

HOUSING RESEARCH AGENDA: Summary Report

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INTRODUCTION

Housing is one of the most basic needs of human beings. Providing affordable, durable and quality homes has always been one of the greatest challenges faced by the society. Over the years, significant research efforts have taken place to help meet the challenge of providing adequate housing. In recent years, there has been a renewed emphasis on housing technology research due to the Partnership for Advancing Technologies in Housing (PATH) program initiatives at the U.S. Department of Housing and Urban Development (HUD) and the National Science Foundation (NSF).

In 2003, the NSF-PATH program sponsored a year-long effort to develop a national housing research agenda. This effort culminated in a three-day workshop held at the University of Central Florida in Orlando from February 12-14, 2004. The invited workshop attendees included principal investigators from past and on-going NSF-PATH projects, faculty/members/researchers from the National Consortium of Housing Research Centers (NCHRC), as well as representatives from NSF and HUD. The workshop was organized into five focus areas: (1) Construction Management and Production, (2) Structural Design and Materials, (3) Building Enclosures, Energy and Indoor Air Quality (IAQ), (4) Housing Technology, Community and the Economy, and (5) Systems Interactions and “Whole House” Approach. The deliberations in these focus areas included two main aspects – compilation of the “state of the art” of current research and development of the future research directions. It is anticipated that the output of this workshop will help various PATH-related agencies, especially the NSF, in defining and funding future research activities.

The workshop report is produced in two volumes. The first volume consists of focus area reports prepared by area leaders based on the position papers and the discussion during the workshop, and the second volume consists of position papers received from the participants. The first volume also contains these final overall recommendations being submitted to the National Science Foundation.

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HOUSING RESEARCH AGENDA WORKSHOP

The emergence of the PATH program in recent years has created awareness for the need to develop and use technologies that radically improve the quality, durability, energy efficiency, environmental performance, and affordability of America's housing. The PATH program has been working to connect the academic research community with housing technology interests by reaching out directly to universities and nonprofit research centers through competitions and joint efforts (PATH 2003).

Since 2000, there has been a partnership in place between HUD-PATH and NSF's Division of Civil and Mechanical Systems to provide basic/developmental research avenues to housing research community. As part of this NSF-PATH research awards program, academic researchers have been conducting research in a variety of housing technology areas. As a result, the NSF-PATH program has brought increased attention and commitment to housing education and research in many major academic institutions nationwide (NSF 2003).

The NSF-PATH solicitations have mostly utilized specific technology research needs highlighted by PATH technology roadmaps (PATH 2003). After 3-4 years of offering housing research opportunities, NSF and PATH leaders felt the need to “take stock” of the research conducted so far. In addition, a comprehensive and systematic development of future research directions was needed in order to ensure the continued success of the NSF-PATH program. This research agenda exercise was meant to help the NSF-PATH program to identify, define, and encourage future research efforts in critical areas of housing technology. It was envisioned that such an effort would complement the on going “road mapping” efforts and that a combination of academia-led basic/developmental research agenda and the industry-led applied research roadmaps will, together, provide short-term and long-term research directions for technological innovations in the housing industry.

Other Related Activities

A coordinated effort to define the research needs of the housing industry was undertaken by the PATH program in the last five years by organizing “road mapping” initiatives in certain specialized aspects of housing technology. Recently completed and on-going “road mapping” efforts include (PATH 2003):

1. Advanced Panelized Construction
2. Whole House Building Process Redesign
3. Manufactured Housing
4. Information Technology Applications
5. Energy Efficiency in Existing Homes
6. Structural Performance of Light Frame Residential Construction

In addition to the above noted “road maps”, there were some other efforts that relate to the overall housing research arena. These include (Syal et al. 2003):

1. PATH sponsored report by Rand Corporation on - Strategies for the Federal Government to Accelerate Innovation in Housing Industry (PATH 2003)
2. “Road maps” by the U.S. Department of Energy on:
 - High Performance of Commercial Buildings
 - Lighting Technology
 - Windows Industry
 - Building Envelope
 - HVAC and Refrigeration

Workshop Focus

The overall purpose of this workshop was twofold – (1) to compile “state of the art” of the housing technology research by summarizing recently completed and on-going NSF-PATH and other related research efforts, and (2) to identify and develop future research directions in major areas of housing technology (Syal et al. 2003).

The workshop was held in Orlando, Florida on February 12-14, 2004. It was hosted by the housing research group at the University of Central Florida (UCF). The workshop schedule included opening ceremonies and introductions on February 12, followed by a day and a half of discussions within focus area groups on February 13 and 14. The workshop was concluded with focus area leaders summarizing the deliberations within their focus areas.

The five focus areas of housing technology research were identified as:

1. Construction Management and Production
2. Structural Design and Materials
3. Building Enclosures, Energy and Indoor Air Quality (IAQ)
4. Community and Economic Impacts of Housing Technology
5. Systems Interactions and “Whole House” Approach

Each of the above-noted focus areas was further divided into subareas. These subareas were finalized with the assistance of the advisory committee and designated focus area leaders (Syal et al. 2003).

1. Construction Management and Production
 - Project Planning and Control
 - Site Based Construction Processes
 - Industrialized Construction
 - Supply Chain Management
 - Other Areas of Importance
2. Structural Design and Materials
 - Innovative and Sustainable Materials
 - Fire Protection
 - Durability Issues in Site Built and Manufactured Housing
 - Performance Based Engineering

- Design for High Wind and Other Extreme Loads
- 3. Building Enclosures, Energy, and Indoor Air Quality (IAQ)
 - Building Enclosure and Moisture Related Issues
 - Impact on Indoor Air Quality
 - Energy Efficiency
 - Utilities
 - Other Areas of Importance
- 4. Housing Technology, Community and the Economy
 - R&D and Diffusion
 - Industry and Firm Characteristics
 - Regulations/Finance/Insurance
 - Land Development (large scale, mixed use, in-fill, and sprawl)
 - Retrofit, Rehab and Maintenance
 - Social Capital and Community Development
- 5. Systems Interactions and “Whole House” Approach
 - Operating the Whole House
 - Programming the Whole House
 - Designing the Whole House
 - Constructing/Manufacturing the Whole House

Organizing Committee and Participants

The organization of the workshop, selection of participants, and the compilation and dissemination of the final report was coordinated by the investigators with the help of an advisory committee. The advisory committee included the principal and co-principal investigators, focus area leaders, a representative from NSF and a representative from HUD. The members of the advisory committee include:

Principal Investigator - Dr. Matt Syal, Professor and Research Director, Housing Education and Research Center, Construction Management Program, Michigan State University, and Immediate Past Chairperson, National Consortium of Housing Research Centers.

Co- Principal Investigator - Dr. Makarand (Mark) Hastak, Assistant Professor and Research Director, Housing Research Center, Division of Construction Engineering and Management, School of Civil Engineering, Purdue University.

Co- Principal Investigator - Dr. Mike Mullens, Associate Professor and Director, Housing Constructability Lab, Department of Industrial Engineering & Management Systems, University of Central Florida.

NSF Representative – Dr. P. N. Balaguru, Program Director, NSF-PATH

HUD Representative – Mr. Dana Bres, HUD-PATH Manager

Focus Area Leaders –

Focus Area-1: Dr Mike Mullens, University of Central Florida

Dr. Mark Hastak, Purdue University

Focus Area-2: Dr. Steven Cramer, University of Wisconsin-Madison

Focus Area-3: Dr. Eric Burnett, Penn State University
Focus Area-4: Dr. Ted Koebel, Virginia Tech University
Focus Area-5: Dr. Carlos Martin, Arizona State University
Mr. Mike O'Brien, Virginia Tech University

There were a total of forty-four participants including the group leaders. Around 25 participants were NSF-PATH awardees and remaining participants were invited from the National Consortium of Housing Research Centers. The list of the participants and their respective focus groups is presented in Appendix-A. All participants were required to submit a 5-10 page position paper. In addition, all NSF-PATH PI's were asked to present a poster highlighting their research. Some other researchers, who expressed interest but could not be invited due to workshop size constraints, were invited to submit a position paper.

FOCUS AREAS DELIBERATIONS / RECOMMENDATIONS

It is commendable that NSF-PATH and HUD-PATH programs have taken the lead in creating opportunities in this critical area of research. This workshop served as an important contribution in that direction by providing systematic future research directions, promoting an integrated approach to research and teaching, bringing various researchers together at one forum, and further stimulating interest in housing technology research in the academic community. The following sections present the deliberations and recommendations of each focus area.

Focus Area-1: Construction Management and Production

Introduction

This focus area examines construction management and production related challenges faced by the housing industry. In reference to the applicable state of the art in construction management, manufacturing systems, and lean construction, the focus area participants have proposed future research directions to bridge the gap between current knowledge and industry needs (Mullens and Hastak 2004).

The focus area participants deliberated on the following subareas: (1) Project Planning and Control, (2) Site Based Construction Processes, (3) Industrialized Construction, (4) Supply Chain Management, and (5) other areas of importance. The following questions were posed to the participants:

1. Can we build a high quality house on-site in mass production?
2. Is a "revolution" or "evolution" needed in housing construction systems? Why? What are the constraints?
3. What is the best direction for this change – migration of factory technologies to the site or site processes to the factory? How do design trends and changing homebuyer demographics/expectations affect this direction?

4. Should housing be hybridized? What housing components might best be produced in a factory? How can new materials/production/construction technologies impact this decision?
5. What are the societal impacts of the suggested change? How do these changes affect key stakeholders (builders, suppliers, homebuyers, local/state/federal government)?

Main Topics of Research

It was generally agreed by the participants that all segments of the housing industry have tremendous potential for enhanced quality and productivity. The focus area participants recommended following main areas of research. They also identified examples of research topics in many of these areas.

1. Enhancing Demand side Pressure for Quality
 - Research effort is required to benchmark current consumer understanding of quality.
2. Developing Fundamental Construction Theory
 - A model is required for optimizing the construction delivery process that should be able to: (1) represent and (2) reason about each task of each activity and the skills required to perform those tasks.
3. Coordinating the Disaggregated Supply Chain
 - Research to determine if it is logistically possible and economically feasible to re-structure the supply chain serving the Housing industry to a JIT system.
 - Research into developing an Integrated Wireless Site (IWS) that provides value added information to all stakeholders including the owner/user, sub-contractors, engineer/architect, and inspectors.
4. Developing Shell and Infill Technologies
 - Lack of innovation in the production method demands that research efforts are required to devise methods to disentangle and separate the various building service systems from the house structural system and from each other.
 - A series of demonstration projects should be undertaken to illustrate the separation between “Shell” and “Infill” by initially using existing products and to demonstrate that homebuilding is ready for process innovation.
5. Balancing Off-site and On-site Production
 - Hybrid approaches to homebuilding must be explored that capture synergies of alternative production systems including site-built and factory built.
 - In terms of building process optimization the following advances are important:
 - ✍ Incorporating advanced technology and equipment with innovative factory layout in the logic of optimal production process.
 - ✍ Advanced technology could include real time data collection tools such as

automatic identification (e.g., bar code scanning, radio frequency identification) that can function effectively in dirty, rough, open (even outdoor) environments.

✍ Customizing Manufactured Housing systems for new building materials, which are an important variable influencing production line activities, manpower requirements, available technologies, and processing time

- The challenge of floating bottlenecks impedes the vision of smooth production flow and requires the development of decision support systems that assist in module scheduling and labor assignment. Technologies are likely to include optimization, simulation, and visualization tools for generating and evaluating alternatives.

6. Addressing deficiencies in the existing housing stock

7. Innovations in Safety, Quality, Schedule and Cost Management Systems

- Further research on economic and environmental benefits that encourage builders to adopt sound waste management practices as a routine part of the construction process.

Focus Area-2: Structural Design and Materials

Introduction

Structural design and materials are two of the key areas in house design. However, for approximately 50 years the structural house design has not been modified to adjust to the changes in materials, methods, and house configurations. Accordingly, the position papers presented by each participant in this focus area were grouped under five categories: (1) Innovative and sustainable material, (2) Fire protection, (3) Durability issue in site built and manufactured housing, (4) Performance based engineering, and (5) Design for high wind and other extreme loads. The following questions were posed to the participants (Cramer 2004):

1. Are current housing structural systems technically failing? Where and in what ways (design, material, performance, construction, code enforcement)? With which societal impacts (affordability, diffusion, market acceptance, regulations, environment, occupant health, etc.)?
2. What are the facts that support the need for research in structural design and materials in housing?
3. Is a "revolution" or an "evolution" needed in housing structural systems? Why? What are the indicators? What are the constraints?
4. How does (or should) structural design and materials interface with the other focus areas?

Main Topics of Research

The focus group was in agreement that significant improvement in structural design and materials in housing is possible through harnessing emerging materials and rethinking the 50 year old design that would capitalize on multifunctional components. Following areas of urgent need were recommended. Participants also identified examples of research topics in these areas.

1. Home safety and security
 - Terror and Domestic Crime: Materials selection and design can play an important role in mitigating or detecting biological, chemical or radiological hazards. Research should be conducted to develop structural frameworks and materials that offer new levels of safety, economy, and aesthetics.
 - Health and Home Environment: Research into design of building envelope using new materials to largely address the mold problem as well as a variety of indoor health threats.
 - Fire: Fire safety in residential buildings could be significantly improved by developing explicit engineering fire-resistant design principles and new fire resistant and nontoxic materials.
 - Natural Hazards: Research is needed to determine appropriate lateral load resistance and functional load paths in house design under high wind and seismic conditions. Also definition of performance levels based on life safety risk and property loss risk are required to significantly reduce losses due to natural hazards.
2. Affordability and constructability of housing
 - To improve affordability and constructability, research is needed to develop building envelopes and structural systems that use new materials and building products that incorporate multiple functions. Affordability can be improved through increased factory-based prefabrication of subcomponent assemblies that follow a performance-based design.
3. Sustainability and durability in housing construction
 - To improve the sustainability of house construction practices, research should be conducted to develop new bio-based materials from renewable sources and materials with triggered biodegradability.
4. Functional house design
 - Significant research is needed to establish a rational performance based design environment for houses and its implementation. New structural design methodology that replaces the current prescriptive design methodology would allow house structural designs to adapt with consumer preferences.

Focus Area-3: Building Enclosures, Energy and IAQ

Introduction

The Building Enclosure focus area group deliberated upon the relative and singular importance of the building enclosure and its performance. The team described the building enclosure as one

of the four physical parts of a building, i.e. the superstructure, the building enclosure, the service systems, and the building fabric. The building enclosure functions as a separator between the indoor and exterior environment of the building. The various functions of a building enclosure include: Support functions, Control functions, Finish functions, and Distribute functions (Burnett 2004). The position papers presented by each participant were grouped under five categories: (1) Building Enclosure and Moisture Related Issues, (2) Impact on Indoor Air Quality, (3) Energy Efficiency, (4) Utilities, and (5) Other Areas of Importance.

The various topics covered during the presentations and discussions addressed the technical and design needs of a building enclosure with focus on the following (Burnett 2004).

1. The importance of water vapor transport as well as the simultaneous transport of heat (energy) and mass (VOCs) as fruitful areas for study.
2. Research to improve moisture control across and within the building enclosure was identified as an area of need particularly to contain mold and related problems.
3. Need for sustained work on hygrothermal modeling.
4. A study to determine the relevance of natural ventilation to promote the drying of exterior wall systems
5. The need to develop tests and models for mold, termites, and other forms of loading
6. Development and application of fiber- reinforced cementitious composites in housing.
7. Suitability of using bio-based materials in building enclosure assemblies.
8. The link between high insurance rates and policies with poor performance of the building enclosure.
9. The DOE Roadmap was identified as an important document and highly relevant to this focus area.

Main Topics of Research

The focus group participants identified the following four research areas:

1. Enclosure component considerations
2. Hygric or hygrothermal concerns (mainly moisture and thermal control)
3. Materials
4. Hazard loadings and the performance of the building enclosure

The group recommended that:

1. There is an overall need for complementary progress in three areas in building science and building enclosures: (i) research (R&D), (ii) education (university), and (iii) training (professional and other client groups).
2. It was suggested that intelligent (holistic) design of building enclosure systems is needed that includes: Informational/Knowledge needs, Material innovation, and Attribute concerns.
3. The group also determined that information; its generation, storage, management, usage and feedback (monitoring data and sensing interactions) needs to be pursued.

Focus Area-4: Housing Technology, Community and the Economy

Introduction

The social systems ranging from the individual consumer to the national structure of the housing industry play an important role in the housing industry. However, research and development in housing technology often ignores them as subjects of inquiry. The specific objective of this focus area was to deliberate the broader social systems (including building firms, consumers, financing, insurance, and community) that influence the successful transfer of housing technology. The participants in the focus area discussed research on residential technology diffusion, industry structure, regulatory controls, underwriting, renovation and rehab, land development, urban design, and health. Ten position papers were prepared by the participants prior to the workshop describing current research and recommending priority topics for future research. The position papers covered six important topics that include: (1) R&D and Diffusion, (2) Industry and Firm Characteristics, (3) Regulations/Finance/Insurance, (4) Land Development (large scale, mixed use, in-fill, and sprawl), (5) Retrofit, Rehab and Maintenance, and (6) Social Capital and Community Development (Koebel 2004).

Main Topics of Research

The focus area participants recommended future research based on the role of technology in improving housing under four broad categories: (i) diffusion of residential construction technology, (ii) impact of technology on renovation and community development, (iii) improved models of community development and social capital, and (iv) housing and health. Each broad category also supports research under several associated subcategories such as consumer demand, governmental regulations, finance, insurance, and business practices to include topics such as:

1. Diffusion of Residential Construction Technology
 - Research on diffusion should address the technical, social, and economic aspects of innovation as well as the information channels and the supplier/vendor characteristics.

- An improved concept screening model for successful transition of building technologies in the new product market.
 - Several research topics were proposed that targeted consumer knowledge and education with respect to innovation, the impact of master planned communities on technology transfer, as well as the impact of improved housing performance on insurance, appraisal, and mortgage issues.
2. Impact of Technology on Renovation and Community Development
 - To research the roles of maintenance and renovation in extending the use and performance of housing
 - Research directed toward improved technologies and practices for rehab and maintenance.
 - The development of a comprehensive built environment decision support model to incorporate characteristics of the built environment and its interaction with social, political, economic, and cultural factors.
 - Technology and diffusion research should incorporate the characteristics of the social systems in which housing production and operation occur.
 3. Improved models of community development and social capital
 4. Housing and Health
 - Research on the relationships between land use development patterns and health problems
 - Development of a multi-disciplinary program addressing the health effects of indoor air quality and the specific contaminants involved.
 - Research on the effects of different land development patterns and urban designs on obesity and related health conditions.

Focus Area-5: Systems Interactions and “Whole House” Approach

Introduction

The objective of this focus area was to deliberate upon the concept and theory of “whole house” technologies and metrics. The focus area participants discussed the historical as well as the current social and technological context of “whole house” enterprise and concluded that a continuing dialogue is necessary to influence societal and intellectual change to impact technological change in the housing industry. The group discussed the social aspects of technologies and contemplated the significance of multiple disciplines and the interaction required to jointly resolve problems in the housing industry (O’Brien and Martin 2004).

The following questions were posed to the participants in discussing the concept of “whole house”:

1. Is the current housing system technically failing?
2. What are the boundaries of the "whole" in "whole house"?

3. How many types of approaches are there to the "whole"?
4. Is a "revolution" or an "evolution needed in housing systems?"

The discussion of the group resulted in a definition and an agenda for the “whole house”. They defined the “whole house” research agenda as “the integration of technologies and processes to satisfy current and anticipate future dynamic and flexible housing performance attributes, technically and socially.” The general consensus of the group was that “contemporary houses are “failures” due to their cost, quality, disaster performance, moisture, mold, and durability issues.” The group felt that sub-optimization of systems, contracts and materials was a significant barrier to achieving the “whole house”. Also, it was felt by some of the participants that the “whole” in the “whole house” should also consider the social dimension in addition to the technical aspect.

Main Topics of Research

The group strongly felt that in the past the descriptions of the “whole house” and of “whole house research” were technologically focused and have been incomplete in considering the social and less technologically focused aspects. The focus area deliberations led to the identification of several research topics:

1. Integrative Materials
2. Integrative Methods
3. Integrative Operations, and
4. “Net-Positive Whole House”

BROADER RESEARCH TOPICS AND THEIR CROSSCUTTING IMPACT

The proposed research topics in each focus area were also evaluated in order to identify the cross cutting impact of the topics across the focus areas, as well as, their impact on homeland security and other fields of research. In evaluating the topics, the workshop participants discussed the interaction between all the constituents of the housing industry including the developers, builders, lenders, insurers, consumers and communities. Table 1 illustrates the identified cross cutting impact of broader research topics.

Each broader research topic was discussed with respect to the two criteria established by NSF. These criteria are listed below. Each criterion has been discussed in greater detail under the focus area reports in this volume.

Criterion 1. What is the intellectual merit of the proposed activity? This criterion addresses the overall quality of the proposed activity to advance science and engineering through research and education.

Criterion 2. What are the broader impacts of the proposed activity? This criterion addresses the overall impact of the proposed activity.

Table 1. Crosscutting Impact of Broader Research Topics

#	Research Topics	Focus Area ¹					Impact on Homeland Security	Other Fields
		1	2	3	4	5		
1	Enhancing Pressure for Quality			X	X			Industrial Engineering, Marketing
2	Developing Construction Theory			X		X		Management Science
3	Coordinating Supply Chain							Management Science
4	Shell and Infill					X		Structures and Materials
5	Off-site and On-site Production		X	X	X	X	X	Industrial Engineering, Architecture
6	Innovations: Safety, Quality etc.			X			X	Structures and Materials
7	Addressing Deficiencies in Existing Housing Stock		X	X	X	X	X	Structures and Materials
8	Home Safety and Security			X		X	X	Health Sciences for airborne hazards
9	Affordability and Constructability	X		X				Industrial Engineering
10	Sustainability and Durability			X		X		Chemical Engineering, Chemistry, Botany, Plant Sciences
11	Functional House Design	X		X	X	X		Architecture, Electrical Engineering
12	Building Science and Building Enclosure	X	X		X	X		Education, Training, R&D
13	Intelligent (Holistic) Design Approach to Building Enclosure		X		X	X		Integration into the overall development, design and construction process
14	Information: Generation, Storage, Use and Feedback	X	X		X	X		Monitoring and performance validation

Table 1. Crosscutting Impact of Broader Research Topics (contd.)

#	Research Topics	Focus Area ¹					Impact on Home Land Security	Other Fields
		1	2	3	4	5		
15	Diffusion of Residential Construction Technology	X	X	X		X		Economics, Sociology, Anthropology
16	Renovation and Community Development	X	X	X		X	X	Economics, Sociology, Psychology, Public Administration & Policy
17	Community Development and Social Capital	X		X		X		Economics, Sociology, Psychology, Public Administration & Policy
18	Housing and Health		X	X		X		Health and Planning
19	Integrative (Reactive) Materials		X	X			X	Health, Chemical Engineering, Chemistry, Botany
20	Integrative Design and Production Methods	X			X			Architecture, Civil, Mechanical Engineering, Constructioun Management
21	Integrative Technical Operations (Professions & Practices)	X						Architecture, Industrial Engineering, Construction Management, Anthropology, Economics, Sociology, STS
22	Net Positive Whole House	X	X	X	X			Architecture, Civil, Mechanical Engineering, Constructioun Management

¹Focus Areas: 1. Construction Management and Production, 2. Structural Design and Materials, 3. Building Enclosures, Energy and Indoor Air Quality, 4. Housing Technology, Community and The Economy, 5. Systems Interactions and “Whole House” Approach

It is important that the proposed research should demonstrate intellectual creativity and expected impact on society. The benefits to society are implied by the various themes covered by the research topics and would be expected to demonstrate reduced risk to life and property. Furthermore, it is expected that technology would be developed that would enhance the affordability, constructability, sustainability, and durability of the housing stock. Similarly, diffusion research should facilitate technology transfer and deployment of successful innovation.

SUMMARY

This report presents the details of the housing research agenda development including deliberations and recommendations by the workshop participants. The research agenda, broader topics and their crosscutting impact are presented under five main focus areas. In addition to developing future research directions, the development of the research agenda served as an important milestone in housing research by bringing major housing researchers together at one forum and by stimulating interest in housing technology research in the academic community. It is hoped that this research agenda would help the NSF-PATH program in encouraging future research efforts in critical areas of housing technology. It is envisioned that this effort will complement the industry-led applied research roadmaps, and together, these will provide short-term and long-term research directions for technological innovations in the housing industry.

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APPENDIX - A

List of Participants

Construction Management and Production

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