INNOVATIONS IN ADDITIVE MANUFACTURING WILL DRIVE THE NEXT LIGHTING TRANSFORMATION

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Images: LRC

FIGURE 1. 3D-printed heat sink for LED lighting systems.

Since the introduction of the first commercially successful light source more than 140 years ago, the lighting industry has gone through numerous transformations in technology, manufacturing, measurement, and application. In the most recent transformation, a white light emitted from a tiny semiconductor chip came on the scene and proceeded to completely change the way we design, manufacture, and even think about lighting. Now twenty years later, LED lighting has matured and replaced most older lighting technologies, and energy savings is guaranteed in nearly every application. With this maturity, however, LED lighting has become a commodity product whose price has continued to fall. While the erosion in price has helped to transform the market by making it more economical for consumers to choose LED lighting, it is not uncommon for these lamps and luminaires, often produced in overseas factories, to suffer from poor quality and performance, leading to disappointment and further decline.

With lighting manufacturers scrambling to stay competitive, the industry has worked to increase its ability and resources to provide greater levels of customisation and quality in luminaires and lighting components. Although LEDs have allowed for new luminaire designs that had not been possible with traditional light bulbs and tubes, there still have been limitations because traditional manufacturing methods cannot produce more intricately designed components at an affordable cost, and traditional materials (namely, aluminium) may result in higher cost and added weight in some applications. Custom designs produced using traditional manufacturing methods can also be very expensive. Additive manufacturing (AM), which has been rapidly changing other industries such as automotive, aerospace, and medical technology, has the potential to solve many of the issues faced by the lighting industry. Since 2015, the Lighting Research Center (LRC) at Rensselaer Polytechnic Institute has been exploring the possibilities of using AM, also known as 3D printing, for innovative lighting products and system components.

WHY ADDITIVE MANUFACTURING?

The latest trends in lighting have involved add-ons that provide more value to a light luminaire than just the photons emitted or energy saved. These include all kinds of sensors and wireless connections to detect and transmit information about both the light source itself and the environment where it is being used. Additionally, architectural designers seek unique lighting solutions that contribute to or harmonise with the visual impact desired for the space. In the commercial building sector, each customer is looking for a different set of value-added components, making customisation of light luminaires a necessity. With AM, the value proposition is mass customisation rather than mass production. In theory, the benefits of AM for lighting include:

- the ability to customise components and luminaires that better match the building space while improving visual appeal and function;
- luminaire designs that can be changed rapidly to match last-minute architectural design changes, reducing construction delays;
- lower costs as a result of fewer integration steps;
- a reduced need for stocking systems and parts (SKUs);
- a movement toward localised manufacturing businesses offering local jobs, reducing requirements and costs for transportation and storage, and cutting carbon emissions;
- an overall better quality, custom light luminaire produced on site and on demand.

In general, the idea is to change architectural lighting practice by changing the present-day supply chain and production model. In the past 18 months, several lighting manufacturers have introduced 3D-printed decorative lighting luminaires in an effort to tap into this growing market, even though the concept is still in its infancy. With 3D-printed lighting soon on the horizon, research is needed to understand how AM can be used and what technology developments are still needed to create successful lighting luminaires. Additionally, the lighting and AM industries need to collaborate to understand each other's processes and requirements.

AM RESEARCH AT THE LRC

In the past five years, LRC researchers have investigated the feasibility of 3D printing the mechanical, thermal, electrical, and optical components of lighting luminaires. AM uses a layer-by-layer "additive" construction process to produce a three-dimensional product. The process depends on the type of 3D printer used and the material being dispensed by the printer. Existing 3D printing processes include vat photopolymerisation (e.g., stereolithography), material extrusion, material jetting, powder bed fusion and others. 3D print materials include polymer, metal, ceramic or various combinations of these. At the LRC, the first step has been to gain further knowledge on how well these different printing processes and materials can be used for producing components such as heat sinks, secondary optics, and mechanical parts.

In one study, we examined whether custom heat sinks with suitable thermal properties could be printed to keep the LED junction temperature low enough to ensure optimal system performance[1]. Past studies have shown that the heat sink contributes to nearly 40 percent of total luminaire cost and that aluminium heat sinks often have thermal conductivity properties that are excessive for many indoor light luminaires. In the LRC lab, we 3D printed heat sinks (Figure 1) using composite polylactic acid (PLA) filaments with thermally conductive fillers and a material extrusion processing method called fused filament fabrication (FFF). We tested and compared the thermal conductivity of these polymer-based heat sinks against a traditionally manufactured aluminium heat sink and a 3D printed metal heat sink. This experiment showed that presently available printing materials have thermal conductivity values adequate for low- to mid-power LED applications with low heat densities, but these values are two to four times lower than required for most high-power LED systems. The 3D-printed metal heat sink had a performance similar to that of the traditionally manufactured aluminium heat sink. We also found that the print orientation and print layer height affected the heat sink's performance.

While the thermal conductivity properties of polymer heat sinks may not yet be at the necessary level for some LED luminaires, the advantage of 3D-printed heat sinks is in the ability to produce novel geometric designs that can produce better heat dissipation through convection (Figure 2). With a higher level of heat dissipation, the thermal conductivity of a polymer material may not need to match that of aluminium.

In another study, we 3D printed several reflective and transmissive secondary optics and used them in LED

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FIGURE 2. Renderings of novel heat sink designs for 3D printing.

Image: LRC

FIGURE 3. 3D-printed secondary lenses for LED lighting systems.

systems to understand the short- and long-term optical properties of 3D-printed optical components; their light transmission and scattering properties as a function of print resolution and print orientation; and their changes in reflected and transmitted light as a function of time[2]. Two types of reflective PLA material and a single type of copolyester with no styrene (CoP) were used to print optics samples in different thicknesses by varying the extrusion width or the number of extrusions. We found that reflective optics with good performance can be additively manufactured from available print materials but better materials are needed to produce reliable transmissive optics. LRC testing showed that reflectance increased as the sample thickness increased and that it remained nearly constant over more than 2,000 hours of testing at a 50°C elevated temperature test environment. For transmissive optics, print resolution and print orientation affect light transmission and scattering, with increased print resolution and in-plane print orientation increasing light transmission and decreasing light scattering; however, transmissivity decreased with every millimeter in thickness. Similar to heat sinks, 3D printing is ideal for novel optics designs not easily produced through traditional manufacturing methods (Figure 3).

Using the knowledge gathered to date, the LRC is now partnering with Eaton Corporation and Xerox Research Centre of Canada on a project to develop a complete, additively manufactured, LED-integrated luminaire with funding from the United States Department of Energy.

COLLABORATION

While continuing our research focus, as a second step the LRC has been working to bring together lighting and AM industry stakeholders to cooperate on research and educational activities. Last year, the LRC established a collaborative alliance of lighting and 3D printer and material manufacturers, known as the Additive Manufacturing for Lighting Consortium (https://www.lrc.rpi.edu/programs/solidstate/3DConsortium.asp), to direct these activities and develop a roadmap toward customisable, value-added lighting luminaires. At the beginning of this year, the LRC and its members conducted a pilot project to print and test several components, including heat sinks, transmissive optical lenses, and mechanical holders for integrating luminaire components. AM manufacturers within the consortium printed samples following common design specifications for those parts, and the LRC compared their performance with similar, traditionally manufactured components. The results are promising with the right combination of print method and material, and consortium members now have a better understanding about which AM print and material technologies work well and what developments are still needed to make AM beneficial to the lighting industry. In regards to education, the LRC has expanded its outreach education programs to include updates on 3D printing research and how lighting luminaire manufacturing can benefit (http://www.lrc.rpi.edu/education/outreachEducation/InHouseInstitute.asp).

Given the promising opportunities that AM can offer to the lighting industry, we expect that interest in 3D printing technology will continue to grow and eventually become an integral part of the manufacture of cost-effective, custom light luminaires within the next few years. Research and collaboration will be essential to progress in this area and to the development of improved materials and processes for making parts that can compare with traditionally manufactured components.

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