Research Spending & Results

Award Detail

Awarded to: MASSACHUSETTS INSTITUTE OF TECHNOLOGY
Doing Business As Name: Massachusetts Institute of Technology
P/D/PI: Neri Oxman
(617) 452-5671
neri@mit.edu
Award Date: 08/16/2011
Estimated Total Award Amount: $106,840
Funds Obligated to Date: $106,839 FY 2011=$106,839
Award Start Date: 09/01/2011
Award Expiration Date: 08/31/2013
Transaction Type: Grant
Agency: NSF
Awarding Agency Code: 4900
Funding Agency Code: 4900
CFDA Number: 47.041
Primary Program Source: 490100 NSF RESEARCH & RELATED ACTIVITY
Award Title or Description: EAGER: Bio-Beams - Functionally Graded Rapid Design & Fabrication
Federal Award ID Number: 1152550
DUNS ID: 001425594
Parent DUNS ID: 001425594
Program: ENGINEERING DESIGN AND INNOVATION
Program Officer: Paul Collopy
(703) 292-2241
pcollopy@nsf.gov

Awardee Location

Street: 77 MASSACHUSETTS AVE
City: Cambridge
State: MA
ZIP: 02139-4301
County: Cambridge
Country: US
Awardee Cong. District: 07

Primary Place of Performance

Organization Name: Massachusetts Institute of Technology
Street: 77 MASSACHUSETTS AVE
City: Cambridge
State: MA
ZIP: 02139-4307
County: Cambridge
Country: US
Cong. District: 07

Abstract at Time of Award

The research objective of this EARly Concept Grant for Exploratory Research (EAGER) is the creation of a research-driven framework for developing, integrating, and evaluating digital fabrication technologies with biologically inspired form generation to support sustainable construction. Functionally Graded Rapid Fabrication (FGRF) is a novel design approach and technological framework enabling the controlled spatial variation of material properties through continuous gradients in functional components. The work will provide research-based evidence for variable-property form generation informed by environmental performance criteria such as variable-density concrete beams and variable-elasticity polymer panels. Spatial variations of material properties are traditionally achieved as discrete delineations in physical behavior by fabricating multiple parts comprised of different materials, and assembling them only after the fabrication process has been completed. Recent advances in Computational Topology (CT) and Solid Free-Form Fabrication (SFF) are promoting the creation of building components with controlled micro- and macro-architectural features. The FGRF approach will combine a novel software environment with a mechanical output tool designed as a 6-axes, 3-D printer to allow computer control of material distribution within a monolithic structure.

If successful, the project will advance the ability of machines to fabricate with variable properties, and will enable the control of their variation according to the desired environmental input. The new approach will expand current fabrication platforms and will be a significant first step toward variable property digital fabrication. Being the first FGM construction technology, the project has the potential to lead to a line of new research. This interdisciplinary award makes contributions to the fields of digital fabrication, computer-aided design, material science and mechanical engineering. As a novel research platform, the FGRF approach has the potential for reaching a large number of designers, engineers and scientists operating at the intersection of digital design innovation and sustainable construction. Through far-reaching collaborations applying new expertise and engaging novel interdisciplinary perspectives across MIT, the investigator will not only invent these tools and discover how to use them, but lead their translation into design applications while evaluating their contribution to a radically new approach in sustainable design & construction. Long term, this research is also expected to contribute to understanding the theory and practice of sustainable rapid fabrication of variable-property construction. Results will be distributed in all of these communities through peer-reviewed publications and conference presentations, as well as through physical installations and demonstrations.

Publications Produced as a Result of this Research

Oxman, N., “Variable property rapid prototyping” VIRTUAL AND PHYSICAL PROTOTYPING, v.6, 2011, p.3-31
Oxman, N., “Variable property rapid prototyping” VIRTUAL AND PHYSICAL PROTOTYPING, v.6, 2011, p.3-31
Project Outcomes Report

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Current rapid prototyping technologies, specifically additive manufacturing platforms, are limited by scale, speed, and the ability to realize graded material properties. 3D printers are generally limited to tabletop-scale non-structural components due to gantry size, material cure rates, layer adhesion, and printing time. Likewise, both computer-aided design tools and digital fabrication processes are thus not set up to deliver variation of properties within solids such as variable density in concrete, variable elasticity in rubber, or variable transluency in glass. As a result, the design process is constrained to the assignment of discrete and homogeneous material properties to a given shape. This limitation hinders the designer's ability to create a tight coupling between form and function, and leads to designs that contain many more parts than would otherwise be necessary.

This research focused on addressing these limitations by developing design and fabrication tools for advanced additive digital fabrication. Specifically, a suite of digital fabrication technologies was developed for delivering functionally graded materials and inhomogeneous structures and to explore the possibility of overcoming gantry size limitations. To demonstrate the utility of our approaches we applied them across disparate scales, spanning the millimeter to multiple meter scale.

We are pleased to report the following results, focused in two main thrusts; the first thrust involves graded property printing while the second introduces new methods of robotically controlled printing.

Graded Property 3D Printing

(a) 3D Printing of Graded Elastic Moduli

A 3D printing platform capable of mixing and simultaneously extruding two materials with varying composition was built to demonstrate variable property printing. A material extrusion head comprising of a nozzle and a mixing chamber was attached to the 2-axis of a 3-axis gantry robot. A compressed air driven system was used to control the amount of each material dispensed from its reservoir to the mixing volume. Several mixing strategies were explored including diffusive, static, and active mixing. The platform was designed to extrude materials, which remain liquid at room temperature prior to mixing and extrusion, and solidify after deposition, i.e., certain epoxies, UV-cure polymers, drying adhesives, and thixotropic fluids. The use of these compounds instead of conventional thermoplastics used in fused deposition modeling printers, allows for a broader range of materials. In particular, since the printing process does not require heating, the platform is compatible with temperature-sensitive compounds and biological molecules. The current work focused on gradients of elasticity and stiffness fabricated in product design for small-scale applications with the addition of limited dynamic responses.

(b) Bitmap Printing as an Enabling Technology for Variable Property Printing

In order to achieve functional gradient 3D printing, we developed a digital environment supporting texture-based algorithms that enable the design and fabrication of graded properties in high spatial resolution. This new technology was applied to the control of elastic modul variation in 16-micron, high-resolution print layer accuracy, 600 DPI X & Y resolution, and up to walls as thin as 0.6mm (0.02477). The Stratasys multi-material printers were used to achieve these accuracies and resolutions.

(c) Variable Density Concrete

Finally, to demonstrate the applicability of gradient property fabrication in large scales we developed two complementary approaches for the design and fabrication of variable density concrete at high spatial resolutions using mechanically foamed cement and a 3D printed scaffold method.

Robotically Controlled Additive Manufacturing

(a) A Digital Construction Platform

To investigate the idea of a multi-functional robotic arm digital fabrication system, an industrial 6-axes robotic arm (KUKA KR5 R850) was utilized in the three conventional categories of fabrication: additive, formative, and subtractive.

To implement additive manufacturing on large scale and enable on-site printing, a new digital platform capable of on-site design, sensing, and fabrication was designed and constructed. The platform tool is comprised of a novel compound robotic arm system comprised of 5-axes Altec hydraulic boom arm for gross movement with the smaller 6-axes KUKA robot for fine positioning. The platform has a working diameter of over 80 feet, is fully mobile based on a GMC truck vehicle, and has a lift capacity of 1,500 lbs with a manipulation capacity of 20 lbs.

(b) Spiderbot – A Cable-driven Printing Platform

Inspired by the camera-positioning platform “Skycam”, we adapted a cable suspended robotic gantry system to provide a platform from which to print large structures. Extrusion nozzle and a reservoir of material were attached to four parallel winching motors, allowing the robot platform to move up and down its supporting cables which are mounted to static connection points above the printing area.

(c) Mobile Swarm Robotic Printing

In order to overcome the limitations of gantry size a multi-nodal fabrication system was designed and built using cable-suspended robots. Designed as portable extruders, the bots operate as a decentralized yet highly communicative environment. This system explored ideas such as synchronous motion, multi-nodal fabrication, lightweight additive manufacturing and the emergence of form through fabrication.

Last Modified: 11/29/2013
Modified by: Neri Oxman

For specific questions or comments about this information including the NSF Project Outcomes Report, contact us.