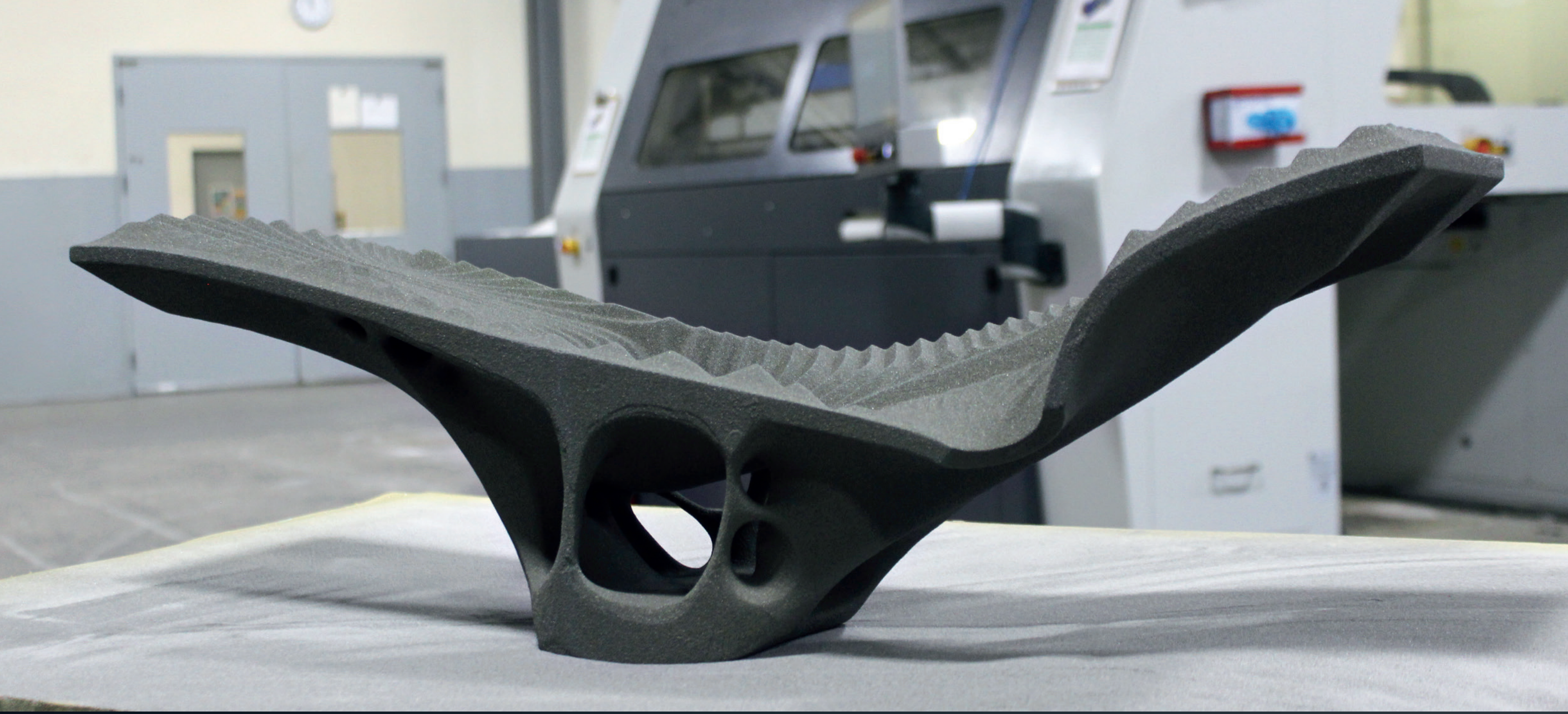


CASE STUDY

Design Research Team Reinvents Eco-Friendly Architecture and Upcycled Materials

Carnegie Mellon School of Architecture is shaping the future of building design by remodeling granular materials such as concrete into new forms that show the potential for materials reuse and sustainable designs enabled by ExOne binder jet 3D printing

Carnegie Mellon University

ExOne™

Cradle rocking planters are developed using ExOne binder jet 3D printing for local industrial-site revitalization while studying surface patterns for plant growth and rainwater collection. Material properties of reclaimed construction materials are being tested for advanced architectural designs that devolumize materials like concrete for more sustainable use and re-use.

Challenge

Investigate advanced manufacturing technologies to shape pulverized construction materials more efficiently with less volume and waste. Contribute to the revitalization of the local community with evidence-based solutions that encourage environmental sustainability and social engagement for communities most affected by historical industrial pollution.

Solution

3D PRINTER
ExOne M-Flex®

MATERIAL
Granular materials, such as concrete

SUMMARY
Carnegie Mellon University (CMU) School of Architecture uses ExOne binder jetting to investigate and re-shape architectural components that capitalize on the low carbon footprint of concrete unit mass. Cradle rocking planters were developed for local industrial-site revitalization to test material properties while studying surface patterns for plant growth and rainwater collection. Binder jet 3D printing offers the material flexibility to investigate reclaimed materials for more sustainable architecture while complex, eco-friendly designs revitalize nature and encourage community growth though environmental engagement and stewardship.

Developed by the team at the Carnegie Mellon School of Architecture, unique patterns that manage rainwater and encourage plant growth are 3D printed into the surface of sand with ExOne binder jetting.

CUSTOMER
Carnegie Mellon School of Architecture

INDUSTRY
Architecture and design

APPLICATION
Urban furniture

LOCATION
Pittsburg, PA

WEBSITE
www.soa.cmu.edu

Carnegie Mellon University

*"Ecologically intelligent customization and bespoke design are truly enabled by technology like binder jetting... You end up shaping materials differently once you start to prioritize climate-specific concerns and environmental ethics, and **3D printing allows us to design without limitations.**"*

Dana Cupkova, Associate Professor, Carnegie Mellon University School of Architecture

Carnegie Mellon School of Architecture

The Carnegie Mellon School of Architecture educates students in the discipline of architecture, emphasizing the role of creativity in architectural design; understanding architecture's historical, social and environmental contexts; critically engaging technology in architectural innovation; and working ethically to achieve social progress and justice in the built environment. It aims to produce discipline-defining designers and thinkers in diverse global contexts.

Its world-class architecture education is enhanced by its position within one of the world's leading research and entrepreneurship institutions, and by the fundamental premise that architectural excellence demands both rigorous training in fundamentals and the development of unique specializations.

Master of Science in Sustainable Design (MSSD) students at the Carnegie Mellon School of Architecture, essential to advancing the sustainable innovations of the future, are seen here displaying a small-scale cradle design with plant growth (left) and testing 3D printed materials and lattice designs (right).

ExOne

ExOne is the pioneer and global leader in binder jet 3D printing technology. Since 1995, we've been on a mission to deliver powerful 3D printers that solve the toughest problems and enable world-changing innovations. Our 3D printing systems quickly transform powder materials — including metals, ceramics, composites, and sand — into precision parts, metalcasting molds and cores, and innovative tooling solutions. Industrial customers use our technology to save time and money, reduce waste, improve their manufacturing flexibility, and deliver designs and products that were once impossible.

"In addition to geometric complexity, the customization abilities of 3D printing enable more efficient use of building materials where old building stock can be recycled and new buildings can be designed for disassembly."

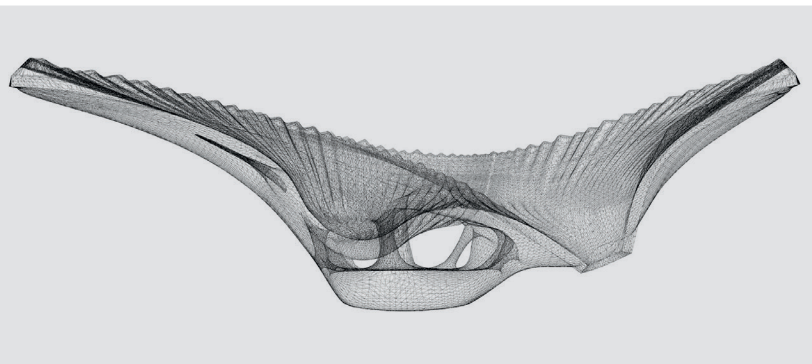
Dana Cupkova, Associate Professor, Carnegie Mellon University School of Architecture

Reinventing Eco-Friendly Architecture and Upcycled Materials Using ExOne Binder Jet 3D Printing

At a hulking iconic steel mill along the banks of the Monongahela River, Pittsburgh continues to reinvent what it means to be the Steel City, turning to new advanced manufacturing tools and ideas to move toward a cleaner, more sustainable future. Carnegie Mellon University School of Architecture Associate Professor Dana Cupkova is a thought leader in this new future and, specifically, how advanced manufacturing technologies are reshaping a new era of material reuse and eco-friendly architecture – increasingly using ExOne binder jet 3D printing that was pioneered and commercialized in the region.

Track Chair of the Master of Science in Sustainable Design program, Cupkova's view of the future for architecture is a circular one, in which materials are managed as a continuous resource that is both finite and precious. New tools such as 3D printing enable use of these materials in innovative new ways that are sustainable while connecting people and communities more to the environment around them.

Key features of her most recent work are large human-sized cradles, or rocking planters, 3D printed from powdered materials, such as sand or recycled concrete, and then infiltrated and coated with bio-based resins to produce structurally strong designs with unique features that help support water management and natural ecosystems. The cradles are to be placed in the community garden and tree nursery on the Hazelwood Green site where Mill 19, once Pittsburgh's most productive steel plant, is part of an ongoing a rebirth as a new advanced manufacturing hub with offices that anchor new community development including housing and urban green spaces.



The cradles are designed to optimize water flow and collection, structural strength with weight reduction, and stable balance control.

A conceptualization of the cradles 3D printed from reclaimed construction materials in the nursey at the Hazelwood Green redevelopment site as they promote ecological growth and a space for communities to interact with nature.

The cradle is a small but significant part of a larger and growing vision around reused and powderized materials, such as concrete, and the role it should play in sustainable architecture going forward, a concept that Cupkova calls CRuMBLE (Concrete Rubble Manufacturing for Building Lifecycle and Environment).

The carbon footprint of concrete as a material is actually much lower than other building materials like steel, aluminum, and plastic. However, the inefficient way we form concrete into large slabs and the amount of waste it generates offsets many of its benefits. In 2015, over 200 million tons of concrete alone entered the waste steam in the United States, with less than a third utilized for remanufacture. According to the Environmental Protection Agency (EPA), 600 million tons of construction and demolition (C&D) material debris were generated in the United States in 2018.

“We use too much concrete – we use it in large, bulky blocks that at scale is no longer environmentally beneficial” Cupkova explains, “and when we demolish existing infrastructure, we dispose of most of that material.”

But binder jet 3D printing recycled concrete that has been pulverized back into powder creates the possibility for concrete to be shaped more efficiently with less volume and waste, and allows the material to be recycled back into use. “Ecologically intelligent customization and bespoke design are truly enabled by advances in digital manufacturing technology like binder jetting,” she said.

Mill 19

Just two miles from the CMU campus, the steel superstructure of Mill 19 at Hazelwood Green is the last remnant from the Hazelwood Works campus of Jones and Laughlin Steel Company. Built in 1943, the skeleton of the 100 by 1,200 foot factory has been refurbished as a hub for advanced manufacturing. Tenants like CMU’s Manufacturing Futures Institute (MFI) are working to advance 3D printing, robotics, artificial intelligence, and IIoT.

Carnegie Mellon University’s global leadership in the research and development of advanced technologies and materials science is rapidly transforming manufacturing and catalyzing economic development. MFI aims to converge mindshare from interdisciplinary efforts across the university to foster innovations. It manages the Mill 19 advanced manufacturing facility housing the ExOne M-Flex® that enables the material research for Cupkova’s mission of building value-added design in modular construction. “Additive manufacturing promises to address the gap between high-performance building design and manufacturing for the future of smarter buildings,” she said.

Drawing a sharp contrast to the steel industry, Mill 19 is designed to be eco-friendly and environmentally sustainable. The building’s roof features 4,784 solar panels, the largest solar installation in Pittsburgh, and captured rooftop water is reused in the cooling tower while stormwater is diverted to rainwater gardens.

The Mill 19 facility within the superstructure of the historical steel factory houses Carnegie Mellon University’s new additive manufacturing laboratory where the ExOne M-Flex® binder jetting system is installed to support cross-departmental research and development at industry-relevant scale.

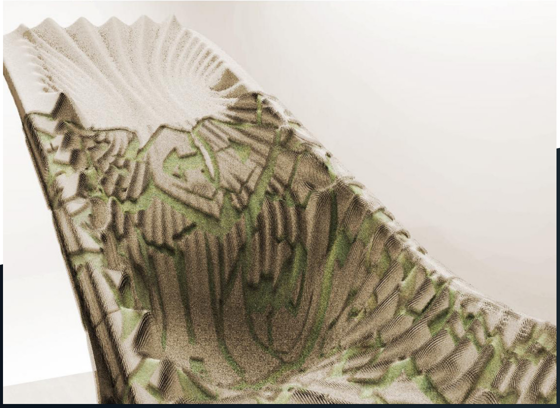
3D Printing Helps Reclaim Nature in the Steel City

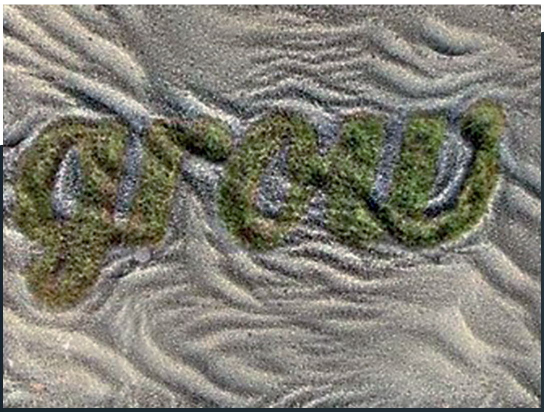
Cupkova is a leader on the connection between research and architectural practice, looking at the relationship between design space and ecology and working to actively incorporate technological innovation toward creative solutions. “You end up shaping materials differently once you start to prioritize climate-specific concerns and environmental ethics, and 3D printing allows us to design without limitations,” she said.

By approaching design through a lens of environmental stewardship, she and her team at the CMU School of Architecture created the cradles as urban furniture encouraging play, curiosity, and community building but that also provide ecological services such as rainwater management in climate-responsive design.

Ecological patterning on the surface of the planters is tailored to the growth of an area’s native plant species while complex water control and storage designs help the cradles become part of the environment itself to capture rainwater. Structural optimization enabled through 3D printing allows Cupkova to design more efficiently, with less material, and also incorporate features like water storage voids to cultivate plants and prevent excess runoff from entering the wastewater system. “The design of the object is shaped in a way that even if humans don’t care, nature cares and uses the shape and material to encourage plant growth. It will care for us,” she explains.

Yet these complex designs are difficult to produce with the limitations of traditional manufacturing methods. Additionally, thermal patterns and climate are location-specific, making it difficult to standardize a design with any ability to scale the concept outside of Hazelwood. Creating custom molds for each location - the traditional way of building with concrete - would increase the carbon footprint of the designs while making production inefficient. Binder jet 3D printing allows designs customized to the environment of any location to be easily and locally created.





“Graffiti” is incorporated into the surface of the planters that optimize water flow, encourage plant growth, and integrate community initiatives and history.

Patterning

Ecological patterning uses the design freedom of 3D printing to integrate the cradles as a part of the built environment with the organisms in the natural environment. Cupkova’s projects reflect the relationships between natural resources like water infrastructure, local ecologies, and design to teach architecture framed around global socio-ecological issues. The unique designs integrated into the cradles are computationally modeled for complex water control logic and custom made with binder jet 3D printing for testing by Cupkova’s team.

"The long-term goal is to integrate what we learn into structural plans and use devolumizing strategies to use concrete more sustainably."

Dana Cupkova, Associate Professor, Carnegie Mellon University School of Architecture

Rethinking Waste Streams

For a city still managing the effects of post-industrial pollution, Cupkova sees reclaiming materials and using environmental upcycling as essential to heal both the land and the community. In addition to the geometric complexity and customization that comes with 3D printing, the flexibility of binder jetting enables the CMU team to reimagine the possibilities of waste stream diversion and explore novel ways to reuse materials.

Starting with a bed of powder, binder jet 3D printing uses an industrial printhead to selectively deposit binder that builds a solid part in unique shapes one thin layer at a time. The design is then infiltrated with a bio-based, high-performance epoxy resin. Cupkova's team has already achieved cement-like strength and material properties in prototype designs built from the standard sand used by foundries in large-format binder jetting systems.

Now, they're advancing their project by moving on to reclaimed materials. "We will be working with local demolition companies to collect existing waste that we can pulverize into granular powder for testing with 3D printing," Cupkova said. Remanufactured into feedstock for binder jetting, her team uses materials like concrete diverted from the waste stream and upcycled to prevent new material production and enable local re-use, further reducing the carbon footprint of the manufacturing process.

Ultimately, with advanced manufacturing techniques, Cupkova's Team CRuMBLE concept is pushing architects to rethink entire lifecycles and enhance material usage with buildings designed for both construction and reuse – a cradle-to-cradle approach. "In addition to geometric complexity, the customization abilities of 3D printing enable more efficient use of building materials where old building stock can be recycled and new buildings can be designed for disassembly," Cupkova said.

Binder is selectively deposited on a bed of powder to build objects one layer at a time before extraction from the 3D printer and infiltration with a bio-based resin. Here quarter-scale cradles in various materials are 3D printed and infiltrated at ExOne facilities for testing by Cupkova's team.

Enhanced Performance Architecture

Looking beyond the cradle project, Cupkova is inspiring the next generation of students to use computations like environmental performance simulations combined with their design skills and advanced manufacturing to look at a more scientific and evidence-based way of using materials. “The long-term goal is to integrate what we learn into structural plans and use devolumizing strategies to use concrete more sustainably,” she said.

Master of Science in Sustainable Design (MSSD) students under the guidance of research associate Matthew Huber investigate environmental issues related to architecture and urban systems at the intersection of building science, design, and technology. They are producing lattice formations that can only be built with additive manufacturing and testing weight reduction strategies and shape sensitive designs. 3D printing today enables environmentally engaged design that considers water management as well as plant growth for air purification and enriched soil. The technology is also working to unlock a future of more efficient and sustainable design strategies, as complex geometries allow for weight reduction through structural optimization and latticing to reduce material use and carbon footprints.

The binder jet process, known for its unparalleled material flexibility, offers potential to integrate recycled print media as well as bioplastic binders and coatings to enhance the process’ sustainability while complex surface morphology allows for advanced ecological and hydrological performance.

Geometric sample printed in concrete with binder jet 3D printing by Lehigh University.

3D Printing with Concrete

While the CMU team explores 3D printing recycled concrete infiltrated for strength, binder jet 3D printing of dry concrete powder geometries has been successfully executed by Lehigh University, as presented in a 2018 paper by Joseph P. Ingaglio, Material Characteristics of Binder Jet 3D Printed Hydrated CSA Cement and Fine Aggregates.

Although the paper noted that additional development was needed to improve the compressive strength of the final output to industry standards for structural applications, the author believes that industry standard strengths can be achieved. “A compressive strength of 25 MPa or greater is obtainable with this 3D printing method in the near future,” he wrote at the time, explaining in a recent discussion that they were able to create “really unique shapes, but it became more of a materials science challenge to achieve the needed density.”

This is precisely the type of research that Cupkova is doing with ExOne’s binder jetting system. Her team is exploring the possibility of reused waste material and bio-based epoxy, as well as water binders to reactive the cement, making the process as environmentally friendly as possible.

"Using 3D sculpting software gives us the opportunity to create architectural details that become more interesting while there is no other way to do the devolumization without 3D printing."

Kirman Hanson, Master of Science in Sustainable Design Student, Carnegie Mellon University School of Architecture

See Photos and Videos
bit.ly/X1Cradle

Using Technology and Design to Build Community

While binder jet 3D printing enables sustainable manufacturing at Mill 19, the technology also provides a community building initiative in the Hazelwood neighborhood. "Innovative architecture bleeds across traditional boundaries and we want to engage local communities to participate in the design process to help us demonstrate how technology can be more accessible in rebuilding places and helping environmental issues," Cupkova says.

Workshops with children at a local community center lead by a local environmental justice artist Edith Abeyta adds another layer to the project, as kids brainstorm artwork, graffiti designs, and other textures to be printed on the undersides of the cradle planters. "That way the surface is structural, ecological, but also hopefully integrates the history and spirit of the community," Cupkova says. A special font was created based on the children's handwriting and additional options to include braille for enhanced accessibility or QR codes to integrate digital interaction are also being explored with the 3D printed designs.

"Additive manufacturing promises to address the gap between high-performance building design and advanced manufacturing for the future of smarter architecture and stronger, healthier communities," Cupkova concluded.

ExOne binder jet 3D printing enables unique lattice designs that lightweight and devolumize use of construction materials (left) while the freedom of design enables unique geometries to be incorporated like designs developed in local community workshops at a local community center (right).

Rocking Cradle project was funded by:
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