NAC Executive Insights

Innovation and Technology Convergence

Key Points

- Where are the opportunities for innovation?
- Where is innovation most needed?
- Where can innovation occur?
- The answer is the same for all three questions – EVERYWHERE!

Introduction

This Executive Insight focuses on broader, more systemic opportunities for innovation. The same processes and thought patterns, however, will also deliver meaningful and important incremental innovations, some of which can be quite valuable. The hope is to view the universe of ideas and potential solutions more broadly upon completion of the reading of the Insight.

To begin, consider open innovations, which use ideas from a broad range of sources as well as a wide range of pathways and approaches to advance a solution. Recognize that innovation is fed by a diversity of perspectives, skills, aspirations, and frustrations. Recognize that innovation may take many forms, ranging from financial through process, offerings, and delivery innovations.

Open innovation often starts with so called "flat questions" that get to the essence of the outcome desired and that are not limited by any preconceptions of what a solution might look like. Innovation requires a change to the questions. Only then can thinking be changed, as well as the actions taken and the results achieved. Flat questions also draw in other types of people and perspectives. At an extreme, think of crowdsourcing the challenge.

So, what is a flat question? Some examples include:

- How is construction and demolition waste in the construction supply chain minimized/reused?
- What are innovative, cost-effective methods to retrofit low income houses to make them strong enough to survive high magnitude earthquakes and typhoon force winds?
- How to enhance situational awareness and optimize operation of the bulk electric system?

- How to accurately measure the soil-structure component of damping and its contribution to the damping of offshore wind turbine structures?

Open innovation often results in unanticipated solutions from the collaboration of diverse parties. Diversity, in all forms, is part of the secret to innovation.

The innovation described next benefitted from a diversity of thinking:

> *An underground oil shale field injected with steam and drained (SAGD) has oil separated from the produced water, which contains high levels of silica. After other contaminants have been removed from the water, the goal is to reheat the water for reinjection. However, the silica precipitate out once through the steam generator, fouling and damaging the tubes. The conventional solution is to separate the silica and ship it offsite as a waste product. Instead, an innovation exercise began by assembling a group of mining, chemical, water, and energy engineers to find an alternate solution. The group's innovation: raise the pH of the water before it goes through the steam generator, thus retarding precipitation and lowering it after passing through the steam generator to expected values. The result: silica is returned to the underground mine and no waste stream is created.*

The opportunities of open innovation are further enhanced by convergence of a wide range of technologies. Think of the universe of possibilities changing as much the change from Newtonian to Relativistic thinking. The next section will look at several aspects of this technological convergence and the potential implications for innovation thinking and efforts.

To begin, however, a simplified engineering and construction (E&C) technology convergence model is presented.

In this simplified model, materials (M) are combined with other organic or inorganic materials and converted by energy (E) into an intermediate state (I) with new properties. These intermediate state outputs are applied by engineering (ENG) and transformed by construction (C) within a changing and changeable frame of reference (FRAME) to deliver a Project. Each stage of this process is informed and shaped by information. This can be seen in the following figure. Note: Mi are inorganic materials and Mo are organic materials.

E&C Transformation Process

$$M + Mi, Mo + E(n) \rightarrow I$$

$$\left\{ \sum I(n) + ENG + C \right\}_{FRAME} \rightarrow PROJECT$$

A robust framework for E&C technology convergence and future trajectories necessitates considering both inorganic (brick, concrete, and ferrous and non-ferrous materials) and organic materials. The important contributions of organic materials to engineering and construction are often overlooked, but their role is growing in importance. The interesting intersections with more traditional construction materials are likely areas ripe for significant innovation.

Organic

Organic materials fall into three broad groups or domains that can be further divided into kingdoms. These include archaea (found in higher temperature and strong acid environments); bacteria; and eukarya, which include humans.

Archaea have an ability to convert inorganic materials into organic materials using them as food. They have been used in bioremediation, especially for oil spills. Their enzymes are used in bio-gas production and sewage treatment. Potential uses also include extraction of certain metals from ores and carbon sequestration in sewage plant sludge. The higher temperature characteristics have been used in other industries and represent a future potential in construction.

Bacteria have already found their way into construction technology with applications in self-healing concrete, mini-factories for materials and polymers, and soil stabilization. In the future bacteria will have more prominent roles in buildings, bridges, and tunnels and perhaps even construction on Mars.

The third domain of organic life are Eukarya. Only four kingdoms will be mentioned here: fungus, slime molds, plants, and animals. Fungus already appears in building materials and holds future promise in green construction. Slime mold has demonstrated its ability in some simple computer problems and in solving route optimization problems.

Plant-based materials have long been used in construction. Now, when combined with other organics and inorganics, new uses are being found. Two examples are (1) increased use of bamboo in construction scaffolding worldwide and (2) translucent wood used in lieu of glass windows providing greater strength while being biodegradable.

The final kingdom is the animal kingdom, of which humans are a part.

Inorganic

Inorganic is the world of materials the E&C industry has traditionally transformed with purpose throughout history. It is where machines, processes, knowledge, and insight are applied. The materials available have transformed, opening up new solutions and technologies not previously available. Many of the new technologies originate in other industries, increasingly without immediate adjacency. This should encourage the industry to scan more broadly in search for improvements, innovations, and new technologies that can be extended into construction.

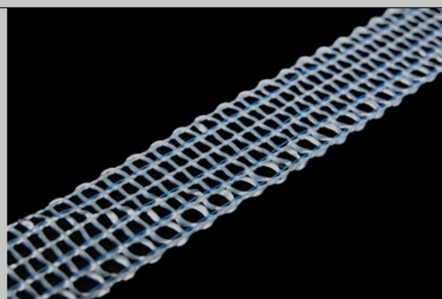
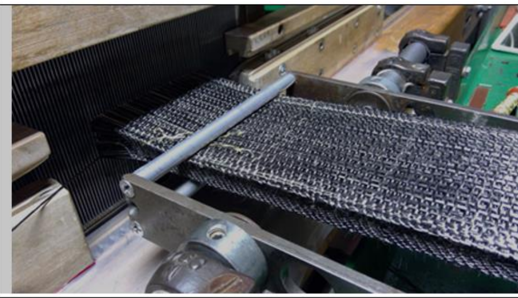
The materials available to the E&C industry can be grouped into four broad categories:

1. **Naturally occurring; natural scale**—iron, copper, aluminum and for simplicity even common carbon steels. Organic building materials such as wood could be included.
2. **Synthesized; change of state**—This is typically the result of a physical, chemical, electromagnetic, or irradiation process. It is also the result of the combination of materials, both organic and inorganic. (Later, this category will be subdivided and feature interesting examples of emerging E&C technologies; historical examples include concrete, stainless steel, and permanent magnets).
3. **Nanomaterials**—Advances in this area range from the creation of classes of physical materials with designer properties to further advances in bioengineering, creating designer organisms. Importantly, the technologies to advance the application of nanotechnology at scale are becoming more widely available. Table 1 highlights some nanomaterial applications.

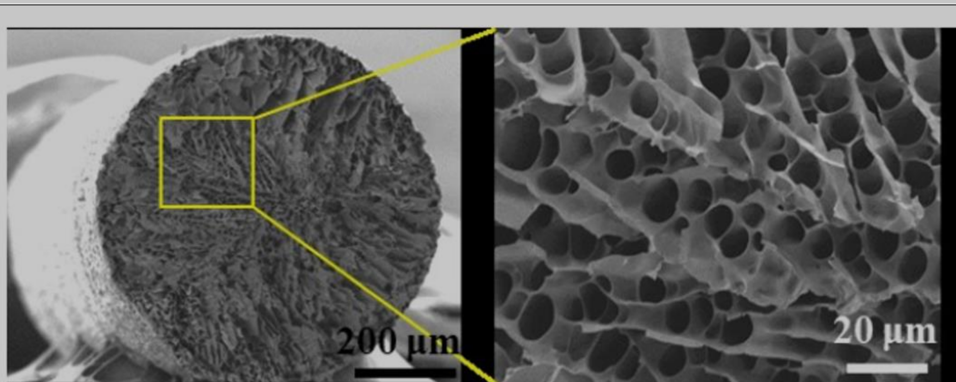
Table 1 - Nanomaterial Applications	
Primary Property	**Select Applications**
Durability/strength	Work clothing
	Bandages that promote healing
	More durable tools (cutting; impacting)
	Nano-cladding (pipes) for abrasion resistance
	Ductile machinable ceramics
Chemical reactivity	Designer pharmaceuticals
	Catalysts for environmental pollutants
	Superabsorbent polymer (hydrogel)
Conductivity/insulation	Graphene
	Aerogels
	High density batteries
	High power magnets
	High sensitivity sensors
	Nano-crystalline ceramics to enhance diesel engine performance

4. **Atomic and subatomic material design**—This atomic level manipulation will influence tomorrow's electronics, enhance traceability of sensitive or dangerous materials or devices, and provide new insights into weld micro-grain structures to accelerate weld analysis.

Synthesized materials help create some innovative properties and uses. The following examples illustrate what is possible.

E-webbings	TPCM
	

Fabric that heats and cools skin with no energy input



A microstructured fibre (left) contains pores (right) that can be filled with a phase-changing material that absorbs and releases thermal energy. Credit: ACS Applied Materials & Interfaces 2020, DOI: 10.1021/acsami.0c02300

Figure 1

Example #1 - E-WEBBINGS®: Woven narrow-fabrics that are conductive, enabling the electronic transmission of data, sensations (light, noise, vibrations, heat), and power that can be stored or used to actuate/transform objects. These unique conductive fibers can be woven in conjunction with other fibers and used in embedded sensors in both wearable and integral technology, including the Internet of Things. (Figure 1, upper left)

Example #2 - TPCM fabrics are comprised of structural and matrix/resin fibers oriented to maximize X, Y and/or Z directional properties. They can produce lighter-weight, quality parts at reduced materials and labor costs, with reduced process complexity and bills of material. Potential fiber combinations include a varied mix of structural yarns and matrix/resin yarns.

TPCM in a customized and engineered weave design provides localized reinforcement where superior properties are required. (Figure 1, upper right)

Example #3 - Structural woven formwork enables manufacture of new types of flexible and embedded fabric formworks for potential use in the construction industry, including fiber systems for reinforcing building components, containment structures, and layered geo-textiles. In-filled with concrete, aggregate, or earth, new formwork fabrics are designed with anisotropic properties to provide enhanced structural performance, permeability, and surface finish compared with commercial off-the-shelf fabrics.

Example #4 – Wool/seaweed bricks are 37 percent stronger than traditional bricks and no need to fire in a carbon-emitting kiln, reducing the carbon footprint.

Table 2 highlights some of the new properties and behaviors enabled by new and emerging materials.

Table 2 - New Properties and Behaviors Enabled	
Driving Material	**Interesting Properties**
Archaea	Bioremediation; carbon sequestration; high temperature/high acid properties
Bacteria	Limestone deposition (crack sealing); carbon-fixing bio-cement; conductive bio-films; living photovoltaics
Plants	Electrical conductivity; chemical resistance; water resistance; piezoelectric behavior; thermoregulation (w/o energy input); shapeshifting
Fungus	Limestone deposition (crack sealing); foam
Animals/human	Android and avatar-like behaviors

Transformative Process Related Technology

Today there is a convergence of technologies across:

- Construction
- Manufacturing
- Media and entertainment

In manufacturing alone, the convergence of numerous technologies resulting in new capabilities occurs in:

- Additive manufacturing (3D printing; filament winding to produce composite pipes and tanks; direct metal laser sintering; fused filament fabrication; laser powder forming)
- Subtractive manufacturing (and construction) (BIM model-driven laser cutting of metals)
- Hybrid manufacturing (additive and subtractive in one machine)
- Labeling and painting – thermal spraying to coat structural members; thin film deposition (plating) with nanomaterials
- Joining – friction stir welding
- Textiles (nanotechnology influencing of properties – antimicrobial; heat resistance; advanced textiles using aramids and meta-aramids (Kevlar®, Nomex®), graphite, Vectran,™ Teflon,™ Dyneema,® and Spectra® as well as composites or other specialty fibers.
- Biotechnology (bio-concrete and other building materials, Mycelium insulation).

E&C Process Related Technology

Changes resulting from the transformation of materials, as discussed above, result in the creation of interesting new properties. Changes in the E&C industry itself include changes in work processes, where technology advances are driven by a combination of knowledge, innovation, and energy related changes in addition to those driven by materials transformation. E&C related work processes may be segregated, as shown in Table 3.

Table 3 - E&C Work Processes
Program management and governance
Project management
Planning and optimization
Engineering and design
Supply chain
Construction management and planning
Construction equipment and tools
Construction labor and productivity
Construction materials
Construction means and methods
Facility O&M

Each of these work processes is further enabled or modified by new materials, new thinking and capabilities related to energy, and emergent uses of information. A range of these areas are impacted by artificial intelligence (AI). Some innovations across these process areas include:

- Project management
    - AI-enabled project health diagnostics
    - Dynamic scheduling based on data streams from project site and supply chain
    - AI-enabled materials and logistics management
    - Knowledge management/just-in-time training
    - Inventory control
- Planning and optimization
    - Holodecks used for city-scale planning and design reviews are becoming more readily available, driven by the entertainment industry.[1]
    - Slime mold route optimization
    - Gamification-enabled stakeholder engagement and planning
    - Pattern recognition-based optimization using AI
- Engineering and design

Engineering and design models will increasingly incorporate AI and advanced optimization technologies into BIM and other design tools. Examples of the application of emerging AI and computational technologies include:

- Real time life-cycle[2] cost tracking and optimization as design progresses
- Carbon footprint associated with materials of construction being employed
- Material optimization as part of a net zero focus related to both energy and the various waste streams associated with the construction process (emphasis on circular economy)

These are only a few of the numerous examples that are occurring today.

[1] NVIDIA Omniverse is one such system. https://www.nvidia.com/en-us/design-visualization/industries/architecture-engineering-construction/

[2] Executive Insight, Lifecycle Control Basis

Tybot	HRP-5P
	

Figure 2 – Construction Robots

In Closing

Tomorrow's breakthroughs will occur at the intersection of energy, organic and inorganic materials, transformed E&C processes, information, and changed frames of reference. AI will be an enabler and an important technology that will open up new innovations—but it will not be the only one. Challenge current paradigms, engage a diversity of thought, and start with the right questions. The E&C industry's potential is only limited by the imaginations and energy of its participants and stakeholders.

About the Author

Bob Prieto was elected to the National Academy of Construction in 2011. He is a senior executive who is effective in shaping and executing business strategy and a recognized leader within the infrastructure, engineering, and construction industries.