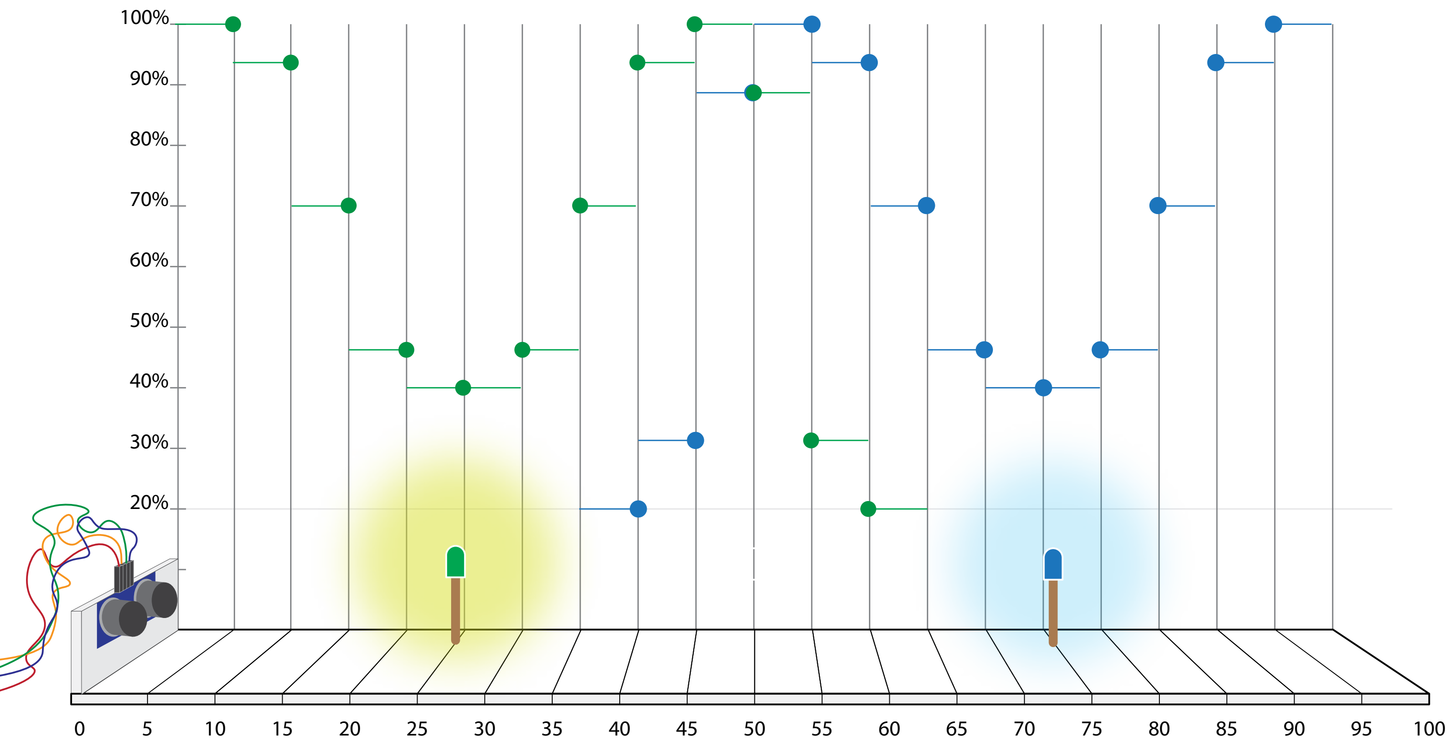
Brightness and Distance Arduino

After proving that the arduino setup with the linear placement of the LEDs and the Socin distance senosr t one end was effective, I went about refining the light interaction.

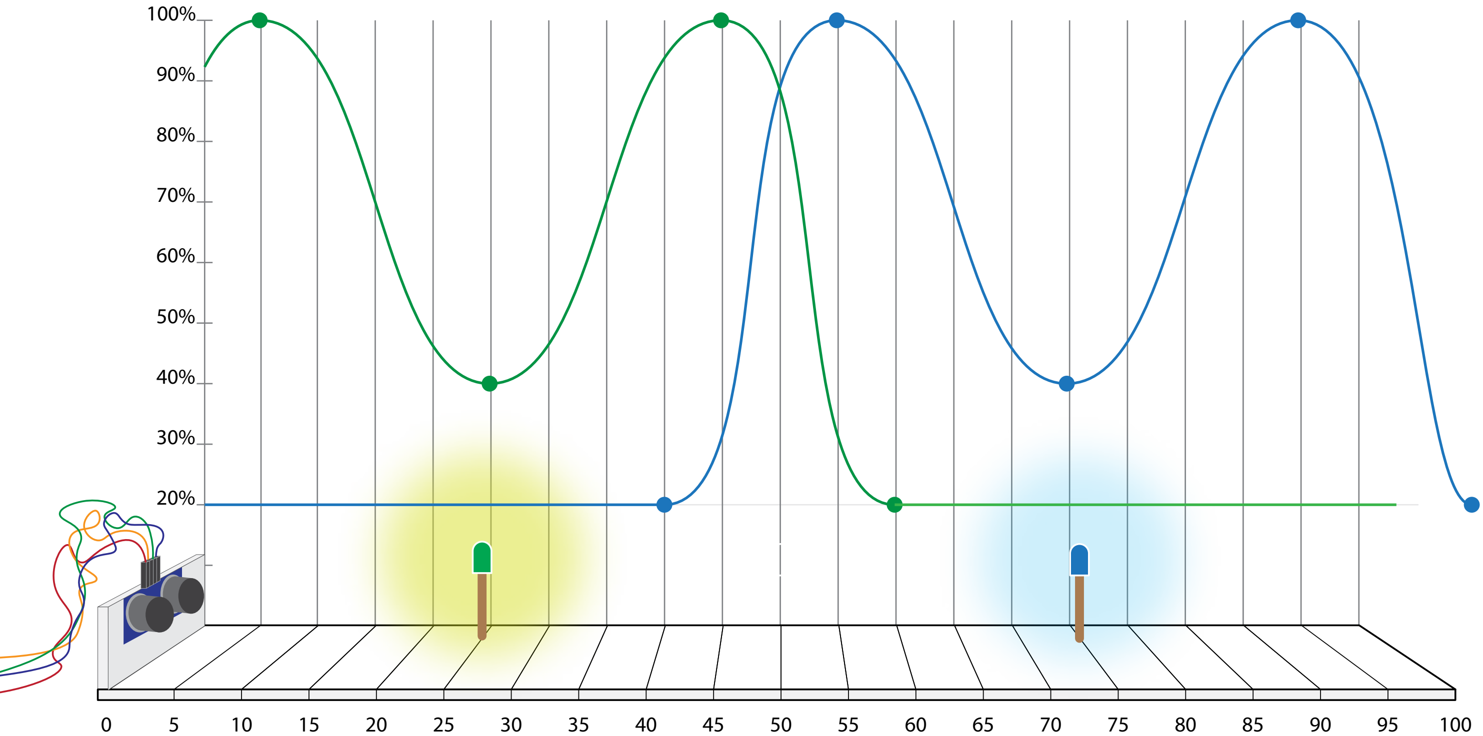
The first change I made was to eliminate one of the LED diodes for a more accurate representation of the fixture spacing. The light given off by a pole mounted lumenaire typically reaches a raduis equal to 2 - 3 times the height of the pole. A standard pedestrian pole is between 8ft and 15ft tall. To keep the numbers even I used a 12ft pole and assumed a light spread raduis of 2.5, spacing the poles about 50ft (50cm in the scale model).

The next change was to match the new criteria of brightness and distance: The light should be **brightest at the furthest distance from the pole**.

Light Levels Graph 2



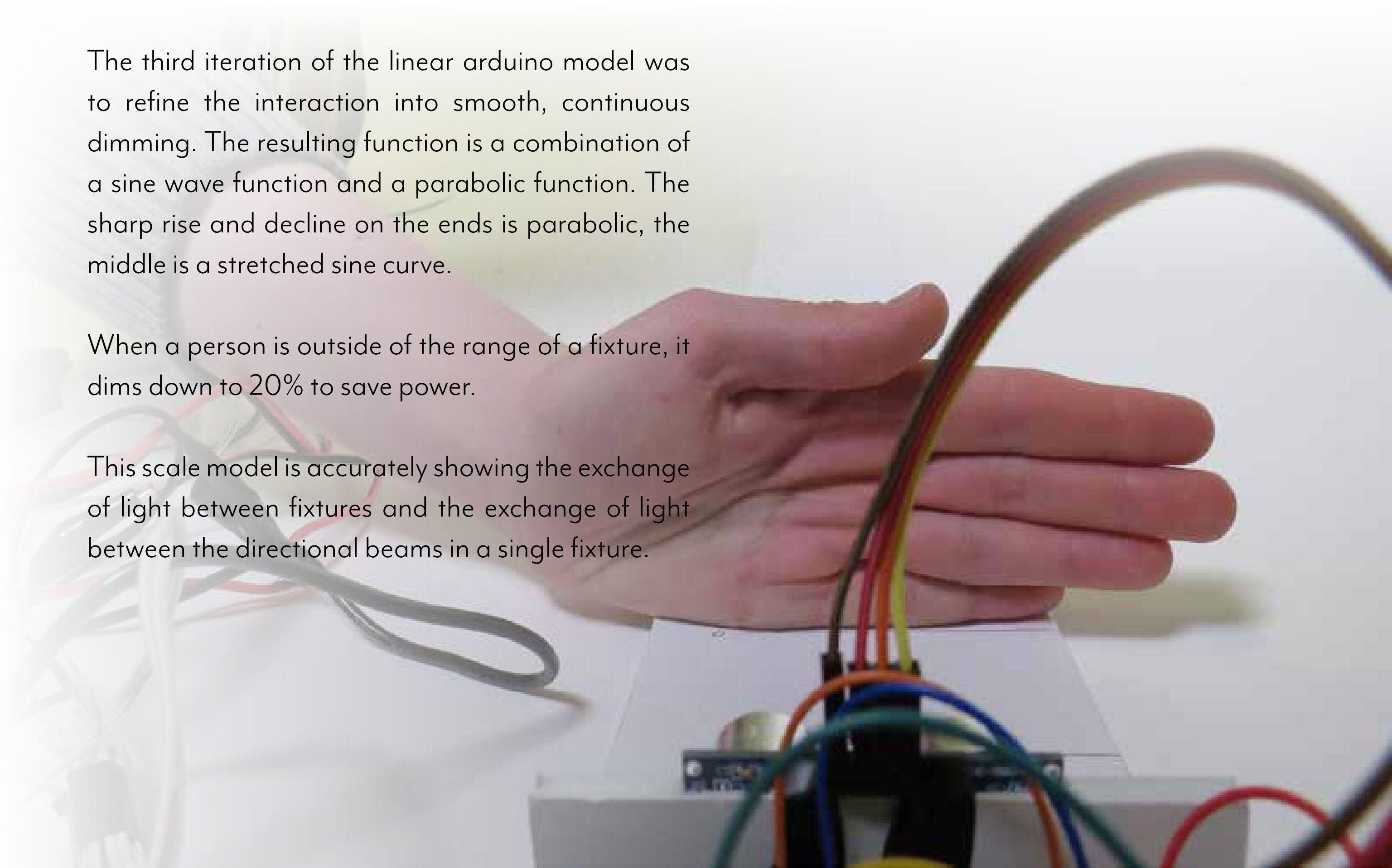
Light Levels Graph 3



The third iteration of the linear arduino model was to refine the interaction into smooth, continuous dimming. The resulting function is a combination of a sine wave function and a parabolic function. The sharp rise and decline on the ends is parabolic, the middle is a stretched sine curve.

When a person is outside of the range of a fixture, it dims down to 20% to save power.

This scale model is accurately showing the exchange of light between fixtures and the exchange of light between the directional beams in a single fixture.



Illuminance Level Code

How bright do pedestrian spaces need to be?

The brightness of a space is determined by the amount of light hitting each surface in the space. Depending on the space, some surfaces are more important then others. For example, the brightness of a space can be measure by the amount of light hitting the top of a worksurface like a desk, or by the light hitting a wall, or the floor. Pedestrain spaces are almost always measured by the brightness of the ground.

The brightness of a surface is measured or calculated (in a light rendering program such as AGi32) with a light meter at points along the surface. The brightness is the amount of light hitting the point, called the illuminence level, measured in foot candles (fc).

How bright each type of space needs to be is layed out in the Illumination Engineering Society (IES) handbook. For example, the brightness of the sidewalk and crosswalk at a busy interection needs to be 3fc.

That is very, very bright for an outdoor environment at night. A better average for pedestrian spaces would be 1.5fc - 2fc average. Of course, these are maximum values when the fixture is at its brightest. The dynamic dimming with distance of the lumenaire I am designing would actually be giving off much less light most of the time. But the maximum brightness should be 2fc at 25ft away from the light pole.

The crosswalk of this busy intersection in Boston should have 3fc on the ground to make sure that pedestrians can be seen by cars.

How bright does this lumenaire need to be?

The resource available for this project mean I am designing this lumenaire without the eqiptment and experts that a manufacturing company would have available, These include optical engineers, electrical engineers, and a very expensive system that measures the light coming from the fixture in direction and intensity. So I am working backwards, designing the lighting environment, then the fixture, then determining the light source and optical lenses that need to be used to produce the effect I am designing.

Each led chip or directional beam must be capable of producing 2fc of illumination on the ground 25 ft away from the pole.

The IES publishes a very large book with lots of charts that say what the standard brightness for every space, surface, and situation. Meeting the IES standards is important, because this is the book the lawers check for liability.

Light Pollution and LEDs

The affordability of LEDs is making is much less expensive to light more at night, and brighter. This is having some unfortuante impacts on our environment, including our health, the wellness of plants and wildlife, and of course, poor astronomers who can no longer see the stars.

In all seriousness though: Light pollution is a growing problem, and LEDs are making it worse.

Only recently have we been able too measure the brightness of the earths surface: and the numbers now show that it is increasing both in brightness and surface area at a rate of 5% per year.

Three Types of Light Pollution

- **Skyglow** - the light pollution that is cause by light from lots of sources being reflected back into the atmosphere. Skyglow is responsible for most of the damage to the environment: plants, wildlife, and people all **need true darkness at night** in order to maintain thier circadian cycles.

- **Light Trespass** - This is the light pollution that comes from light landing where it is not supposed to - such as a traffic light shining into a bedroom window at night. Ray's directional control make this the easiest form of light pollution to address, by simply not turning on the light in the directions that would create light trespass.

Addressing Light Pollution

- **Glare** - This is the form of light pollution when the light is **too bright**. We expereince glare as pain in our eyes, and it also damages our eyes. For Ray to be a light that addresses the human experience, glare reduction should be a design priority.

Glare from streetlights

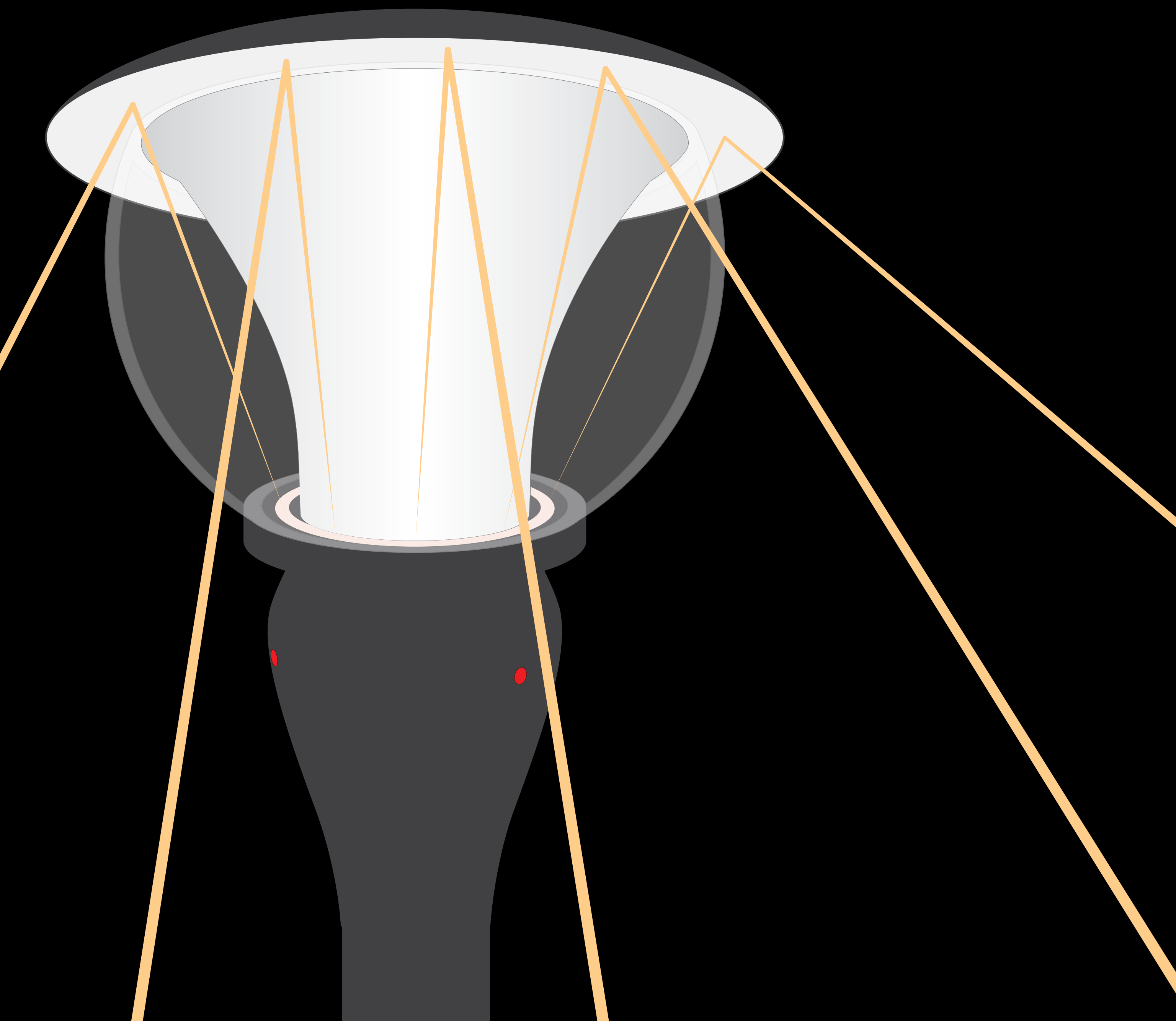
Light tresspass in a residential neighborhood

Normal skyglow compared to during a power outage

Benchmark 5

The fixture should be designed to reduce its impact on growing light pollution

Indirect Light Source



Indirect light sources have the lamp of the lumenaire (in this case the LED chips) out of the line of sight. This makes it impossible to look directly at the bright light (the main cause of glare.) The light that enters the space is bounce from the lamp onto a reflector. The reflector is a smooth matte white surface that diffuses the light so it is less painful to look at but still spreads around the space.

Direct Light Source

In a direct light source the lamping is visible to the eye and the light is streaming directly from the lamp into the environment.

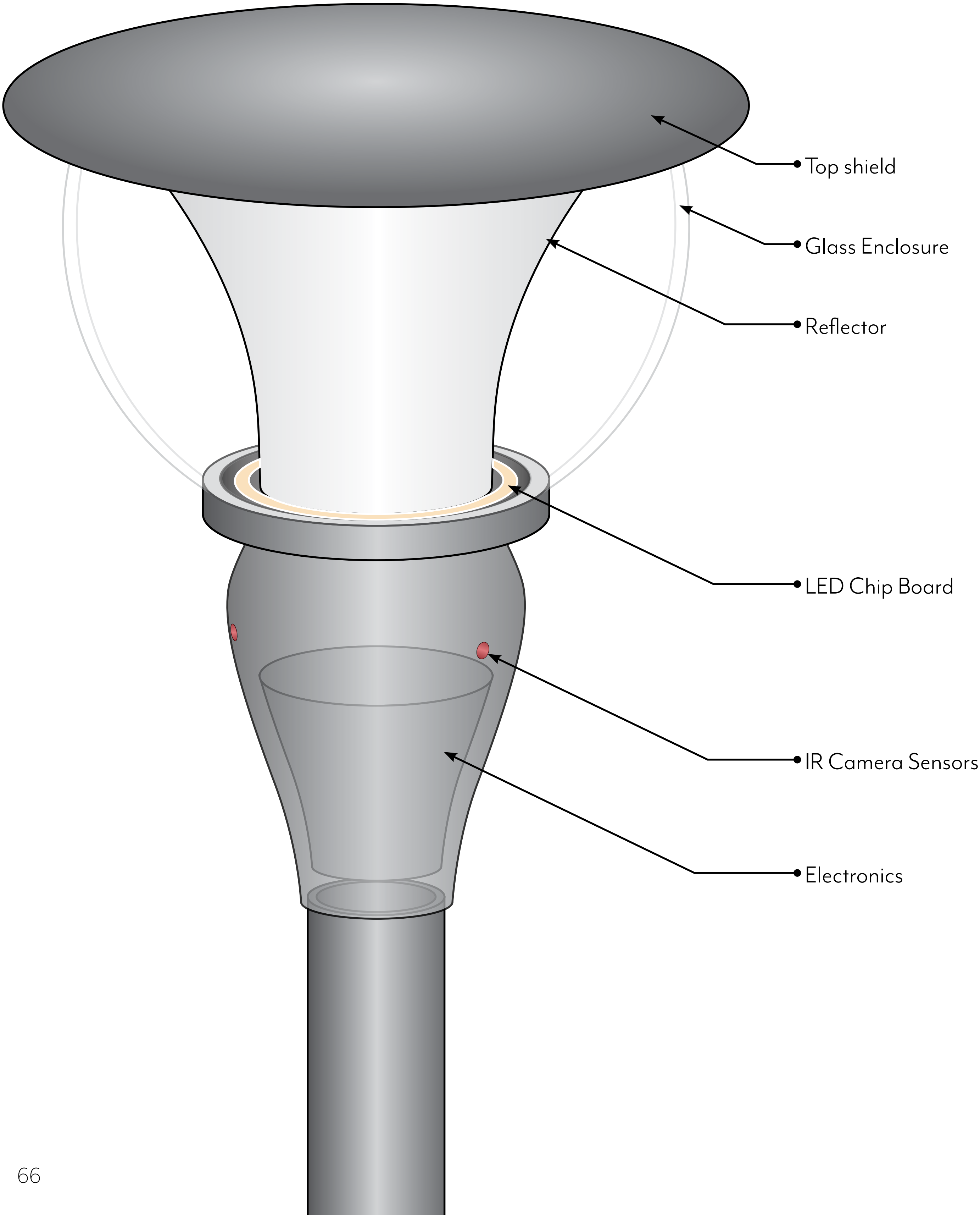
Even in photographs, direct light sources create glare . Sometimes the photographic effect is pretty, but it person it hurts the eyes.

Direct light sources do have the advantage of being more directional, which is a key design criteria. This early concept rendering shows the directional light coming from six angled LED panels with the sensors embedded in the center.

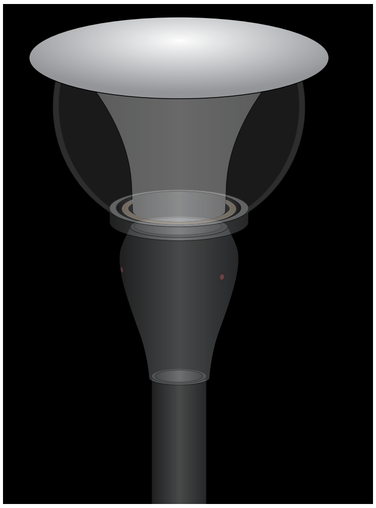
After research and further iterations, I decided that the glare the direct lighting produced, combined with the dynamic dimming, would make the panels look glitchy, and remove some of the mystery of the lighting experience.

The challenge of producing directional light with an indirect source remained, but the advantage of reducing glare in pedestrians' eyes was worth it.

Key Components

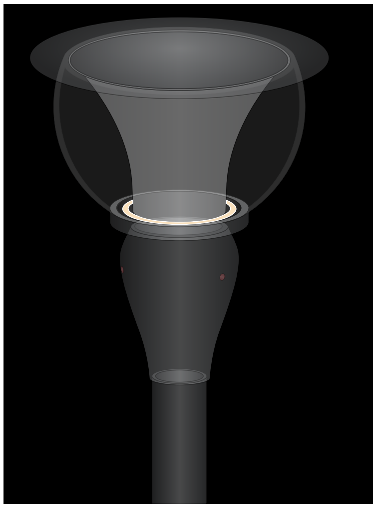


Materials and Processes



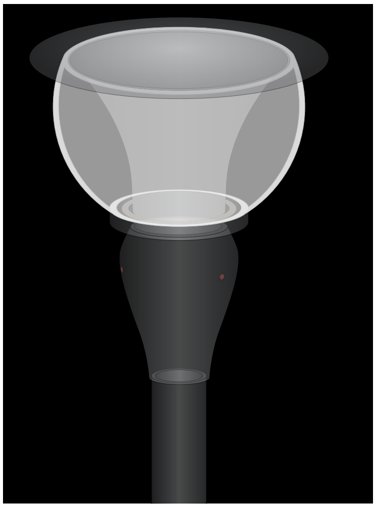
Top shield

- This component prevents light from going up inot the sky, addressing the skyglow aspect of light pollution



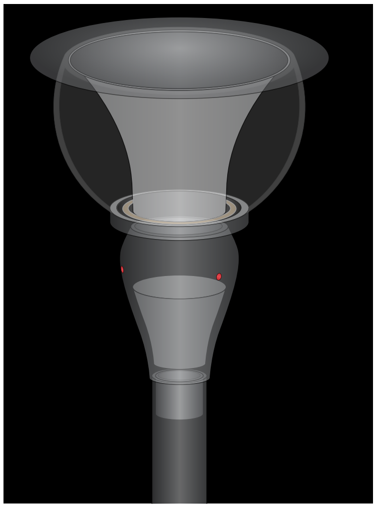
LED Chip Board

- The LED chips are built into a circular circuit board, that is wired to allow each LED to be controlled separately



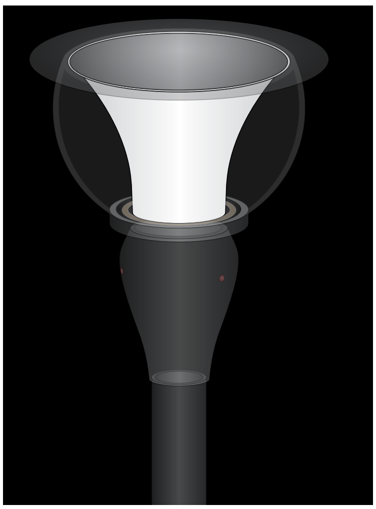
Glass Enclosure

- Clear blow molded glass will seal the LEDs anf reflector from bugs, dirt, and weather



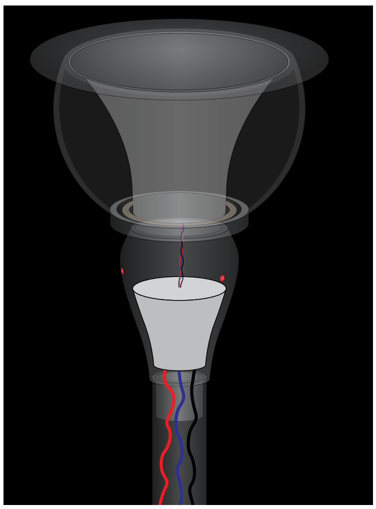
IR Camera Sensor

- The cameras areset into the sensor houb, which houses both the cameras and the image processing and controlling electronics



Reflector

- Spun aluminum is powder coated a smooth matte white. The hollow form houses the passive heat sink for the LEDs

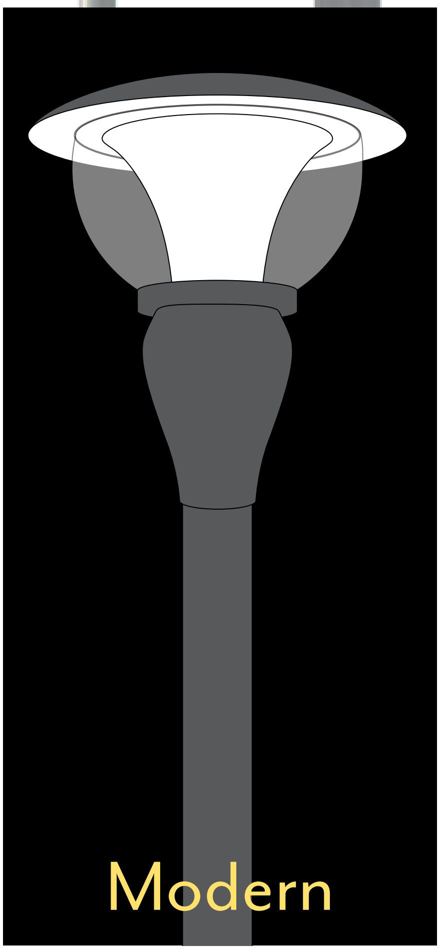


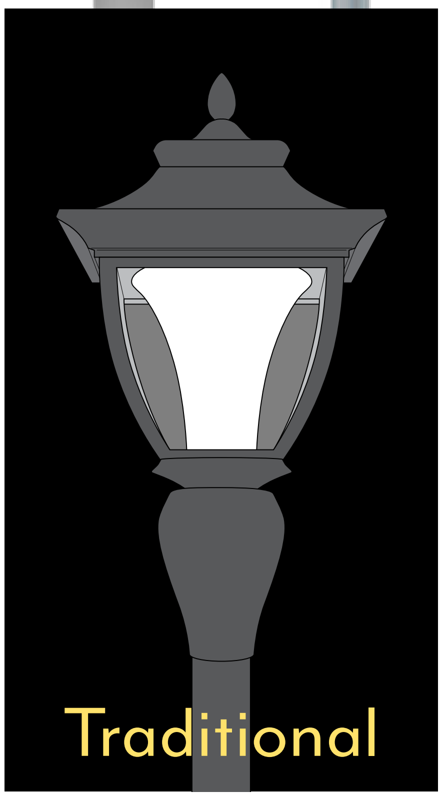
Electronics

- The electrocis are weather proofed by potting in a low heat resin. Wire ports for power and date run out the top and bottom of the block for simple installation.

Styles of Light Pole

After identifing the key components I was able to understand how to shape the components to give Ray different styles. To determine what those style should be, I consulted with Inga Birkenstock on the fixtures that she prefered to specify. By analyzing her list and cross referencing with other manufactures, I determined there were 5 main appearence families.

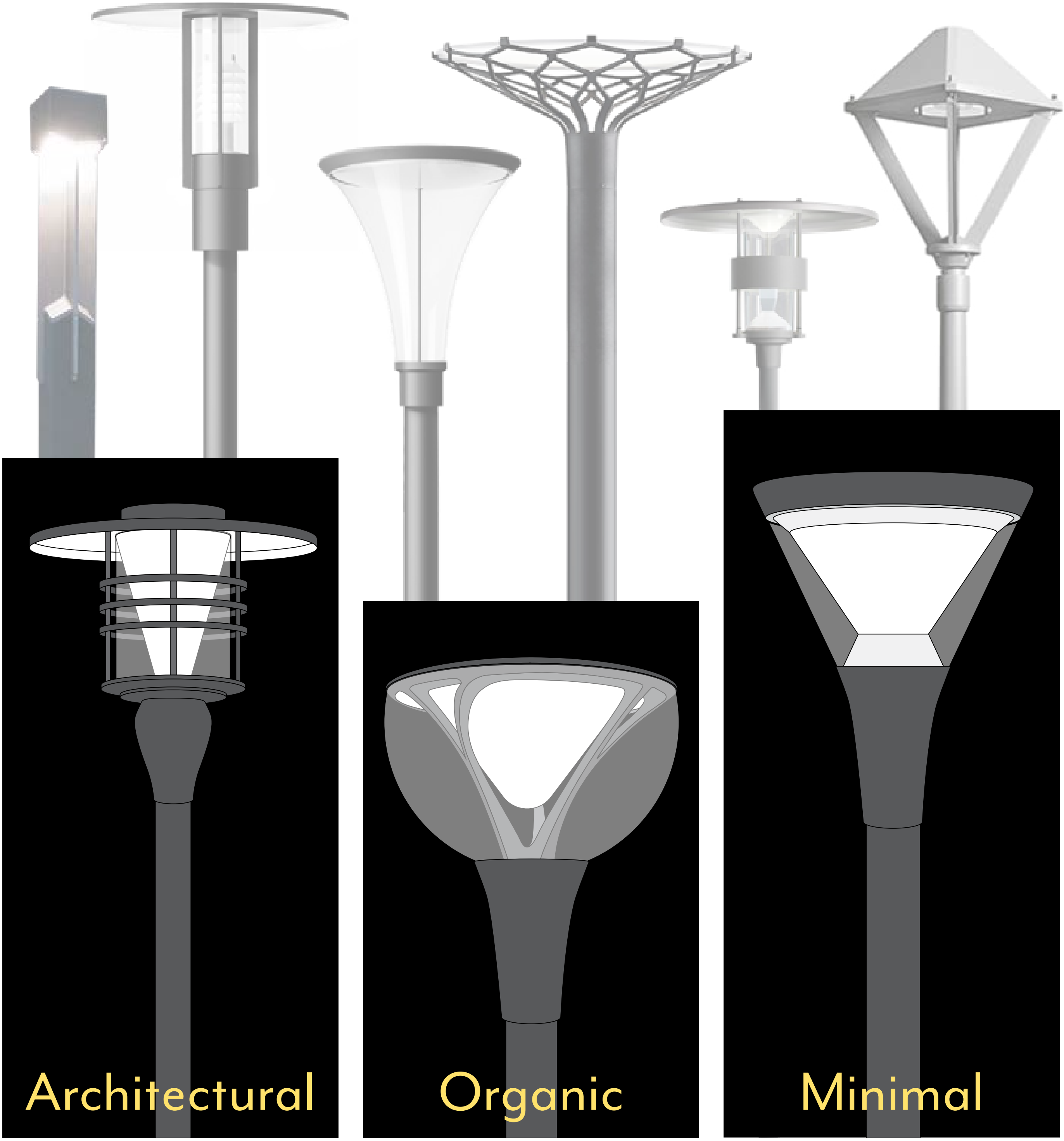




Inga Birkenstock is the principal of Birkenstock Lighting Design. She has 30 years experience in lighting and interior design.

The modern style is characterized by volumous shapes that combine multiple volumes with curves and geometric forms.

The traditional style is a more historic look. Features of this style include finials, fluted poles, and flat panes of glass enclosure.

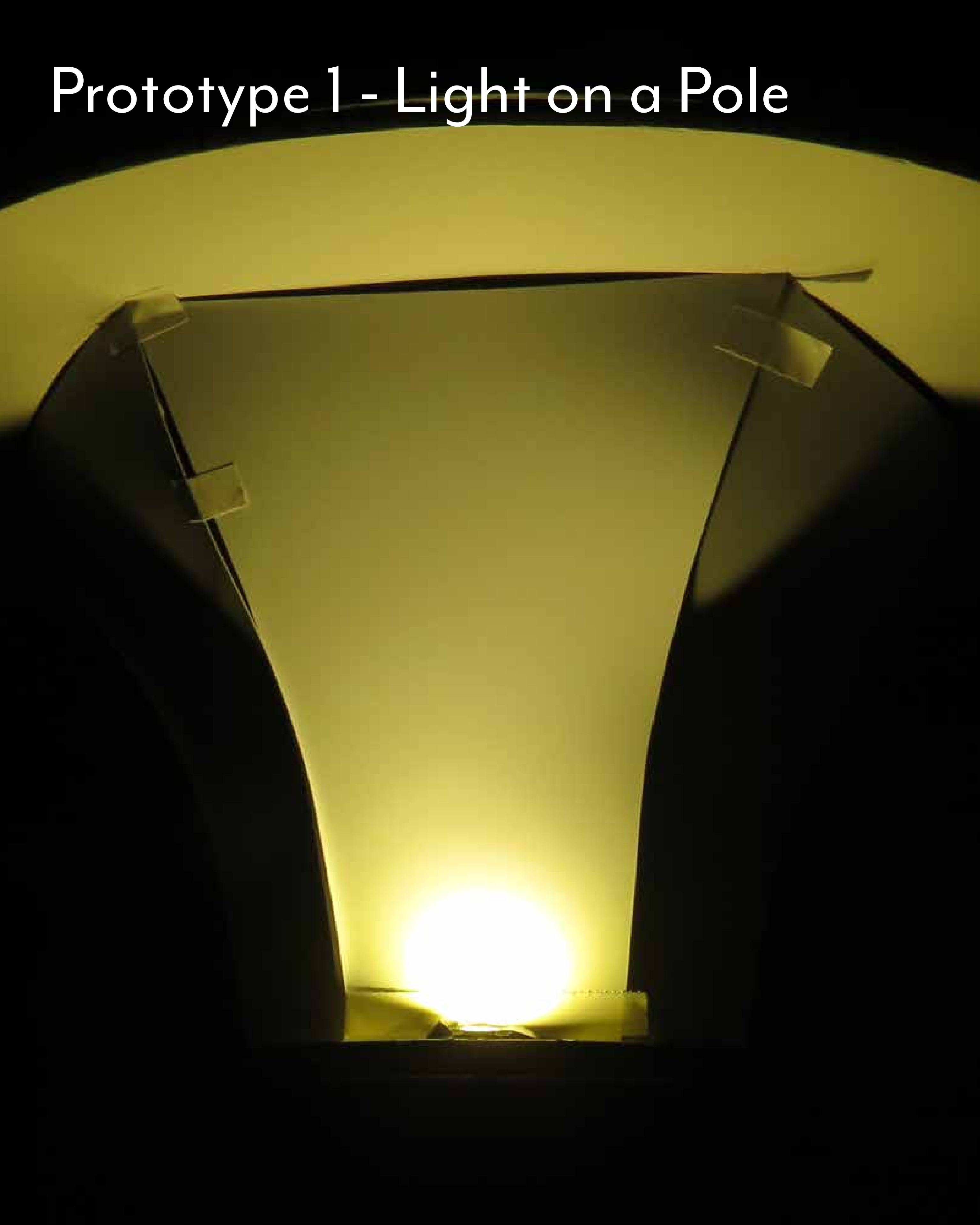


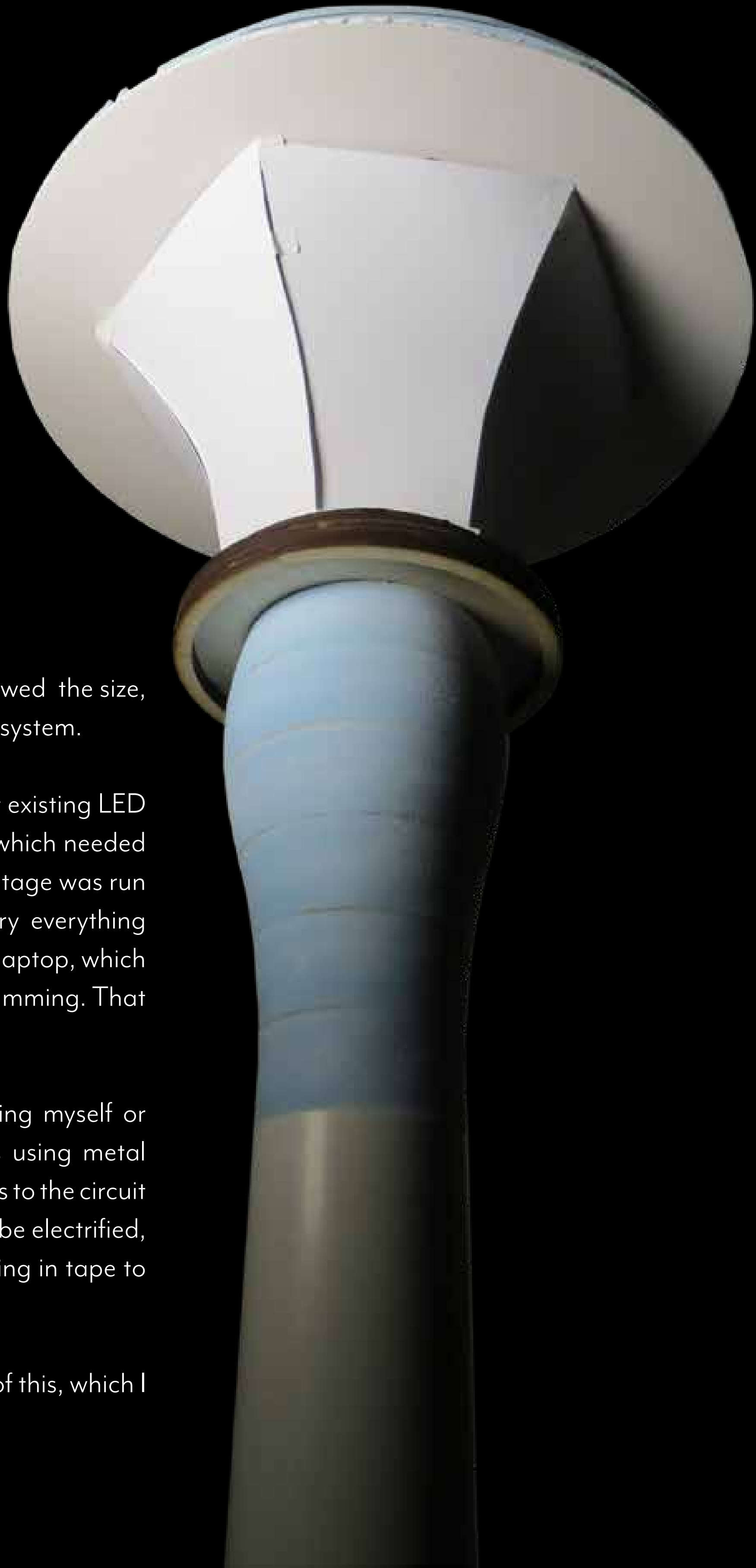
The architectural style is associated with geometric planes and lines. Minimizing the solid volumes produces a style that is visually light, but striking.

The organic style is inspired by natural forms. It is scuptural with complex three dimensional curves to make the light feel grown in place.

The minimal style streamlines all of the components into a single form with simple geometry. Lack of embelishment makes a minimal light pole flexible.

Prototype 1 - Light on a Pole





Prototype one was a "big-ugly" that showed the size, rough form, and rough effect of the Ray system.

The biggest challenge was adapting my existing LED diode arduino wiring to the LED chips, which needed a separate power source. If that high voltage was run through the arduino board, it would fry everything and make it useless. Also potentially my laptop, which was connected to the arduino for programming. That was a scary hour or so.

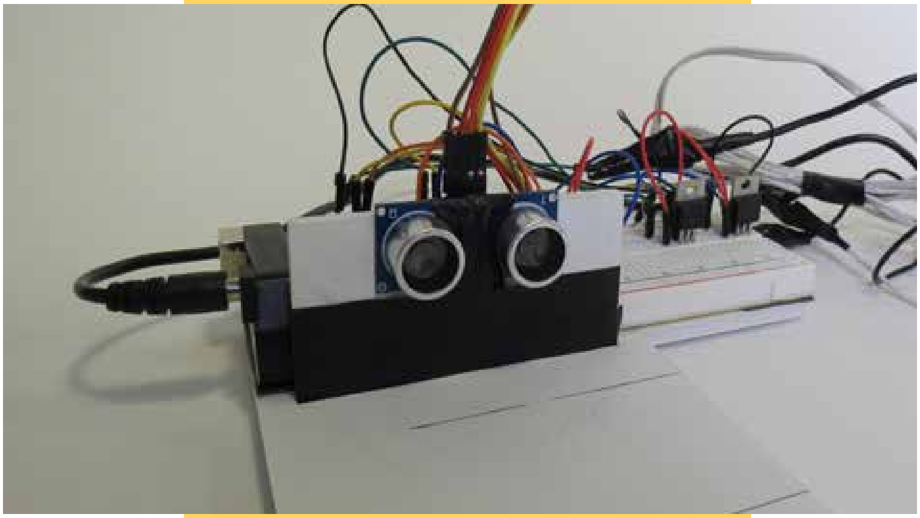
A similar challenge was not electrocuting myself or shorting out the circuit, because I was using metal alligator clips to connect the heavier wires to the circuit wires. I found out that the entire clip will be electrified, and it is very important to wrap everything in tape to prevent electrocution.

Lots of learning occuring in the making of this, which I will cover on the next page.

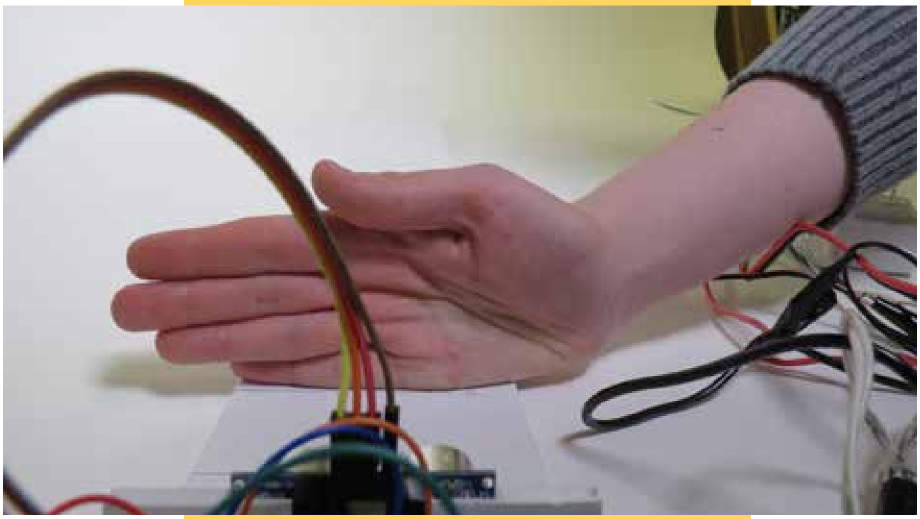
Lessons of Prototype 1

- Heat managment is acrucial part of designing an LED lumenaire
- Arduino boards do not have enought PWM ports to control as 6 LED chips at once.
- Direct light from these LED chips is very bright and does create glare - so the indirect illumination was a good choice.
- Simplify wire management for assembly and installation
- Use a central axis for alignment of components and account for tolerances

One of two high powered LED chips mounted to a brass plate to distribute the heat



Wire managment is a priority for the next model - the circuitry kept getting unplugged when the model moved



Calibrating the sensor with the scale model.

IES and IALD Review

I coordinated with the local Illumination Engineering Society (IES) and International Association of Lighting Designers (IALD) to review and critique my design up to this point.

Feedback

- Light the path in front of the person, not on the person.

Response

- Comptuter vision data can be analyzed with predictive algorthims to light the path ahead of a person and also to function as wayfinding.

Feedback

- This is similar to a concept that won a lot of awards a few years ago, but it has not been sucessfull due to energy code requirements

Response

- Exterior projects get a higher power allowance in code. Also the premise of the Ray system is that it is dim most of the time - saving more power overall.

Feedback

- This sounds expensive.

Response

- Provide the fixture and controls with different levels of experience to accompodate different price points. Also make other fixture that are not just a pole.

Lillian Knoerzer (IALD Regional Coordinator)

“Placing the light directly on the people may make them feel exposed. If the light was ahead of them it would be a better experience.”

Jared Widmer (IES Former President)

“I have seen proposed lights that work this way, but they fail interior energy code. Exterior public code has a higher energy allowance, so this is a great place to use the concept.”

Adam Carangi (IES Manufacturing Rep)

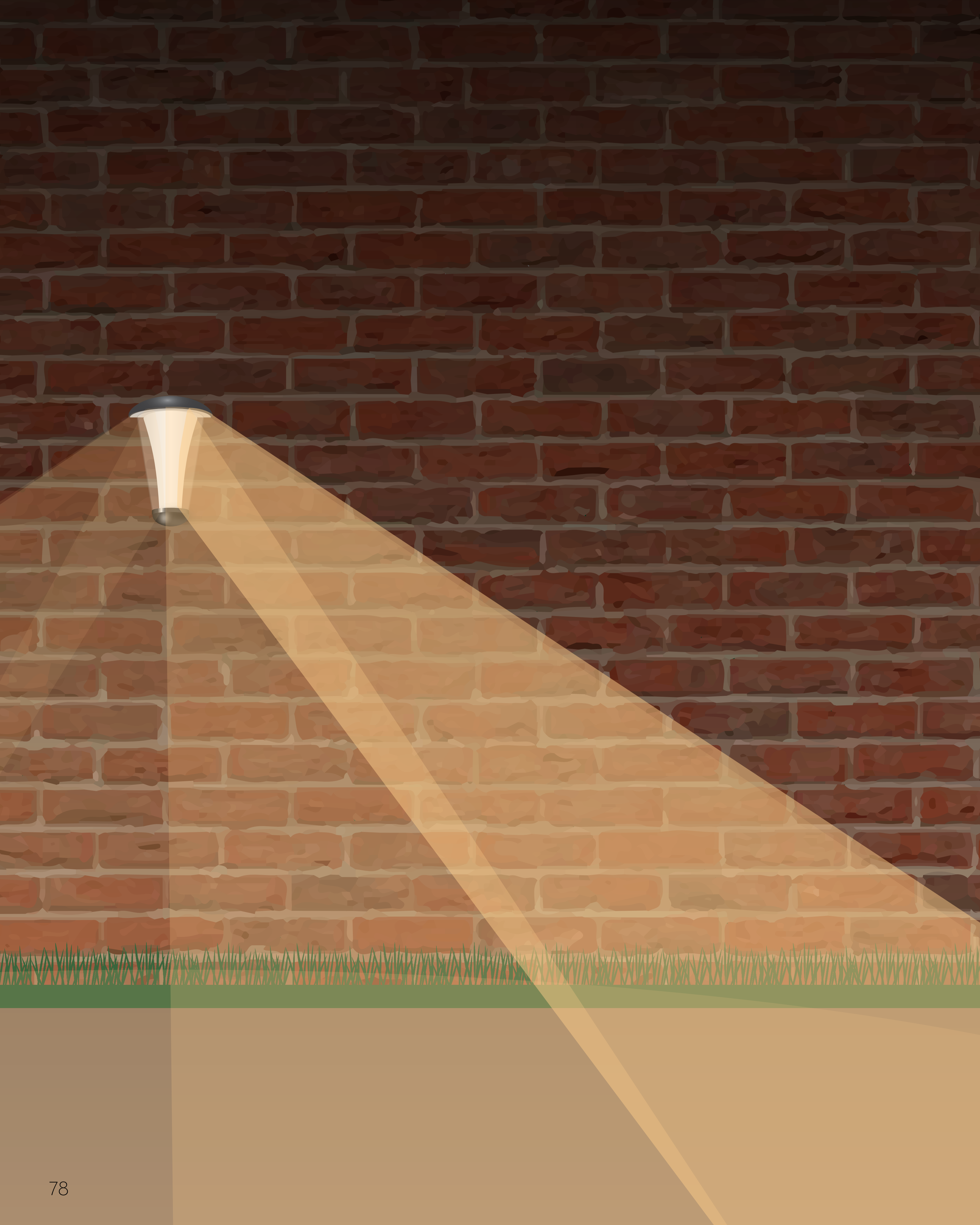
“This sounds really expensive, but if it was available in different sized fixtures with different degrees of control that would reduce the cost and make it more appealing to investors.”

Final Design

The Ray Fixture Family - Modern Collection

- Wall Sconce
- Post-top Lumenaire
- Bollard

- Manufacturing, Assembly, and Installation
- Final Light Level Interaction
- Moving Forward



Ray Wall Sconce

The wall sconce is intended for pedestrian spaces and paths that run around buildings. This fixture saves money on the sensors, because it only needs to detect peopel over 180 degrees instead of all the way around.

The Sconce can be mounted at 8ft - 12ft high, as long as the light sourec is not visible from the ground to make use of the indirect illumination and avoid glare.

Ray Light Pole

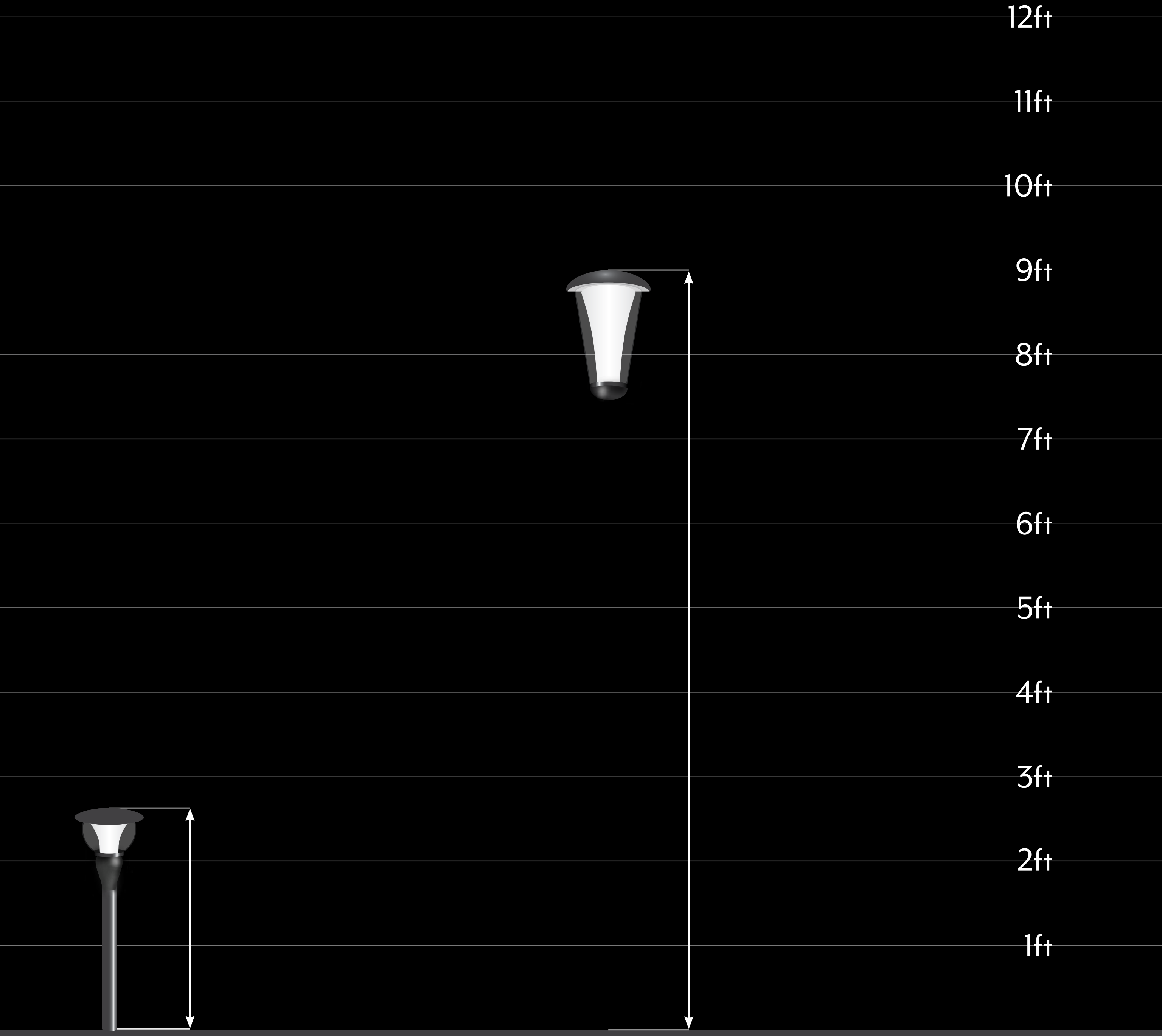
The Light Pole is for large open areas such as parks. The top sensor hub and lumenaire can be retrofit to any existing 4in diameter pedestrian pole. The height can range from 10ft to 15ft tall, with a spread of light and pole spaces ratio at 2.5 times the height.


BOOK

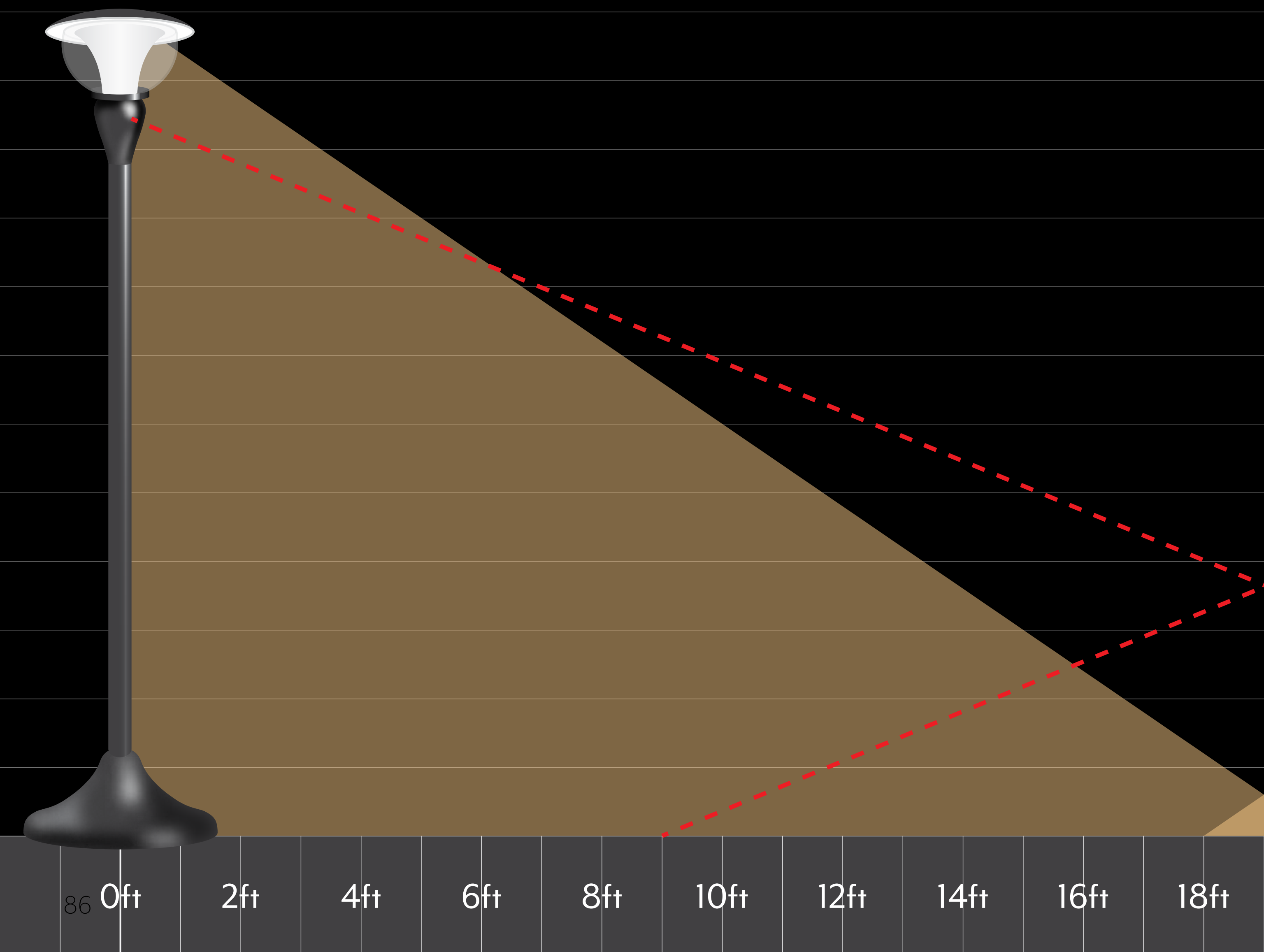
Ray Bollard

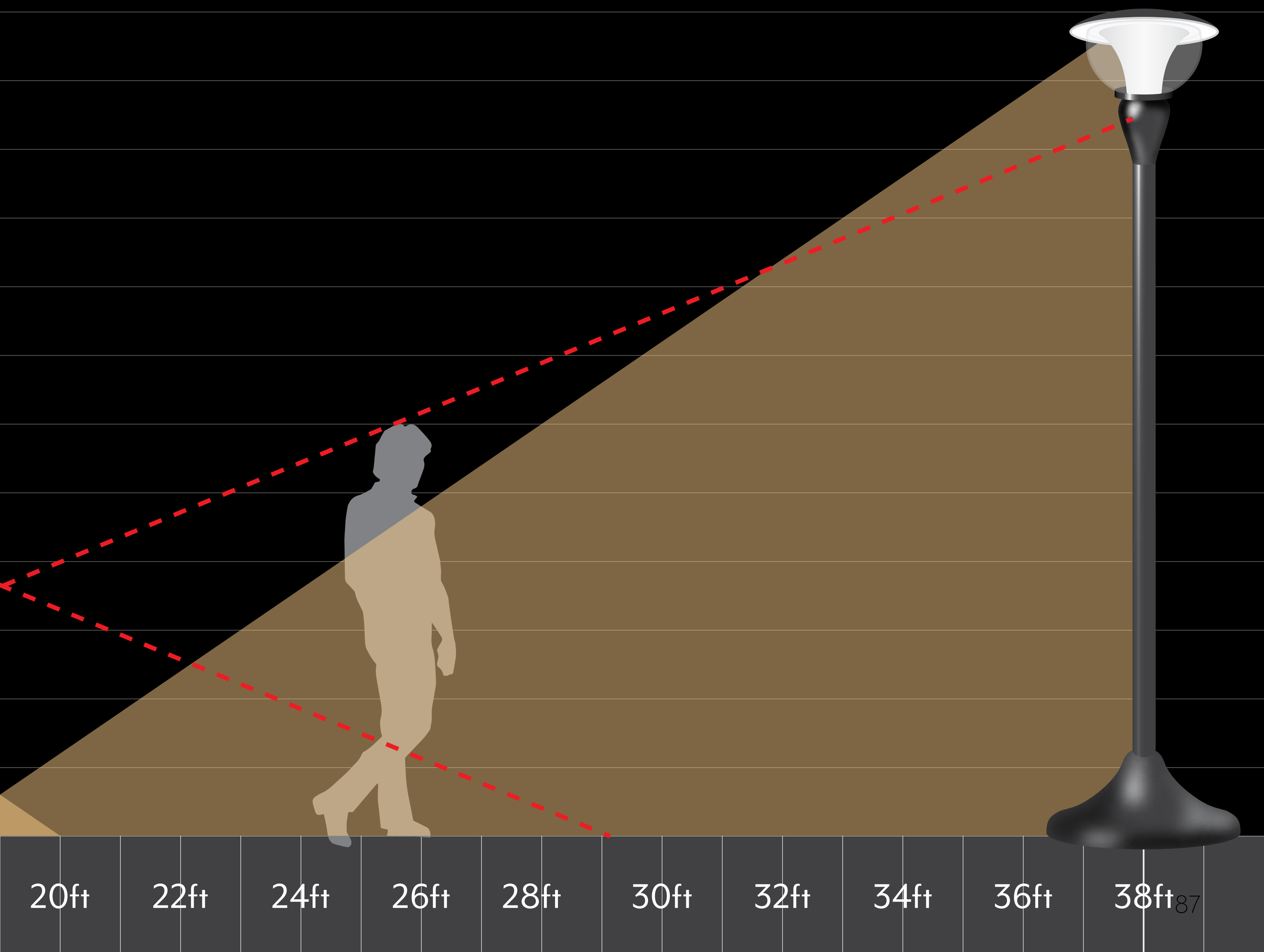
The Bollard has the same 360degree sesnor system as the pole, but in a smaller package. This makes it appropriate for tighter spaces such as sidewalks, or anywhere there should be a physicl separation between the pedestrian space and the street.

Fixture Mounting Heights

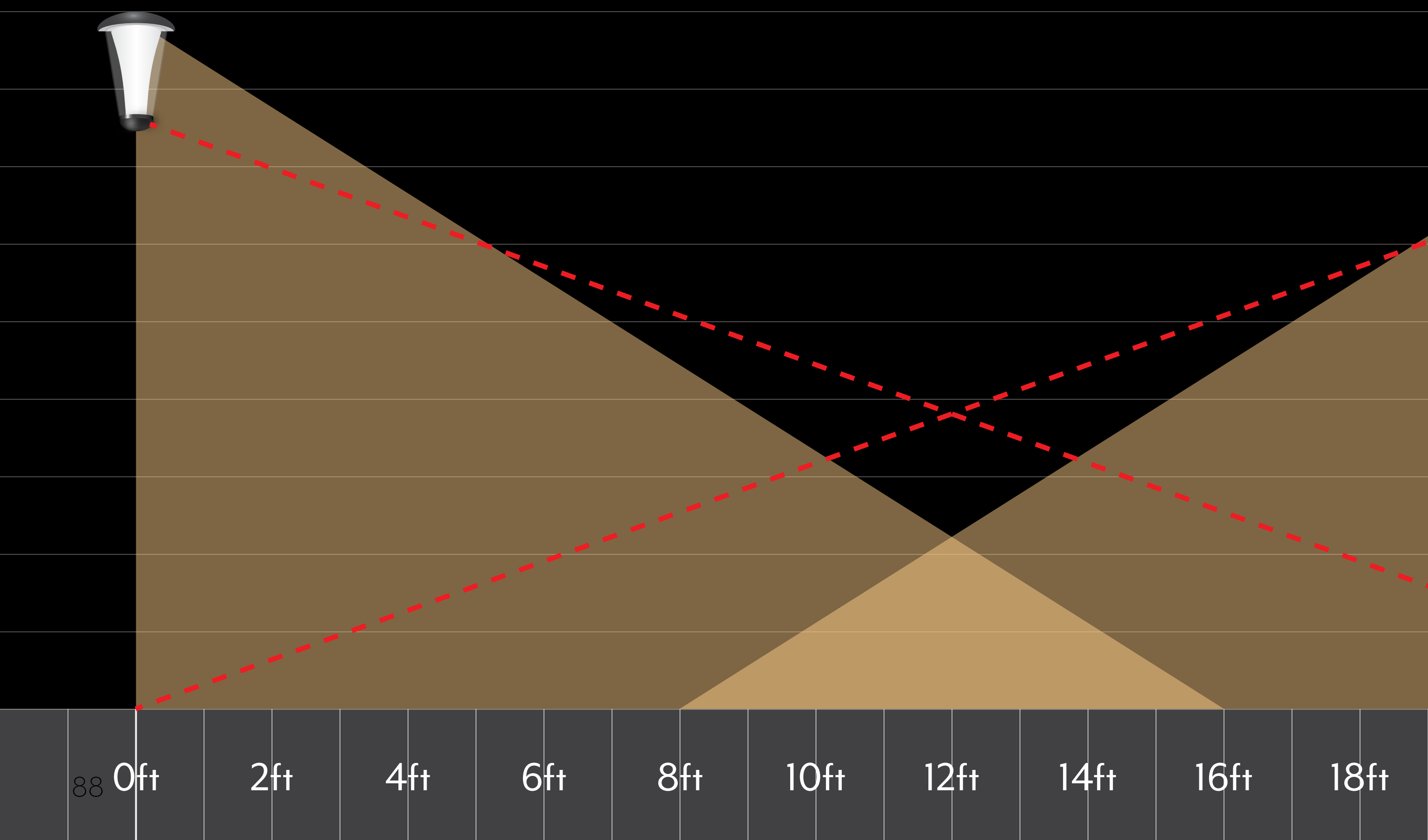

12ft
11ft
10ft
9ft
8ft
7ft
6ft
5ft
4ft
3ft
2ft
1ft

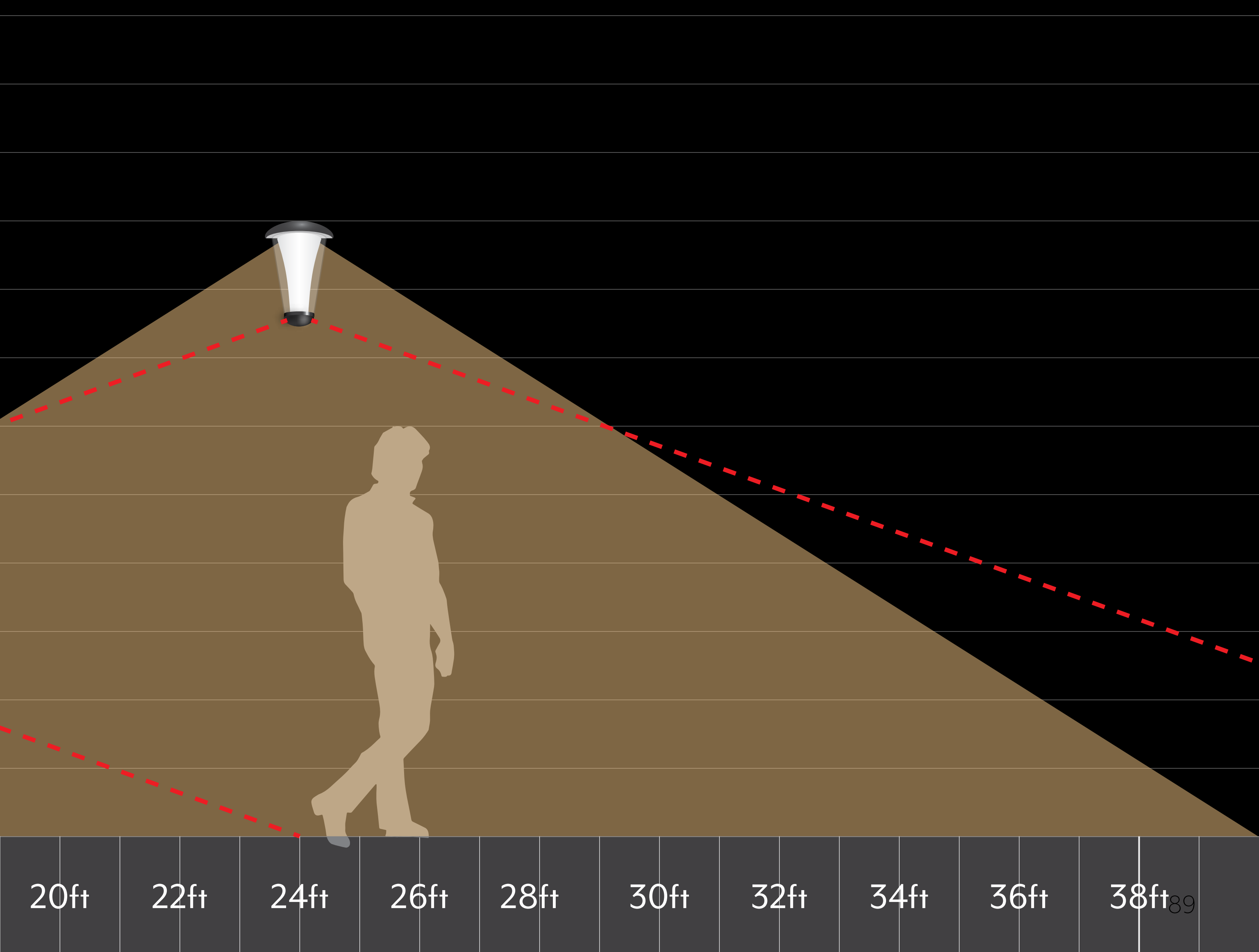
Pole Spacing and Sensors



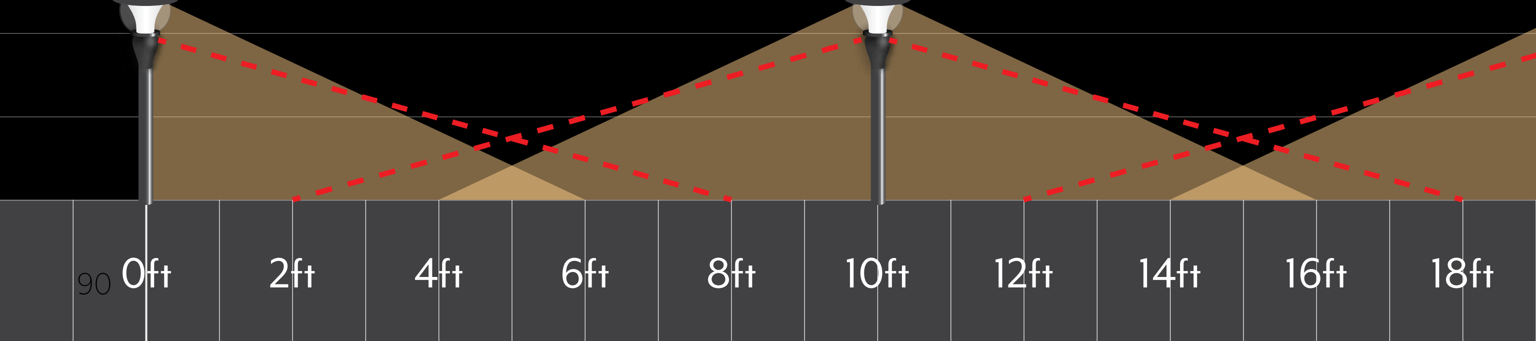

20ft
22ft
24ft
26ft
28ft
30ft
32ft
34ft
36ft
38ft

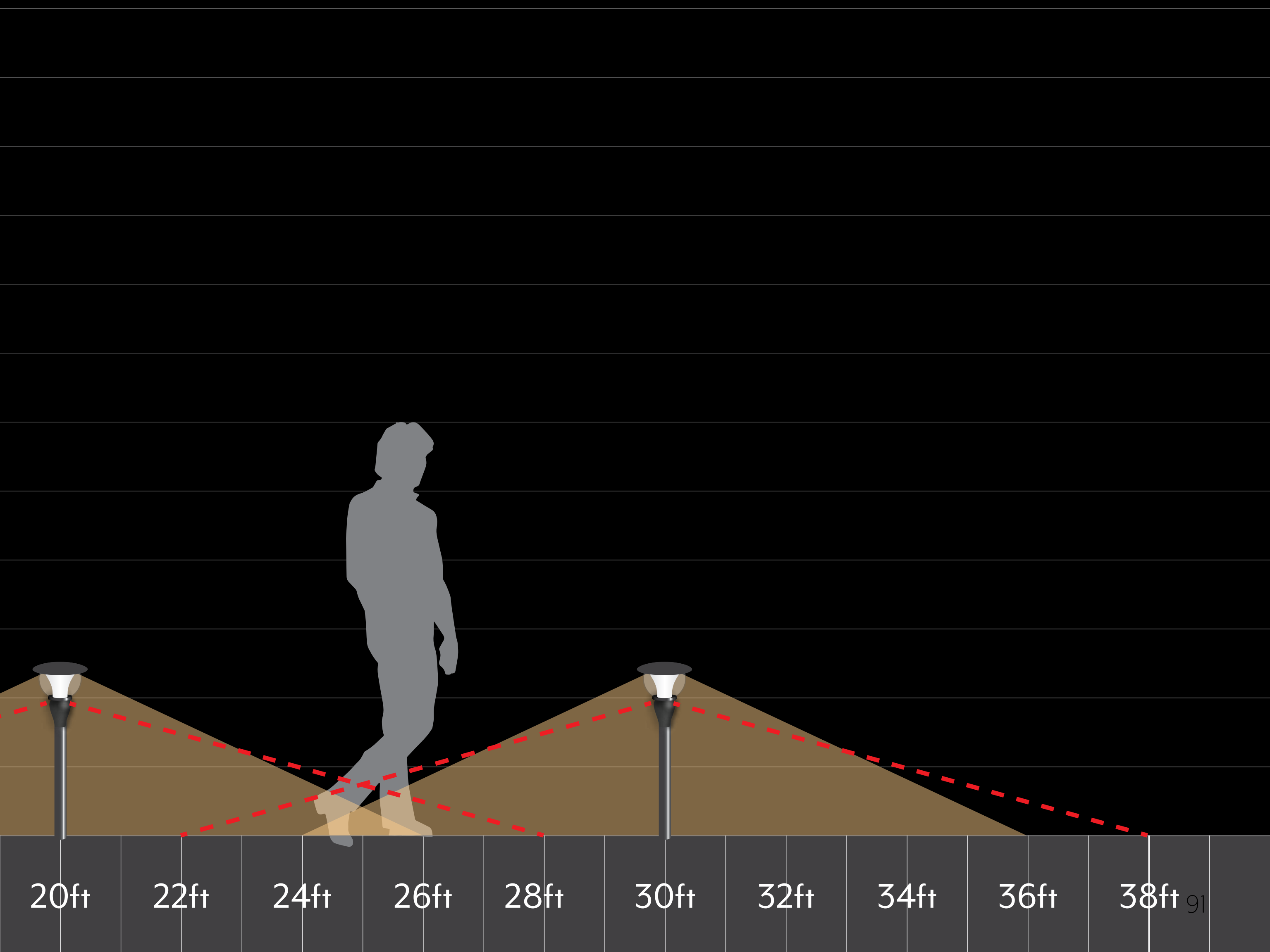
Sconce Spacing and Sensors



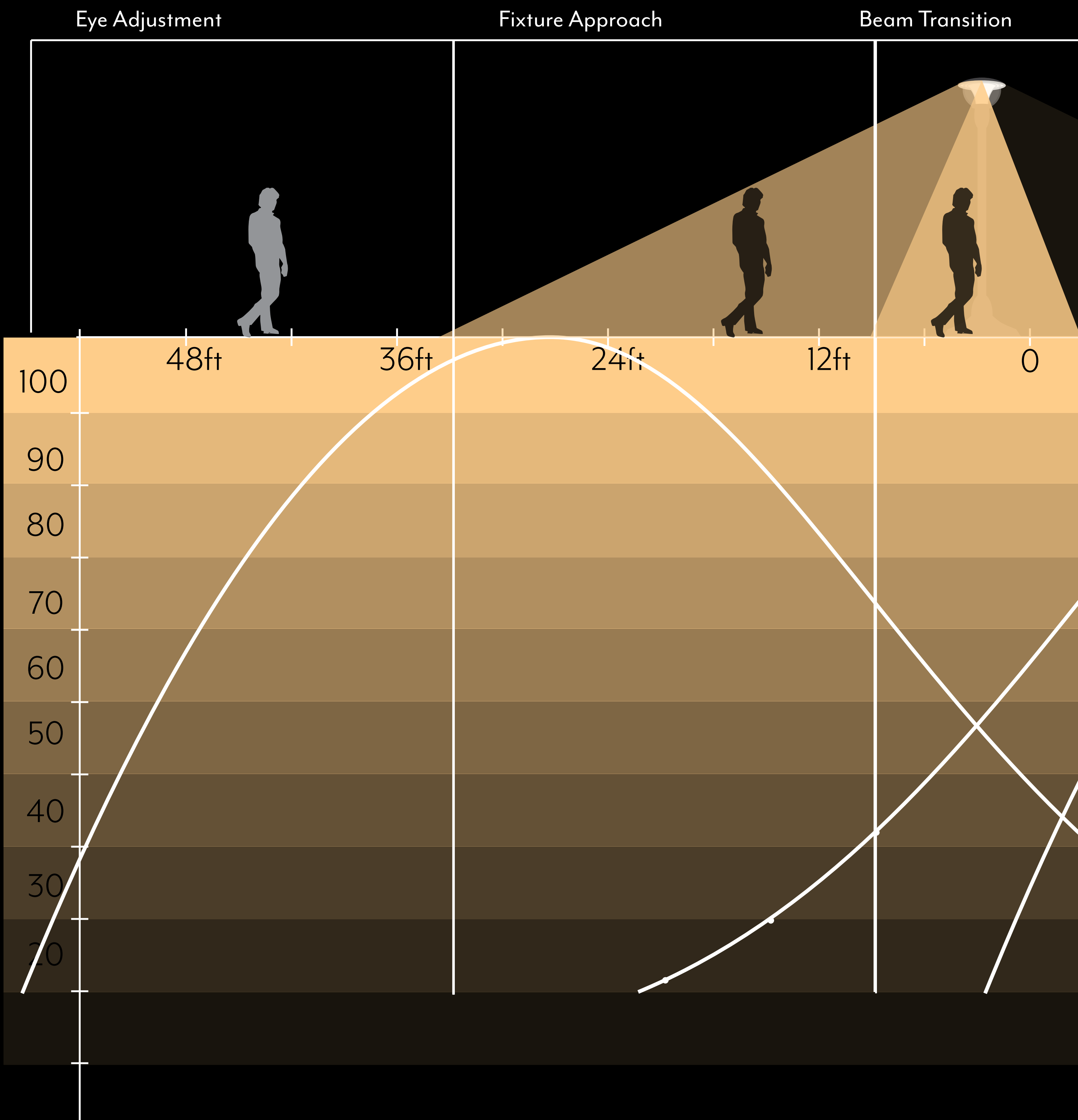

20ft
22ft
24ft
26ft
28ft
30ft
32ft
34ft
36ft
38ft

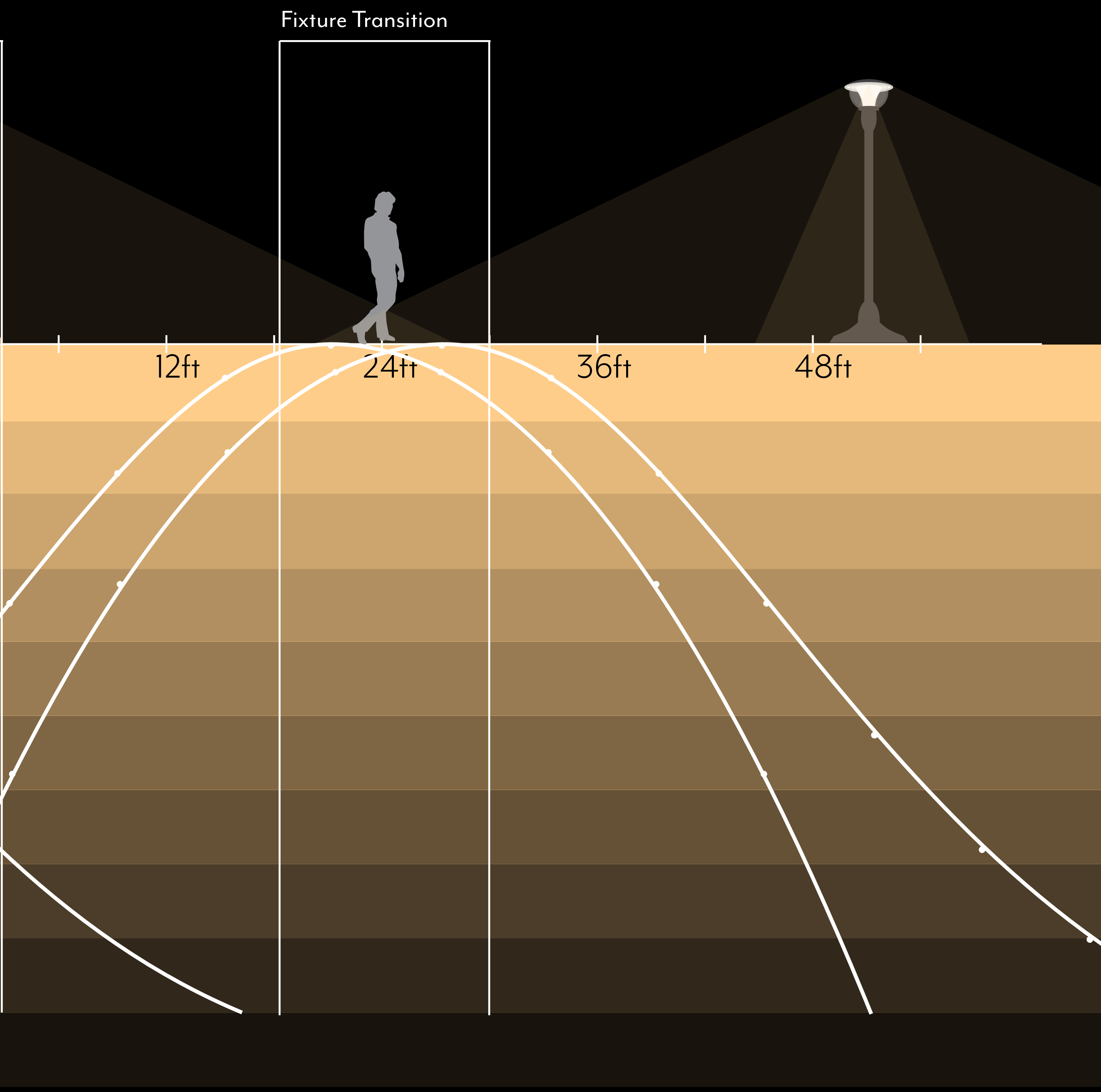
Bollard Spacing and Sensors



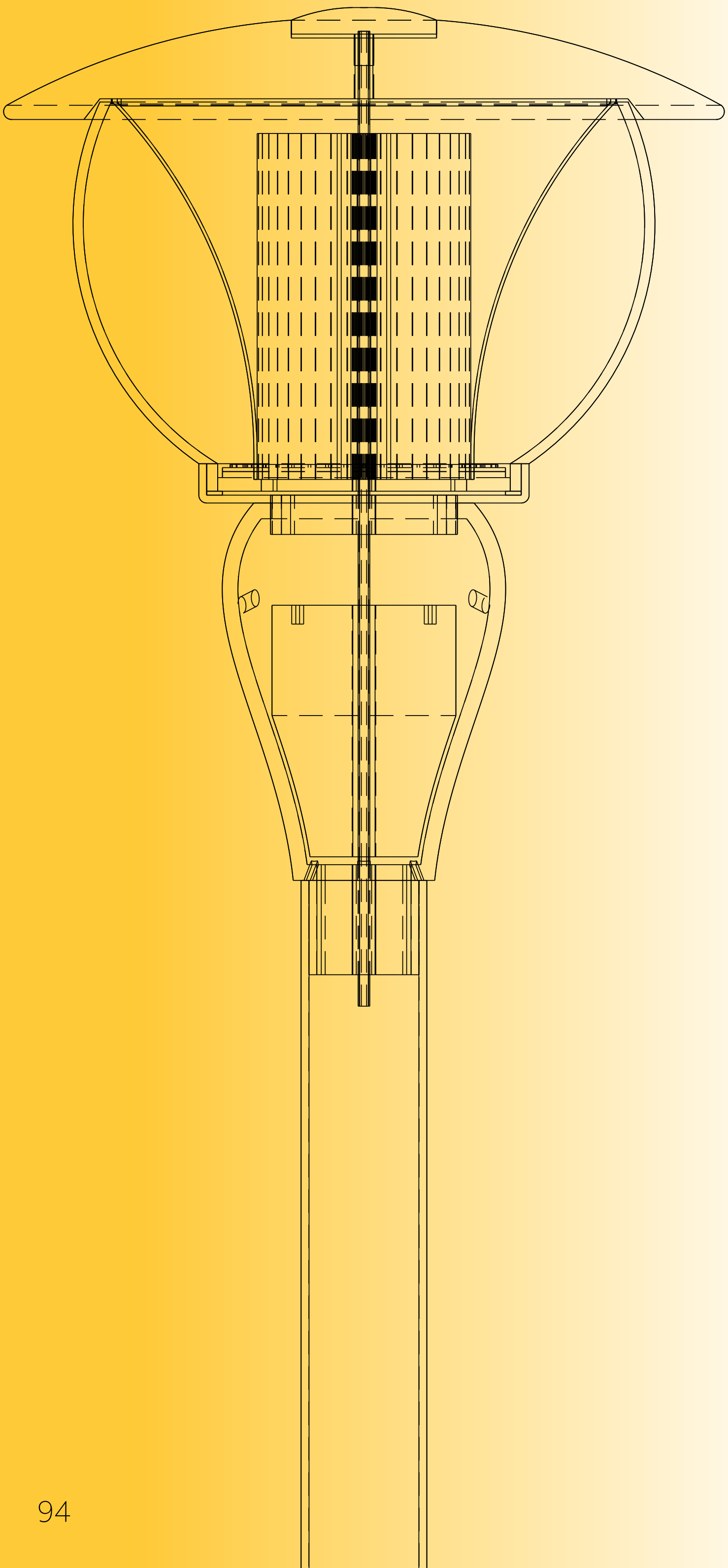

20ft
22ft
24ft
26ft
28ft
30ft
32ft
34ft
36ft
38ft

Zones of Illumination




Fixture Transition
12ft
24ft
36ft
48ft

Design Details



Top Shield

Finial

Glass Enclosure

Reflector

Aluminum Heat Sink

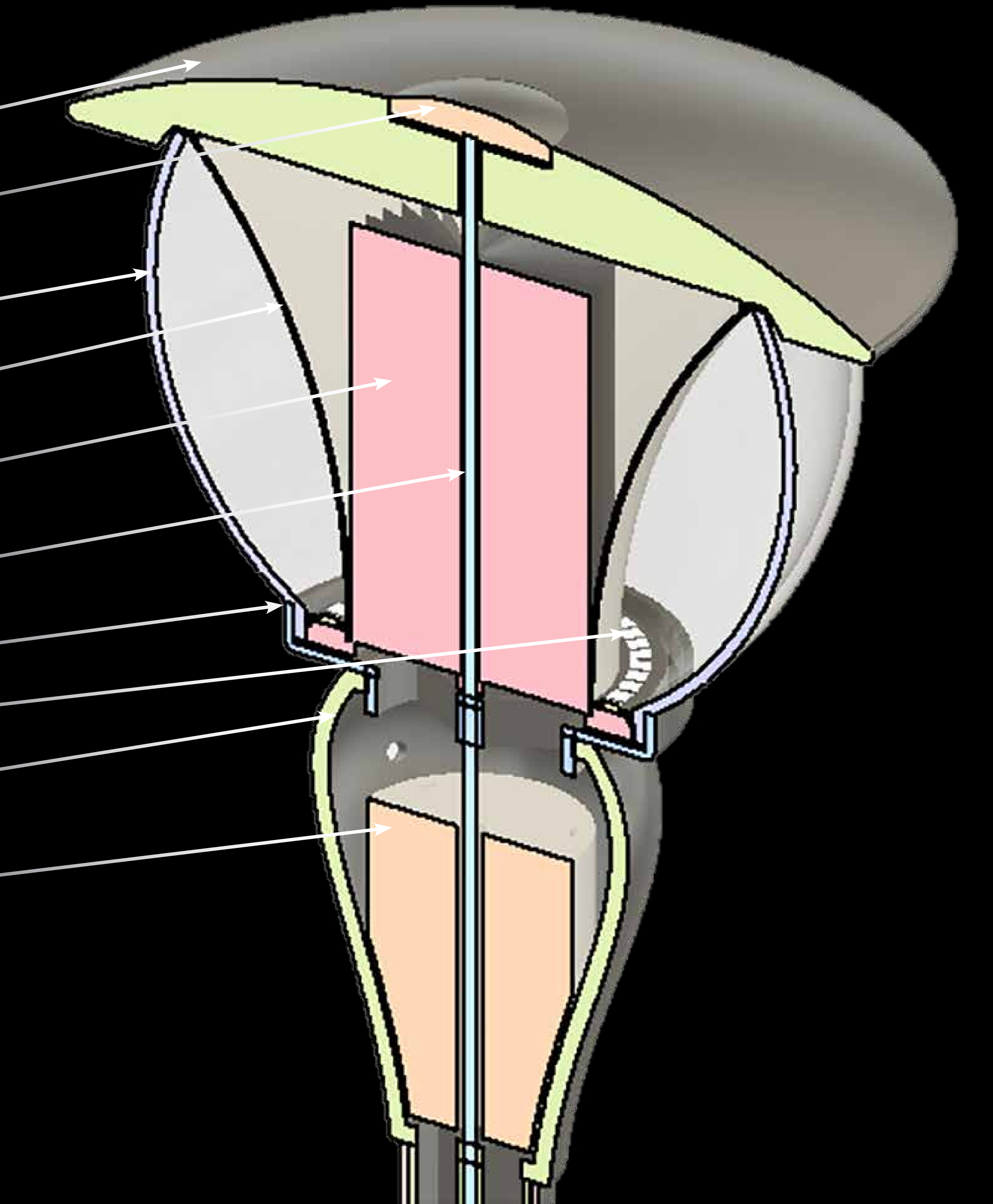
Steel Axis Rod

Lumenaire Base

LED Chip Board

Sensor Hub

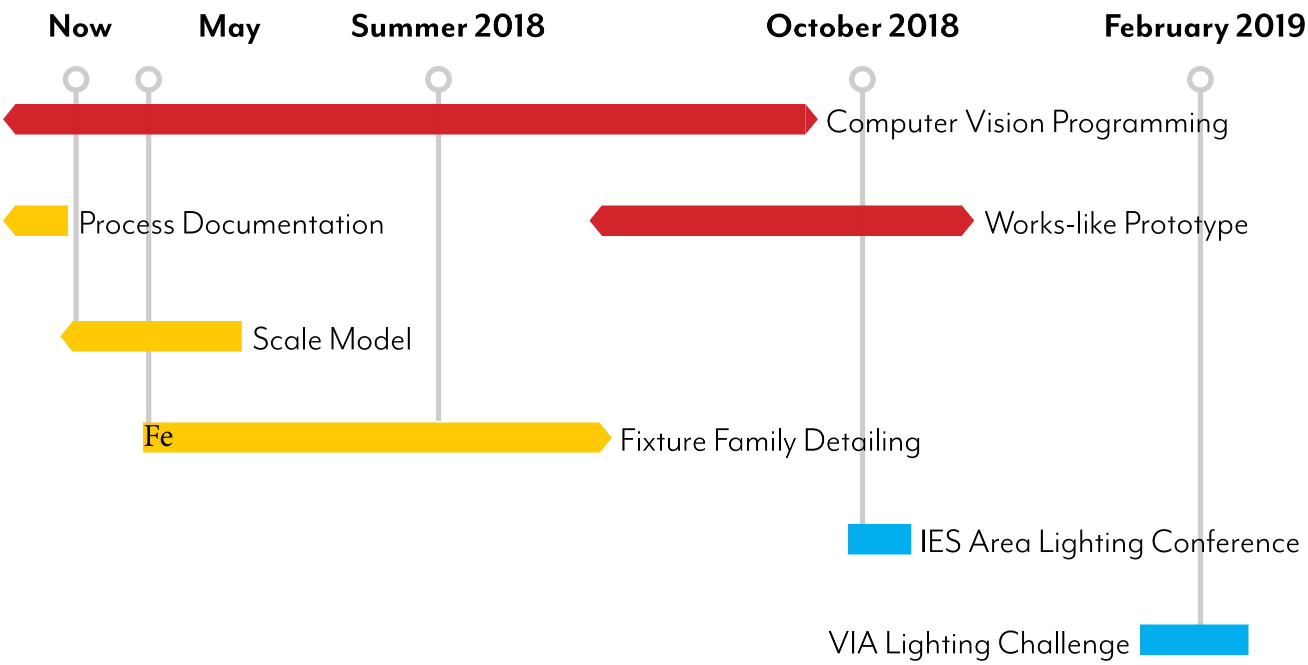
Electronics Block

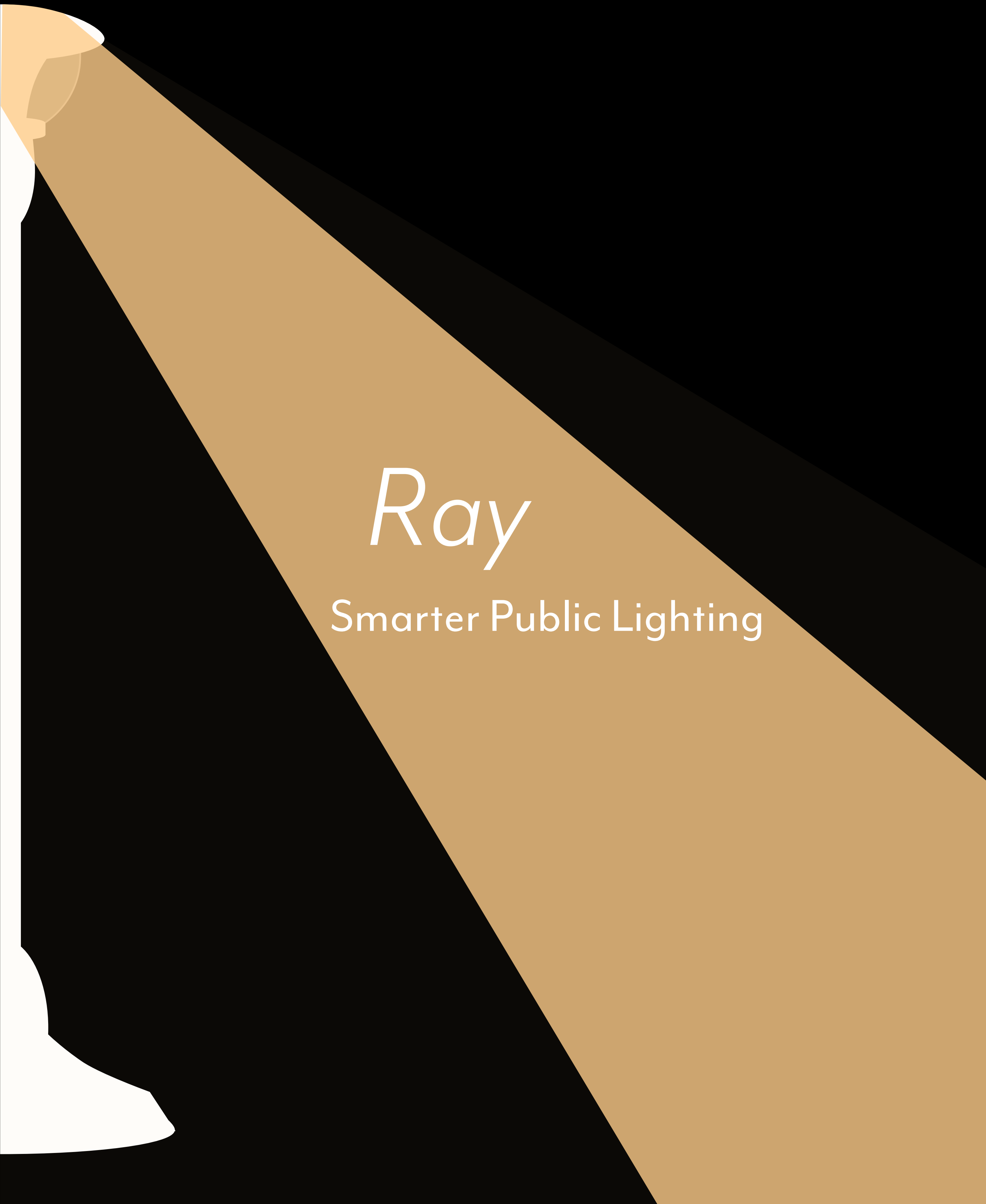


Moving Forward

The ultimate goal for this project is to fully validate the benefits of dynamic, interactive public lighting. To do this, I would like to partner with a lighting and controls manufacturer to build, program, and install a case study in a pedestrian space. Before I can do that, I need to get a full scale model working that uses the computer vision cameras to detect people. I would also like to develope the other styles of fixture for a more diverse product range.

The Ray lighting system has a lot of potential to change how we think about the future of public lighting. This processes synthesized so many factors of what public lighting affects and is affected by. I think that some of this connections need to be shared with the lighting community, so I am hoping to attend the IES Area Lighting Conference in October 2018, as well as speak on the potential benefits of smart lighting infrastructure as part of the Via Lighting Challenge in Berlin in February 2019.




Ray
Smarter Public Lighting

angelarosebanner@gmail.com
www.linkedin.com/in/angelarosebanner/
(443) 360-7961