



# 3D

## CONCRETE PRINTING (3DCP) CURRICULUM

Training for Architecture,  
Engineering, and Construction  
(AEC) Professionals



## **Disclaimer**

The work that provided the basis for this publication was supported by funding under an award from the U.S. Department of Housing and Urban Development. The substance and findings of the work are dedicated to the public.

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**Important note:** The content of the following 3D Concrete Printing Curriculum was developed in 2023–25 and designed to meet the capabilities of the existing technology. As technology in the architecture, engineering, and construction industry evolves, note that certain curriculum components may need to be revised for optimal learning efficiency.

# **3D Concrete Printing (3DCP) Curriculum**

Training for Architecture, Engineering, and Construction Professionals

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Blacksburg, VA

April 2025

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## **List of Abbreviations and Acronyms**

**3D:** three-dimensional

**3DCP:** three-dimensional concrete printing

**AEC:** architecture, engineering, and construction

**ASTM:** American Society for Testing and Materials

**CLO:** Curriculum Learning Outcomes

**KC:** key competencies

**MLO:** Module Learning Outcomes

**VCHR:** Virginia Center for Housing Research

## **1. Authors' Profiles**

### ***Kereshmeh Afsari, Ph.D.***

Kereshmeh Afsari is an assistant professor of construction engineering and management at Virginia Tech and the founder and managing director of the Automation and Robotics in Construction and Design Engineering (ARCADE) Research Lab in the Myers-Lawson School of Construction. Her research focuses on emerging technologies and robotics in construction and design. Dr. Afsari has a Ph.D. in architecture, focused on design computation, from Georgia Institute of Technology; an M.S. in digital architectural design from the University of Salford; and a joint B.S./M.S. in architectural engineering from Iran University of Science and Technology.

### ***Andrew McCoy, Ph.D.***

Andrew McCoy is the director of the Virginia Center for Housing Research (VCHR), a professor in the Department of Building Construction at Virginia Tech, and an associate director of research at the Myers-Lawson School of Construction at Virginia Tech. Dr. McCoy has leveraged his passion and expertise in construction, technology, and housing to cultivate teams and environments that promote affordable and energy-efficient housing. Dr. McCoy and his research team at VCHR focus on housing affordability, housing education, and building technology. Through his hard work, dedication, and strategic implementation of technological innovations, he aims to create a more sustainable and economically resilient community. Dr. McCoy attended the University of Virginia, where he earned a B.A. in architecture and architectural history, before attending Virginia Tech, where he earned an M.S. in construction science and management and a Ph.D. in environmental design and planning. Dr. McCoy holds the Beliveau Professorship in Virginia Tech's Department of Building Construction.

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### ***Alexander Brand, Ph.D., P.E.***

Alexander Brand is an assistant professor in Virginia Tech's Department of Civil and Environmental Engineering. Dr. Brand's program areas are transportation infrastructure and systems engineering and structural engineering and materials. His research focuses on materials science of civil infrastructure materials, advanced characterization techniques to study the micro- and nanostructure development in cementitious materials, the use of recycled and by-product materials in concrete, and concrete pavement engineering. Dr. Brand attended the University of Illinois at Urbana-Champaign, where he earned a B.S., M.S., and Ph.D. in civil engineering. He holds a professional engineering license in the state of Virginia.

### ***Nathan King, DDes***

Nathan King is the codirector of the Center for Design Research, where he leads efforts in design technology and social impact. His interests include design technology, robotics and autonomous systems, social impact, international outreach, design research, and technologies for inclusion

and impact. Dr. King is the industrialized construction research lead at Autodesk, where he and his team focus on the future of industrialized construction and the development of strategic initiatives related to robotics, automation, and the future of the industry. Dr. King was recently elected for a multiyear term on the editorial board of the *International Journal of Architectural Computing* by the global membership of the Association for Computer Aided Design in Architecture. He attended Randolph-Macon College, where he earned a B.A. in studio arts and art history; Virginia Tech, where he earned an M.S. in architecture focused on industrial design; and Harvard University, where he earned a Doctor of Design degree.

***Vida Babajaniniashirvani, Ph.D. Student***

Vida Babajaniniashirvani is a graduate research assistant at the Virginia Center for Housing Research, pursuing a Ph.D. in environmental design and planning at the Myers-Lawson School of Construction. Her research interests focus on cutting-edge technologies, such as 3D concrete printing, to evaluate both the barriers and the opportunities for enhancing human-centered processes through automated machine capabilities. She graduated from the Polytechnic University of Milan with an M.Sc. in building and architectural engineering with a focus on technology, and she worked for a building information modeling (BIM) company in Milan as a junior BIM specialist on a large-scale project in Abu Dhabi.

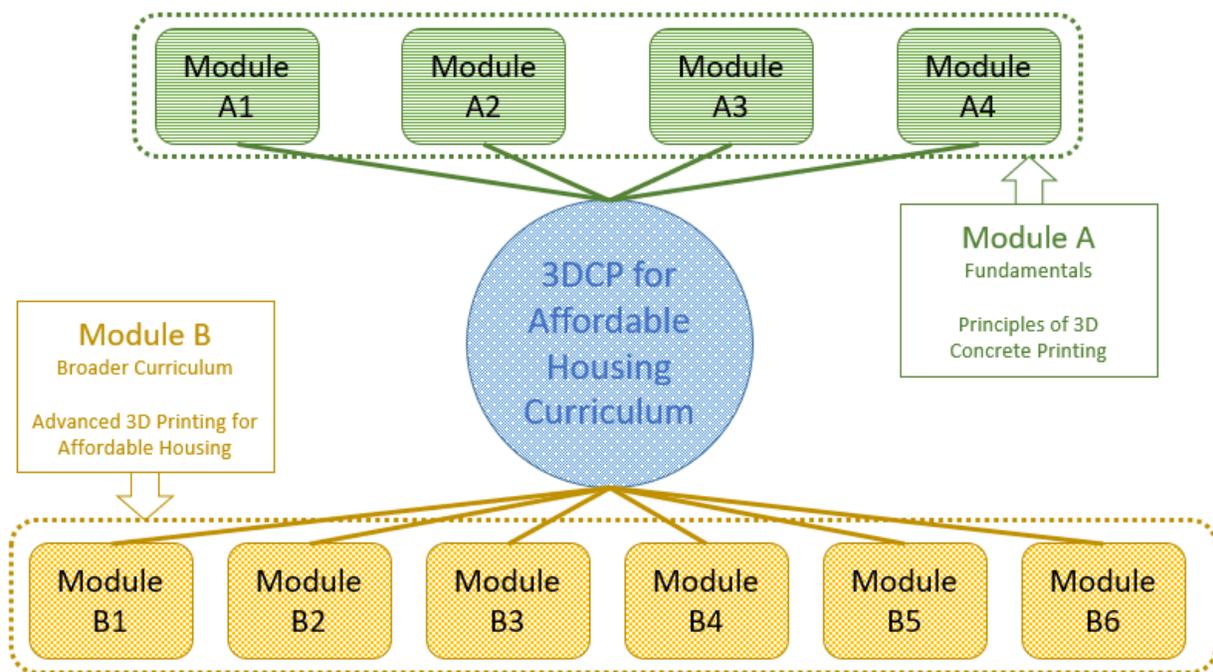
***Nicky Pond, Master's Student***

Nicky Pond is a graduate research assistant pursuing an M.S. in building construction science and management at Virginia Tech. Her research interests are centered around utilizing emerging technologies to streamline construction processes. She worked for a general contractor as an assistant virtual design and construction manager, implementing technological solutions and enhancements on a mega-project in southern Florida. She has a B.S. in building construction from Virginia Tech with a focus on virtual design in construction.

## 2. Executive Summary

This report outlines a curriculum for the adoption of three-dimensional concrete printing (3DCP) fundamentals as they relate to the development of affordable housing. Through the expansion of education and the prevalence surrounding 3DCP technology, it can be used as an opportunity to develop affordable housing options. Exhibit 1, which provides an overview of the developed curriculum, is segmented into two main modules: Module A illustrates the fundamentals and principles of 3DCP, and Module B illustrates advanced techniques of 3DCP for affordable housing. Detailed information regarding each item is provided throughout the report. Each main module contains respective submodules in which learners can pick and choose from topics of interest. Ten modules were generated as part of this curriculum: four modules are in the fundamentals segment, and six modules are in the advanced segment. The curriculum provides a flexible method to educate designers, technicians, construction professionals, and managers on 3DCP. Furthermore, the curriculum design can be broadly integrated into construction and workforce development programs to equip the next generation of construction experts with 3DCP knowledge and integrate skills in affordable housing development.

**Exhibit 1. Overall Outline of the Developed Curriculum Modules**



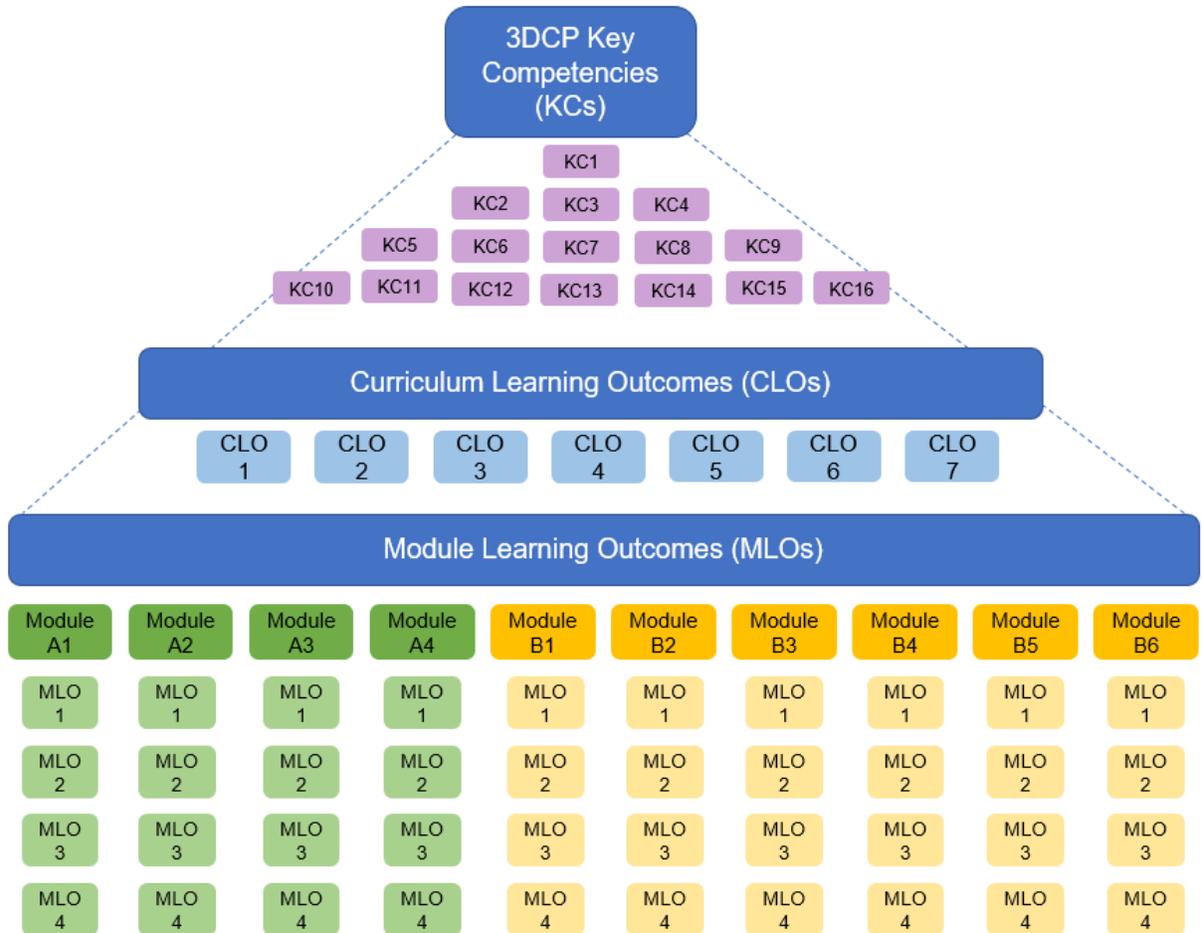
Source: 3D Concrete Printing (3DCP) Curriculum Report Data

### Terminology and Definitions

The three following terms play a pivotal role in this report. Exhibit 2 outlines the relationship between these three terms, which are described below. Detailed information regarding each term is provided throughout this report.

- **Key Competencies (KCs):** Competency areas (skills and knowledge) necessary for success in 3DCP. A paper for the *American Society of Civil Engineers International Conference on Computing in Civil Engineering* preestablished these competencies (Babajaniniashirvani, Afsari, and McCoy, 2024).
- **Curriculum Learning Outcomes (CLOs):** Overarching learning objectives that trainees and students are expected to attain upon completion of all 10 3DCP modules in the curriculum, reflecting comprehensive goals.
- **Module Learning Outcomes (MLOs):** Specific knowledge, skills, and competencies that trainees and students are expected to demonstrate upon completion of a particular module within the curriculum. MLOs provide clear expectations and benchmarks to assess the effectiveness of educational goals.

**Exhibit 2. Overall Outline of KCs, CLOs, and MLOs in 3DCP Curriculum**



3DCP = three-dimensional concrete printing.

Source: 3D Concrete Printing (3DCP) Curriculum Report Data

### **3. Introduction**

The emergence of three-dimensional concrete printing (3DCP) technologies provides a viable solution to construction material and labor shortages and supply chain risk and introduces new opportunities for jobs with advanced skills. In short, 3DCP has begun a shift from onsite manual labor tasks (e.g., masonry, concrete finishing) to more technical supervisory tasks. However, the complexity of 3DCP technologies requires updating teaching practices in construction education and professional development. Robotic technologies, information modeling, materials science, and additive manufacturing have enabled the 3D printing of buildings. The research team's recent work has shown that 3DCP technologies have great potential to address the needs of affordable housing. The construction industry needs a skilled workforce to bridge these skills and implement that potential.

The adoption of 3DCP requires a new generation of the construction workforce skilled with fundamental knowledge in these topics and beyond, catered to worker type, education, and skill level. No established curriculum provides students at all levels with deep and broad training on 3D concrete printing and housing. This lack of content could result in slower adoption and production of affordable housing.

Recognizing this gap, the research team developed a fundamental training curriculum for the architecture, engineering, and construction (AEC) industry, placed into a broader, multifaceted curriculum on the use of 3DCP in the design and construction of affordable housing. Not only does the curriculum provide fundamental knowledge, but it also teaches the technical skills and practical experience of 3DCP while maintaining a focus on tangential topics, such as building performance, robotics, additive manufacturing, materials science, and digital modeling and construction.

This accessible education platform and emergent technologies can be used to bend the cost curve in affordable housing. 3D concrete home printing is an innovative construction method that can revolutionize the development of affordable housing, reducing construction times, costs, and supply chain stress. A new generation of design and construction trades and managers is required to enable the implementation of 3DCP, including printer operators, contractors, architects, engineers, and G-code developers who are equipped with 3DCP knowledge. The curriculum provides an innovative educational foundation and a workforce development framework for the next generation of construction workers and professionals by integrating 3DCP knowledge with affordable housing topics.

This developed curriculum fosters the adoption of 3DCP fundamentals across the AEC industry and for affordable housing development. It provides flexible pathways to 3DCP education for construction workers and managers with required skills in affordable housing development.

This curriculum is integrated with the existing "Housing Camp" in the Virginia Center for Housing Research (VCHR) and consists of two categories comprising 10 curriculum modules. The following sections describe the curriculum in more detail.

#### 4. 3DCP Key Competencies (KCs)

To identify the key competencies (KCs) necessary for three-dimensional concrete printing (3DCP) training, the research team first reviewed the most recent 3DCP publications in the architecture, engineering, and construction (AEC) industry to identify the main focus areas. The team then conducted a focus group study of seven AEC experts in 3DCP to further investigate the core competencies from an industry perspective.

The literature review revealed 12 main focus areas in 3DCP, whereas the expert focus group organized the 3DCP focus areas into 16 categories, with 12 aligning with those previously identified in the literature. This assessment and alignment of publications and industry perspectives provide an updated understanding of the knowledge and skills critical for the successful adoption of 3DCP via workforce development across the identified KC areas. Exhibit 3 summarizes the 3DCP KCs identified from the focus group study and those identified in the existing literature.

**Exhibit 3. Identified Key Competencies in 3D Concrete Printing (3DCP)**

Item	Key 3DCP Competencies (Focus Group)	Key 3DCP Focus Areas (Literature Review)
1	Knowledge of Concrete Mixes	Concrete Mixes
2	Printer Operations and Specifications	Operations of Printer Equipment & 3D Printer Specifications
3	3D Modeling and Visualization	3D Modeling and Visualization
4	Energy Modeling Knowledge	Energy Modeling
5	Building Performance Analysis	Building Performance Analysis
6	Knowledge of 3D Printer Technology and Software	3D Printing Simulation (slicer software)
7	Structural Modeling and Analysis	Structural Engineering (e.g., reinforcement, mathematical modeling)
8	3D Printer Equipment Maintenance	3D Printer Equipment Maintenance
9	Knowledge of Concrete Testing	Concrete Testing
10	Building Systems (e.g., mechanical, electrical, and plumbing) Knowledge	Building Systems (e.g., mechanical, electrical, and plumbing)
11	Lifecycle Assessment Knowledge	Lifecycle Assessment
12	Safety	3D Printer Safety
13	Architectural Design Knowledge for 3DCP	-
14	Construction Management Knowledge	-
15	Knowledge of the 3D Concrete Printing Process	-

16	Knowledge of Codes and Standards	-
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The 16 KCs for 3DCP that the focus group identified are described below. Further information on the established competencies may be found in the research team’s paper, “Investigating Key Competencies for 3D Concrete Printing in Affordable Housing” (Babajaniniashirvani, Afsari, and McCoy, 2024).

1. **Knowledge of Concrete Mixes.** The focus group emphasized that expertise in cement chemistry and mechanics is critical for successful 3DCP. This expertise includes understanding factors such as consistency, pump operation, climate suitability of different mixes, curing and cooling of concrete, and how to adjust mixes for optimal printing results. Several participants noted that the concrete mix is one of the most common early challenges of 3DCP. Experts highlighted that concrete mix knowledge is a “gateway” because it unlocks the ability to reliably print buildings and scale up 3DCP technologies. They also noted that standardizing methodologies that translate material properties into optimal structural designs for printing is needed for 3DCP progress.
2. **Printer Operations and Specifications.** Knowledge of different printer types and their operational constraints was another KC the focus group emphasized. Participants noted that knowledge of maximum print heights and depths, maneuverability on graded sites, position limitations near obstacles, optimal print speed, layer times, designing for cold joints, weather protection needs, onsite printer assembly, and troubleshooting print issues are key factors. They also highlighted the need for proper equipment training for printer operators, technicians, and integrated trades.
3. **3D Modeling and Visualization.** Two experts focused on integrating construction knowledge with digital modeling expertise. They expressed that those who strictly focus on the technical aspects of 3D modeling without construction experience lack critical perspectives and that skill sets in software programs for building information modeling and computer-aided design modeling (e.g., geometric surface modelers such as Rhinoceros 3D) to prepare, translate, and simulate digital models for printer toolpath simulation are essential.
4. **Energy Modeling Knowledge.** Using accurate energy models as a design tool is critical for optimizing 3D concrete printed buildings and managing client expectations on performance and costs. As one focus group member shared, their client desired an extremely energy-efficient home, but the high cost of achieving net-zero standards through techniques such as superior insulation exceeded their budget, nearing \$400 per square foot. Developing skills for energy modeling that satisfy the client’s desires and fulfill practical requirements is key. Examples include analyzing approaches to thermal bridging, building envelope air and vapor sealing, and using different insulation materials to quantify effectiveness.
5. **Building Performance Analysis.** Building performance analysis skills are critical for 3DCP buildings to ensure the long-term viability and acceptance of this emerging technology. Key analysis areas include thermal efficiency, moisture control, weatherproofing, acoustical qualities, durability and structural integrity over time (e.g., resistance to cracking), coordination of windows (daylight quality) and insulation installation, and overall energy modeling to balance operational performance with affordable construction costs. Experts noted that approaches to this testing could involve

different exterior wall-sealing methods, such as Thorocoat, exterior insulation and finish systems, silane, siloxanes, fluid-applied membranes, or bare concrete. Mockup walls with various types of finishes (wall assemblies) and performance testing under varied conditions are needed to fully understand these building performance factors in 3DCP buildings.

6. **Knowledge of 3D Printer Technology and Software.** Experts briefly mentioned the need for in-depth knowledge of 3D printer technologies and leveraging various types of software. This knowledge includes troubleshooting and optimizing printer operational software, expertise in slicing programs for toolpath simulation to digitally translate concrete mixes and designs, and coding skills to customize toolpaths and material flow.
7. **Structural Modeling and Analysis.** Experts extensively discussed the need for expertise in structural analysis to model, test, and validate the performance of 3D-printed building components. They highlighted the complexities of printed layer interfaces and the necessity to simplify computational models for practical design. Experts further highlighted the need to understand differences in failure mechanisms compared with other building methods; properly accounting for factors such as layer interfaces, bulging, and load transfers in structural evaluations; and determining optimal reinforcement schemes, spanning capabilities, wind and seismic loading capacities, and roof and foundation connections as critical for ensuring durable, safe structures. As one participant noted, although structural engineers have core competencies in design and analysis, additional training for 3DCP specialized knowledge is imperative to cover knowledge gaps.
8. **3D Printer Equipment Maintenance.** 3DCP success requires consistent equipment maintenance and troubleshooting over time and across projects. Focus group experts noted that expertise in machine calibration, specifically during harsh weather conditions; resolving error events; and handling unexpected printing disruptions is paramount.
9. **Knowledge of Concrete Testing.** Experts emphasized the importance of concrete materials knowledge, including the ability to produce and test consistent, durable mixes. They pointed out that typical tests, such as slump testing, are limited for assessing variables that affect 3DCP. Instead, developing standardized testing protocols tailored to the 3DCP technology's continuous printing process can help reduce overtesting requirements. Experts also stressed the potential for testing moisture and (resulting) mold growth during 3DCP building operation.
10. **Building Systems (MEP) Knowledge.** Experts highlighted the need for competency in integrating building systems—e.g., mechanical, electrical, and plumbing (MEP)—in 3DCP designs and details. One expert stressed the necessity of focusing on penetrations for doors, windows, electrical, and plumbing. Another expert emphasized the impacts of the enclosure systems on MEP systems and the need for redundant designs and systems.
11. **Lifecycle Assessment Knowledge.** The focus group mentioned several considerations regarding the long-term performance and viability of 3DCP housing, such as balancing energy efficiency, sustainability goals, structural integrity, and lifecycle assessment factors over time. They noted that an analysis of 3DCP projects over extended time frames and under variable conditions is required to systematically gather data on durability, comfort, and energy and cost effectiveness. The analysis could also identify problems and solutions to improve overall lifecycle quality and determine whether 3DCP can viably deliver on sustainability and performance aims in the long run.

- 12. Safety.** Experts strongly emphasized the need for training in properly and safely operating the various machinery and equipment used in 3DCP construction, including the safe handling of dry concrete, cranes, forklifts, skid steers (to set up printers), pumps, and printers. As one participant noted, specific training in U.S. Occupational Safety and Health Administration standards, implementing additional 3DCP safety guidelines, and proper operations of all onsite equipment is essential.
- 13. Architectural Design Knowledge for 3DCP.** Experts emphasized architectural expertise for designing buildings suited to the constraints of 3DCP. Designing for 3DCP incorporates physical constraints imposed by printer specifications, including maximum printable volumes and site accessibility limitations. Experts noted the need to detail connections for building components such as windows, doors, roofing, utilities, and finishes in 3DCP buildings to ensure that performance factors such as weatherproofing, thermal values, and durability are achieved and for code compliance.
- 14. Construction Management Knowledge.** Focus group experts also discussed the need for coordination across trades for efficient and proper execution in printed buildings per code requirements, emphasizing quality control during printing and material assessment. Experts emphasized job site logistics, such as printer mobilization and alternate concrete hopper loading methods closer to the ground to minimize dust. More broadly, KCs in overall construction workflows, project budgeting, personnel training, and blending new automated techniques with conventional trades were noted as crucial for driving adoption while ensuring craftsmanship.
- 15. Knowledge of the 3D Concrete Printing Process.** Although specific technical knowledge is important, a comprehensive perspective of 3DCP processes is also essential for 3DCP success. Experts suggested that KCs should include integration of printer operations with material preparation and site logistics—an “umbrella” application of 3DCP goals. Mechanical engineering skills for equipment reliability and troubleshooting integrated with complementary knowledge—such as detailing connections to other building systems and hands-on printing experience in varied weather conditions—can support broader applications. Also, preparation using offsite prefabrication of 3DCP models (at a reduced scale) allows for learning and envisioning alternative implementations.
- 16. Knowledge of Codes and Standards.** Focus group discussions highlighted the importance of knowing building codes and standards specific to additive construction methods such as 3DCP. The experts noted that developing foundational building code knowledge and updating model codes for 3DCP will enable broader adoption by ensuring that projects adhere to the latest unified regulations.

## 5. 3DCP Curriculum Learning Outcomes

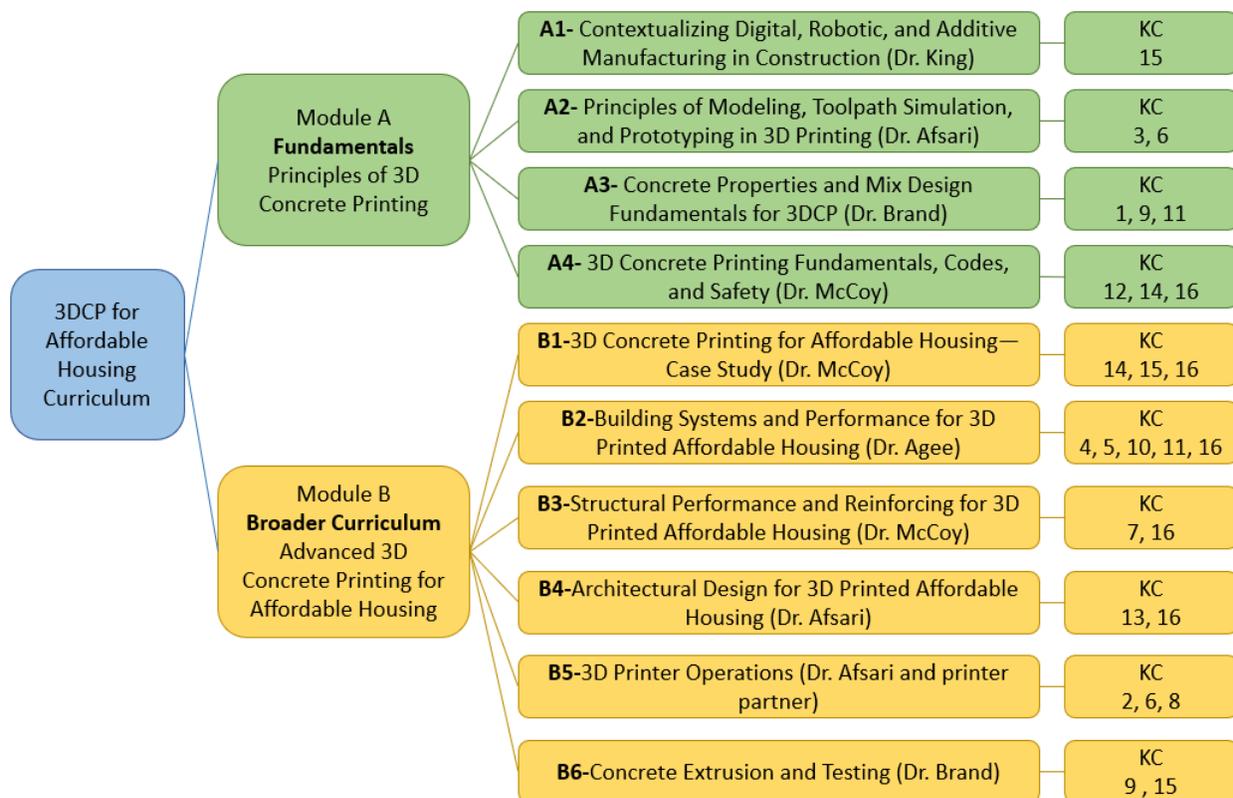
Based on the previous section, which identified 16 3DCP key competencies (KCs), the research team established the following learning outcomes for the entire 3DCP curriculum:

1. Understand principles underlying digital fabrication and additive manufacturing and fabrication techniques, including 3DCP technologies, processes, and workflows (KC 15).
2. Demonstrate proficient application of 3DCP construction management principles tailored for affordable housing while ensuring that safety compliance remains at the forefront (KC 12,14,15,16).
3. Apply strategies for building systems, including MEP, energy modeling, and lifecycle assessment, while focusing on sustainability and optimizing building performance in 3DCP projects (KC 4,5,10,11).
4. Develop strategies for optimal structural performance in 3DCP projects by incorporating advanced design principles, material selection, and innovative construction techniques (KC 7).
5. Analyze architectural design in accordance with 3DCP constraints, compatibility with technology, and compliance with codes and standards (KC 13,16).
6. Develop an understanding of and proficiency with 3D modeling, toolpath simulation, prototyping, and operating and maintaining 3D printer equipment and accessories to optimize outcomes and precision (KC 2,3,6,8).
7. Understand the properties of concrete materials, the mixing process, pumping, extrusion, and the importance of testing throughout the construction process to ensure optimal performance of 3DCP structures and determine the carbon footprint (KC 1,9,11).

## 6. 3DCP Curriculum Modules Outline

The overall curriculum is aimed at 3DCP for affordable housing and is separated into two categories: Module A and Module B. Module A is classified as the fundamentals of the 3DCP course and covers the principles of 3DCP through four submodules. Module B is classified as the broader curriculum of the course and covers advanced 3DCP for affordable housing through six submodules. Each module has specified learning outcomes and key competencies (KCs) that trainees will possess upon successful completion of the module to achieve the overall curriculum’s seven learning outcomes. Exhibit 4 shows the structure of the 3DCP curriculum. Each module KC maps back to exhibit 1.

**Exhibit 4. Required Competencies Mapped to Learning Outcomes**



Source: 3D Concrete Printing (3DCP) Curriculum Report Data

This new 3DCP curriculum will be integrated with the existing “Housing Camp” that the Virginia Center for Housing Research developed and manages. The Housing Camp is grounded in *adaptive lifelong learning* yet built on *competency credentialing*.

One key insight in the development of the curriculum is that students rarely acquire knowledge or skills in credit-hour units. Traditionally, a single credit hour would require 750 minutes of in-class time and approximately 30 hours of out-of-class work. This curriculum aims to be more granular and flexible. The courses break down the traditional credit hours, with each course requiring approximately 250 minutes of in-class time and 10 hours of out-of-class work.

The courses are *mostly asynchronous*, meaning students can learn at their own pace. However, recognizing the importance of collaboration and networking, courses also have a real-time interaction component (*synchronous online or face-to-face*). Most courses also include learning tasks that require students to work with one or more other learners.

As an adaptive curriculum, it caters to multiple audiences: (1) lifelong learning professionals inside and outside the residential construction industry, (2) young students interested in the industry, and (3) underserved demographics of the industry. As a result, the existing Housing Camp curriculum (exhibit 5) includes a breadth of learning, from “Construction” to “Design” topics, in the 250-minute module format and a depth of learning, with multiple courses under one topic area that can be “stacked.” The curriculum can be mixed and stacked, combining courses in “Construction” with those in “Data and Analysis,” for example, catering the education to a learner’s needs and interests.

**Exhibit 5. Existing Virginia Center for Housing Research Housing Camp Curriculum**

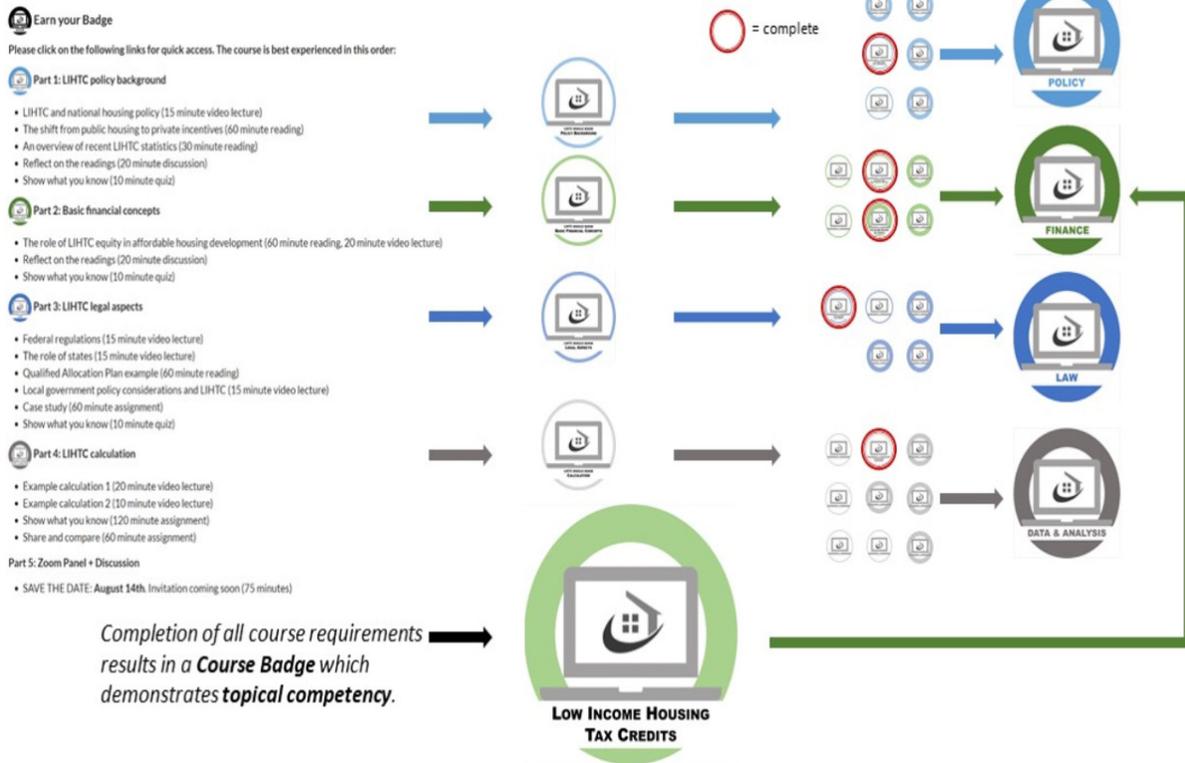
CONSTRUCTION	POLICY & LAW	DATA & ANALYSIS	FINANCE	DESIGN
Human Factors in Zero Energy Housing	Local Housing Policy	Housing Data & Analysis 1	Federal Rental Assistance Policies	Design Review and Design Principles
Humidity Control in Housing	Low Income Housing Tax Credits	Housing Data & Analysis 2	Historic Preservation & Affordable Housing	Historic Preservation & Affordable Housing
Humidity Control in Housing	Federal Rental Assistance Policies	Humidity Control in Housing	Low Income Housing Tax Credits	Humidity Control in Housing
Innovation in Residential Construction				Pathways towards Net Zero Energy Housing
Moisture Control & Durability				
Pathways Toward Net Zero Energy Housing				
Fundamentals of Residential Construction				
Residential Construction Technologies				

Source: 3D Concrete Printing (3DCP) Curriculum Report Data

Because of Virginia Tech’s access to the Badgr and Portfolium platforms, each course has a unique Course Badge associated with it and evidence in a digital portfolio tied to that badge—something that shows that students have acquired knowledge and skill, such as a report, spreadsheet, video, or illustration. Each of these badges is created by an issuer at Virginia Tech to recognize an achievement and is embedded with data to verify its authenticity and explain what it represents. Course Badges can be earned at an individual pace; learners may pick from topics that interest them. Some courses also have modules within them, so the completion of a course results in both a Course Badge and several smaller Module Badges, all of which contribute to earning a Pathway Badge. Pathway Badges demonstrate mastery within a specific

topic area, such as Finance, Policy & Law, Construction, Design, or Data & Analysis. The badge's validity is grounded in instructor verification and institutional affiliation, similar to letter grades on a transcript. The example in exhibit 6 illustrates how different topical area modules contribute to badges that serve a learner interested in gaining knowledge of the Low-Income Housing Tax Credit program.

**Exhibit 6. Existing Badging Options**



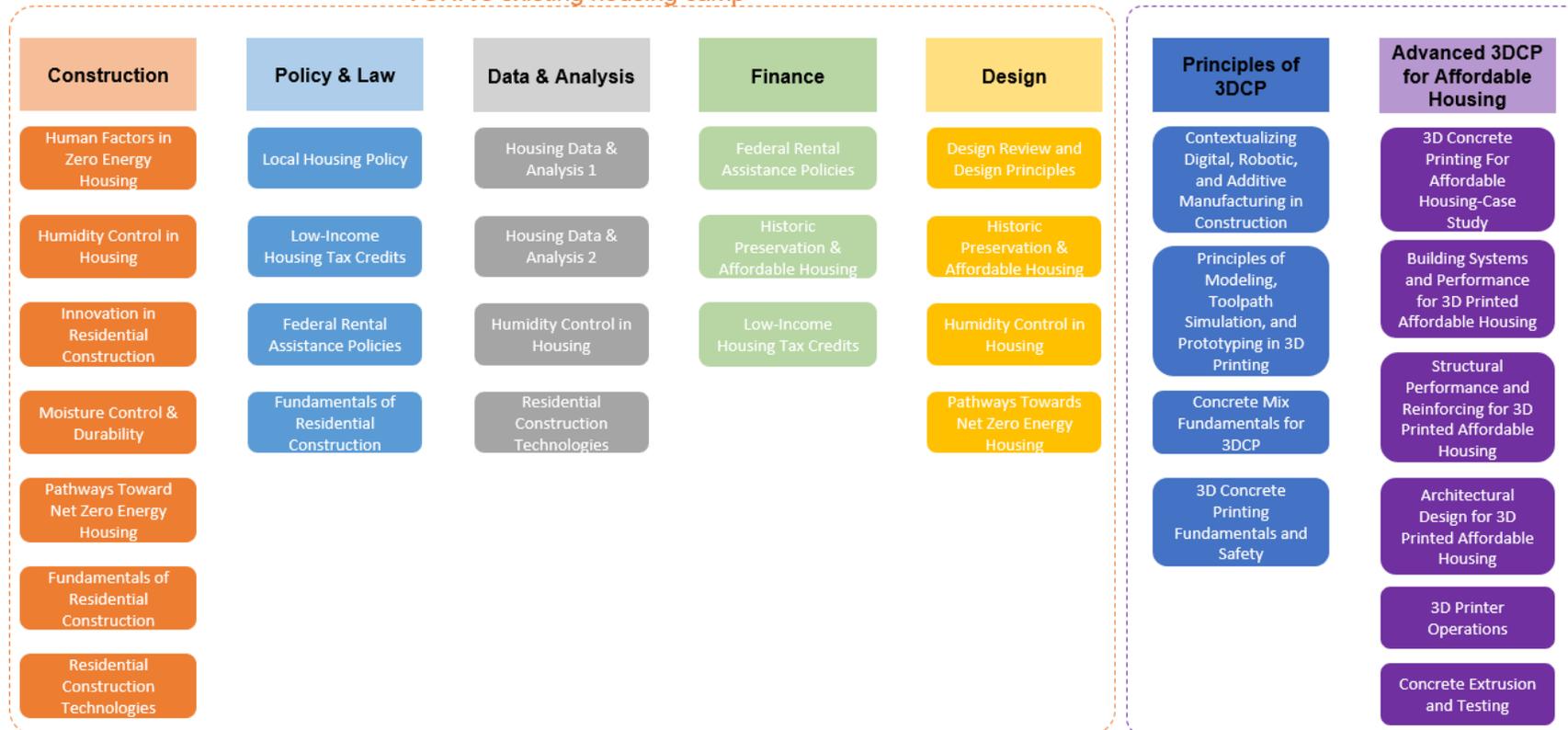
LIHTC = Low-Income Housing Tax Credits.  
 Source: Virginia Center for Housing Research (VCHR)

Exhibit 7 presents the new curriculum next to the original Housing Camp modules as separate topical areas, yet they could be easily merged and stacked for badges and certificates if a learner passes enough modules. Combining the new 3DCP modules with the existing Housing Camp modules offerings allows learners to become proficient in basic and advanced 3DCP topics while also rounding out their education to include the broader concepts of the industry. Together, these modules allow learners to become much more well-rounded in their housing education.

**Exhibit 7. Integrated Housing Camp With 3DCP Modules**

VCHR's existing housing camp

New 3DCP Modules



3DCP = three-dimensional concrete printing. VCHR = Virginia Center for Housing Research.  
 Source: 3D Concrete Printing (3DCP) Curriculum Report Data

## 7. 3DCP Modules Syllabus

As explained in the previous section, this 3DCP curriculum includes 10 submodules under two major categories. Course descriptions, learning outcomes, and detailed information for each module are provided below. The learning outcomes align with the identified 3DCP KCs and the overall curriculum learning outcomes.

### 7–1. Module A1—Contextualizing Digital, Robotic, and Additive Manufacturing in Construction (Lead: Dr. King)

- **Course Description:** This course provides a foundation for understanding the context, opportunities, and challenges associated with the widespread adoption of additive manufacturing technologies for construction. The module provides a framework for understanding early-age 3DCP adoptions and the associated technologies that may lead to future advancements.
- **Course Delivery Method:** Online (synchronous and asynchronous).
- **Course Learning Objectives:**
  - Understand the landscape of digital workflows from design to construction.
  - Understand key contextual aspects relating to the development and dissemination of automation and additive technologies within the construction industry.
  - Define the 3D printing process based on different hardware typologies.
  - Understand emerging technology areas of 3D printing for construction.
- **Key Topics and Weight Breakdown:**
  - 20 percent—Computer-Aided Design, Engineering, and Manufacturing (CAx).
  - 20 percent—Robotic Hardware Typologies.
  - 20 percent—Additive Manufacturing and Construction.
  - 20 percent—Design for Additive Manufacturing (DFAM).
  - 20 percent—Technology Futures for Additive Construction.
- **Instructions:**
  - In-class hours—Synchronous and asynchronous online (5.4 hours).
    - Lecture—Synchronous (2.4 hours).
    - Discussion—Covers key topics in prerecorded lectures and is intended to encourage critical thinking about the tools and technologies in the context of construction. Asynchronous (3 hours).
  - Out-of-class hours—Asynchronous (22.25 hours).
    - Recorded lecture—Will cover topics that are slow to change. Asynchronous (2.25 hours).

- Major assignment—A case study outside of construction focusing on why a technological process solution was chosen. To be submitted in the form of a report (10 hours).
- Quiz—Using a combination of short answer and multiple choice, complete an exam that would evaluate the (1) knowledge and (2) ability to apply the knowledge to a series of short cases (10 hours).

## **7–2. Module A2—Principles of Modeling, Toolpath Simulation, and Prototyping in 3D Printing (Lead: Dr. Afsari)**

- **Course Description:** This course offers training in digital modeling and prototyping techniques for 3D printing. The course emphasizes geometric modeling for 3D printing purposes, along with analysis of the building models for effective 3D printing. It also explains 3D printer toolpath simulation and methods to generate computer numerical control for 3D printer operation. The course also provides hands-on experience in creating 3D-printed prototypes.
- **Course Delivery Method:** Online (synchronous and asynchronous).
- **Course Learning Objectives:**
  - Understand 3D geometric modeling techniques.
  - Apply 3D modeling techniques to create models for 3D printing, and evaluate 3D models for effective 3D printing.
  - Simulate 3D printer toolpath, and generate computer numerical control for the 3D printer.
  - Create scaled-down 3D printed prototypes.
- **Key Topics and Weight Breakdown:**
  - 10 percent—Introduction to 3D Modeling Methodologies.
  - 20 percent—Introduction to Surface Modeling.
  - 20 percent—3D Geometric Modeling for 3D Printing.
  - 20 percent—Simulating the Model for 3D Printing (slicer software).
  - 20 percent—Prototyping Scaled-Down Models with a 3D Printer.
  - 10 percent—Troubleshooting in 3D Printing.
- **Instructions**
  - In-class hours—Synchronous and asynchronous (5 hours).
    - Lecture—Synchronous (0.6 hour).
    - Individual consultation—Synchronous (0.4 hour).
    - Self-paced 3D modeling tutorials—Asynchronous (2 hours).

- Self-paced prototyping tutorials—Asynchronous (2 hours).
- Out-of-class hours—Asynchronous (10 hours).
  - Quiz—3D modeling (1 hour).
  - Quiz—Troubleshooting in simulation and printing (1 hour).
  - Major assignment—3D modeling (4 hours).
  - Major assignment—3D printer toolpath simulation and G-code (4 hours).

### **7–3. Module A3—Concrete Properties and Mix Design Fundamentals for 3DCP (Lead: Dr. Brand)**

- **Course Description:** This course covers the basic principles of concrete materials, with a particular focus on application for 3DCP, including the topics of concrete components, cement hydration reactions and kinetics, fresh concrete properties, hardened concrete properties, standardized tests for evaluating fresh and hardened concrete, concrete mix design procedures, chemical admixtures, supplementary cementitious materials, fiber reinforcement, concrete batching and mixing, concrete curing, determining the carbon footprint and sustainability of cement-based materials, and principles of lifecycle analysis.
- **Course Delivery Method:** Online (synchronous and asynchronous).
- **Course Learning Objectives:**
  - Explain the cement hydration process and early-age concrete properties.
  - Generate a concrete mix design following established procedures, and characterize the relevant fresh and hardened concrete properties for 3DCP.
  - Describe best practices for quality and durable concrete.
  - Discuss the carbon footprint of cement-based materials and how sustainable decisions can be made within a lifecycle analysis framework.
- **Key Topics and Weight Breakdown:**
  - 20 percent—Fundamentals of cement and concrete.
  - 20 percent—Fresh and hardened concrete properties.
  - 20 percent—Concrete mix design.
  - 15 percent—Concrete admixtures and other additives.
  - 15 percent—Concrete mixing, placing, and curing.
  - 10 percent—Sustainability and carbon footprint of concrete, including the basics of lifecycle analysis.
- **Instructions:**

- In-class hours—Synchronous and asynchronous (5 hours).
  - Lecture—Synchronous (0.8 hour).
  - Individual consultation—Synchronous (0.2 hour).
  - Self-paced recorded lecture—Asynchronous (4 hours).
- Out-of-class hours—Asynchronous (10 hours).
  - Quiz 1—Fundamentals of cement and concrete and fresh and hardened properties (1 hour).
  - Major assignment—Use ACI 211.1 to design various concrete mixtures, including plain cement concrete, chemical admixtures, and supplementary cementitious materials. Analyze the sustainability of the various mixtures by considering the carbon footprint, and discuss the lifecycle (4 hours).
  - Minor assignment 1—Quantify concrete fresh and hardened properties on the basis of provided data (2 hours).
  - Discussion of concrete sustainability, assignment review and help, and project consultations (1 hour).
  - Quiz 2—Concrete mix design, concrete mixing/placing/curing (1 hour).
  - Minor assignment 2—Revise mix designs on the basis of different requirements for 3D printing (1 hour).

#### **7–4. Module A4—3D Concrete Printing Fundamentals, Codes, and Safety (Lead: Dr. McCoy)**

- **Course Description:** As future managers in the construction industry, employees need to understand fundamental theories that provide a basis for industry practices. This course covers the fundamentals of 3DCP construction management and applies them to a sample project, emphasizing the practical and safe application for built-environment professionals.
- **Course Delivery Method:** Online (synchronous and asynchronous).
- **Course Learning Objectives:**
  - Understand the phases of 3DCP construction project management and appropriate methods.
  - Define 3DCP project activities, including production, procurement, administration, and milestones. Activities will range from preconstruction planning (printer mobilization, site logistics) to project management (printing processes and maintenance) to close-out and scaling of the work.
  - Analyze the details of the 3DCP drawing document, and define relevant items for construction project management, including codes, safety, and operations.
  - Apply estimating and scheduling skills based on quality, quantity, and cost of

materials for a sample project.

- **Key Topics and Weight Breakdown:**

- 20 percent—Phases of 3DCP construction project management and appropriate methods.
- 20 percent—Project activities, including production, procurement, administration, and milestones.
- 20 percent—Details of the drawing document and defining relevant items for construction project management, including codes, safety, and operations.
- 20 percent—Estimating skills based on quality, quantity, and cost of materials for a sample project.
- 20 percent—Scheduling skills based on quality, quantity, and cost of materials for a sample project.

- **Instructions:**

- In-class hours—Synchronous and asynchronous (5.10 hours).
  - Lecture—Synchronous (3 hours).
  - Individual consultation—Synchronous (0.9 hour).
  - Quiz 1—3DCP Readings: Media Articles Quiz. Asynchronous (0.1 hour).
  - Quiz 2—3DCP Readings: Scientific Literature Quiz. Asynchronous (0.1 hour).
  - Minor assignment 1—Defining and Listing Project Activities for 3DCP: Work Breakdown Structure. Asynchronous (0.1 hour).
  - Minor assignment 2—Scheduling Project Activities for 3DCP: Productivity. Asynchronous (0.1 hour).
  - Minor assignment 3—Costing Project Activities for 3DCP: Costs. Asynchronous (0.2 hour).
  - Discussion—To encourage comprehension of each assignment and lecture. Asynchronous (0.6 hour).
- Out-of-class hours—Asynchronous (10.41 hours).
  - Reading 1—3DCP Readings: Media Articles and Discussion Assignment (1.5 hours).
  - Quiz 1—3DCP Readings: Media Articles Quiz (0.33 hour).
  - Reading 2—3DCP Readings: Scientific Literature and Discussion Assignment (1.5 hours).
  - Quiz 2—3DCP Readings: Scientific Literature Quiz (0.33 hour).

- Minor assignment 1—Defining and Listing Project Activities for 3DCP: Work Breakdown Structure (1.25 hours).
- Minor assignment 2—Scheduling Project Activities for 3DCP: Productivity (1.25 hours).
- Minor assignment 3—Costing Project Activities for 3DCP: Costs (1.25 hours).
- Major assignment—3DCP Cost Pro forma: Combining Cost, Schedule, and Cash Flow (3 hours).

**7-5. Module B1—3D Concrete Printing for Affordable Housing—Case Study (Lead: Dr. McCoy)**

- **Course Description:** This module focuses on 3DCP processes in affordable housing, featuring a case study of an affordable house built using 3DCP technology. The course addresses the project features of the case study, including the design, construction, and operations process; aspects of construction management; challenges of 3DCP technology and lessons learned in building affordable housing; and the codes and standards involved in 3DCP affordable housing. Learners will create an exercise of execution planning for the implementation of an affordable housing example project and evaluate it through discussions.
- **Course Delivery Method:** Online (synchronous and asynchronous).
- **Course Learning Objectives:**
  - Understand affordable housing principles.
  - Understand the process of 3DCP in affordable housing.
  - Understand the construction management of 3D printing affordable housing, including safety and operations.
  - Understand codes and standards related to 3D-printed affordable housing.
- **Key Topics and Weight Breakdown:**
  - 20 percent—Review of affordable housing principles.
  - 20 percent—3DCP case study: features and constraints of 3DCP in the example affordable housing project.
  - 10 percent—3DCP case study: design, construction, and operation processes in 3D printed affordable housing.
  - 20 percent—3DCP case study: construction management aspects and challenges of 3DCP for affordable housing, including safety and operations.
  - 10 percent—3DCP case study: codes and standards in 3DCP for affordable housing.

- 20 percent—Execution planning for a 3DCP affordable house and creating a process map from an operational standpoint.
- **Instructions:**
  - In-class hours—Synchronous and asynchronous (5 hours).
    - Lecture—Synchronous (3 hours).
    - Panel—Synchronous (0.9 hour).
    - Discussion—Synchronous (0.9 hour).
    - Quiz 1—Synchronous (0.1 hour).
    - Quiz 2—Synchronous (0.1 hour).
  - Out-of-class hours—Asynchronous (10 hours).
    - Recorded lecture 1 (1 hour).
    - Recorded lecture 1 (1 hour).
    - Discussion (1 hour).
    - Quiz 1 (1 hour).
    - Quiz 2 (1 hour).
    - Assignment (5 hours).

## **7–6. Module B2—Building Systems and Performance for 3D Printed Affordable Housing (Lead: Dr. Agee)**

- **Course Description:** This course introduces learners to 3DCP building systems integration and performance planning. It provides an overview of common residential energy simulation, thermal comfort, and hygrothermal (moisture) tools to inform 3DCP design decisions. The course identifies and reviews best practices for the integration of mechanical, electrical, and plumbing systems in 3DCP projects.
- **Course Delivery Method:** Online (synchronous and asynchronous).
- **Course Learning Objectives:**
  - Understand 3DCP building energy, thermal performance, and lifecycle topics and tools.
  - Analyze 3DCP building energy, thermal, and lifecycle performance.
  - Evaluate and manage moisture risks in 3DCP.
  - Plan and specify appropriate mechanical, electrical, and plumbing systems for 3DCP.
- **Key Topics and Weight Breakdown:**

- 20 percent—Start at the end: What are the performance goals of your 3DCP project? How to “start at the end” and use systems requirements to manage risk and meet 3DCP project goals.
  - 20 percent—Building science for 3DCP: Heat, air, and moisture management.
  - 20 percent—Human factors of 3DCP: How to design/build building enclosures and systems (mechanical, electrical, plumbing) to promote indoor environmental quality in 3DCP projects.
  - 20 percent—Simulation tools of the trade: How to integrate energy, thermal comfort, hygrothermal tools, and lifecycle simulation(s) to inform 3DCP design. Relevant codes and standards will also be discussed.
  - 20 percent—Diagnostic tools of the trade: How to use common diagnostic and monitoring equipment to measure energy, thermal, and moisture outcomes in 3DCP projects.
- **Instructions:**
    - In-class hours—Synchronous and asynchronous (4.6 hours).
      - Lecture—Synchronous (1 hour).
      - Individual consultation—Synchronous (0.6 hour).
      - Recorded lecture—Asynchronous (2.4 hours).
      - Discussion—Asynchronous (0.6 hour).
    - Out-of-class hours—Asynchronous (10 hours).
      - Recorded lecture (2 hours).
      - Major assignment 1—Simulation 1 (2 hours).
      - Major assignment 2—Simulation 2 (2 hours).
      - Major assignment 3—Monitoring plan (1 hour).
      - Quiz 1—Building performance concepts (1 hour).
      - Quiz 2—Codes, standards, guidelines (1 hour).
      - Discussion—Assignment review/help/personal project consultation (1 hour).

### **7–7. Module B3—Structural Performance and Reinforcing for 3D Printed Affordable Housing (Lead: Dr. McCoy)**

- **Course Description:** As future printers within the construction industry, workers need to understand the principles of structure for residential buildings. This course covers the basics of concrete structural elements and design for 3DCP buildings at the residential

scale and applies them to a sample project, emphasizing the practical and safe application for built-environment professionals.

- **Course Delivery Method:** Online (synchronous and asynchronous).
- **Course Learning Objectives:**
  - Understand the basics of structural loads for 3DCP homes, including relevant codes and standards.
  - Understand the basics of structural reinforcement for 3DCP homes.
  - Analyze 3DCP drawing document details, and perform basic modeling of relevant items for structural integrity and reinforcement.
  - Define the structural parameters of a sample project.
- **Key Topics and Weight Breakdown:**
  - 20 percent—Basics of structural loads for a residential building.
  - 20 percent—Basics of structural loads for a residential 3DCP building.
  - 20 percent—Materials and methods for a residential 3DCP building.
  - 20 percent—Analysis of residential 3DCP project design details to identify structural requirements, including codes.
  - 20 percent—Analysis of an actual residential 3DCP project using (basic) modeling of structural load paths.
- **Instructions:**
  - In-class hours—Synchronous and asynchronous (5 hours).
    - Lecture—Synchronous (3 hours).
    - Individual consultation—Synchronous (0.90 hour).
    - Quiz 1—Asynchronous (0.10 hour).
    - Quiz 2—Asynchronous (0.10 hour).
    - Discussion—Asynchronous (0.90 hour).
  - Out-of-class hours—Asynchronous (10 hours).
    - Reading 1 (1 hour).
    - Reading 2 (1 hour).
    - Quiz 1 (0.75 hour).
    - Quiz 2 (0.75 hour).
    - Minor assignment 1 (0.75 hour).

- Minor assignment 2 (0.75 hour).
- Major assignment (5 hours).

**7–8. Module B4—Architectural Design for 3D Printed Affordable Housing (Lead: Dr. Afsari)**

- **Course Description:** This course offers training in architectural design principles for 3D-printed affordable housing. The course provides an overview of architectural design approaches considering 3D printer constraints and provides hands-on training with 3D modeling that is compatible with 3D printing. The course explains the detailing process for 3D printed affordable housing and the relevant building codes and standards.
- **Course Delivery Method:** Online (synchronous and asynchronous).
- **Course Learning Objectives:**
  - Understand 3D printing constraints for architectural design.
  - Develop 3D models for 3D printed housing.
  - Apply architectural detailing principles for 3D-printed affordable houses.
  - Understand codes and standards related to 3D-printed housing.
- **Key Topics and Weight Breakdown:**
  - 20 percent—Design with 3D printer constraints.
  - 20 percent—3D modeling principles for 3D printed houses.
  - 10 percent—Analysis of architectural models for 3D printed houses.
  - 20 percent—Architectural detailing for 3D printed houses and transitions to other building systems (e.g., wall sections for thermal performance).
  - 10 percent—Architectural drawings and permit sets for 3D printed houses.
  - 10 percent—Codes and standards for 3D printing.
  - 10 percent—Reading drawings of a 3D printed house and understanding constraints, details, and other considerations.
- **Instructions:**
  - In-class hours—Synchronous and asynchronous (5 hours).
    - Lecture—Synchronous (0.6 hour).
    - Panel—Synchronous (0.4 hour).
    - Self-paced recorded lecture—Asynchronous (4 hours).
  - Out-of-class hours—Asynchronous (10 hours).
    - Quiz—Reading drawings of 3D-printed housing projects (1 hour).

- Major assignment—3D modeling principles for 3D printing in a sample project (4 hours).
- Major assignment—Detailing for 3D-printed affordable housing (4 hours).
- Minor assignment—Codes and standards (1 hour).

### **7–9. Module B5—3D Printer Operations (Lead: Dr. Afsari and printer partner)**

- **Course Description:** This course provides hands-on training with 3D printer equipment, including robot printer, accessories (e.g., mixer, pump), printer software, and robot control. The course also provides an operational understanding of printing, cleaning, and maintenance procedures, considering health and safety measures, emergency stops, and troubleshooting.
- **Course Delivery Method:** Synchronous in-person and online (synchronous and asynchronous).
- **Course Learning Objectives:**
  - Understand 3D printer equipment, accessories, and specifications.
  - Apply knowledge of 3D printer software and robot control.
  - Apply operational procedures and safety for printing and cleaning.
  - Understand 3D printer equipment maintenance and troubleshooting.
- **Key Topics and Weight Breakdown**
  - 20 percent—3D printer equipment and accessories.
  - 20 percent—3D printing software, robot control, and emergency stops.
  - 20 percent—Printing procedure and health and safety.
  - 20 percent—Cleaning procedure and health and safety.
  - 10 percent—Printer equipment maintenance and troubleshooting.
  - 10 percent—Test prints and dry run.
- **Instructions:**
  - In-class hours—Synchronous and asynchronous (10 hours).
    - Hands-on training with equipment—Synchronous (5 hours).
    - Test print example, dry run, and cleaning—Synchronous (4 hours).
    - Self-paced recorded lecture—Asynchronous (1 hour).
  - Out-of-class hours—Asynchronous (5 hours).
    - Major assignment—Develop 3D printing standard operating procedure (4 hours).

- Discussion—Assignment review and help, project consultations (1 hour).

## 7–10. Module B6—Concrete Extrusion and Testing (Lead: Dr. Brand)

- **Course Description:** This course covers the basic principles of 3DCP extrusion and testing, including mixing, pumping, extrusion, nozzle types, gantry and robotic arm printers, anisotropic properties of 3DCP, and how to test and quantify the anisotropic properties of 3DCP.
- **Course Delivery Method:** Online (synchronous and asynchronous).
- **Course Learning Objectives:**
  - Describe the layer-by-layer manufacturing process of 3DCP.
  - Quantify the anisotropic properties of 3DCP resulting from the manufacturing process and how the hardened properties of 3DCP will differ from conventional cast concrete.
  - Explain the general process of mixing, pumping, and extrusion in 3DCP, and differentiate the different printer types available.
- **Key Topics and Weight Breakdown:**
  - 10 percent—Comparison of hardened properties of 3DCP vs. conventional cast concrete.
  - 10 percent—Anisotropic properties of 3DCP.
  - 25 percent—How to quantify the properties directionally relative to the print layers—that is, how to modify existing American Society for Testing and Materials (ASTM) standards for concrete testing—because no ASTM standard exists for 3DCP.
  - 15 percent—Layer-by-layer construction of 3DCP.
  - 20 percent—3DCP process (mixing, pumping, and extrusion).
  - 20 percent—Different printer types for 3DCP.
- **Instructions:**
  - In-class hours—Synchronous and asynchronous (5 hours).
    - Lecture—Synchronous (0.80 hour).
    - Individual consultation—Synchronous (0.20 hour).
    - Recorded lecture—Synchronous (4 hours).
  - Out-of-class hours—Asynchronous (10 hours).
    - Quiz 1—3DCP processes and hardened concrete properties (1 hour).

- Major assignment—Analysis of ASTM standards for conventionally cast concrete, analysis of anisotropic properties of 3DCP, and analysis to compare conventionally cast and 3D printed concretes (4 hours).
- Minor assignment—Exploration of different printer types and nozzle geometries (4 hours).
- Discussion—Assignment review and help, project consultations (1 hour).

## 8. Two Selected 3DCP Modules—Initial Training and Evaluation

This section provides a summary of the content in two selected modules. These modules include A2—Principles of Modeling, Toolpath Simulation, and Prototyping in 3D Printing and B1—3D Concrete Printing for Affordable Housing Case Study. The team selected these two modules to develop further and offer to the first cohort of trainees for initial evaluation.

### 8–1. Module A2—Principles of Modeling, Toolpath Simulation, and Prototyping in 3D Printing (Lead: Dr. Afsari)

This module, led by Dr. Kereshmeh Afsari, focuses on digital modeling and prototyping techniques for 3D printing. The module contains several synchronous lectures and a variety of recorded lectures, quizzes, and assignments for participants to complete at their own pace (asynchronous online).

Topics in this module include the following:

- Getting started with Rhino.
- Getting familiar with the Rhino user interface.
- Setting up a Rhino file with proper units.
- Drawing 2D geometric shapes in Rhino.
- Generating 3D surfaces in Rhino.
- Editing geometry in Rhino.
- Preparing Rhino files for 3D printing.
- 3D printing, tool path simulation, and prototyping using slicer software.
- Parametric modeling using Grasshopper.

**Module A2 offering to the first cohort of trainees:** This module was delivered in the summer of 2024 to six people from the construction industry as the first cohort of trainees. The course was administered through Virginia Tech Professional Development using the Canvas platform and the Zoom video conferencing platform. The course included three synchronous lectures and two Q&A sessions online. It also included two major assignments (for modeling and for simulation and prototyping) and two quizzes. The six trainees were identified and introduced by 3DCP partner TNT Development. Module A2 training took 2 weeks, and all six trainees completed learning about 3D modeling with Rhino, preparing 3D models for 3D printing, 3D printer toolpath simulation, and preparing G-code for prototyping. The module participants completed post-training evaluation surveys and provided their feedback.

### 8–2. Module B1—3D Concrete Printing for Affordable Housing Case Study (Lead: Dr. McCoy)

This module, led by Dr. Andrew McCoy, focuses on the 3DCP process by examining a case study of an affordable house built using 3DCP technology. The module contains a variety of lectures, discussions, and quizzes, some of which are synchronous and others self-paced (asynchronous online).

Topics in this module include the following:

- Introduction to additive manufacturing and 3DCP processes.

- Project overview and scheduling, highlighting the planning, preconstruction, construction, and post-construction phases and activities within each.
- Market research, including housing typology of the local market and size and pricing estimates.
- Design constraints associated with the 3DCP house, including weather resistance, insulation, connection details of 3DCP material to other house components, and technology considerations and limitations.
- Housing requirements of the 3DCP house, including creating an affordable single-family home in a neighborhood setting, approximately 1,400 to 1,500 square feet in size, with a three-bedroom, two-bathroom layout and efficient plumbing and mechanical systems.
- Overview of the process from concept to completion: design and 3D modeling to surface modeling, to 3D printing simulation, to computer numerical control, to actual 3D printing, to the completed house.
- 3D printing specifications, including wall height, thickness, details, cavity walls, and wall ties.
- The 3D modeling process, which includes modeling surfaces representing the centerlines of the wall, exporting them to the appropriate file type, importing them into the 3D printer interface, and slicing them for simulation.
- 3D printer simulation and program principles.
- 3D gantry printer setup, including laying out z verticals, establishing y1 and y2, and establishing x carriage with nozzle.
- Printing operations, system requirements, and required personnel.
- Challenges of the 3DCP case study, including manufacturing outdoors with concrete due to risk, carbon issues, and production; demand for a skilled workforce; education among not only construction teams but also code officials and consumers; and temporary power.
- Opportunities of the 3DCP case study, including printing indoors with non-concrete materials, learning from the building failures and future litigation over those failures, and military and space applications.

**Module B1 offering to the first cohort of trainees:** This module was delivered in the summer of 2024 to six people from the construction industry as the first cohort of trainees. The course was administered through Virginia Tech Professional Development using the Canvas platform and the Zoom video conferencing platform. The course included three assignments with three associated discussions. The six trainees were identified and introduced by 3DCP partner TNT Development. Module B1 took 3 weeks, and all six trainees learned about affordable housing principles, the 3DCP process in building an affordable house, codes and standards, and execution planning for 3DCP affordable housing. One part-time graduate student assisted with the delivery of these two modules.

## 9. Learning Evaluations

Upon completion of modules, participants have the opportunity to partake in a short survey aimed at evaluating the extent to which the content met the learning objectives outlined for the course. The 10-question survey was developed to gauge feedback on the modules through a mix of scaled questions and open-ended questions that allow participants to express opinions on the course and content.

For this evaluation, survey questions use a 5-point Likert scale (strongly agree, agree, neither agree nor disagree, disagree, or strongly disagree). This evaluation includes learning outcomes covered through module content, the effectiveness of the instructor's teaching, obtaining a deeper understanding of content, interest in subject matter stimulated by the module, contribution of module material and readings to learning, and the value of out-of-class assignments. Survey questions also use short answers, with questions covering what the instructor did that contributed the most to learning outcomes, what the participant could have done to be a better learner, an additional comment section regarding the course and instructor, and what additional information or materials could have facilitated learning. These open-ended questions provide a more in-depth evaluation of students' perceptions of teaching and learning.

## 10. References and Further Reading

Afsari, Kereshmeh, Vida Babajaniniashirvani, and Andrew McCoy. 2024. “3D Concrete Printing (3DCP) Education in the Construction Industry.” *Proceedings of 60th Annual Associated Schools of Construction International Conference 5*: 39–47.

Babajaniniashirvani, Vida, Kereshmeh Afsari, and Andrew McCoy. 2024. “Investing Key Competencies for 3D Concrete Printing in Affordable Housing.” *Proceedings of i3CE 2024 ASCE International Conference on Computing in Civil Engineering*, Pittsburgh, PA.



U.S. DEPARTMENT OF HOUSING AND URBAN DEVELOPMENT  
FEBRUARY 2026