Core elements of construction engineering knowledge for project and career success

- Need, definition, three types of activities
- Knowledge elements: fundamentals, resources, operations
- Learning methods
- Conclusions, implications, continued learning

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Market drivers for construction engineering

- Increased construction safety, quality, and sustainability, including design and the supply chain
- Increased infrastructure, engineered construction
- New materials, construction-applied resources
- Increased system complexity for criteria such as life safety, building energy efficiency, air quality
- Integrated project delivery and work processes; IT-enhanced planning, coordination, monitoring
- Construction process modeling, starting with BIM
- Changing construction workforce, skill levels

Definitions:

Construction engineering: a series of technical activities throughout the project to assist in meeting all types of project objectives. The activities include design, resource supply, and integration.

Construction management: "... a professional management practice consisting of an array of services applied to construction projects and programs ... a discipline and management system..." CMAA
1. Design temporary works, work processes
   • Temporary works to provide the production environment for construction
   • Construction processes, means and methods, to build the work

2. Provide resources
   • Technical information
   • Permanent materials and equipment
   • Construction-applied that do not remain

3. Integrate project phases, work processes, projects
   • Construction input to design; interpreting plans and specifications
   • Technical input to work coordination in an area
   • Best practice transfer to future projects
Four Knowledge elements

1. Technical fundamentals: engineering, performance, applications, methods of operation
2. Materials of construction: design and construction properties; influence on field operations
3. Construction-applied resources: availability, performance, applications, limitations
4. Field construction operations: sequences, production rates, potential problems, avoidance

1. Technical fundamentals

- Materials science and engineering
- Mechanics, forces
- Geotechnical and structural engineering
- Fluid mechanics, thermodynamics, heat transfer
- Electric power
- Process control and instrumentation

2. Materials of construction

- Design properties: chemical, physical, performance, special restrictions
- Construction properties: links with operations, cost, availability, potential for substitution, toxicity
- Link with operations: major type; properties
Examples of materials properties

<table>
<thead>
<tr>
<th>Material</th>
<th>Key design properties</th>
<th>Key construction properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete</td>
<td>strength in shear, bending, compression, bearing, MoE permeability, durability, creep</td>
<td>cement temperature, shrinkage, rate of setting and strength gain influence of admixtures workability for all construction operations lateral pressure in concrete forms shrinkage, delay of adjacent placements</td>
</tr>
<tr>
<td>Reinforcing steel</td>
<td>strength, tensile, grades, standard sizes, details configuration, location in placement, cover, corrosion protection</td>
<td>standard sizes and details fabrication tolerances, preassembly density, congestion in placement number and types of splices release and delivery by placement location tolerances, ability to cold work</td>
</tr>
<tr>
<td>Structural steel</td>
<td>strength, tensile, compressive, shear Dimensions, properties of structural shapes configuration, location</td>
<td>standard details fabrication tolerances, potential to automate delivery for erection, fit with shipping envelope, erection plan weldability; heat treatment, hardness</td>
</tr>
</tbody>
</table>

3. Construction-applied resources

- Consumable and salvageable materials
- Tools, simple or complex
- Construction equipment
- Knowledge elements: how it works, performance, best applications, limitations, risk, potential for automation
Knowledge about construction-applied resources

<table>
<thead>
<tr>
<th>Examples of resources</th>
<th>Most productive applications</th>
<th>Conditions and use for the best results</th>
<th>Unit and systems capacity and performance metrics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete pump</td>
<td>medium to large placements</td>
<td>access for placing boom</td>
<td>weight, kg placement rate, m³/hr</td>
</tr>
<tr>
<td></td>
<td>vertical and horizontal</td>
<td>reliable supply of pumpable concrete</td>
<td></td>
</tr>
<tr>
<td></td>
<td>transport less than</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>rated capacity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Concrete admixture</td>
<td>placement requiring</td>
<td>hot weather, cold weather, high density</td>
<td>required dosage</td>
</tr>
<tr>
<td></td>
<td>special concrete properties</td>
<td>reinforcing steel</td>
<td>change in properties of plastic concrete</td>
</tr>
<tr>
<td>Concrete vibrator</td>
<td>internal consolidation of</td>
<td>higher congection of reinforcing</td>
<td>class, size, frequency, radius of influence</td>
</tr>
<tr>
<td></td>
<td>concrete placement</td>
<td>lower slump concrete</td>
<td>m³/hr placement rate</td>
</tr>
<tr>
<td>Crawler crane</td>
<td>erecting structural steel</td>
<td>accessible site</td>
<td>weight, ground pressure</td>
</tr>
<tr>
<td></td>
<td>setting large components</td>
<td>large structure</td>
<td>working reach, load</td>
</tr>
<tr>
<td></td>
<td></td>
<td>requiring multiple crane locations</td>
<td>hoisting rate</td>
</tr>
<tr>
<td>Welding machine</td>
<td>welding connections for</td>
<td>full penetration welds</td>
<td>power, voltage, amperage, deposition rate</td>
</tr>
<tr>
<td></td>
<td>structural steel, piping</td>
<td></td>
<td>kg/hr</td>
</tr>
</tbody>
</table>

4. Field construction operations (a)

- **Knowledge elements:** sequences, production rates, potential problems, avoidance
- **Earthwork:** erosion control, clearing and grubbing, stripping topsoil; excavating, hauling, placing; compacting, testing; finishing, checking final line, grade
- **Concrete work:** formwork, reinforcing steel, embedments; batching, transporting, placing, finishing, curing; special methods
4. Field construction operations (b)

- **Structural steel:**
  - detailing, fabricating; transporting, shaking out; raising, plumbing, connecting, testing
- **Permanent equipment:**
  - review submittals, fabricate, test, transport, receive, store, install, connect, test

4. Field construction operations (c)

- **Piping and ductwork:**
  - detail, coordinate, fabricate; transport, erect, support, connect, clean, test
- **Electrical systems:**
  - detail, coordinate, fabricate, erect, support connect raceway; position, pull, terminate, test electrical cable
Knowledge about field operations

- "King or queen" demands or conditions: project objective, resources, design, site, vicinity
- Critical information needs in the field
- Performance requirements for resources
- Best “flow” of the work
- Risks and contingency plans; “mothers for all”
- Potential problems and how to obviate
- Critical success factors for the crews in the field
Examples of construction engineering-intensive activities

- Excavate and support a tunnel
- Build an engineered fill
- Dewater, excavate, and support a foundation
- Precast, transport, erect a large beam
- Plan and provide resources for a deck cycle
- Erect and connect a tier of structural steel
- Fabricate and install a building enclosure
- Set, align, and connect major equipment
- Detail, coordinate, fabricate, erect, connect, and commission a service or process system

Levels of construction engineering knowledge

<table>
<thead>
<tr>
<th>Employer organization</th>
<th>Technical fundamentals</th>
<th>Materials of construction</th>
<th>Construction Resources</th>
<th>Field operations</th>
</tr>
</thead>
<tbody>
<tr>
<td>GC, self perform; specialty contractor</td>
<td>- quantitative • apply to design • deep “feel” for links to other 3 elements</td>
<td>- quantitative • design properties • construction properties</td>
<td>- quantitative • performance applications • limitations, quality, safety</td>
<td>- quantitative • sequences, production rates, problems</td>
</tr>
<tr>
<td>GC, CM at risk</td>
<td>- apply to review other’s design • qualitative sense of links</td>
<td>- mix of quantitative, qualitative for design review</td>
<td>- mix of quantitative, qualitative in plan review</td>
<td>- mix of quantitative, qualitative in plan review</td>
</tr>
<tr>
<td>Program or project manager, Prof. CM</td>
<td>- limited qualitative applications in design and construction</td>
<td>- limited qualitative applications in design</td>
<td>- limited qualitative applications in plan review</td>
<td>- limited qualitative applications in plan review</td>
</tr>
</tbody>
</table>
Learning approaches

- Lecture with examples, reading, problem sets
- Active and cooperative methods in class sessions
- Integrated, project-based, team focused, IT intensive
- Construction engineering practicum, an experiment, with a class session and a group exercise each for earthwork, concrete work, and steel construction

Conclusions: construction engineering knowledge

- **Need**: new project types, operational constraints, materials, IT-enabled resources
- **Career advantage**: learn from CEM courses, excel early, keep learning
- **Elements**: two fundamental, two applied, all beneficial and highly related
- **Learning methods**: combine traditional, active, and integrated for all elements

Implications and recommendations

- **Young engineers**: combine experience-based and fundamental learning, iteratively
- **Regular and adjunct construction faculty**: related fundamental and empirical topics
- **Industry professionals**: seminars, courses, shared information, career advising
- **Construction researchers**: develop model-based tools to bring jobsite to the classroom; scope and structure representation and reasoning for construction process models
Individual benefits from construction engineering

- Background for design, estimating, and construction management courses
- Basis for success in initial jobs, continued learning, development
- Increased potential for innovation
- Shared technical understanding, rapport with design, operations
- Advantages for licensure

How will construction engineering help my career?

- Technical basis for planning, modeling, and analysis of construction operations.
- Increased communication, credibility, rapport and shared motivation and understanding with other members of project teams.
- Foundation for deeper, faster self-directed learning from experience in design and construction.
- Increased personal productivity.
- Critical resource for analysis, innovation, and vision regarding project and, later in careers, operations and general management.

Activities to keep learning

- Ask everyone; know can learn from all; + attitude.
- Get very good at something; add value early.
- Participate in professional or trade organizations such as technical committees of ASCE, CII, AIA, AGC, DBIA, CMAA, or others.
- Learn more about engineering fundamentals and materials from different disciplines; take FE exam.
- Iterate between empirical (OJT) learning (often about resources and operations) and increased understanding of fundamentals and materials.
Examples of getting very good at something

Knowledge sources for continued learning

- Crafts and superintendents on the job by observing, analyzing, asking, and applying the results
- Design engineers by reviewing codes and standards, asking about design basis, and analyzing the design criteria and process
- Owners and operators by asking about performance or program criteria for the project and tracing how they are implemented and verified
- Suppliers of key materials and equipment by asking about appropriate integration and the most favorable applications of their products