Strategies in Light
TECHNOLOGY + APPLICATION = TRANSFORMATION
August 24-25, 2021

3D Printing for Lighting:
What's the Big Picture?

N. Narendran, PhD
Lighting Research Center | Rensselaer Polytechnic Institute
Troy, New York

3D printing revolution

- National Intelligence Council's Global Trends report published March 2021, identifies 3D printing as driving a revolution in modern manufacturing.
  - Assesses the key trends that will shape the strategic environment for the United States during the next two decades.

Smart Materials and Manufacturing Are Building a New World

By 2040, advances in novel materials, coupled with smart manufacturing, will reshape the production of everything from consumer goods to high-end military systems, reducing costs, extending capabilities, shifting supply chains, and enabling entirely new design options. The period of rapid change we are entering is often referred to as a fourth Industrial Revolution because of its potential to improve standards of living while possibly disrupting traditional industries, jobs, supply chains, and business models.

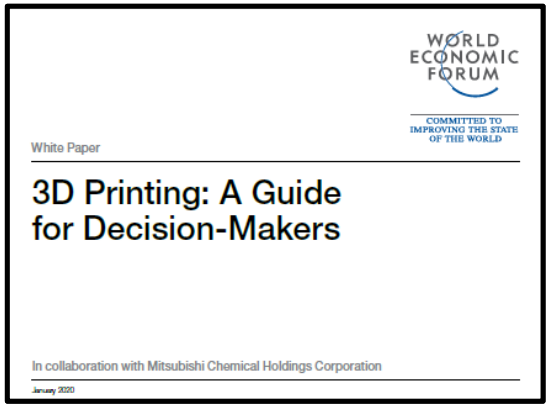
Increased Design Options. Additive manufacturing (AM), more commonly known as 3D printing, is being used to fabricate an increasing variety of materials, from titanium to explosives, in smaller facilities and with less expertise, bringing advanced manufacturing capabilities to small companies and individuals worldwide. Despite some technical hurdles and questions of reliability, AM is driving a revolution in modern manufacturing by enabling rapid prototyping, highly customized parts, onsite production, and the fabrication of shapes that would otherwise be impossible.

National Intelligence Council. 2021. Global Trends 2040: A more contested world. https://www.dni.gov/index.php/gt2040-home/gt2040-structural-forces/technology

3D printing is recognized as the future of manufacturing

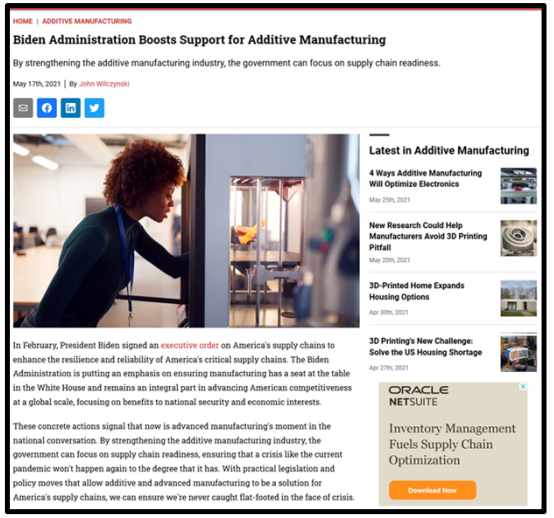
- World Economic Forum white paper (2020)
  - *3D Printing: A Guide for Decision-Makers*
  - Provides guidance on how to deal with business and policy challenges, related to 3D printing revolution.

https://www.weforum.org/whitepapers/3d-printing-a-guide-for-decision-makers



- Biden Administration to boost support for 3D printing to alleviate supply chains disruptions (May 2021)
  - 3D printing predicted to revolutionize the manufacturing industry
  - US Department of Defense published its *Additive Manufacturing Strategy* (January 2021)

https://www.manufacturing.net/additive-manufacturing/blog/21439930/biden-administration-boosts-support-for-additive-manufacturing

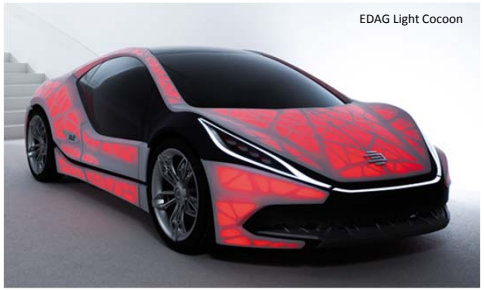


3D printing is already changing many industries

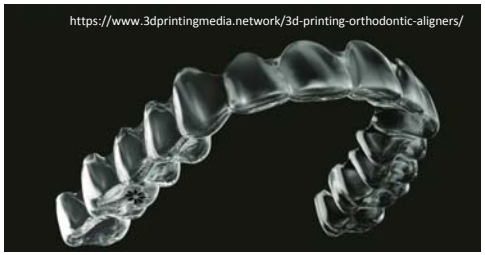
- 3D printing has been rapidly changing several industries
  - Aerospace
    - Boeing and Airbus announced 600 and 1000 3D-printed parts respectively in their new planes
  - Automotive
    - Quality-focused automotive manufacturers are using 3D printing today
      - BMW, Audi, Porsche, Ford, Volvo, Bugatti, GM, Rolls Royce, Daihatsu, VW, Alfa Romeo
        - https://3dprintedparts.com/2021/07/07/3d-printing-for-the-automotive-industry/
  - Healthcare
    - Dental
      - 3D printing offers mass customization of orthodontic aligners
      - Local, faster production
    - Hearing aids
      - True custom fit, enhanced sound and comfort

https://3dprint.com.cdn.ampproject.org/c/s/3dprint.com/262742/boeing-777x-takes-first-flight-with-over-600-3d-printed-parts/amp/

EDAG Light Cocoon



https://www.3dprintingmedia.network/3d-printing-orthodontic-aligners/



How about 3D printing for lighting?

3D printing for lighting

- For over a decade, lighting manufacturers have used 3D printing for prototyping (form and fit analysis).
- More recently, several companies have adopted 3D printing technology to manufacture end-use, decorative components for luminaires.
  - Some of these components are made with recycled or recyclable materials
    - CDs, recyclable wood and corn pulp materials, PET water bottles, PLA

Signify

Decimal https://settingmind.com/decimal-is-manufacturing-3d-printed-light-fixtures/

Gantri

Signify

LumenART

Interplay Lighting (Acuity Brands)

HP

LimeLite (AUS)

3D printing for lighting

- Tempo Lighting
  - manufactures components for LED based lighting systems for theater venues using Stratasys printers

www.stratasys.com/explore/blog/3d-printing-illuminates-the-movies

- AEC Illuminazione
  - manufactures several luminaire components using HP MJF printers

https://youtu.be/hCsR7UFB2xM?list=LL

- Gantri
  - manufactures custom table, floor, and wall lamps using printing technologies including Ultimaker printers

https://ultimaker.com/learn/gantri-shedding-light-on-unique-3d-printed-designs

3D printing materials for lighting fixture

- Many companies have started developing materials for 3D printing
  - Henkel offers materials for
    - housings for LED light fixture
    - optically clear optics for lighting applications

      https://loctiteam.com/wp-content/uploads/2020/07/DSGN0006589_Case-Study-LED_A4_V5_.pdf
  - Covestro is one of the companies that offer recycled PET material for 3D printing

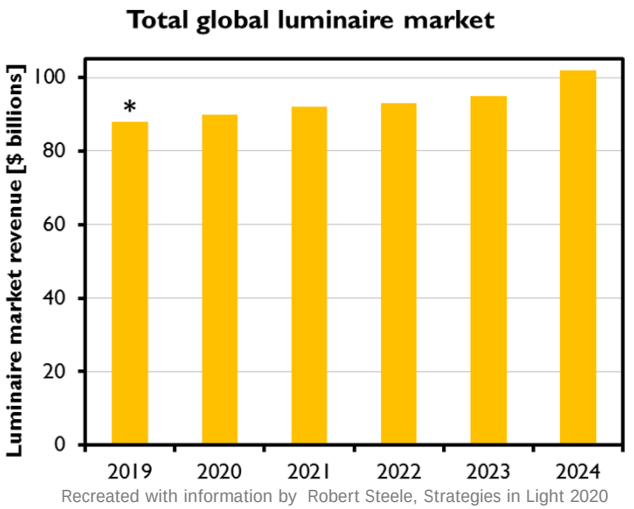
    https://www.dsm.com/additive-manufacturing/en_US/insights/infocenter-news/2021/2021-05-04-covestro-introduces-3d-printing-material-made-from-recycled-pet.html
  - Desktop Metal offers metal printers and materials for different industries
    - metals, composites and carbon fiber materials
      - Copper and other metals for heat sinks

LED housing printed using SLA and LOCTITE material.

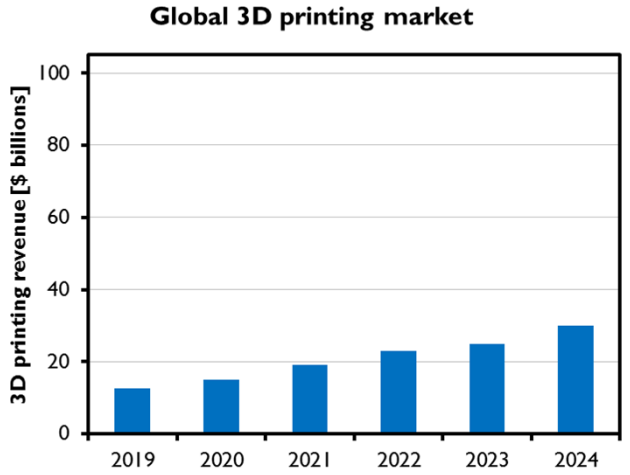
Henkel, Nexa3D

Lighting and 3D printing markets

- Lighting luminaire market size:
  - $88 billion in 2019
    - projected to reach $100B by 2024
- 3D printing market size:
  - $13 billion in 2019
    - projected to reach $30 billion by 2024
- Lighting offers a significant opportunity to the 3D printing industry
- 3D printing can enable the lighting industry to produce cost-effective, high quality, custom lighting fixtures in the US

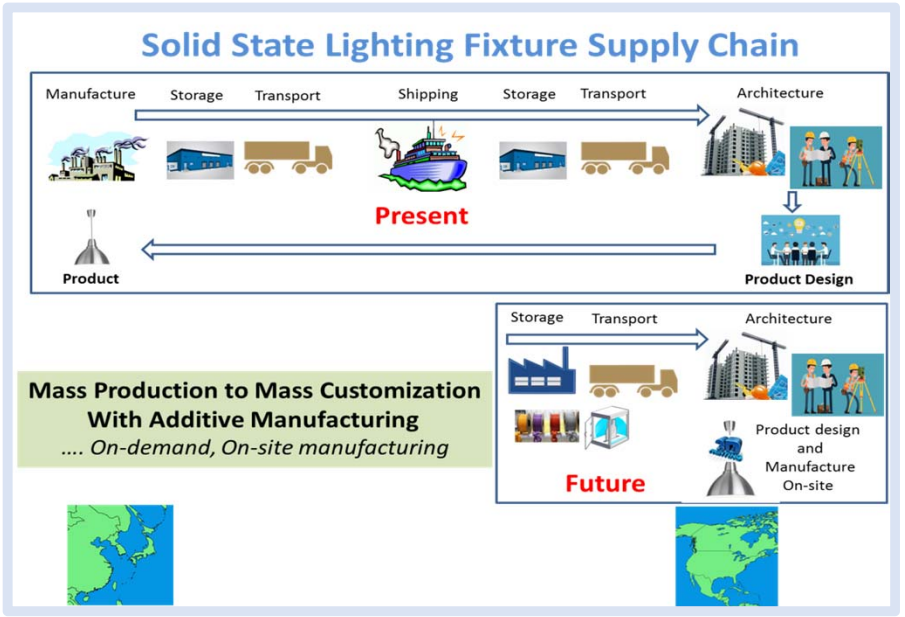


Recreated with information by Robert Steele, Strategies in Light 2020



Benefits of 3D printing LED lighting products

- Current lighting industry
  - LED lighting fixtures or subassemblies are manufactured overseas and shipped to the US
    - LED products have become a commodity
  - Problem
    - Long lead time to receive manufactured products, Increased carbon footprint, Questionable reliability, Prone to supply chain disruptions
- Lighting trends for the next five years
  - Lighting fixtures with more functionality
  - Sensors, radios, microprocessors, etc. (IoT ready)
- 3D printing holds the promise to revolutionize the lighting industry
  - Affordable custom lighting fixtures, made on-site, on-demand
  - Bring lighting fixture manufacturing jobs back to the US

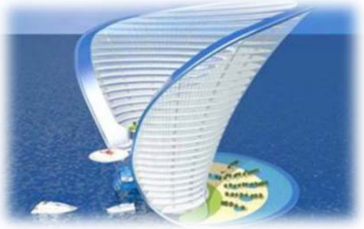


Our Vision - *Change Architectural Lighting Practice*

- On-demand, on-site, manufacturing of custom light fixtures using 3D printing

Change Architectural Lighting Practice

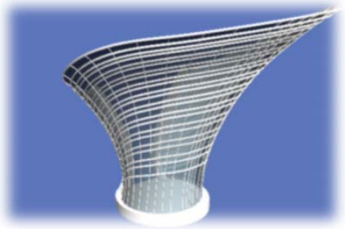
Building design



Construction

Interior finishing

Custom lighting fixture design



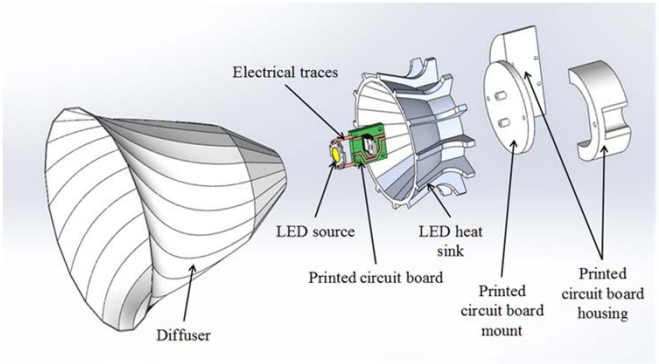
On-site 3D printing

Interior lighting with custom fixtures

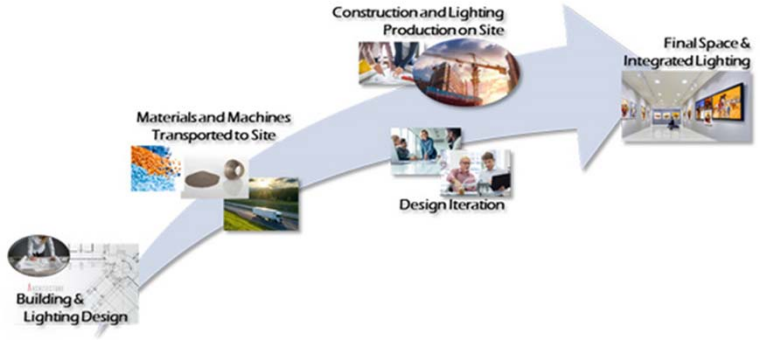
Preparing to realize this vision

- In 2015, the LRC started exploring the possibilities and challenges for 3D-printing complete, functional LED lighting fixtures using commercially available printing technologies and materials
  - LED lighting fixture subsystems include
    - Thermomechanical, electrical, and optical
- In 2019, the LRC formed **ASSIST 3D Printing for Lighting**, an industry consortium to lead the next revolution of the lighting industry
  - **Inaugural members**

carbon — Accelerator | Advisory | Talent
Desktop Metal
DSM — BRIGHT SCIENCE. BRIGHTER LIVING.
FINELITE — Better Lighting
Henkel
hp
HUBBELL Lighting
PROTOLABS — Manufacturing. Accelerated.
tempo
Ultimaker
Varroc — EXCELLENCE



Mass Production to Mass Customization With Additive Manufacturing
.... On-demand, On-site manufacturing



https://www.lrc.rpi.edu/programs/solidstate/3DConsortium.asp

Consortium activities

- The objective is to bring together lighting and 3D printing industry stakeholders to get to know each others' capabilities and needs
  - Work together to prepare for the next lighting revolution

- Initial study: Understand the state of 3D-printed components for light fixtures
  - LRC characterized and benchmarked 3D-printed components produced by consortium members against parts made with traditional methods
    - Thermal – MR16 lamp heat sink to maintain Tc <105°C
    - Optical – 25° beam TIR lens
    - Mechanical – lamp holder

Consortium Members

amerlux

Desktop Metal

Ford

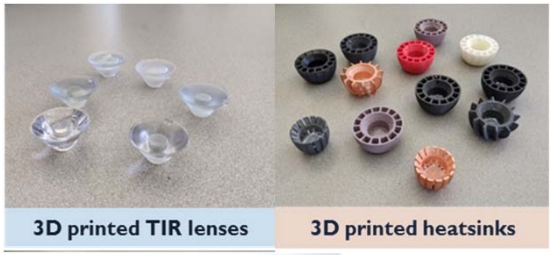
hp

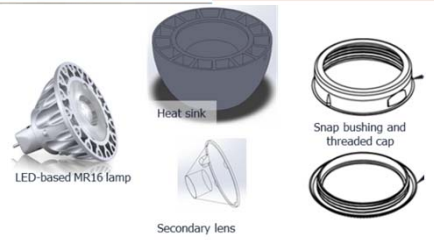
HUBBELL Lighting

stratasys

SYNOPSYS

Ultimaker



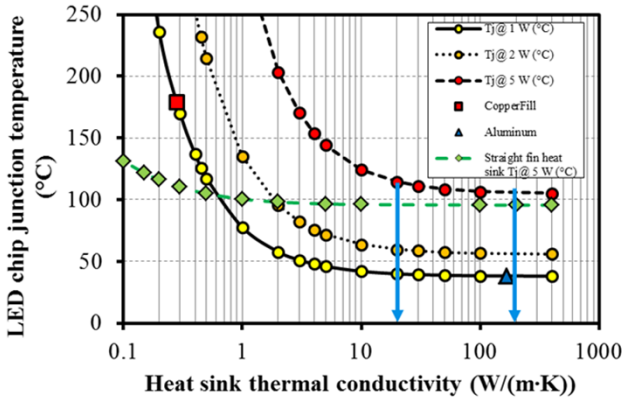


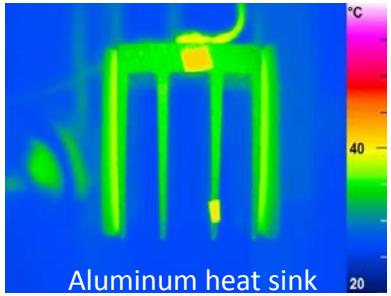
Research Activities

Thermomechanical

Heat sinks for thermal management

- Heat sinks are required in LED light fixtures to ensure reliable performance
  - Most heatsinks are made out of metal
    - Aluminum
  - LRC studies showed that aluminum is an overkill for most indoor LED light fixtures
- 3D-printed composite heatsinks can be a good solution
  - Composites with tailored thermal conductivity
- Considerations for designing and making effective heat sinks
  - Thermal conductivity of the material
    - To conduct the heat away from the LED junction
  - Geometry of the heatsink to help convection





Heat sink geometry effects thermal performance

- Heat sink geometry plays an important role in thermal management
- Horizontal ½ symmetry design is better compared to the lattice design
- Opportunity for 3D printing heatsinks
  - Creating novel heat sinks that are functional yet unique, contributing to the fixture aesthetic
    - Cannot be easily done with traditional manufacturing methods

Lattice design

Horizontal (1/2 symmetry)

Heat Sink Concepts: Complex Functional Component + Design Feature

Joe Alexandersen, Ole Sigmund, Knud Erik Meyer, Boyan Stefanov Lazarov, "Design of passive coolers for light-emitting diode lamps using topology optimization" J Heat and Mass Transfer, 122 (2018) pp. 138-149.
Privitera, O. 2018. Print Parameter Effect on Thermal Performance of 3-D Printed Components for Solid State Lighting Fixture Applications. NYC IES Thesis Award Presentation.

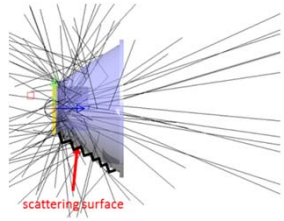
Research Activities

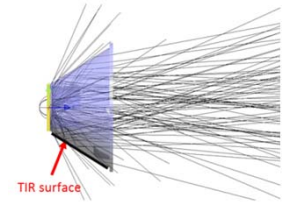
Optical

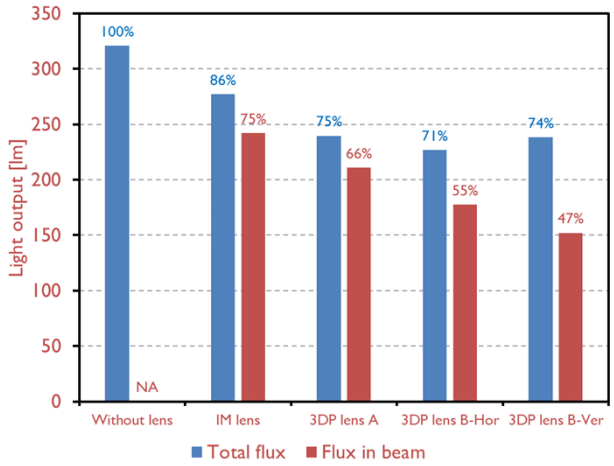
Optical components

- Optical components are needed to tailor the beam to improve system efficacy and beam distribution
  - Reflectors and lenses

- LRC researchers characterized TIR lenses produced by consortium members
  - Beam distribution
    - ~30° FWHM was achieved
  - Efficiency
    - ~10% lower than to injection molded lens
    - Optical efficiency and beam distribution is lower than target due to scattering of the light at the side walls
    - Print resolution and post processing could reduce scattering



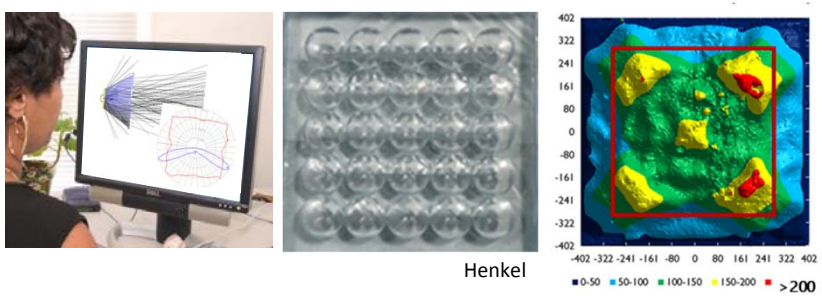




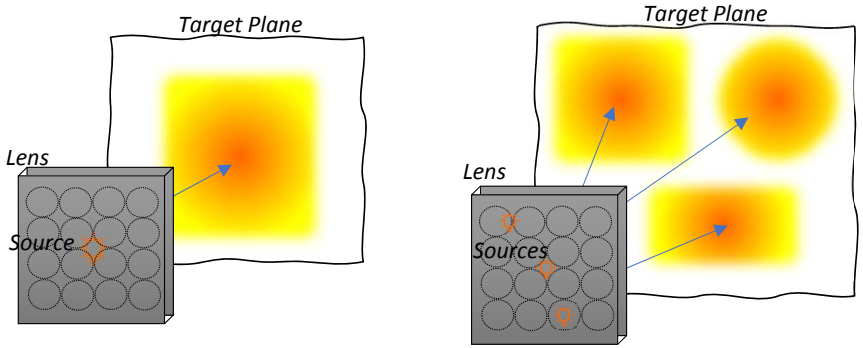
Sponsor: ASSIST 3D for Lighting

3D printing offers an opportunity for novel optics

- Optical ray tracing to design novel optics to achieve high application efficacy and custom beam distributions



- Ph.D. Student thesis study (Akila Udage, 2021)
  - Novel optics to produce multiple beam patterns from the same lens by changing the LED(s) position

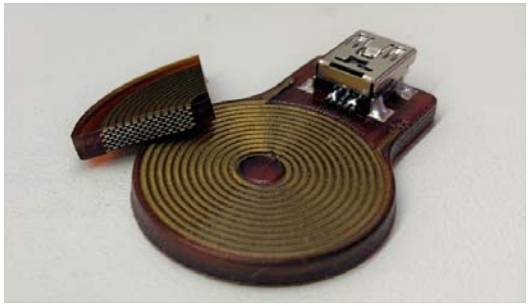


Research Activities

Electrical/electronics and Communication

Electrical components

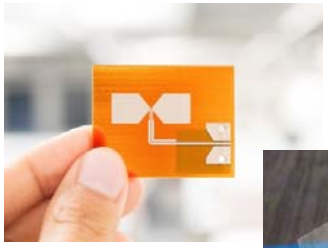
- Electrical components are needed for the operation and control of the light sources, and for communication
  - LED drivers, sensors, interconnects, antennas, etc.
- 3D-printed electronics have advanced drastically the design possibilities for printed circuit boards (PCBs)
  - Multiple sided boards
  - 3D layers, with interconnects in all directions
  - Functional circuits by combining conductive and dielectric materials
  - Flexible and rigid materials
  - Possible to print resistive, capacitive, and inductive components; high frequency antennas



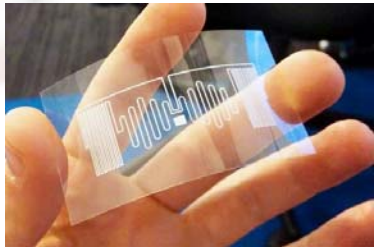
Nano Dimension

Electrical components

- High frequency antennas
  - A research focus area for 3D printing electronics
  - Control over the dielectric value of the inks results in improved antenna performance
    - Lower dielectric constant reduces parasitic capacitance in the circuit – enabling wider traces, thus stronger signals

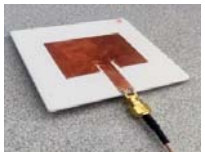


Nano Dimension

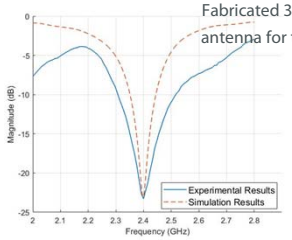


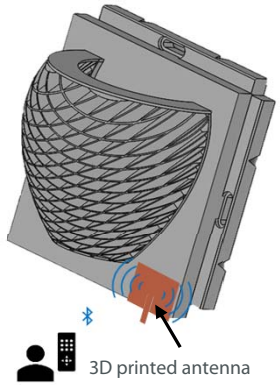
Voltera

- LRC study
  - Problem: Bluetooth radio signal attenuated by fixture housing
  - Objective: To investigate the use of 3D-printed antennas for connected lighting systems with Bluetooth low energy
  - Results: Showed 3D printing antenna on external surface of a light fixture can improve signal strength and thus the reliability of communication



Fabricated 3D-printed antenna for the study.





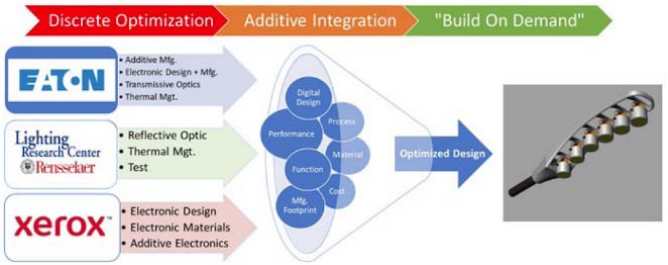
Reference: A. Udage, and N. Narendran; "Investigation of the use of 3D-printed antenna for connected lighting systems" IESNA Virtual conference, Aug 9-13th, 2021

Industry Collaboration: 3D-printed SSL luminaire

- Objective: To produce an additively manufactured SSL luminaire
  - Fully functional, 3D-printed outdoor luminaire with high application efficacy
    - Optimized for cost, material, and performance
    - Designed and 3D printed thermomechanical, optical, and electrical components and analysis

- Team activities
  - LRC – Optimized heat sink, and reflective & transmissive optics for high application efficacy
  - Eaton – AM, materials, system integration
  - Xerox – Printed electronics

Sponsor US DOE



Project goals

Category	Proposed Target
Material Reduction	≥50% reduction
Manufacturing Process	≥ 50% reduction in process steps
Application Efficacy	130 lm/W
First Cost	≤ 50% Baseline

3D printing for lighting gains recognition

- A recent US DOE report
  - Identifies several opportunities for increased US presence within the LED lighting supply chain
    - Manufacturing lighting fixture components using 3D printing with fewer process steps or more automation
    - Manufacturers have indicated that R&D is needed to support 3D printing and to make it competitive in the United States

- 3D printing has the potential to solve many of the issues faced by the lighting industry
  - Reduce manufacturing and transportation carbon footprint
  - Avoid supply chain disruptions
  - Better quality and reliability
  - Bring back manufacturing jobs to each locality

https://www.energy.gov/eere/buildings/articles/new-report-examines-led-manufacturing-supply-chain-opportunities-domestic

3D printing for lighting and architecture

Architecture: 3D-printed homes

- The construction industry has already begun to use 3D printing

- First 3D-printed house for sale in New York (Feb. 2021)
  - Livable area: 1,900 ft²
  - Print time: 48 hours, spread over eight days
  - Builder: SQ4D, Inc.

- 3D printing promises to build houses faster, cheaper, and more accurately with fewer people
  - 3D printable materials expected to provide thermal and noise insulation, and permeability advantages over traditional materials

www.designboom.com/architecture/first-permitted-3d-printed-house-sq4d-hits-the-market-us-02-18-2021/

https://www.ctpost.com/realestate/article/A-look-at-the-Northeast-s-first-3D-printed-home-16069237.php

https://3dprintingindustry.com/news/google-3d-printing-78016/

https://all3dp.com/2/2019-best-companies-building-3d-printed-houses/

Architecture: 3D-printed homes

- The momentum for 3D printing in architecture is building up globally

Netherlands

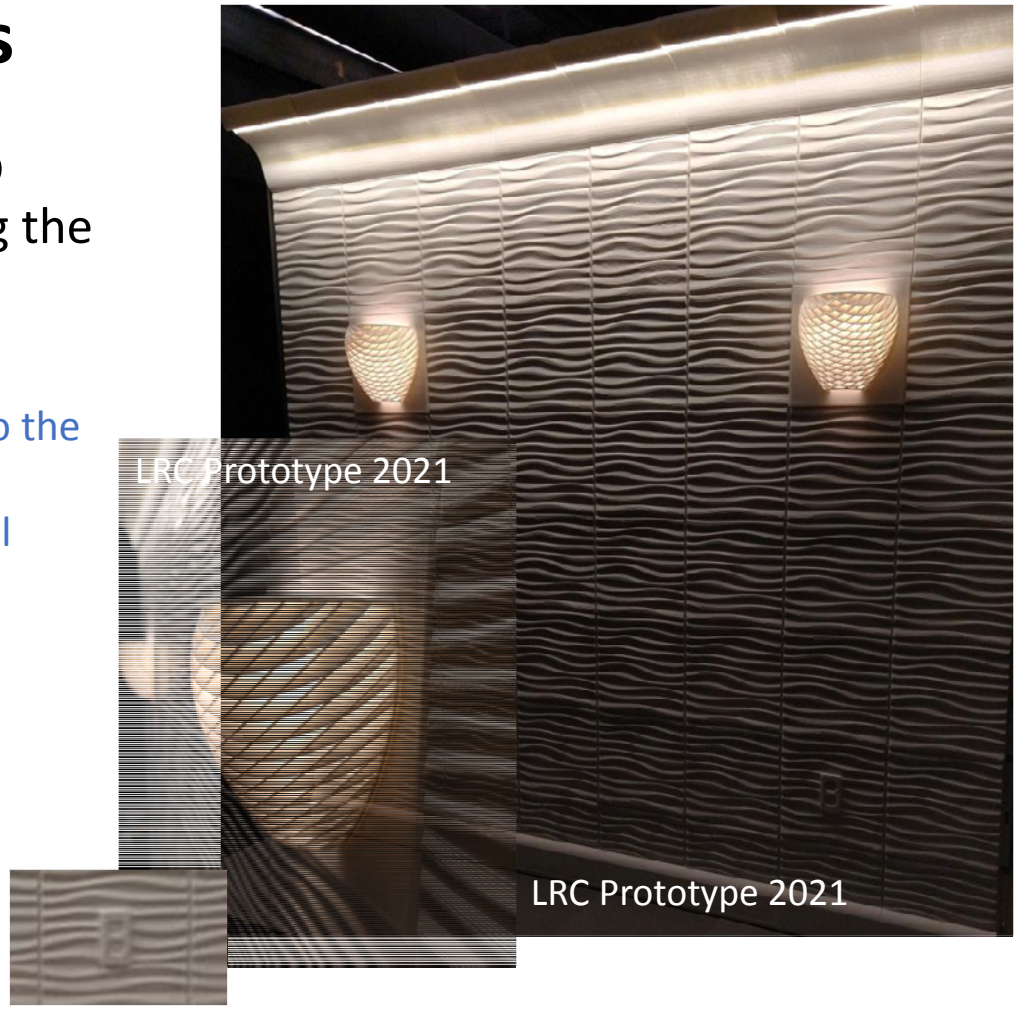
India

Germany

Mexico

Architecture: Building interiors

- LRC researchers have been exploring how 3D printing can reduce time and cost of finishing the interior walls of the buildings
- 3D printing building interior
  - Prewired decorative wall panels mount directly to the building's frame
  - Includes 3D-printed lighting fixtures and electrical outlets
  - Include insulation and acoustic features



Architecture: Building interiors

- 3D printed finished wall panels
  - Print on-demand, on- or near to job site
  - Reduced time and cost
    - Avoids multiple-step process that needs to be coordinated among different trades:
      - installing electrical boxes
      - installing drywall, taping, finishing
      - installing light fixtures
      - installing trims and moldings
      - installing decorative wall finishes
      - painting

Building and finishing an interior wall

Getting the message out

LRC's outreach education

- In-person and online programs
  - 3D Printing for Lighting (next 6-week class starts September 8, 2021)
  - Graduate and undergraduate education
    - PhD students
  - Latest research findings are shared in these classes

    Topics covered:
    - Introduction to the 3D printing process
    - Comparison of 3D printing processes and technologies
    - 3D object creation with computer-aided design (CAD)
    - Optical component printing, including transmissive and reflective optical components
    - 3D printing heat sink design and printing
    - Measurement and analysis of 3D-printed components

www.lrc.rpi.edu/education/outreachEducation/3d.asp

Hands-on experience at LRC's institutes

3D-printed light fixtures by LRC students

Summary

- The National Intelligence Council has identified AM as a game changer in their Global Trends reports
  - One of the advanced technologies that could boost economic productivity while addressing concerns due to growing world population, rapid urbanization, and climate change
  - Lighting will follow other industries in taking advantage of the benefits of 3D printing
- The opportunity and timing for committing to 3D printing for lighting is now
  - The World Economic Forum, the US DOE, and the Biden Administration at large recognize the potential positive impact of 3D printing on the US economy
- Understanding the state of the art in 3D printing can help lighting manufacturers get started in transitioning to digital manufacturing
    - Several lighting companies are already exploring how to use 3D printing in their production lines
- 3D printing is one way to transform lighting's commodity business model into a value-added business model

National Intelligence Council. 2012. Global Trends 2030
National Intelligence Council. 2021. Global Trends 2040: A more contested world. https://www.dni.gov/index.php/gt2040-home/gt2040-structural-forces/technology

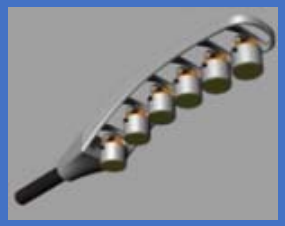
3D printing for lighting adoption roadmap

1 to 5 years

Functional components

- Mounting hardware
- Housings
- Decorative shades and diffusers
- Heat sinks for low to medium power dissipation (10-50 W)

5 to 10 years



Integrated luminaires

- Heat sinks for high power dissipation (>100 W)
- Integration of drivers, sensors, and antennas
- Long life, advanced TIR and reflective optical elements

10+ years

3D printed fixtures

Architecture integration

- More than 20% of the light fixtures are 3D printed
- Manufactured on- or near job site
- Custom lighting elements integrated into architecture

Acknowledgements

- ASSIST 3D Printing for Lighting sponsors
- Strategies in Light organizers
- LRC's 3D printing for lighting research team

N. Narendran, Ph. D.
Director of Research
narenn2@rpi.edu

Indika Perera, Ph. D.
Research Scientist

Jean Paul Freyssinier, M.S.
Senior Research Scientist

Jennifer Taylor, M.S.
Senior Communications Specialist

Sachintha De Vas Gunawardena
Ph. D. Student

Akila Udage
Ph. D. Student