

# CONSTRUCTION RESEARCH CONGRESS 2022

*Infrastructure, Sustainability, and Resilience*

---

SELECTED PAPERS FROM THE CONSTRUCTION  
RESEARCH CONGRESS 2022

---

March 9–12, 2022  
Arlington, Virginia

SPONSORED BY

Virginia Polytechnic Institute and State University  
Construction Research Council  
Construction Institute of the  
American Society of Civil Engineers

EDITED BY

Farrokh Jazizadeh, Ph.D.  
Tripp Shealy, Ph.D.  
Michael J. Garvin, Ph.D., P.E.



Published by the American Society of Civil Engineers

Published by American Society of Civil Engineers  
1801 Alexander Bell Drive  
Reston, Virginia, 20191-4382  
[www.asce.org/publications](http://www.asce.org/publications) | [ascelibrary.org](http://ascelibrary.org)

Any statements expressed in these materials are those of the individual authors and do not necessarily represent the views of ASCE, which takes no responsibility for any statement made herein. No reference made in this publication to any specific method, product, process, or service constitutes or implies an endorsement, recommendation, or warranty thereof by ASCE. The materials are for general information only and do not represent a standard of ASCE, nor are they intended as a reference in purchase specifications, contracts, regulations, statutes, or any other legal document. ASCE makes no representation or warranty of any kind, whether express or implied, concerning the accuracy, completeness, suitability, or utility of any information, apparatus, product, or process discussed in this publication, and assumes no liability therefor. The information contained in these materials should not be used without first securing competent advice with respect to its suitability for any general or specific application. Anyone utilizing such information assumes all liability arising from such use, including but not limited to infringement of any patent or patents.

ASCE and American Society of Civil Engineers—Registered in U.S. Patent and Trademark Office.

*Photocopies and permissions.* Permission to photocopy or reproduce material from ASCE publications can be requested by sending an e-mail to [permissions@asce.org](mailto:permissions@asce.org) or by locating a title in ASCE's Civil Engineering Database (<http://cedb.asce.org>) or ASCE Library (<http://ascelibrary.org>) and using the "Permissions" link.

**Errata:** Errata, if any, can be found at <https://doi.org/10.1061/9780784483954>

Copyright © 2022 by the American Society of Civil Engineers.  
All Rights Reserved.  
ISBN 978-0-7844-8395-4 (PDF)  
Manufactured in the United States of America.

# Preface

The Construction Research Congress (CRC) 2022 Organizing Committee, Virginia Polytechnic Institute & State University (Virginia Tech), the Construction Research Council, and the Construction Institute (CI) of the American Society of Civil Engineers (ASCE) are pleased to present the CRC 2022 Proceedings. CRC is one of the leading international conferences in the area of construction engineering and management. The Congress is held every two years, which provides a university the opportunity to serve and host colleagues across the world for the interactive exchange of ideas, knowledge and research findings. CRC 2022 was hosted by Virginia Tech and its Vecellio Construction Engineering and Management Program (VCEMP) in the Department of Civil and Environmental Engineering. The conference was held in Arlington, VA on March 9-12, 2022. CRC 2022 was part of the first-ever joint conference of the Construction Research Congress and the Construction Institute Summit. This combination of academic and industry experts promoted wide-ranging discussions about finding real solutions to the most pressing societal and industry problems.

The theme of the CI & CRC Joint Conference was: "Next Generation Construction." The joint conference's technical program provided insights on the latest research and industry practices that will lead to next generation techniques, technologies, and strategies to meet the many 21st century challenges in construction and the built environment. This unique setting allowed academic and industry peers from around the world to share insights with one another to promote progress in both research and practice.

The Conference Proceedings contain 405 peer-reviewed technical papers, which were developed from over 690 abstract submissions. All submissions went through a two-step review process with a minimum of two external reviewers per paper, by a scientific community of hundreds of international construction experts. The work was exhibited at the conference in short presentations. The resulting proceedings are divided into four volumes:

- Volume I: Infrastructure Sustainability and Resilience (69 papers)
- Volume II: Computer Applications, Automation and Data Analytics (144 papers)
- Volume III: Project Management and Delivery, Controls, and Design and Materials (113 papers)
- Volume IV: Health and Safety, Workforce, and Education (79 papers)

On behalf of the Organizing Committee, Virginia Tech, the Construction Research Council and the ASCE Construction Institute, we hope that the CRC 2022 proceedings reflect the vitality of the first-ever CRC and CI Joint Conference as well as our community's research and its potential to better our industry.

Michael J. Garvin, PhD, PE, NAC  
Farrokh Jazizadeh, PhD  
Tripp Shealy, PhD

Organizing Committee  
Virginia Tech

# Acknowledgments

The editors would like to thank and recognize everyone who volunteered their time, effort, and expertise to make CRC 2022 a successful conference. CRC 2022 could not have happened without the leadership and support of the following individuals:

**Conference Chair:**

Michael J. Garvin, Virginia Tech

**Technical Committee Co-Chairs:**

Farrokh Jazizadeh, Virginia Tech

Tripp Shealy, Virginia Tech

**Track Chairs:***Infrastructure Systems, Sustainability and Resilience*

Ali Mostafavi, Texas A&M University

Soowon Chang, Purdue University

Cristina Poleacovschi, Iowa State University

Cheng Zhang, Purdue University Northwest

*Computer Applications, Information Modeling, and Simulation*

Jiansong Zhang, Purdue University

Xinghua Gao, Virginia Tech

Yilong Han, Tongji University

*Advanced Technologies and Data Analytics*

Arsalan Heydarian, University of Virginia

Kristen Cetin, Michigan State University

Javier Irizarry, Georgia Tech

*Automation in Construction*

Youngjib Ham, Texas A&M University

Kevin Han, North Carolina State University

*Engineering and Materials Design, Quality, and Value Management*

Ingrid Arocho, Oregon State University

Sharareh Kermanshachi, University of Texas, Arlington

*Project and Organizational Management and Planning*

David Jeong, Texas A&M University

Farook Hamzeh, University of Alberta

Katherine Madson, Iowa State University

*Construction Scheduling, Estimating, Economics, and Controls*

Islam El-Adaway, Missouri University S&amp;T

Diana Franco Duran, University of Virginia

*Contracting, Project Delivery, and Legal Issues*

Bryan Franz, University of Florida

Jose Guevara, University of the Andes, Columbia

*Construction Education*

Anthony Sparkling, Purdue University

Mohamed Elzomor, Florida International University

*Health, Safety, and Workforce Issues*

Alex Albert, North Carolina State University

Sogand Hasanzadeh, Purdue University

Christofer Harper, Colorado State University

**Virginia Tech Staff:**

Rachel Atwell, VCEMP Program Administrator

**ASCE's Construction Institute (CI) Staff:**

Katerina Lachinova, CI Director

Susan Long, CI Manager, Conferences &amp; Programs

Monica Bradford, CI Coordinator, Marketing &amp; Conferences

**Virginia Tech Graduate Student Volunteers:**

Brooke Baugher

Chi Nguyen Anh

Emma Coleman Todoroff

Esteban Amezcuita Radillo

Josh Trump

Kase Poling

Manik Ahmed

Mayank Khurana

Mo Hu

Mostafa Meimand

Paulo Dias Ignacio Junior

Tianzhi He

Ushma Manandhar

Wendell Grinton

Yueyan Gu

Finally, the editors would like to thank all of our colleagues who provided reviews for submitted papers. We are grateful for your contributions to the success of the conference.

# Contents

<b>A Web-Based System to Optimize Project Waste Management Decisions .....</b>	<b>1</b>
Boushra Barakat and Issam Srour	
<b>Economic Viability of Solar Panels for Single Family Homeowners .....</b>	<b>11</b>
Pramen P. Shrestha and Mythili Pragada	
<b>Transitioning to the Next Era of Modular Construction: Reconfiguration, Reuse, and Building Stock Agility .....</b>	<b>19</b>
Chris Rausch, Sheida Shahi, Aziz Dhamani, and Carl Haas	
<b>Graph-Based Simulation for Cyber-Physical Attacks on Smart Buildings .....</b>	<b>28</b>
Rahul Agarwal, Na Meng, Xinghua Gao, and Yuqing Liu	
<b>A Framework for Evaluating Societal Impacts Caused by Disruptions to Inland Waterways.....</b>	<b>38</b>
Katherine Madson and Jennifer Lather	
<b>Key Components in Schedule Development of Post-Disaster Reconstruction Projects.....</b>	<b>48</b>
Elnaz Safapour and Sharareh Kermanshachi	
<b>Post-Hurricane Recovery Process: Analysis of the Public and Subject Matter Experts' Perspectives Using Structural Equation Modeling (SEM).....</b>	<b>57</b>
Behzad Rouhanizadeh and Sharareh Kermanshachi	
<b>Investigation of Causal Relationships among Factors Affecting Post-Disaster Reconstruction Process: Adoption of Social Network Analysis (SNA) Method .....</b>	<b>69</b>
Behzad Rouhanizadeh and Sharareh Kermanshachi	
<b>Analysis of the Resilience Management Dimensions Based on Project Complexity Level .....</b>	<b>80</b>
Thahomina Jahan Nipa, Sharareh Kermanshachi, and Ronik Ketankumar Patel	
<b>Analysis of Investment Decision-Making Factors in Resilience Improvement of Transportation Infrastructure .....</b>	<b>90</b>
Thahomina Jahan Nipa, Sharareh Kermanshachi, and Sanjna Karthick	
<b>Critical Success Factors for Green Building Promotion: A Systematic Review and Meta-Analysis .....</b>	<b>101</b>
Linyan Chen, Albert P. C. Chan, Emmanuel K. Owusu, and Xin Gao	

<b>Development of Innovative Strategies to Enhance the Resilience of the Critical Infrastructure.....</b>	<b>111</b>
Thahomina Jahan Nipa, Sharareh Kermanshachi, and Karthik Subramanya	
<b>Understanding How Green Contractors Displayed Social Sustainability Actions due to the BLM Movement in 2020 .....</b>	<b>121</b>
Rodolfo Valdes-Vasquez and Deniz Besiktepe	
<b>Preliminary Analysis of Environmental Focus Roofing Strategies in Colorado's Front Range Region .....</b>	<b>131</b>
Joe Oakman and Rodolfo Valdes-Vasquez	
<b>The Impact of Natural Disaster Affected Housing Service Sector on the Interrelated Industries.....</b>	<b>139</b>
KwangHyuk Im	
<b>The Envision Rating System Helps Shape Public Preferences for Sustainable Stormwater Design .....</b>	<b>151</b>
Mo Hu and Tripp Shealy	
<b>Digitization, Digitalization, and Digital Transformation (3Ds): Explicating the Disparities and Applications of the 3Ds in the Construction Industry .....</b>	<b>161</b>
Emmanuel Kingsford Owusu, Albert P. C. Chan, Linyan Chen, and Peter Amoah	
<b>Experimental Study of Mechanical Connectors for Application in Rebar Cages.....</b>	<b>171</b>
Masood Vahedi, Hamed Ebrahimian, and Ahmad M. Itani	
<b>Human-in-the-Loop Model Predictive Operation for Energy Efficient HVAC Systems .....</b>	<b>178</b>
Mostafa Meimand and Farrokh Jazizadeh	
<b>Natural Disasters, Inequality, and Civil Infrastructure Systems: Developing Equitable Pathways toward Resilience .....</b>	<b>188</b>
Mostafa Batouli and Deepti Joshi	
<b>Online Engagement of Facility Users in Rehabilitation Decision Making .....</b>	<b>198</b>
Ahmed Attalla and Tamer El-Diraby	
<b>Transportation Asset Data Management: BIM as a Holistic Data Management Approach .....</b>	<b>208</b>
Ashtarout Ammar, Gabriel Dadi, and Hala Nassereddine	
<b>Framework for Measuring Infrastructure Vulnerability and Resiliency of Communities during a Flood Disaster .....</b>	<b>218</b>
Anisha Deria, Pedram Ghannad, and Yong-Cheol Lee	

<b>Designing a Communication Practice to Build Community Capacity for Safer Housing .....</b>	<b>229</b>
Briar Goldwyn, Amy Javernick-Will, Abbie Liel, and Matthew Koschmann	
<b>Exploring Challenges to Implement an Integrated Urban Infrastructure Management Approach .....</b>	<b>240</b>
Sebastian Vasquez and Felipe Araya	
<b>Connecting Pre-Existing Characteristics of Water Utilities to Impacts during the COVID-19 Pandemic .....</b>	<b>249</b>
Lauryn Spearing, Nathalie Thelemaque, Felipe Araya, Jessica Kaminsky, and Kasey Faust	
<b>Knowledge and Perception of Single-Family Residential Building Resilience and Its Impact on Disaster Evacuations Decisions .....</b>	<b>259</b>
Giovanna Fusco and Jin Zhu	
<b>Identifying the Commonalities between Lean Construction and LEED Requirements.....</b>	<b>269</b>
Emel Sadikoglu, Sevilay Demirkesen, and Chengyi Zhang	
<b>Unifying Assessments of Sustainability and Resilience in Civil Infrastructure Systems: The Case of Masonry Structures .....</b>	<b>278</b>
Samir Jung Pandey, Arif Mohaimin Sadri, and Wallied Orabi	
<b>Critical Review of Sustainability, Resilience, and Their Unifying Assessments for Civil Infrastructure Systems.....</b>	<b>288</b>
Samir Jung Pandey and Arif Mohaimin Sadri	
<b>Integrating Social Equity and Vulnerability with Infrastructure Resilience Assessment .....</b>	<b>299</b>
Sunil Dhakal and Lu Zhang	
<b>Smart Building Conceptualization: A Comparative Analysis of Literature and Standards.....</b>	<b>310</b>
Alireza Borhani, Atieh Borhani, Carrie Sturts Dossick, and Julie Jupp	
<b>Identifying and Assessing Critical Indicators of Resilience in Active Construction Sites .....</b>	<b>319</b>
M. Ahmed Rusho, Md. Nizamul Hoque Mojumder, Lu Zhang, and Arif Mohaimin Sadri	
<b>Factors and Indicators to Assess Sustainable Development Goals (SDG) in Public Works Procurement.....</b>	<b>328</b>
Laura Montalbán-Domingo, Tatiana García-Segura, Amalia Sanz-Benlloch, and Eugenio Pellicer	

<b>Vulnerability of Southwest Florida Water Infrastructure under the Impacts of Hurricane.....</b>	<b>337</b>
Long D. Nguyen and Seneshaw Tsegaye	
<b>Incorporating the Human Factor in Modeling Interdependent Infrastructure Systems .....</b>	<b>346</b>
Joseph Jonathan Magoua, Fei Wang, and Nan Li	
<b>Comparison of Different Blue–Green Infrastructure Strategies in Mitigating Urban Heat Island Effects and Improving Thermal Comfort.....</b>	<b>357</b>
Siqi Jia and Yuhong Wang	
<b>Measurement and Verification and Model Validation to Evaluate Energy and Demand Savings from Smart Building Technologies in a Residential, Controlled Laboratory .....</b>	<b>367</b>
Yiyi Chu, Debrudra Mitra, and Kristen Cetin	
<b>A Unified Tool to Foster Front-End Planning and Sustainability in Infrastructure Projects .....</b>	<b>376</b>
Valentina Ferrer, Piyush Pradhananga, and Mohamed Elzomor	
<b>Evaluation of Safe-to-Fail Criteria for Coastal City Flooding .....</b>	<b>386</b>
Rubaya Rahat, Mohamed Elzomor, and Piyush Pradhananga	
<b>Understanding COVID-19’s Impacts on Multisector Stakeholder Values on Housing Resilience .....</b>	<b>396</b>
José E. Velázquez-Díaz, Parasar Gosain, N. Emel Ganapati, and Lu Zhang	
<b>Analyzing Critical Impacting Factors on the Future of Bridges to Support Bridge Planning.....</b>	<b>406</b>
A. M. M. Muhaimin, Lu Zhang, Xuan Lv, Nipesh Pradhananga, and Vamsi Sai Kalasapudi	
<b>A Review of a Socio-Technical System Approach for Interdependent Infrastructure Systems Resilience Analysis: Present Status and Future Trends .....</b>	<b>416</b>
Chen Xia and Yuqing Hu	
<b>Using Wastewater Flow to Understand Water System’s Demand Behavior during the COVID-19 Pandemic in an Urban Metropolitan City in Texas.....</b>	<b>427</b>
Amal Bakchan, Arkajyoti Roy, and Kasey M. Faust	
<b>Digital Twin Cities: Data Availability and Systematic Data Collection .....</b>	<b>437</b>
Michael Jacobellis and Mohammad Ilbeigi	

<b>Information Fusion and Finite Element Model Simulations for Bridge Condition Prognosis with Conflicting Data .....</b>	<b>445</b>
Zhe Sun, Ying Shi, and Pingbo Tang	
<b>Socioeconomic and Housing Vulnerability's Role in Decision Time for Reconstruction in Puerto Rico after Hurricane Maria .....</b>	<b>455</b>
Tonmoy Sarker, Cristina Poleacovschi, Ivis Garcia, Carl F. Weems, Kaoru Ikuma, and Chris Rehmann	
<b>Energy Infrastructure Scenarios for Reducing Distribution Losses and Carbon Emissions Using Multimethod Simulation with GIS .....</b>	<b>464</b>
Soowon Chang	
<b>Empirical Analysis of Factors Associated with Financial Loss due to Hurricane Harvey .....</b>	<b>472</b>
Frederick Chung and Baabak Ashuri	
<b>A Data Integration Approach for Assessment of Rainfall-Induced Slope Failure Susceptibility .....</b>	<b>480</b>
A. Baral and S. M. Shahandashti	
<b>Developing a Sustainability and Resilience Monitoring Scheme for Infrastructure Projects Using Sustainable Development Goals (SDGs).....</b>	<b>490</b>
Shantanu Kumar and Mohammed S. Hashem M. Mehany	
<b>Water Utilities and the COVID-19 Pandemic: A Review of Pandemic-Related Research .....</b>	<b>501</b>
Nathalie Thelemaque, Lauryn A. Spearing, Kasey M. Faust, and Jessica Kaminsky	
<b>Governing Contractor Greenwashing Behaviors in Construction Projects: The Heterogeneous and Interactive Roles of Contractual Governance and Trust .....</b>	<b>512</b>
Zilun Wang, Ge Wang, Yuan He, and Yang Li	
<b>Impacts of the COVID-19 Pandemic on Services Utilization and Energy Consumption in Healthcare Facilities: Evidence from Shanghai Municipal Hospitals .....</b>	<b>522</b>
Yongkui Li, Lingyan Cao, Jiansong Zhang, and Yi Jiang	
<b>Toward Sustainable Management of Disaster Debris: Three-Phase Post-Disaster Data Collection Planning .....</b>	<b>532</b>
Hiba Jalloul, Juyeong Choi, Sybil Derrible, and Nazli Yesiller	
<b>Evaluating Management Risks in Megaprojects: Case of International Defense Construction .....</b>	<b>541</b>
M. Scott Stanford, Evan P. Dicks, and Patrick C. Suermann	

<b>Disasters as Mega-Disruptions to Construction Supply Chains.....</b>	<b>551</b>
Erin Arneson	
<b>Benchmarking Drinking Water Consumption during Construction Phase.....</b>	<b>560</b>
Jeanette Hariharan, Hashem Izadi Moud, Kenneth Sands, Craig Capano, Kailey Stockinger, and Jalen Vowels	
<b>Comparing Impacts of Indoor Environmental Quality Factors on Satisfaction of Occupants with Different Genders and Ages between Office- and Home-Based Work Environments .....</b>	<b>569</b>
Xingzhou Guo and Yunfeng Chen	
<b>Managing Leakages in Intermittent Water Supply Systems: The Role of Network Zoning and Supply Scheduling .....</b>	<b>578</b>
Saad Aljadhari and Abdulrahman Bin Mahmoud	
<b>Construction Assessment Framework of Electrical Transmission Structures from Decommissioned Wind Turbine Blades.....</b>	<b>588</b>
Yulizza Henao, Russell Gentry, Tristan Al-Haddad, Lawrence C. Bank, and John E. Taylor	
<b>Power Infrastructure Resiliency and Maintenance Planning: The Socioeconomic Impact of Disruptions to North Carolina Power Infrastructure.....</b>	<b>599</b>
Rachael Sherman, Stephanie Pilkington, and Aishwarya Ajay Parmar	
<b>A Literature Review on the Human Dimension in Water-Energy Nexus .....</b>	<b>608</b>
Zheng Ren, Jintao Zhang, Iram Sifat, Wenjun Xiang, Wei Zhang, Baikun Li, and Jin Zhu	
<b>Homeowners' Motivations to Invest in Energy-Efficient Technologies in Residential Buildings of Rural Midwest America.....</b>	<b>618</b>
Linnel Ballesteros, Cristina Poleacovschi, Kristen Cetin, Ulrike Passe, Anne Kimber, Diba Malekpour Koupaei, Tanya Sharma, and Forrest Douglass	
<b>Assessment of the Relative Importance of the Main Parameters Used in the Selection of the Urban Heat Island Mitigation Strategies.....</b>	<b>627</b>
Bahareh Bathaei and Mohamed Abdel-Raheem	
<b>Challenges and Risks in Resilience Management of Water and Wastewater Infrastructure .....</b>	<b>637</b>
Nikhitha Adepu, Sharareh Kermanshachi, Elnaz Safapour, and Apurva Pamidimukkala	
<b>Analyzing the Resilience of Construction Firms through Resilience Indicators .....</b>	<b>648</b>
Sai Akhila Boddi Reddy and Ingrid Arocho	

**Economics of Energy Efficient Electrical Appliances Used in Homes .....655**  
Miranda Garcia, Mohamed Abdel-Raheem, Mark Hernandez, and Shaun Morin

**Constructing Electric Conductive Pavement Using a More Sustainable Method .....664**  
Mohammad Anis and Mohamed Abdel-Raheem