Nanotechnology and Its Impact on Construction

RT 251

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# Construction Industry Institute (CII)

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- Day & Zimmermann International, Inc.
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- Kleer Power Construction
- Lauren Engineers & Constructors, Inc.
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- WorleyParsons
- Zachry
- Zurich
Agenda

– Introduction to Nanotechnology
– Background Review
– Examples to Products and Application Areas
– Drivers in Construction, Benefits, Barriers, and Path Forward
– Risk Management
– Survey Results and Top Product Areas for Construction
– Question & Answering
Nanotechnology is not new …

Nanotechnology has been applied in ancient manufacturing by adding gold/silver or during careful manufacturing using carbon nanotubes.
Nanotechnology in future everyday life

Corrosion
- Nano-particle paint to prevent corrosion
- Thermo-chromatic glass to regulate the influx of light

Structures
- Piezo mats prevent annoying vibrations
- Hip joints made from biocompatible materials
- The helmet maintains contact with the wearer
- Bucky-tube frame is as light as a feather, yet strong

Energy
- Fuel cells provide power for mobile phones and vehicles

Maintenance
- Photovoltaic film that converts light into electricity
- LEDs are now powerful enough to compete with light bulbs
- Scratchproof, coated windowpanes using the lotus effect

Cooling
- Organic Light Emitting Diodes (OLEDs) for displays

Economic Growth → Social Progress → Minimizing Ecological Footprint
What is Nanotechnology?

- Nano is a Greek word and means “Dwarf”
- Research and technology development
- Understand, create, use, and control matter
- Dimensions of <100 nanometer, “nanoscale”
- Fundamentally new properties and functions because of their nanoscale structure
- Ability to
  - image, measure, model, and manipulate matter on the nanoscale to exploit those properties and functions
  - integrate into systems spanning from nano- to micro- to macroscopic scales
- Examples: Structures, devices, and systems
Literature Review (1)

- Nanofabrication Techniques and Tools
  - “Top Down”
    - Created by processing of bulk materials
    - Current technology
    - Exploiting properties of nanoscale structures (e.g., nanoparticles)
  - “Bottom Up”
    - Designing and manipulating individual molecules from “bottom up”
    - Future technology, a.k.a. molecular manufacturing
Literature Review (2)

• Materials and Properties
  – TiO₂
  – Fullerenes
  – Carbon Nanotubes
  – Silica
  – Alumina
  – Magnesium and Calcium Nano-particles
  – Clays
  – Aerogels
Literature Review (2)

- **Application Areas**
  - Concrete
  - Steel
  - Wood
  - Asphalt
  - Glass
  - Coatings
  - Composites
  - Fire Protection and Safety
  - Water
  - Energy
  - Nano-Computing, Electronics, and Semi-Conductor
  - Metrology

Packaging: 30%
Automotive: 17%
Construction: 16%
Electrical: 16%
Other: 16%

Coatings: 73%
Composites: 12%
Other: 15%

Source: Freedonia 2007
Why Nanotechnology?

- **Current State**
  - R&D surging: Global Nano R&D ~$6-9 Billion
  - Nano patents in the U.S. to date: 4,000 (nearly 50% of the world)
  - Over $50 Billion in Nano-products sold in 2006

- **Near Future**
  - Estimated Market: $2.6 Trillion by 2014
  - By 2015 15% of global manufacturing will use Nano
Why Nanotechnology in Construction?

- Skyrocketing construction cost after a decade of modest inflation
- Increasing worldwide demand for larger quantities

Challenge of Consumption
Example: Cement and Concrete

$104 Billion/Year Market in U.S. alone

Source: Chaturvedi and Ochsendorf, 2004
Characterization of Materials
Example: Cement and Concrete

Ordinary Cement Paste: w/c = 0.5

High performance concrete (w/c = 0.4)

1900–1985 Industrialization/Standardization

1985-95 Re-discover Diversity

Source: Constantinides and Ulm, 2004
Improved Performance
Example: Cement and Concrete

• Opportunities for Nano-concrete
  – Material (55% of Initial Cost)
  – Labor (45% of Initial Cost)
    • Decrease schedules by 20%

• Properties
  • Tougher
  • Density (Weight!)
  • Low ductility, weak in tension
  • Durability (Cracking!)

• Environmental load
  • CO₂ <10%
  • Smog eating, reduce pollution by 40%

Source: Lafarge 2008
Needs Analysis Summary

**Definition/Value**
- Use less
- Higher functionality
- Last longer
- Lower maintenance
- Less ‘Loss of Use’
- etc.

**Characteristics**
- Higher strengths
- Improved ductility
- Greater durability
- Improved recyclability
- etc.

**Properties**
- Compressive strength
- Flexural strength
- Shear strength
- Ductility/toughness
- Impermeability
- Abrasion
- E-Modulus
- etc.

**Impact**
- Quality
- Cost
- Schedule
- Safety
- Reduced environmental impact
- etc.
Construction Industry Potential

- About 600 products total (after Wilson Foundation)
- New paradigm of living
  - Affordable
  - Self-sufficient energy: heat exchange, lighting, solar/heat energy
  - Quality of life, e.g. aesthetics
  - Life cycle and maintenance and environment
  - Sensors and connecting to electronics
  - Coatings for windows, roofs, and facades
  - Glass – increase R-value
  - Control of pathogens in homes
  - Termite resistant composite wood
  - Increasing structure integrity
  - Increasing adhesives properties
- Water filtration
  - Reduces bacteria by 99.9999%, viruses by 99.99%, and parasites by 99%
  - Cost ~$2 and good for 1 year or 700 liters
Steel


corrosion resistant construction steel

ROADMAP: Chart 1 - Bulk Construction Materials

Advanced Bulk Materials

Negligible / zero / positive environmental impact, sustainable resources, pre-set grading of properties replaced by properties optimized for applications

Peter JM Bartos, 2006
Drivers in the Construction Industry

- Drivers of progress:
  - Competitiveness
  - Investment return
  - Social responsibilities
  - Environmental concerns

- Nanotechnology will set new standards for the construction industry
- “Visionaries”
- Impact on “Bottom-Line”
- Capital for Research and Development
- Understanding of Nanotechnology
  - Missing link between construction industry and Nanotechnology R&D
- Top Down Buy-Ins
Benefits and Barriers

There is a fine line between the good and the bad

Source: Bell, 2006
Benefits and Barriers Summary

• Benefits
  – Materials & Properties
    • Strength and Durability
    • Wear and Tear Resistance
    • Corrosion Resistance
    • Fire Resistance and Retardants
    • Aesthetics
  – Economical
    • Life-Cycle and Maintenance Cost
    • Labor
    • Pricing and Profit
    • Customer Satisfaction
    • Market Value and Brand Image
  – Sustainability
    • Energy Efficiency
    • Material Consumption
    • Social and Ethical Benefits
    • Reduced levels of several environmental pollutants
    • Potential for numerous LEED point credits

• Barriers
  – Safety Concerns
  – Security Concerns
  – Regulatory Agencies – EPA, FDA, OSHA
  – Lobbyist(s)
  – Corporations’ established positions
  – Corporations’ investment in current equipment
  – Lack of properly trained personnel and cost of training
  – Lack of Understanding (F.E.A.R – False Expectations Appearing Real)
  – Lack of capital by Nanotechnology companies
  – Cost of Commercialization
  – Process must be “Green”
Examples of Nanomaterials, Projected Market Share, and Applications in Construction

- Bulk quantities
- Cost of manufacturing

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Ceramic</td>
<td>179</td>
<td>1,500</td>
<td>1-1000</td>
<td>UV absorber, plastics, coatings, photocatalytic coatings, glasses</td>
</tr>
<tr>
<td>Metal</td>
<td>89</td>
<td>770</td>
<td>10-10000</td>
<td>Antimicrobial effect</td>
</tr>
<tr>
<td>Nanoporous</td>
<td>54</td>
<td>690</td>
<td>10-10000</td>
<td>Insulation, optics, polymers, silicon, oil pipelines</td>
</tr>
<tr>
<td>Carbon Nanotubes</td>
<td>43</td>
<td>260</td>
<td>10-10000</td>
<td>Structural composites, memory, sensors, thermal management, display layers, coatings</td>
</tr>
<tr>
<td>Nanotstructured Metal</td>
<td>28</td>
<td>198</td>
<td>100-10000</td>
<td>Hard coatings or structural components in aerospace, equipment, pipelines, anti-corrosive coatings</td>
</tr>
<tr>
<td>Dendrimers</td>
<td>12</td>
<td>42</td>
<td>100-10000</td>
<td>Coatings, composites, inks, adhesives</td>
</tr>
<tr>
<td>Quantum dots</td>
<td>4.3</td>
<td>38</td>
<td>~1000</td>
<td>Optoelectronic applications like LEDs, displays, solar cells, inks and paints</td>
</tr>
<tr>
<td>Fullerenes</td>
<td>2.5</td>
<td>60</td>
<td>~1000</td>
<td>Composites, antioxidant additives fuel cells, lubricant</td>
</tr>
<tr>
<td>Nanowires</td>
<td>&lt;1</td>
<td>16</td>
<td>~1000</td>
<td>Electronics, for example, Conductive layers for displays, solar cells, logic devices</td>
</tr>
</tbody>
</table>
Why Risk Assessment?

Example:
Risk of Nanotechnology to the Environment

Davis et al., and EPA 2008
CII Member Company Survey

Objectives:

- Experience level
- Current and projected involvement
- Expected potential and impact
- Benefits, risks, and barriers
- Nanotechnology success stories and other comments.
Survey Results (1)

- 149 data liaisons contacted to identify key personnel within organization
- 34 returned, 6 responses stated to have no expertise in Nanotechnology
- More than 60% of the participants had 10 plus years of industry experience
- 8% called themselves “experts” in Nanotechnology
- 15% knew more than 5 Nano products
- 4% knew more than 5 Nano products that relate to construction
- 12% have a dedicated or outsourced Nano R&D program
- 12% allocate more than 5% of their R&D budget towards Nanotechnology (8% invest more than $1 Million per year)
- 70% could not identify any of the listed fabrication tools and techniques
- 15% knew a problem that Nanotechnology could solve in construction
- 30% require a ROI of more than 15% before investing in Nanotechnology
- 65% believe Nanotechnology will have little or no impact on construction
- Questions to funding & products under development were not well answered
- The vast majority has little interaction with universities and R&D agencies
- The majority does not know whether enough standards and regulations exist
Survey Results (2)

Areas with the biggest impact of Nanotechnology in construction

- Composites: 22%
- Concrete: 12%
- Coatings: 22%
- Concrete: 12%
- Steel: 5%
- Glass: 3%
- Chemicals & Fluids: 12%
- Sensors & Metrology: 12%
- Don't know: 12%
- Composites: 22%
Survey Results (3)

Biggest risks and barriers to Nanotechnology in construction

- Implementation time: 18%
- Don’t know: 21%
- Overall ROI: 22%
- Quality/Consistency: 14%
- Volume/Mass production issues: 7%
- Inefficient technology transfer: 11%
- Lack of awareness: 7%
- Overall ROI: 22%
- Quality/Consistency: 14%
- Volume/Mass production issues: 7%
- Inefficient technology transfer: 11%
- Lack of awareness: 7%
- Implementation time: 18%
- Don’t know: 21%
5. Examples of Use, Benefits, Limitations for Top 5 Nano-Products in Construction

<table>
<thead>
<tr>
<th>Product categories</th>
<th>Score</th>
<th>Main Uses</th>
<th>Key Benefits</th>
<th>Key Limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Composites</td>
<td>8.46</td>
<td>Building materials (Polymer, Steel, Piping), Energy applications, Protective clothing.</td>
<td>High strength, lightweight, durable structures, ductility, wear and corrosion resistance, earthquake resistance.</td>
<td>Technical limitations and bulk volumes, environmental impact during disposal phase.</td>
</tr>
<tr>
<td>Coatings</td>
<td>8.31</td>
<td>Functional surfaces, exterior and interior building surfaces, Industrial piping, Glass.</td>
<td>UV protection, antimicrobial, Scratch, corrosion resistance, water proofing, durability, self-cleaning, longer life, aesthetics.</td>
<td>Cost to produce, not available in bulk.</td>
</tr>
<tr>
<td>Concrete</td>
<td>7.53</td>
<td>Bulk material in building construction and capital structures (nuclear, power plants, dams).</td>
<td>Strength and durability, long lasting, aesthetics, schedule.</td>
<td>Manufacturing cost at the level of mass production, higher Initial investment, lobbying, environmental at end of life-cycle...</td>
</tr>
<tr>
<td>Energy</td>
<td>6.57</td>
<td>Energy storage, production, transmission, extraction, catalysts, devices for solar and wind energy</td>
<td>Cost and efficiency of exploration, for example, oil, longer life of batteries, less losses</td>
<td>Technical limitations, Manufacturing cost at the level of mass production</td>
</tr>
<tr>
<td>Sensors &amp; Metrology</td>
<td>6.17</td>
<td>Remote destructive evaluation technique (NDE), for example, cracks, fire protection sensors</td>
<td>Low maintenance, minimum infrastructure requirements, Precise and accurate measurement techniques</td>
<td>Product acceptance, Standards and Guidelines</td>
</tr>
</tbody>
</table>
Conclusions and Recommendations

• Nanotechnology can have a **positive impact on our daily life and on the construction industry** and provide better facilities that are essential for businesses and civilizations.

• To sustain or profit, the construction industry has to expect changes which will originate from Nanotechnology (short, medium, long term).

• Overall* only a few companies seem to have **Nanotechnology expertise or dedicated R&D programs** in place to face the changes Nanotechnology will bring.

• A **disconnect** exists between the construction industry and Nanotechnology R&D (other industries as well).

• **Recommendations:**
  – Collaboration and other engagement
  – Maintain a world-class research and development program
  – Facilitate technology transfer
  – Develop educational resources, a skilled workforce, and the supporting research infrastructure and tools
  – Support responsible development of nanotechnology

* Assumption: CII Member Companies are leaders of new technology in the construction industry.
Thank you for your attention!

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