*Guest Editors' Introduction*

# Recent Findings and Results of Grants from the Cooperative Research in Housing Technologies Program: Where Do They Fit Within the Framework of the Past 55 Years of Housing Technology Innovation at HUD?

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*The views expressed in this article are those of the authors and do not represent the official positions or policies of the Office of Policy Development and Research, the U.S. Department of Housing and Urban Development, the U.S. Government, or the academy.*

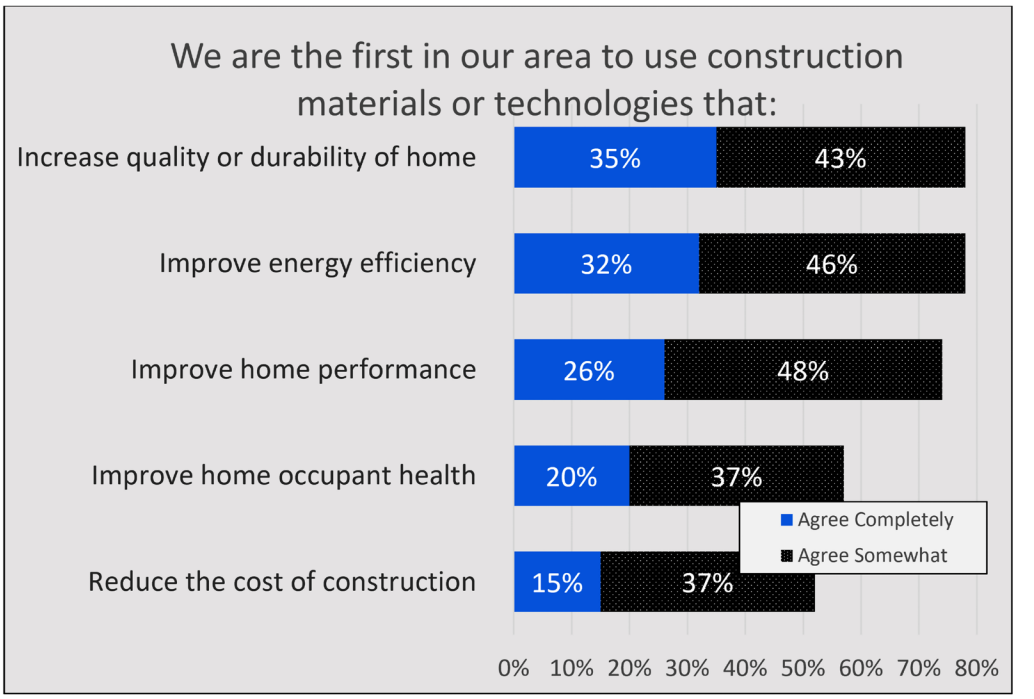
This symposium presents findings and results from the research program Cooperative Research in Housing Technologies (CRHT), sponsored by the U.S. Department of Housing and Urban Development (HUD). HUD managed a total of 10 CRHT grants from fiscal year (FY) 2019 to 2022. This issue includes articles on all 10 projects.

HUD's mission is ***to create strong, sustainable, inclusive communities and quality affordable homes for all***. Housing technology researchers often view "quality affordable homes" through a technology lens by seeking the next housing innovation that will solve the affordable housing crisis

or resolve issues of affordability in general.[1] Advanced housing technology itself is not a panacea for the affordability of housing. In fact, HUD research has shown that a new paradigm in housing technology can take 15 to 25 years to achieve its full market potential (Koebel et al., 2004). In a recent survey of 300 home builders, Home Innovation Research Labs found that home builders were more likely to adopt a new technology that improved the performance of their homes rather than reduced the cost of construction (exhibit 1) (Hudson, 2022). Although that may be true, a builder has a logical limit to the ability to absorb those costs or articulate the value to a homebuyer customer while doing nothing to address the overall question of affordability.

**Exhibit 1**

Homebuilders' Motivation to Adopt New Technologies




*Source: Hudson, 2022*

Almost from its inception, HUD has attempted to assist in improving the affordability and durability of the nation's housing stock through investments in science and technology. However, significant challenges to such improvements, such as land use and zoning requirements, raise barriers to affordability; building codes do not support innovation; risk aversion is widespread among builders, developers, and consumers; and lack of investment in innovative housing technologies poses a challenge. The role of HUD has been to sponsor studies and demonstrations that better inform

[1] For purposes of this article and symposium, the terms *innovation* and *technology* are used interchangeably and limited in scope. Thus, innovation/technology is the introduction of something new that results in an improvement of function or performance. Homebuilding innovations can include new construction methods, materials, techniques, processes, or products that greatly improve the functions of homes.

regulators, builders, developers, and consumers as they make decisions that affect the housing market and make significant impacts on the supply and availability of affordable housing.

## Short History of Housing Technology Research at HUD[2]

Before the creation of HUD in 1965, federal research, development, and demonstration activities related to housing, metropolitan growth, and urban problems were relatively small, disparate projects. Efforts in the 1930s and 1940s by New Deal agencies such as the Federal Housing Administration, Tennessee Valley Authority, Farm Security Administration, and Federal Emergency Relief Administration; prefabricated defense housing; and the postwar Veterans' Emergency Housing Program were exceptions to that observation.[3] Also notable were the Housing Acts of 1948 and 1949 for promoting technical research to improve housing construction and affordability. The 1950s also saw some Levittown communities and other mass-produced housing, at least with some modular or prefabricated components.

In the 1960s, following several advisory committee evaluations and recommendations, the Demonstration Cities and Metropolitan Development Act of 1966, Section 1011, directed HUD, led by Secretary Robert C. Weaver, to conduct research about the "ecological factors involved in urban living" as well as studies and demonstrations on ways to apply innovative technologies to housing construction, rehabilitation, and maintenance and to urban development activities.[4]

Thus began the two distinct objectives for research to reach the 1949 Act's goal of "a decent home and a suitable living environment for every American family."[5,6] In this article, the authors follow the latter track. Within that track, later research on improvements in housing production would disaggregate into researching construction techniques and how to overcome regulatory barriers that drive up the cost of production.

In 1967, HUD commissioned a study and report by the National Research Council of the National Academies of Sciences and Engineering (NRC) on recommendations for "long-range planning for R&D [research and development]" at HUD (NRC, 1969). NRC came down mainly on the side of the first strategy of social intervention, but it did recommend that HUD focus (1) on ways to use currently available technology—such as improvements in factory-produced housing—and (2) only secondarily on the pursuit of research opportunities in new technology.

## Section 108, HUD Act of 1968: A Vital Authorization for Building-Technology Advancement

The 1968 Housing and Urban Development Act looked beyond the annual vision and instead established a 10-year housing goal of 26 million new homes, 6 million of them for low- and

[2] For a more thorough review of the history of HUD housing technology research programs see NRC, 2008.

[3] Many of these exceptions were efforts to actually build housing that supported their programs, so the research could be implemented quickly in the construction of large numbers of houses.

[4] Sec. 101, Pub. L. 89–754, 80 Stat. 1255 (November 3, 1966).

[5] Sec. 2, Pub. L. 171, 63 Stat. 432 (July 17, 1949).

[6] For more on the tension between technology and social science research at HUD, see HUD (2016).

moderate-income families. Ultimately, more than 17 million homes were built from 1969 to 1979. The same act's Section 108 directed HUD to encourage the use of new technologies in the development of low-income housing.

That mandate called for HUD to solicit and approve no more than five plans by public or private entities for the development of low-income housing "using new and advanced technologies...where local building regulations permit the construction of experimental housing" or where local zoning laws permit variances for the construction of "experimental housing."[7]

In addition to encouraging the use of new technology in low-income-housing production, the demonstration was meant to "encourage large-scale experimentation in the use of such technologies."[8,9]

Before Secretary Weaver left office after the 1968 presidential election, HUD began to implement the mandate of Section 108 of the 1968 HUD Act.

## Austin Oaks, Surplus Lands, and In-Cities Demonstrations to Jump-Start Section 108 and Operation Breakthrough

In December 1968, President Lyndon Johnson dedicated a 10-unit building technology demonstration known as Austin Oaks. He used the dedication to discuss the Housing Act of 1968 that had passed earlier that year, his role in implementing the first public housing in the nation more than 30 years earlier, and the national challenges that remained as his presidency ended.

The housing design competition prized speed, affordability, and energy efficiency, so several National Aeronautics and Space Administration space shuttle fabricators designed and built homes in the cul-de-sac (Wilson, 2021). As part of the pilot program, an interdisciplinary research team from the University of Texas at Austin deployed engineers to measure the energy performance of the 10 homes over time, and concurrently, a team of sociologists and architects used participatory design techniques to answer the question, Can families of different races live together?

That pilot program, although small in stature, illuminates the tensions within federal government approaches of the late 1960s: a belief in the top-down application of space-age technology to solve complex social problems while also endeavoring to embrace the bottom-up practices of participatory design that were coming out of the civil rights movement.

In addition, the outgoing administration had initiated through the Office of Urban Technology and Research an experimental housing project to study how zoning, building codes, labor rules, and local financial and administrative policies constrain the rapid adoption of cost-saving housing production technologies. This project was called the "in-cities" Experimental Housing Project. The Office of Urban Technology and Research advised the incoming administration that one of the most important R&D matters requiring HUD's attention was the development of a major innovative housing demonstration potentially ten times the size of the in-cities experiment in response to Section 108 of the 1968 Act.

[7] Sec. 108, Pub. L. 90-448, 82 Stat. 476 (August 1, 1968).

[8] Sec. 108, Pub. L. 90-448, 82 Stat. 476 (August 1, 1968).

[9] Administratively, from 1967 to 1969, the title of the R&D office switched from Urban Technology and Research to Urban Research and Technology and then simply to Research and Technology.

Under the direction of the Urban Renewal Administration at HUD, the White House coordinated a Surplus Lands Community Development Demonstration. The sites included Fort Lincoln and the former National Training School for Boys in the District of Columbia. One of the goals was to be a national showcase for the practical application of new systems and technologies in architecture, site development, and construction. Others were at Louisville, Kentucky; San Antonio, Texas (Fort Sam Houston); and San Francisco (Fort Funston and Fort Miley). Thus was born the foundation for the next generation of housing technology: Operation Breakthrough under the next secretary, George Romney.

## Continuation of R&D Housing Technology Programs Under Secretary Romney (1969–72)

Secretary George Romney and his staff reviewed the various housing technology research and demonstrations begun by the preceding administration and transferred those initiatives to a new brand name: Operation Breakthrough.[10] The program was outlined in May 1969 at meetings held by HUD with members of the building industry, labor unions, and state and local governments under a new assistant secretary for research and technology, Harold B. Finger (exhibit 2).

**Exhibit 2**

Photo of HUD Secretary Romney and Assistant Secretary for Research and Technology Finger, circa 1969

*Harold B. Finger (far left) and Secretary Romney (far right). Photo credit: Art Rosfeld.*

[10] Secretary Romney had served as president of American Motors Corporation before his election as governor of Michigan prior to his service as Secretary.

Further research authority evolved with the passage of Title V of the 1970 Housing and Urban Development Act, which reemphasized Section 108 of the 1968 HUD Act. It stated "the Secretary shall require, to the greatest extent feasible, the employment of new and improved technologies, methods, and materials in housing construction, rehabilitation, and maintenance...with a view to reducing costs, and shall encourage and promote the acceptance and application of such advanced technology, methods, and materials by all segments of the housing industry...."[11]

## Operation Breakthrough 1969–75

Operation Breakthrough, which continued the demonstrations from the 1968 Housing Act, was a demonstration program that supported national industrial manufacturers in trying their hand at the industrialization of home building, with specific focus on improving production volume. Ultimately, Operation Breakthrough produced nine prototype housing projects on sites nominated by local and state governments, representing urban peripheral, suburban, and semirural neighborhoods. It built nearly 3,000 units from 1971 to 1973. During FY 1971, however, Congress approved only $30 million for HUD research and technology, and other issues led to attacks on the demonstration.

By 1975, Finger's successor, Michael H. Moskow, drew down the curtain on Operation Breakthrough with his Report Number 4, summarizing the pluses and minuses. More importantly, two things occurred: HUD reorganized the office to include policy, which broadened the technical focus by means of new staff and leadership, and which had an emphasis different from technology—namely, that of the second strategy of the social science experiments, such as the Experimental Housing Allowance Program. No more large-scale technology experiments have been conducted through the present time.

## Solar Demonstration Program

The Solar Demonstration Program of 1975–82 consisted of the Solar Heating and Cooling Demonstration Program and the Passive Solar Residential Design Competition. Both programs were created to respond to the energy crisis of the early 1970s.

The Solar Demonstration Program was intended to help bring the solar industry to the point that it could economically serve the housing industry with efficient and cost-effective heating and cooling equipment. During the life of the program, HUD awarded 943 grants, and solar systems provided hot water, space heating, or space cooling for 10,098 dwelling units (HUD, 1976; NRC, 1985).

The Passive Solar Residential Design Competition was a competition and award program to encourage the design, construction, and marketing of passive solar homes (HUD, 1980). That initiative was the first time the federal government conducted activities that directly supported the promotion of a technology to consumers.[12] The program also helped serve as the technical foundation for energy efficiency improvements that have been made in the residential sector.

[11] Housing and Urban Development Act of 1970, Title V, §§ 501–504, Pub. L. 91–609, 84 Stat. 1784–1786 (December 31, 1970).

[12] It is important to note that HUD's engagement with American housing is limited largely to the residential affordable rental properties administered by the Office of Public and Indian Housing and the Office of Housing. Other HUD programs typically provide financing only for existing or new housing, with virtually no technical engagement by HUD.

## Small Directed Research Activities 1980s–90s

During the 1980s and 1990s, HUD conducted small research activities across a number of topical areas rather than a specific major initiative. The most significant of those activities was work to advance understanding of alternatives to wood framing.[13] HUD supported the development of building code provisions for three alternatives to wood framing: light-gauge steel framing, structural insulated panels, and insulating concrete forms. HUD published numerous research reports on all three alternatives, often in close collaboration with industry stakeholders. HUD also conducted research to develop lead paint regulations. That focus ultimately led HUD to establish the Office of Lead-Based Paint. Finally, HUD research supported improved regulations for the manufactured-housing industry. The research included activities on wind safety, fire safety, permanent foundations, metal roof installation, and energy standards (HUD, 1996).

## Partnership for Advancing Technologies in Housing, 1998–2008

However, what had been dropped in the post-Operation Breakthrough studies—building technologies—was taken up again in the late 1990s under the Clinton Administration, albeit with a different emphasis. The Partnership for Advancing Technologies in Housing's (PATH's) mission was to collaborate with public- and private-housing-industry experts to expand the development and use of new technologies that make American homes safer, more durable, and more energy efficient without sacrificing affordability. That emphasis was based on findings by the National Science and Technology Council (NSTC), which developed the National Construction Goals in the mid-1990s (NSTC, 1995). National Construction Goals stipulated—

- 50 percent reduction in project delivery times.
- 50 percent reduction in operations, maintenance, and energy costs.
- 30 percent increase in occupant productivity and comfort.
- 50 percent fewer facility-related illnesses and injuries.
- 50 percent less waste and pollution.
- 50 percent greater durability and flexibility.
- 50 percent reduction in construction illnesses and injuries.

Thus, technological innovation was geared toward construction quality and sustainability rather than the industrial production focus of Operation Breakthrough. Investments in innovation appear to be associated with the cyclical nature of the housing industry (Martin and McCoy, 2019). Thus, the demise of the PATH program coincided with the recession in 2008. At that time, support for the PATH program waned both in Congress and at HUD.

[13] This effort led to the development of building code provisions for light-gauge steel framing, structural insulated panels, and insulating concrete forms, which are notable because homes built with those technologies are almost exclusively in the private market, with little HUD engagement.

## Sustainable Construction in Indian Country, 2011–16[14]

In HUD's Fiscal Year 2010 Appropriations Act, Congress enacted the Transformation Initiative, which made up to 1 percent of program funds available for (1) research, evaluation, and program metrics; (2) program demonstrations; (3) technical assistance; and (4) information technology. The Sustainable Construction in Indian Country (SCinIC) initiative was a congressionally mandated effort of the Transformation Initiative. SCinIC sought to promote and support sustainable construction practices in Native communities and thereby help tribes provide their members with healthier, more comfortable, and more resource-efficient homes.

The initiative consisted of several interrelated activities. HUD, other federal agencies, and key stakeholders worked to identify and overcome barriers to the adoption of sustainable construction practices in Indian country. Participating tribes also received technical assistance to support their adoption of sustainable construction practices in residential construction or rehabilitation projects, and HUD provided training on sustainable construction practices.

## Cooperative Research in Housing Technologies, 2019–Present

Cooperative Research in Housing Technologies is a current HUD housing technology research effort. The CRHT program represented a HUD response to a recommendation by the National Research Council (NRC, 2008). Specifically, Recommendation 4-2 stated that HUD "should provide small research grant competitions…that focus on basic and enabling research in technology and maintain a distance from implicit product endorsement or demonstration" (NRC, 2008). With that recommendation in mind, HUD sought applications for "co-operative agreements for pre-competitive research in homebuilding technologies that provide the homebuilding industry with new, innovative construction products or practices that lead to more affordable, energy efficient, resilient,[15] and healthier housing" (NRC, 2008). Two notices of funding opportunities were published: in April 2019 and May 2020.[16]

It is important to note that the basic goals of HUD building technology research programs have remained the same through the years. It is imperative that HUD building technology research continue focusing on affordability and volume production. Among federal agencies involved in housing, affordability is a concern unique to HUD. However, much has changed in the past 57 years. The threat of climate risk and energy insecurity are now important considerations in addition to the ultimate goal of expanding access to quality affordable housing at all income levels. As a result, readers will recognize that many of the symposium articles have a primary or secondary focus on energy efficiency, resilience, and/or healthy housing, but all are grounded in affordability.

[14] For more information on the Sustainable Construction in Indian Country initiative, see https://www.huduser.gov/portal/SCinIC/home.html.

[15] *Resilient* refers to a technology that provides durability and is disaster resistant, adaptable for future requirements, and maintainable.

[16] Two other funding opportunities limited to historically black colleges and universities were also published in September 2020 and June 2021. However, that research was not sufficiently advanced to be included in this symposium.

## Featured Symposium Articles

This symposium presents 10 new research articles on projects funded by HUD through the Cooperative Research in Housing Technologies grant competition. In addition to descriptions of their research and findings, each author opened their monographs by revisiting their rationale for proposing the effort. Specifically, the authors were asked to describe—

- Why HUD funding is required and how the resulting knowledge will help the Department and industry improve the quality and performance of housing.
- The significance of the work, including its relationship to past efforts and those proposed for the future. The authors were asked to clearly describe how their work builds on existing knowledge and how it would foster innovation in homebuilding in the future.
- How the effort will change the homebuilding process, including the broader impact expected, practical implications, and why the information will be accepted by relevant stakeholders.
- Anticipated changes to building codes, design processes, or construction that are expected to be necessary to support widespread use of the result of this effort.

## Synopses of the 10 Research Articles

1. Christine Barbour and James Lyons of Newport Partners, LLC examined technical and regulatory solutions for effective air sealing of area separation walls in attached housing to reduce housing costs and increase efficiency, safety, and indoor air quality. Townhomes and duplexes represent some of the most-affordable forms of new housing options in the United States, yet the separation wall between adjacent dwelling units is a major problem area that is jeopardizing energy efficiency, fire safety, code compliance, and housing affordability. This article summarizes field and regulatory solutions to consistently design and construct cost-effective area separation walls and serves as an example of the need to harmonize codes through a holistic lens and adopt innovations to reduce complexity and maintain affordability. The results of this project give builders and municipalities a clearer understanding of these issues and enable them to apply balanced technical and regulatory solutions as the energy code landscape rapidly accelerates to meet climate change goals.

2. Jeff Carney, Ravi Srinivasan, Stephen Bender, Bill O'Dell, Ryan Sharston, Abdol Chini, and Forough Foroutan of the University of Florida developed prototype designs for rapid manufacture and placement of postdisaster housing. Advanced modular housing design (AMHD) addresses the design of housing that can be rapidly built in factories that can cope with future major events and become major community assets. The natural disasters considered in the development of the AMHD include hurricane-force winds, flooding, and storm surges. The attributes required for AMHD postdisaster housing include high structural strength, high levels of energy efficiency, energy self-sufficiency, and deconstructability. HUD support for the research has the potential to spur innovation across the manufactured and modular homebuilding industries to develop innovative solutions for postdisaster housing.

3. John W. van de Lindt of Colorado State University, Maria Koliou of Texas A&M University, and Pouria Bahmani of Washington State University designed and tested several generic connectors for use in cross-laminated timber (CLT) balloon-style construction. The research provides results that demonstrate and document a rational design procedure for CLT balloon-style construction for use in seismic regions of the United States. The effort will conclude with a U.S. code proposal that can be adopted by local jurisdictions and national-level provisions and design codes developed in coordination with a stakeholder-based expert panel.

4. John B. Peavey, Nay B. Shah, Chinedu Moneke, Kevin Kauffman, and Elina Thapa of Home Innovation Research Labs developed residential resilience guidelines for builders and developers. The research identified and converted the existing breadth of general ideas and policies on resilience to specific and actionable guidelines and criteria that can be understood and integrated into residential design and construction practices for both multifamily and single-family communities. The resulting resiliency framework may lead to the establishment of voluntary or incentivized above-code programs that are critical to fostering early market transformation.

5. Victor Braciszewski, Stet Sanborn, Justin Tholen, and Harshana Thimmanna of SmithGroup; Tyler Pullen and Carol Galante of the University of California, Berkeley, Terner Center for Housing Innovation; and Jamie Hiteshew of Factory_OS examined the integration of a heat pump water heating system to increase energy efficiency and reduce cost in modular construction. The authors provide an analysis of the potential for heat pump water heating systems in particular, due to the high proportion of typical building energy usage associated with water heating. To encourage further adoption, the research assessed the advantages of and the challenges to combining such systems with modular construction practices, with the goal of optimizing for cost efficiency, quality installation, and performance of this major energy-saving technique. Ideally, modular manufacturers beyond Factory_OS will adopt heat pump water heaters and homebuyers will insist on it.

6. Emanuel Levy, Jordan Dentz, and Yi-Jia Liao of the System Building Research Alliance reimagined and reengineered the design and fabrication of the heating, ventilating, and air-conditioning (HVAC) system in manufactured housing, with all components installed in the plant under the HUD quality control regime. This study explores two hardware integration and product configuration options that improve home performance and quality. It also explores changes to commercial arrangements, including the equipment distribution, inventory, and servicing necessary to align commercial interests that will ultimately benefit the homebuyer. Besides improvements to the quality of installation, the affordability of the HVAC system can be improved through bulk purchase of HVAC systems by home manufacturers.

7. John Peavey, Ed Hudson, and Zachary Summy of Home Innovation Research Labs investigated two critical construction issues related to three-dimensional concrete printing (3DCP). First, they identified barriers to adoption of 3DCP technology such as lack of building codes or standards, lack of design and construction guidance, and lack of technical expertise to implement the new technology. Second, the team evaluated the integration of 3DCP components—primarily

walls—with conventional building product components such as windows and doors, plumbing, electrical, and wall connections between roof and foundation. In addition, the article describes the results of qualitative research by home builders and contractors at jobsites and through a national survey to find the challenges and opportunities that will accelerate the adoption of 3DCP. The results of this research will inform builders that currently use traditional stick framing techniques on the pros and cons of building with 3DCP walls.

8. Isabelina Nahmens and Ondřej Labík of Louisiana State University; Alison Donovan, Kalee Whitehouse, Damon Lane, Desmond Kirwan, and Leslie Badger of VEIC; and Ankur Podder and Shanti Pless of National Renewable Energy Laboratory developed and implemented techniques for the installation of solar panels and battery storage (S+S) in modular housing at the factory. The team identified the potential barriers (e.g., first cost, permitting, utility interconnection, finished-module transportation, future battery replacement) and the value (e.g., resiliency benefits, opportunities for utilities, clean energy equity for affordable housing, new markets for modular factories) of incorporating S+S into factory-built housing. Through a case study and factory information modeling, the team analyzed the factory-installed solar plus storage approach, which resulted in an approximately 27 percent potential total cost reduction compared with on-site installation. Results from this project set forth a new strategy for resilient construction to all-electric zero-energy modular homes and redesign of resilient power systems from backup generators to S+S.

9. Mohammad Aghajani Delavar, Hao Chen, and Petros Sideris of Texas A&M Engineering Experiment Station describe their efforts to demonstrate, document, and validate a rational design procedure for 3D concrete printing residential construction, accounting for seismic loads; and to develop, in coordination with a stakeholder-based peer review panel, a best-practices document to serve as a building code proposal that can be adopted by local jurisdictions and national-level provisions and design codes. The article further describes large-scale testing of 3D concrete printed walls with and without integrated reinforced concrete elements, the development of design capacity equations, and a comprehensive seismic collapse assessment study of a set of 3D printed archetype buildings to demonstrate their margin against seismic collapse. The resulting building code proposal, if accepted, will facilitate widespread adoption of 3D concrete printing in seismic regions.

10. Nafisa Tabassum and Rifat Bulut of Oklahoma State University conducted a thorough examination of current state-of-the-art knowledge and recent developments in slab-on-ground foundations constructed over expansive soils. Expansive soils are soils that swell or shrink ground surface during times of wet and dry conditions. Degradation of a foundation through swell and shrink cycles can severely affect a home's resilience and long-term durability. Climate change has exacerbated the problem by increasing rainfall in some areas and by bringing rain to normally dry areas. Research results show that commonly used foundation design software might not account for the effects of climate change on expansive soils. The findings of this work could improve the resilience of slab-on-ground foundations to climate change if accepted by standards and code bodies that maintain these standards.

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