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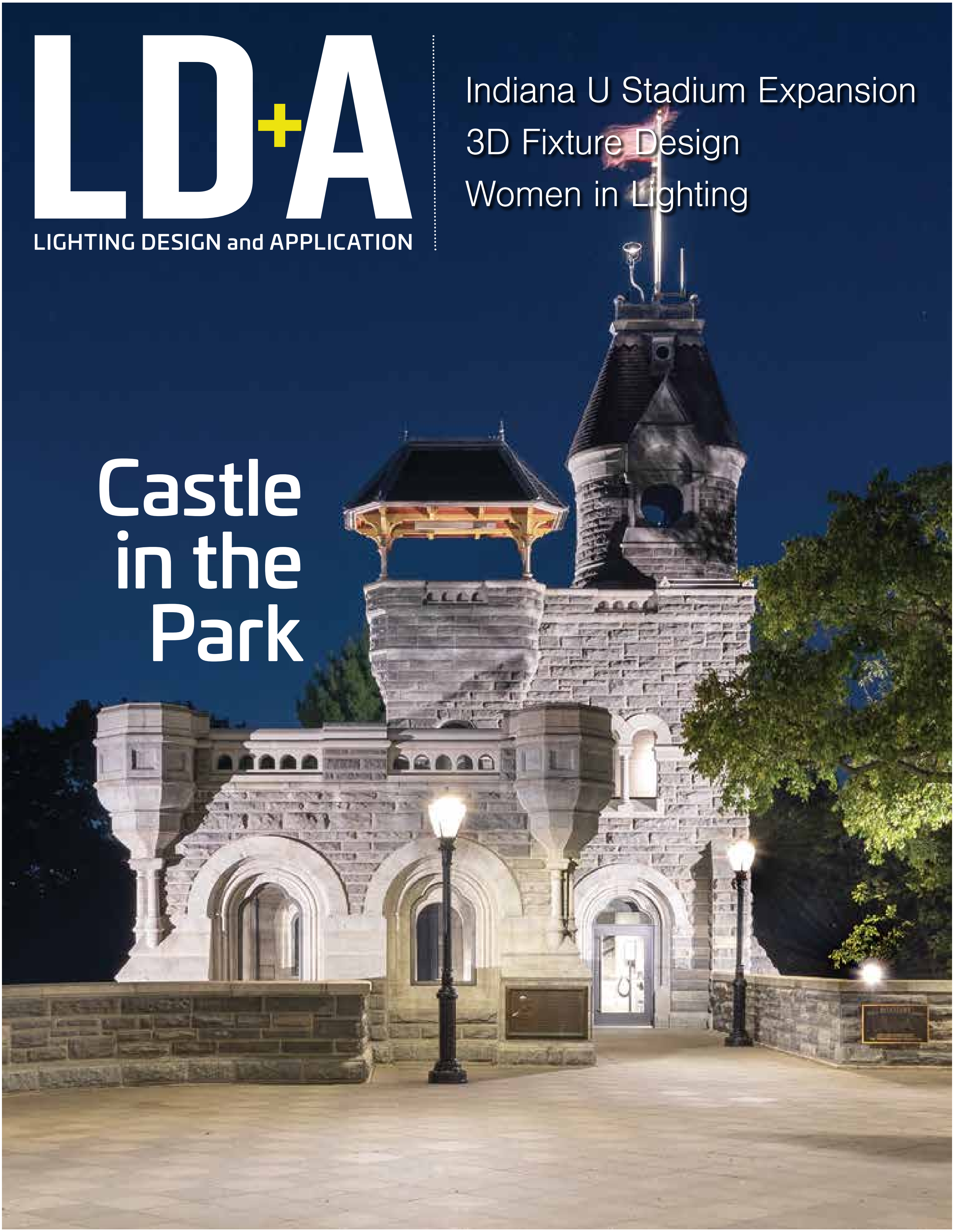

Castle in the Park

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3D Printing: Can It Work for Lighting?

Lighting industry news in recent years has been awash in stories proclaiming both the death of the lighting industry as we know it and its potential rebirth through new value-added technologies and applications. One such technology that has made its way to the forefront is additive manufacturing, better known as 3D printing. Additive manufacturing has been declared by some as the future of manufacturing and as a game-changer for the global economy.

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A number of industries have already adopted 3D printing on a large scale, including automotive, aerospace and medical technology. In just the past few months, aircraft manufacturing giants Boeing and Airbus both announced that the Boeing 777X and Airbus A350 XWB will have 600 and 1,000 3D-printed parts, respectively. Similar news has appeared from the automotive and medical and dental industries as well, indicating the maturing of the 3D printing industry. But can 3D printing work for lighting?

First, what is 3D printing? In general, it is a process by which 3D objects are formed by the addition of materials one layer at a time, thus the name "additive" manufacturing. Presently, there are several 3D printing processes, including vat photopolymerization (e.g., stereolithography), material extrusion, material jetting and others. The print process chosen depends on the type of material to be used for printing, whether it be polymer, metal, ceramic or some combination.

If 3D printing is working now for a number of uses, the next question becomes: Why 3D printing for lighting? Where is the value in additive manufacturing of lighting parts and fixtures and what problems can be solved? It has become clear that the erosion of both price and fixture quality has hit the lighting industry hard. LEDs have become a commodity product, and the majority of LED fixture manufacturing has moved overseas. This has forced U.S.-based manufacturers to seek ways of reducing costs without compromising quality. Recent trends in the lighting industry include lighting fixtures with built-in radios for wireless connection to control light and color, and with sensors for detecting a variety of factors like occupancy, daylight, toxic gases and others to make built environments more intelligent. Such trends call for custom light fixtures.

With a 3D printing solution, the value proposition becomes mass customization, rather than mass production, and the ability to customize fixtures that better match with the built environment and improve visual appeal and function. Scientists at Rensselaer's Lighting Research Center (LRC) envision the future of architectural lighting practice involving on-site, on-demand printing of cost-effective, custom light fixtures. In theory, these custom fixtures can be made at a reduced cost because they are manufactured close to the construction site, have fewer integration steps, and have a reduced need for transport and storage. Additionally, fixture designs can be changed rapidly to match last-minute architectural design changes.

Overall, the vision is to change architectural lighting practice by changing the current supply chain and production model. With additive manufacturing, fixture production would move to local manufacturing businesses offering local jobs, which would reduce requirements for transportation and storage, cut carbon emissions and result in better quality, custom light fixtures. In fact, a few lighting manufacturers have already begun to market 3D-printed light fixtures, primarily for decorative lighting. In terms of market size, this year the 3D printing industry is expected to grow above $21 billion, tripling since 2016,[1] while the lighting fixture market is expected to grow above $35 billion this year.[2]

This brings us to the primary question to be addressed: Can 3D printing work for lighting? When LEDs first came onto the scene 20 years ago, one big obstacle was that LED chip manufacturers from the semiconductor industry didn't understand the requirements for successful lighting fixtures, and lighting manufacturers didn't understand the operational needs of LED chips. Many years of collaboration, communication and research were necessary to bring these two disparate industries together.

Today, 3D printing and lighting are on a similar track. At the LRC, we have been investigating the feasibility of currently available 3D printing materials, technologies and processes at supporting the thermomechanical, electrical and optical needs of lighting fixtures. The LRC also established last year 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 this research and develop a roadmap toward customizable, value-added lighting fixtures. With the goal of understanding the potential of 3D printing for lighting, the LRC has published some preliminary findings for two types of lighting components: heat sinks and secondary optics.

Heat sinks

Metal heat sinks are commonly used in LED systems to keep LED junction temperatures low for optimum system performance. Studies have shown that the heat sink is one of the highest cost components in a light fixture today, reaching nearly 40% of the total fixture cost. LRC studies have shown that thermal conductivity properties of aluminum heat sinks are excessive for most indoor light fixtures. Additive manufacturing of composite material heat sinks could potentially reduce the weight and cost of an LED system, optimize the thermal management and produce better visual appeal.

A 3D-printed decorative wall sconce developed and manufactured at the LRC (designed by Oshadhi Madihe Eshwarage, LRC).

$21 billion

Estimated size of the 3D printing industry in 2020

Source: *ComputerWorld*

LRC researchers studied whether custom heat sinks with suitable thermal properties could be printed to keep the LED junction temperature below 85°C to ensure optimum system performance. In this study, we investigated composite polylactic acid (PLA) filaments with thermally conductive fillers and used a processing method called fused filament fabrication (FFF) to test the thermal conductivity of heat sinks that

A 3D-printed heat sink atop a fixture printed at the LRC (left), and a rendering of a novel heat sink design (designed by Olivia Privitera, LRC).

were 3D printed in our laboratory.

In general, we found that presently available materials have a thermal conductivity adequate for low- to mid-power LED fixture applications with low heat densities. However, the tested composite materials had thermal conductivity values that were two to four times lower than required for most high-power LED systems. Alternatively, 3D-printed metal heat sink performance was similar to that of traditionally manufactured aluminum heat sinks. We also found that the print orientation and print layer height affected the heat sink's performance.[3]

Another aspect to be considered for optimum thermal management is the geometric shape of the heat sink. 3D printing offers the advantage of creating novel geometric shapes than can enhance heat dissipation through convection. Some of these shapes cannot be made with traditional manufacturing methods. Furthermore, 3D-printed heat sinks can enhance the aesthetics of the light fixture, unlike traditional metal heat sinks.

Secondary optics

LED light fixtures require secondary optics for beam shaping. Typically, optical components are either reflective or transmissive, and the properties of the optical component affect fixture efficiency and beam quality. At the LRC, we 3D printed several reflective and transmissive secondary optics and used them in LED systems to understand: 1) how short and long-term optical properties are affected by using 3D-printed optical components; 2) light transmission and scattering properties as a function of print resolution and print orientation; and 3) reflected and transmitted light as a function of time.[4] For reflective optics, 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.

The results showed that reflectance increased as the sample thickness increased and that the reflectance remained nearly constant over more than 2,000 hours of testing at a 50°C ambient temperature. For transmissive optics, the results showed that both print resolution and print orientation affected the light transmission and scattering of the samples, with increased print resolution and in-plane print orientation increasing light transmission and decreasing light scattering. However, transmissivity decreased by approximately 1.5% for every mm in thickness. In general, high performance reflective optics can be printed using presently available commercial materials, but better materials are needed for making reliable transmissive optics. We also found that 3D printing is ideal for creating novel optics that cannot be easily made using traditional manufacturing methods.

The future success of 3D printing for lighting will require research, collaboration, and education. Within the Additive Manufacturing for Lighting Consortium, the LRC and its members have begun a pilot research project to print and test several components, including heat sinks, transmissive optical lenses and mechanical holders for integrating fixture components, and compare their performance with similar traditionally manufactured components. The results thus far show comparable performance for 3D-printed parts and those made using traditional methods. In terms of education, the LRC has expanded its outreach education programs to inform workshop attendees of the state of the 3D printing industry and how lighting fixture manufacturing can benefit (*http://www.lrc.rpi.edu/education/outreachEducation/InHouseInstitute.asp*). The LRC has also recently partnered with Eaton Corporation on a project to develop a complete, additively manufactured, LED-integrated luminaire under funding from the U.S. Department of Energy.

In conclusion, rapid advancements in 3D-printable materials and methods show promising results for making custom parts for light fixtures. The LRC and its consortium members have already produced improved materials and processes and made parts that can compete with those made using traditional manufacturing methods. At the present rate of progress, we anticipate 3D printing will become an integral part of the manufacture of cost-effective, custom light fixtures within the next few years. ◎

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