Construction Industry Challenges and the need for Innovation

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Purdue University, USA

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Purdue College of Engineering

**13 Schools and Divisions**

- Aeronautics and Astronautics
- Agricultural & Biological
- Biomedical
- Chemical Engineering
- Civil Engineering
- Construction Engineering and Management
- Electrical and Computer
- Engineering Education – First-Year
- Engineering/Multidisciplinary/Interdisciplinary
- Environmental and Ecological
- Industrial
- Materials
- Mechanical
- Nuclear
Solutions for Profitability & Assessment of Risk in Construction

**RESEARCH AREAS**
- Infrastructure Management
- Disaster Risk Reduction
- Profitability and Strategic Planning
- International Construction
- Contemporary Issues
  - Housing Industry
  - Intelligent Planning Units (IPU)
  - Composites in Construction
  - Construction Analytics
  - Interactional Analysis

**BENEFITS TO THE INDUSTRIES**
- Capital Rehabilitation Planning
- Deferred Maintenance
- Post Disaster Housing
- Disaster recovery/rehabilitation of industries/communities
- Resilience and Capacity Building
- Profitability of construction firms
- Dynamic interactive risks in global construction
- Composites in Construction
- Protocol for Construction Analytics
- Theory of Intelligent Planning Units (IPUs)

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Deferred Maintenance
Infrastructure Rehabilitation
Infrastructure Planning
Infrastructure Management
Risk Assessment

Housing Industry
Capital Efficiency
Construction Analytics
Interactional Analysis
Project Controls

Disaster Risk Reduction
Composites in Construction
Theory of Intelligent Planning Unit (IPU)
History of Construction

Neolithic buildings in Skara Brae, Scotland, a UNESCO world heritage site (9000 BC to 5000 BC). Tools – mostly stone, bone etc.

3000 BCE
Water proof great bath, sanitation, water delivery system throughout the city of Vatican City. City layout on a grid pattern.

https://www.britannica.com/place/Great-Bath-Mohenjo-daro

Neolithic buildings in Skara Brae, Scotland, a UNESCO world heritage site (9000 BC to 5000 BC). Tools – mostly stone, bone etc.

History of Construction

Pyramids of Djoser (2630 BC). Tools – over 100,000 slaves worked on these pyramids over years.

The Roman Aqueducts – Italy (145 BC). Used to bring in water for the Roman Empire using gravity flow.

AchitChand Baori – India (900 AD). Constructed to solve the water problem, v-shaped structure 13 stories high, 100 ft deep with 3500 perfectly level steps.

https://www.readersdigest.ca/travel/world/10-architectural-wonders-ancient-world/
https://engineering.rowan.edu/_docs/civil/environmental/cee-materials-reading-assignment.pdf
History of Construction

Sacsaywaman, Peru (900 – 1200 AD)
A stone fortress in Cusco, Inca Empire. Stones weighing ~200 ton
https://www.readersdigest.ca/travel/world/10-architectural-wonders-ancient-world/

Great Wall of China, (7th century BC)
A great engineering feat in history, 21000 Km long.

A Roman street, Pompeii (300 BC)
https://en.wikipedia.org/wiki/Roman_roads

History of Construction

Burj Khalifa, Dubai (2010)
Tallest building in the world, 828 meters high with 160 stories

Golden Gate Bridge, USA (1937)
1.7 miles long.

Three Gorges Dam (2003)
181 meters tall

The Millau Viaduct, France, 2004
At 343 meters the tallest bridge in the world
History of Construction – use of Material and Technology

- Earthen Bricks
- Stone
- Wood
- Copper/Bronze
- Iron/Steel
- Mortar/Pozzolans

History of Construction – Challenges faced

- Labor intensive,
- Manual tools,
- Rudimentary technology,
- Environmental issues,
- Disease
- Safety
Universal connectivity and real-time decentralized decision-making

- Internet of Things,
- Digital Twin,
- Additive manufacturing (3D Printing),
- Cloud computing,
- Cyber-Physical Systems (CPS) and,
- BIM.

https://www.i-scoop.eu/industry-4-0/
https://www.buildingtransformations.org/articles/construction-4-0
Construction Now – New Challenges

GRAND CHALLENGES FOR ENGINEERING

- Make order energy economical
- Provide energy from fusion
- Develop carbon sequestration methods
- Manage the nitrogen cycle
- Provide access to clean water
- Restore and improve urban infrastructure
- Advance health informatics
- Engineer better medicine
- Reverse engineer the brain
- Prevent nuclear terror
- Secure cyberspace
- Enhance virtual reality
- Advance personalized learning
- Engineer the tools of scientific discovery

GRAND CHALLENGES FOR ENGINEERING

Construction Now – New Challenges

United Nations SDGs (2015 – 2030)

SUSTAINABLE DEVELOPMENT GOALS

1. NO POVERTY
2. ZERO HUNGER
3. GOOD HEALTH AND WELL-BEING
4. QUALITY EDUCATION
5. GENDER EQUALITY
6. CLEAN WATER AND SANITATION
7. AFFORDABLE AND CLEAN ENERGY
8. DECENT WORK AND ECONOMIC GROWTH
9. INDUSTRY, INNOVATION, AND INFRASTRUCTURE
10. REDUCED INEQUALITIES
11. SUSTAINABLE CITIES AND COMMUNITIES
12. RESPONSIBLE CONSUMPTION AND PRODUCTION
13. CLIMATE ACTION
14. LIFE BELOW WATER
15. LIFE ON LAND
16. PEACE, JUSTICE, AND STRONG INSTITUTIONS
17. PARTNERSHIPS FOR THE GOALS

SUSTAINABLE DEVELOPMENT GOALS
### Construction Now – New Challenges

- Cost, schedule, quality, safety, and sustainability
- Shortage of skilled labor
- Adoption of technology
- Contractual constraints
- Low productivity
- Pandemic
- Supply chain issue
- Interdependencies
- Environmental Issues/Sustainability

### Construction now – use of Technology

**Universal connectivity and real-time decentralized decision-making as an outcome of Construction 4.0**

- Internet of Things,
- Digital Twin,
- Additive manufacturing (3D Printing),
- Cloud computing,
- Cyber-Physical Systems (CPS) and,
- BIM
- Laser Scanning

**Additionally**

- New material/FRP
- Intelligent Planning Units
- Smart Objects
Construction Industry/University Collaboration for Innovation

- Center for Intelligent Infrastructure
- Missouri Consortium for Construction Innovation
- Purdue Consortium for Construction Innovation
- Construction Industry Institute
- CIB (International Council for Research and Innovation in Building and Construction
- CICID, Hong Kong
- Construction Research Institute of Canada
- Etc.

Construction Industry Institute
17 Best Practices

- Advanced Work Packaging
- Alignment
- Benchmarking & Metrics
- Change Management
- Constructability
- Disputes Prevention & Resolution
- Front End Planning
- Implementation of CII Research
- Lessons Learned
- Materials Management
- Partnering
- Planning for Modularization
- Planning for Startup
- Project Risk Assessment
- Quality Management
- Team Building
- Zero Accidents Techniques

https://www.construction-institute.org/resources/knowledgebase/best-practices
Adding value for global research

Global network for collaboration
- 40 expert Working Commissions & Task Groups
- Conferences, webinars, publications, 30 partner journals, research database, research roadmaps
- World Building Congress 2025

Supporting tomorrow’s talent
- 18 Student Chapters
- New global network for Early Career Researchers
- “CIB in Conversation”

Campaigning on issues which matter, eg impact, research classification

40 Working Commissions and Task Groups (March 2022)
CIB ‘Vistas’: Global Collaboration - People and the Planet - Futures

www.cibworld.org
Sustainable development

“Development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (UNISDR 2009, Brundtland Commission in 1987).

- Sustainability addresses the time continuous effects of any strategy on the economy, environment and society over the lifecycle of the infrastructure
- Therefore, strategy selection for capacity building should address resilience as well as the sustainability aspects.
Interdependence of Infrastructure for Societal Resilience

Failure of infrastructure after disasters and their impact on community recovery
Disasters - Global Issue

Network Failure

Mass Care

Power Grid Failure

Food and Water Insecurity

Types of Infrastructure

<table>
<thead>
<tr>
<th>Civil</th>
<th>Civic</th>
<th>Social</th>
<th>Environmental</th>
<th>Financial</th>
<th>Education</th>
</tr>
</thead>
<tbody>
<tr>
<td>Utility Systems</td>
<td>Emergency Centers</td>
<td>Homes</td>
<td>Landscape</td>
<td>Disaster Funds</td>
<td>Training</td>
</tr>
<tr>
<td>Water, Gas, Electricity</td>
<td>Hospitals</td>
<td>Religious Centers</td>
<td>Wastelands</td>
<td>Insurance</td>
<td>Programs</td>
</tr>
<tr>
<td>Transportation Systems</td>
<td>Police</td>
<td>Community Centers</td>
<td>Mangroves</td>
<td>Donors</td>
<td>Feedback Mechanism</td>
</tr>
<tr>
<td>Roads, Bridges, etc.</td>
<td>Governance, etc.</td>
<td>NGOs</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Interdependencies between the seven infrastructure layers

<table>
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<tr>
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<td>Utility Systems</td>
<td>Emergency Agencies</td>
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<td>Disaster Funds</td>
<td>Mangroves</td>
<td>Training</td>
</tr>
<tr>
<td>Water, Gas, Electricity</td>
<td>Schools, Hospitals</td>
<td>Religious Centers</td>
<td>Insurance</td>
<td>Debris Site</td>
<td>Programs</td>
</tr>
<tr>
<td>Transportation Systems</td>
<td>Police, Governance</td>
<td>Households</td>
<td>Donor Funds</td>
<td>Forests</td>
<td>Feedback Mechanisms</td>
</tr>
</tbody>
</table>

Criticalities between the seven infrastructure layers

- Civil Infrastructure
- Civic Infrastructure
- Social Infrastructure
- Financial Infrastructure
- Environmental Infrastructure
- Cyber Infrastructure

Interrelationship between infrastructure types
Sustainable resilience-enhancing strategies should be considered while selecting various alternate strategies for capacity building to enhance resilience.

Sustainable resilience-enhancing strategies are those strategies that contribute indefinitely to the development & well-being of both the consumers & infrastructure whilst not overdrawning natural resources or over-burdening the environment in an irreversible manner.

Global Leadership Forum for CEM Programs (GLF-CEM)

Task Force on Resilience in Construction Industry

Pandemics and recessions have revealed the need to extend the definition of Resilience in construction industry. This Taskforce aims to explore and perhaps define Resilience in the Construction Industry by looking at:

- **Different shocks and stresses**: Natural hazards, Pandemic, Supply chain delay, Recession, Legislation
- **Different levels**: City, Community, Organization, Individual
- **Different technical infrastructure**: engineering, networks, and assets
- **Different mitigation strategies**: Local supply chain, Modularization and Prefabrication, Remote Working, etc.
Getting Ready for 2030: A People, Process, and Technology Roadmap for Offsite Construction (CII RT371)

Motivation

Why 1 - Shortage in Skilled Labor
Why 2 - Suboptimal Project Outcomes
Why 3 - Poor Productivity
Why 4 - Inadequate Leverage of Technologies
Why 5 - Uncertainties Associated with Jobsites

PI: Islam El-adaway, Mark Hastak and Kim Needy

Size of Global Offsite/Modular Construction Market

- Compound annual growth rate (CAGR) ≈ 9.6%
Key Quotes on the 2030 Vision for Offsite Construction

- "The percentage of offsite construction will continue to increase."
- "We will get more and more automated...like video games...to reduce the number of workers on the jobsite."
- "Going offsite will be huge and advantageous to hiring and attracting more or higher qualified people into the industry."
- "The definition of construction workforce will change...people at the job site and on the manufacturing floor."

Most-used Offsite Construction Characteristics

<table>
<thead>
<tr>
<th>2020</th>
<th>2030</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single-trade Prefabrication</td>
<td>Modularization</td>
</tr>
<tr>
<td>Customized Components</td>
<td>Standard Components</td>
</tr>
<tr>
<td>Permanent Structures</td>
<td>Portable/relocatable Structures</td>
</tr>
<tr>
<td>Single-skilled Labor</td>
<td>Multi-skilled Labor</td>
</tr>
<tr>
<td>High-skilled Labor</td>
<td>High-skilled Labor</td>
</tr>
</tbody>
</table>

- Offsite construction typologies
  - Modularization
- Type of components for offsite construction
  - Standard Components
  - Portable/relocatable Structures
- Type of structures for offsite construction
- Labor skillset for offsite construction
- Labor skill level for offsite construction
  - Multi-skilled Labor
  - High-skilled Labor
Top 3 Workforce Occupations in Highest Need for Training in Offsite Construction

<table>
<thead>
<tr>
<th>Category</th>
<th>Rank #1</th>
<th>Rank #2</th>
<th>Rank #3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design and Engineering</td>
<td>BIM and 3D/4D/nD information modeling</td>
<td>QA/QC engineers</td>
<td>Planning engineers</td>
</tr>
<tr>
<td>Construction and</td>
<td>Construction managers</td>
<td>Constructability specialists</td>
<td>Field interface management personnel</td>
</tr>
<tr>
<td>Management</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Administrative</td>
<td>AWP professionals</td>
<td>Computer IT professionals</td>
<td>Project controls professionals</td>
</tr>
<tr>
<td>Onsite Craft</td>
<td>Offsite module installation personnel</td>
<td>Lifting, cranes, and rigging personnel</td>
<td>Instrumentation and control personnel</td>
</tr>
<tr>
<td>Offsite Fabrication</td>
<td>Computer-aided manufacturing professionals</td>
<td>Assembly, fabrication, and production personnel</td>
<td>Planners, expeditors, and sequence managers</td>
</tr>
</tbody>
</table>

Key Offsite Construction Skills to Incorporate into Training

Design and Engineering
- Fabrication package creation and detailing
- Stability and constructability of components and modules
- Supply chain and procurement
- Logistics and transportation
- Offsite construction philosophy
- Design for manufacturing and assembly
- Design freeze
- Offsite typologies

Construction and Fabrication
- Automation, robotics, and computer-automated technologies
- Placement, assembly, and installation
- Manufacturing and fabrication processes
- Operation management and process planning
- Good manufacturing practices
- Integration of onsite and offsite activities
- Offsite construction philosophy

Administrative
- Manufacturing and factory knowledge
- Offsite construction philosophy
- Systems thinking and integration
- Process streamlining
- Personnel information systems
Top 5 Technologies To Invest In and Train the Workforce on for 2030

- Remote Monitoring
- Smart Sensors
- Artificial Intelligence Interface
- Extended Reality
- Integrated Real-Time Management Information Systems

We still need to address the issue of complexity in the built environment

Philosophy of an Intelligent Planning Unit (IPU) to facilitate offsite construction
Philosophy of an Intelligent Planning Unit (IPU)

- **IPU Brick**
- **IPU Room (or Space)**
- **IPU Building**
- **IPU City**

**Nanotechnologies** (P1 - P5)

**IPU Physical Entities**

IoT Nano sensor

IPU Brick

**IPU Application**: IPU physical entities in the complex built environment

- **Intelligent Planning Units (IPUs) in Construction**

  - **IPU Application**: IPU physical entities in the complex built environment

  - **Intelligent Planning Units (IPUs)**
  - **Component (Intelligent brick)**
  - **Nanoparticles**
  - **Space (Intelligent room)**
  - **Infrastructure (Intelligent building) Block (Intelligent campus)**
  - **City or County**
  - **State**
  - **Country**
  - **World**

When it scales up...
Three-phase Implementation Process of an IPU

1. IPU Application: IPU replication, mutation, and combination (a composite IPU)
   - Objective
   - Properties & Specifications
   - WHY
   - HOW
   - WHAT
   - WHERE
   - WHEN

2. IPU Network: IoT Nano sensor

3. IPU Application
   - Composite IPU #1
   - Composite IPU #2
   - Composite IPU #3
   - Composite IPU #4

IPU Replication, Mutation, and Combination
- DNA structure
- Nano particles

IPU Application & IPU Network
- Measurement
- Collection
- Analysis
- Virtual world ➔ Real world

Challenge 1: Automatic Connection
Challenge 2: Continuous Analysis
Challenge 3: Automatic Alerts

Three-phase Implementation Process of an IPU

1. IPU Planning
2. Measurement
3. Collection
4. Analysis
5. Virtual world ➔ Real world
IPU : Impact on the KPIs

Positive Impact on the KPIs
1. Cost
2. Schedule
3. Quality
4. Safety
5. Sustainability
6. Variety in IPU available
7. Competition among IPU developers/Suppliers

Three-phase Implementation Process of an IPU

- **IPU Network**: IPU interaction using the emerging concept of IoT technology

![Diagram of IPU Network](image)

- Intelligent Green Space
- Intelligent Central City
- Intelligent Residential City
- Intelligent Industrial City

![Diagram of IPU Implementation Process](image)
Will workers still exist on future construction sites?

Impacts of Mental Load and Time Pressure on T&D Line Workers

External Stressors in the Construction Industry

Task stressors
- Time Pressure
- Mental Demand

Environmental stressors
- Extreme Heat

Social stressors
- Peer Pressure
- Social Influence

Replacing Pole and Moving Energized Powerlines: 3 Experimental Conditions

i) Normal
ii) Time Pressure
iii) Time Pressure + Cognitive Demand

Duration: Subject's own pace
Duration: Normal–10 Seconds
Duration: Normal–10 Seconds

Dr. Sogand Hasenzadeh - sogandm@purdue.edu
Impacts of Mental Load and Time Pressure on T&D Line Workers

Multi-Model Mixed Reality (MR) Environment

Worker-AI Teaming to enhance inclusivity in the Construction Industry of the Future

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Construction – Future

Construction on Mars?
https://www.bustheworld.com/elon-musk-said-mars-is-independent-will-he-build-his-own-country/

Construction on Moon?
NASA Artemis Project

Construction Engineer of the Future
Engineering Areas of Growth?

Robotics  Centric  Artificial  Sustainable
Human  Intelligence  New  Resilient
Intelligence  Autonomous  Material
Required Knowledge Areas

Engineering Education Research and Recommended Practices
In Conclusion

- A snapshot of “Construction Industry Challenges and the Need for Innovation”
- Construction is a very robust industry that has innovated for ages in delivering complex and challenging projects
- Cost, Schedule, Quality, Safety, and Sustainability remain the KPIs
- Challenges exist
  - Shortage of skilled labor
  - Adoption of technology/Human-System Interface
  - Contractual constraints
  - Low productivity
  - Pandemic and Supply chain issues
  - Resilience of the industry
  - Interdependencies
  - Environmental Issues/Sustainability
  - Safety
- Lot of opportunity exists but there is a strong need for innovation to resolve the challenges ahead that could be addressed with Industry/University Collaboration

Thank you

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