SESSION 1 PANEL:
Can 3D Printing Revolutionize the Lighting Industry?

N. Narendran, PhD
Lighting Research Center, RPI
Panel Moderator
Our panel today

**Dustin Kloempken**  
Application Engineer  
Hewlett-Packard  
United States

**Sridhar Nimma**  
Engineering Leader / Specialist  
R&D and Innovation (printed electronics, sensors, and additive manufacturing)  
Eaton  
United States

**Hugo da Silva**  
VP of Additive Manufacturing  
DSM  
Netherlands

**Willem Sillevis Smitt**  
Senior Director Strategic Marketing  
Lumileds  
United States

**Aaron Smith**  
VP of Technology and R&D  
Finelite, Inc.  
United States
Why consider 3D printing for lighting?

- Industry trend
  - LED lighting fixtures or subassemblies are manufactured overseas and shipped to U.S.
    - Commodity market (low cost)
    - Increased carbon footprint
- Lighting trends for the next five years
  - Lighting fixtures with more functionality
    - Sensors, radios, processors, etc. (IoT ready)
- 3D printing could further add value
  - Affordable custom lighting fixtures, made on-site, on-demand

![Solid State Lighting Fixture Supply Chain](image-url)

Mass Production to Mass Customization
With Additive Manufacturing
... On-demand, On-site manufacturing
What is our vision for SSL and 3D printing?

• Ultimately, the goals are to
  • Change architectural lighting practice
    • Integrate lighting design into building design
    • Manufacture on-site, on-demand
  • Impact
    • Blended light fixtures
      • Building design and improved visual appeal
    • Faster fixture design revisions and manufacture
      • Bring back jobs to construction locations
    • Reduction of cost
      • Energy-efficient manufacturing, shorter transportation distances, reduced storage time
    • Reduced environmental pollution
      • Manufacturing, transportation, and storage
    • Economy
      • Bring back manufacturing jobs
What needs to happen?

• Need to ensure that functional thermo-mechanical, electrical, and optical components can be fabricated using current and future 3-D printing technologies and materials to produce complete SSL lighting fixtures
  • Developments needed
    • Materials
      • Mechanical
      • Thermal
      • Electrical
      • Optical
    • Printers and processes
    • Electronics integration
      • Drivers, sensors, connectors, etc.
Areas to be addressed by the panel today

**Dustin Kloempken**
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United States

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Sr. Manager, Global Leader  
Additive Manufacturing  
Center of Excellence  
Eaton Corporation  
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**Aaron Smith**
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**Willem Sillevis Smitt**
Senior Director Strategic Marketing  
Lumileds  
United States
The (near) Future of Product & Lighting Design

Dustin Kloempken
Application Engineer – 3D Printing
HP
United States
What is the purpose of a door handle?
Why is a door handle typically solid?
What does your part need to do?

Goal:
- Optimize product design process
- Reduce supply chain costs
- Produce low volume, high value equipment via more cost efficient processes

Solution:
- A part called a “SOL actuator support” bracket was identified as a good part candidate
  - Positions a sensor that calibrates the color quality of print in the inkjet printer

Results:
- Designed for performance
- Lighter and cheaper part with the same reliability
- Physical inventory → Digital inventory
- Part now qualified for “just-in-time” manufacturing processes
CNC machining cost relates to number of steps required to remove material

- Programming of cutter paths
- Building jigs to hold parts being machined
- Fabricating custom cutters
  - For when standard sizes cannot create desired geometry
- Wasted material
  - Machined chips
- Set up for machining
  - Multiple Machines needed to cover all operations
- Break down of machining set-ups
- Storage of jigs

These costs are magnified as a percentage of costs for short runs common for low volume production
CNC machining cost relates to number of steps required to remove material.

Subtractive Process

- Programming of cutter paths
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These costs are magnified as a percentage of costs for short runs common for low volume production.
Printing costs related to amount of material consumed

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<th>CNC</th>
<th>MJF</th>
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<tr>
<td></td>
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<td>Weight (g)</td>
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<tr>
<td>Aluminum</td>
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<td>355</td>
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<tr>
<td>Topology Optimized</td>
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<td></td>
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<tr>
<td>Topology + Lattice</td>
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<tr>
<td>Lattice Structure</td>
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<tr>
<td>Final</td>
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85% lighter, 70% cheaper
Printing costs related to amount of material consumed

Additive Process

85% lighter, 70% cheaper

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<td>Volume (cm³)</td>
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</tr>
<tr>
<td>Weight (g)</td>
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<td>55</td>
</tr>
<tr>
<td>Cost</td>
<td>$22</td>
<td>$5.90</td>
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</tbody>
</table>

MJF Savings: 73% (85%)
Subtractive vs Additive Manufacturing

- Machined prototypes take days to weeks to make depending on design complexity
  - Programming of cutter paths
  - Building of fixtures to hold parts during machining
  - Number of CNC machines (or set-ups if constrained to one machine) for all operations
- CNC process machines one part at a time
- Each design iteration requires:
  - cutter path programming
  - Building of fixtures potentially--depending on extent of change
- More Aluminum used in part than necessary for function to minimize machining cost
  - Material wasted: Close to 40% of block removed (wasted)
- Even this simple part needs multiple operations in different orientations that require multiple stations or multiple set ups

- HP Multi Jet Fusion parts can be available as fast as 24 hours
  - Complexity of design does not impact lead time
  - No fixtures needed to be built
- Multiple parts printed simultaneously
  - As many as can fit in build volume
  - Simultaneous availability of alternative designs accelerates optimization of design
- 85% lighter than CNC (due to material and lattice structure)
- Virtually all unused material captured for reuse
Subtractive vs Additive Manufacturing - Timing
Subtractive vs Additive Manufacturing - Timing

HP Multi Jet Fusion

Days

$$

Days to weeks

Fabricate Part

Layout Design

Test

Manufacture

Iterate Design

3D Print Part

Potential Time-to-Market Advantage or Part Design Optimization Time

NB: The delta increases per iteration

CNC

Layout Design

Test

Manufacture

Iterate Design

Quality of CNC’ed plastic parts ≠HP MJF because of machined in stresses

This benefit accrues every design iteration

HP Multi Jet Fusion parts = production parts

Quality of CNC’ed plastic parts ≠HP MJF because of machined in stresses
Re-imagining the lightbulb

What does a lightbulb really need to do?

- Provide light
- Ideally: Not burn out quickly/last a long time
  - Accomplished via proper thermal management
  - Use durable materials
Heat Sinks Reimagined

Can AM dissipate heat correctly?
Are the materials durable enough?
Heat Sinks Reimagined
Heat Sinks Reimagined
What does your design need to do?
Provide optimal output quality

HP Branded Powder

Certified for
HP Jet Fusion 3D Printers

HP Certified Powder

Any Powder (Fully Open)

OPEN PLATFORM
Color provides visible and hidden information

Photoluminescent materials visible under UV light

Visible color

Embedded information

HP Confidential
Marking and anti-counterfeiting

Embedded information

Parts can be identified, oriented, and tracked during assembly into systems
Enhanced functionality for obsolescence tracking

3D layers of color indicate changes in the surface

Embedded 3D color used as a passive wear indicator

New rack:

Worn rack:
How are you going to reimagine the lightbulb?
Materials for Additive Manufacturing

Hugo da Silva
Vice President Additive Manufacturing/3D Printing
DSM
The Netherlands
Introducing DSM Additive Manufacturing
OUR PURPOSE IS TO CREATE BRIGHTER LIVES FOR ALL.
DSM Additive Manufacturing Vision

APPLICATION AT THE CENTER

PARTNERSHIPS & ECOSYSTEM

EMBRACING NEW BUSINESS MODELS

SUSTAINABLE
Additive Manufacturing Adoption
Additive Manufacturing Adoption

![Diagram of Additive Manufacturing Adoption]

- **Concept models**
- **Visual prototypes**
- **Functional prototypes**
- **Production Tools**
- **Low volume / Specialized products**
- **Mass production**
- **Production Ramp Up**
- **Production Ramp Off**
- **Spare parts production**

**Time**

**Quantity**

**Competitive pressure**

**3D print value**

*Courtesy of Ultimaker*
Different Technologies for 3D Printing Polymers

Key is to find the combination of design, materials and printing technology for the application.
Materials for Lighting
What Can You Expect Today?

Aesthetical prototype (1993 - 2025)
- Design validation

Functional prototype, Small series (2019 - 2025)
- Functional validation
- Small series (functional) parts

OEM’s production series (2021 - 2025)
- Direct manufacturing

Today

Tomorrow

Future
Which Parts of a Luminaire Are Interesting for AM?
LED Heat Sink

- Engineering plastic material enables the production of unique lightweight design heatsinks for lamps.
- Compared to traditional plastics, it delivers excellent cooling of the lamp while securing electrical safety.

Benefits
- Reduces the weight of heat sinks with 50% compared to aluminum
- Allows for high level of design freedom compared to metal
- Reliable solutions due to its thermo-conductivity
- 85% lower CO2 footprint than with an equivalent die cast aluminum heat sinks
Aluminum; 150 W/mK

\[ T_{LED} = 125.7°C \]
\[ T_{min} = 115.1°C \]

TC plastic; 5 W/mK

\[ T_{LED} = 130.5°C \]
\[ T_{min} = 113.4°C \]
White Diffuser

- Traditionally, white diffuse reflectors are made from polycarbonate.
- This material typically has a high level of discoloration.
- Solution: highly reflective materials specifically developed for such applications
- The materials have a bright white color in order to reflect light or to match the appearance of the application.

Benefits
- Arnite® RFLX significantly outperforms one of the best-available polycarbonates in light/heat degradation tests.
- Thickness of the reflector can be minimized to save on material costs.
Thank you!

Hugo da Silva  
Vice President DSM Additive Manufacturing/3D Printing

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3D-Printed Electronics

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Eaton Corporation
United States
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Providing power management technologies that are more reliable, efficient and safe.

Dedicated to improving people’s lives and the environment.
Lighting Division Business Overview

- Sales ~$2.0B
- > 20% of sales outside the US
- Top 2 player in North America; Top 3 globally
- > 5000 employees
- Broad product portfolio, diverse end markets
- Leadership technology and customer access
Luminaire Assemblies: Where are we today?

Typical Roadway Assembly

- Assembly line model
- Complex assemblies
- Many designs / components
  - Electronic content: discrete LED board, driver, sensors, communication, wire harnesses, connectors, etc.

Typical Luminaire Manufacturing Flow

- Significant labor content
- Complex supply chain
- Large inventory
- Long cycle times
- Long time to market
Luminaire Assemblies: Where do we want to be?

**Integrated Roadway Concept**

Eaton Concept Prototype (2017)*
- Fully printed, integrated circuitry with LED, driver, sensors and antennas
- Minimal part count
- Simplified assembly

**Integrated Manufacturing Flow**

- Fully Integrated CAD Design
- Machine Download and Debug
- Manufacture AM Luminaire
- Post Process
  - Test
  - Inventory
  - Ship

- Metal Material Resource
- Polymer Material Resource
- Optical Material Resource
- Electronics and Sensor Material Resource

**Integrated Manufacturing Approach**

- “Print on demand” model
- Few components and assemblies
- Integrated mechanical/electronics
  - **Electronic content**: Fully printed, integrated electronic functionality
- Reduced operations and mfg. footprint
- Consolidated supply chain
- “Near” zero inventory
- Faster time to market

Printed Electronics for Lighting: 2019

**Design Tools**
- Predominantly 2D with "in house" design rules
- 3D emerging, integrated with AM tool
  - Constrained to specific materials and processes

**Materials (inks, pastes)**
- **Available**
  - Dielectric
  - Conductor
  - Resistive
- **Emerging**
  - Ferromagnetic
  - Piezo
  - Semiconductor

**Components (active, passive, sensors)**
- Mostly discrete
- Printed: Resistors, small value capacitors and magnetics, some sensors (T, RH, antennas)

**Substrates**
- Aluminum, Steel, ceramic, FR4, polymer/flex, specialized polymer

**Interconnect**
- Discrete + solder or conductive epoxy
- "Edge" connect
- Printed over component termination

**Processing**
- 2D: screen, gravure, slot-die, ink/aero jet
- 3D: Ink/aero jet, in-mold
- Thermal cure/sinter

**Circuit Traces/Wiring**
- Available: Silver, Copper, Carbon
- Emerging: Carbon Nanotube filled, discrete round gage wire
3D Printed Electronics for Lighting: What’s Missing?

Integrated Design Mindset
• Combine functionality (electrical, mechanical, optical)
• Eliminate redundancy
• Leverage the AM capability where it makes sense

Tools
• Seamless CAD for mechanical and electrical
• Open Platform Printers with ability to use various electronic inks and processes

Materials
• Higher conductivity (for circuit traces, wiring)
• Improved dielectric properties (for metal substrates)
• Functional inks (sensor)

Processing
• 3D capability with good parameter control
• Non-thermal / localized curing (UV, laser, induction)

Component Attachment
• 3D placement
• Joining materials (to meet reliability requirements)
Closing Thoughts ...

• 2D Printed Electronics for Lighting is ready today

• 3D Printed Electronics is being driven by rapidly developing adjacent markets
  • Wearables
  • Consumer electronics
  • Medical / Biosensing

• Leading applications may not have the requirements demanded by Lighting right now...
  • High Power
  • High Reliability
  • Low Cost

... but the technology is advancing quickly

DOE Announces Selections for SSL R&D Funding Opportunity (Round 13)

**Recipient:** Eaton Corporation (Menomonee Falls, WI)

**Title:** Additively Manufactured Solid-State Luminaire

**Summary:** This project seeks development of an additive manufacturing process for LED luminaires that includes mechanical and thermal management structures, electrical and electronic structures and optical and light reflector structures.
LED Light Engines for 3D Printing

Willem Sillevis Smitt
Senior Director Strategic Marketing
Lumileds
United States
Light Engine Requirements

- Integrated monitoring and protection
- Small
- Optically integrated
- Color selectable
- Safe
- Scalable
- Easy to fault free integrate
### Challenges and solutions

<table>
<thead>
<tr>
<th>Challenge</th>
<th>Prevent overheating</th>
<th>Prevent electrical overstress</th>
<th>Has to be scalable</th>
<th>Has the right color point</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solution</td>
<td>Thermal monitoring and current throttling</td>
<td>Constant voltage power supply and on-board current regulation - Example 48VDC power distribution</td>
<td>Variable length light engine</td>
<td>Color selectable light engine</td>
</tr>
<tr>
<td>Exists today?</td>
<td><img src="image1.png" alt="Image" /></td>
<td><img src="image2.png" alt="Image" /></td>
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# Challenges and solutions

<table>
<thead>
<tr>
<th>Challenge</th>
<th>Fault free easy fixture assembly</th>
<th>Safety</th>
<th>Controls integration</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Solution</strong></td>
<td>Clean environment Testing</td>
<td>Can be inherent with low voltage</td>
<td>Requires protocol specific interface card</td>
</tr>
<tr>
<td></td>
<td>Skilled and trained workforce</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Exists today?</strong></td>
<td><img src="image1.png" alt="Image of a clean environment" /></td>
<td><img src="image2.png" alt="Image of a low voltage environment" /></td>
<td><img src="image3.png" alt="Image of a protocol specific interface card" /></td>
</tr>
</tbody>
</table>
Examples of current light engine capabilities

- Optical integration
  - Light guide based
  - Collimating optic based
- Driver and controls integration
  - AC–DC or DC–DC, multi or single channel
- Status monitoring and closed loop feedback
  - Including reporting and data logging
- Control system integration
  - Integration on board through protocol translation
- Self programming
  - Embedded LED test data
- Color selecting
LED light engine as the backbone of the fixture
Conclusions

• Current state of light engine technology provides a solid foundation for on-site 3D printed fixtures

• 3D printing approaches fit well with a vision of light engines as platforms that can be the backbone of light fixtures

• Current assembly practices have to be re-thought when brought on construction site
3D Printing Manufacturing Challenges Today

Aaron Smith
VP of Technology and R&D
Finelite, Inc.
United States
Project Concept:
• Decorative component
• Combine parts
• Complex shapes
• Tailoring
• Reduce cost
• 10 units to 1000 units
• Just in time

Dimensions = 12” x 4” x 1”
Challenges
Limited production partners
- Build size
- Finish
- Material selection
- Cost
- Delivery at volume
Reference:
### Part Cost / Lead-time

<table>
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<tr>
<th>Qty.</th>
<th>Total Cost</th>
<th>Cost per unit</th>
<th>Lead-time (days)</th>
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<tr>
<td>1</td>
<td>$382</td>
<td>$382</td>
<td>3</td>
</tr>
<tr>
<td>10</td>
<td>$2,972</td>
<td>$297</td>
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<tr>
<td>200</td>
<td>$57,669</td>
<td>$288</td>
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Dimensions = 12” x 4” x 1”
Current outlook:
• Traditional processes still have an advantage for our business model and scale
• Big low cost parts not yet viable
• Continue to look for production opportunities
Summary
Summary

• Vision for 3D printing for lighting
  • Affordable custom lighting fixtures designed by architects and lighting designers that can be manufactured on-site when needed

• 3D printer technologies and materials must be capable of producing complete SSL lighting fixtures (mechanical, thermal, electrical, and optical elements)
  • Need newer materials and single printing technology capable of making all types of components

• 3D printing materials
  • Optical and thermal materials need the most development

• 3D printing fits well with the vision of future of light engines as platforms that form the backbone of light fixtures
  • However, current assembly practices have to be re-thought

• 3D printer technologies are gearing up to compete with traditional manufacturing technologies in cost and speed
  • Need education to rethink optimized design process for 3D printing (different than traditional designs)

• For many lighting fixture manufacturers the current 3D printing technology cannot compete with traditional processes on cost
  • Further development needed for broader adoption
Thank you!

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