GEORGIA TECH NANOTECHNOLOGY RESEARCH AND INNOVATION SYSTEMS ASSESSMENT GROUP (CNS-ASU RTTA1) & NANO IN THE CITY (CNS-ASU-TRC2)

NANOTECHNOLOGY IN BUILDING CONSTRUCTION:

AN INDUSTRY STUDY OF INNOVATION

The Center for Nanotechnology in Society ARIZONA STATE UNIVERSITY

ASU SCHOOL of SUSTAINABILITY ARIZONA STATE UNIVERSITY

Innovation Models in Construction

We consider several *plausible* models of innovation in the building construction industry.

〉 *Linear model (technology push)*

Invention (e.g. a compound) → Innovation (productize) → Diffusion (build and sell) → Consumption (users use)

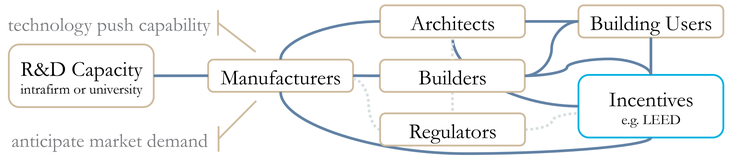
Here, we cannot differentiate between builders as end-users and as sources of innovation.

〉 *Lead user (market pull)* [7]

Identify Need (e.g. client requirement) → R&D (i.e. devise solution) → Prototype (i.e. user developed) → Commercialize (manufactures build)

The literature indicates that construction firms do not maintain strong R&D capabilities. Many firms retain less than 10 employees. Are some end-users lead users?

〉 *A systems model with market pull and technology push characteristics* [8,9]



Scenario: End users are influenced by LEED certification guidelines. The builder, attempting to meet its client's needs, searches for technologies to satisfy energy efficiency, design, and cost criteria. Manufacturers monitor the market for trends and leverage internal and external R&D to provide new product features. Regulation lags innovation at local and federal levels.

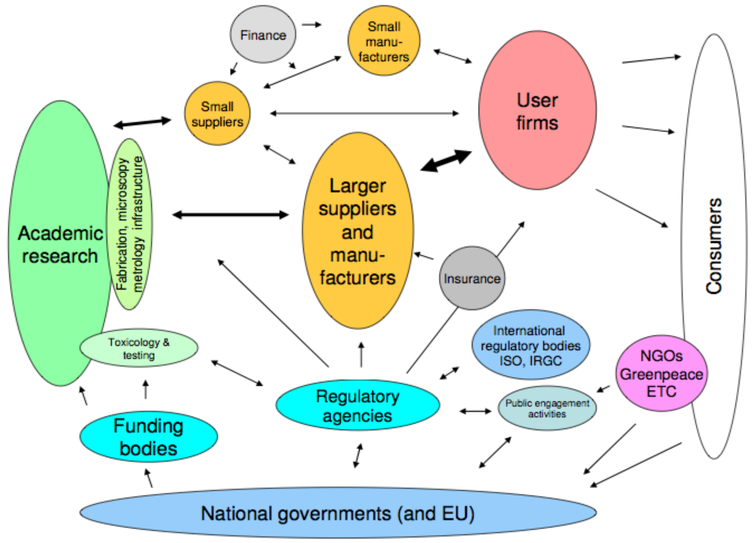
EXISTING APPLICATIONS

Staying clean! Right: Rome's Jubilee Church maintains its bright white appeareance with TiO2 particles. Left: London's St. Pancras Railway Station employs self-cleaning nano-enabled windows.

Guiding Principles

Assessment of innovation models needs to consider the guiding principles of anticipatory governance and sustainability.[12] From anticipatory governance we draw upon *foresight, engagement, integration, and ensemblization.*[13] In the realm of sustainability the principles of *socio-ecological system integrity, livelihood sufficiency, intra & intergenerational equity, democratic governance, unintended consequences, resource efficiency, and systemic integration of principles.*[14]

Governance Actors and Interactions



Depiction of governance actors and their interaction.[11]

Nanotechnology in Building Construction

Application	Nano-enabled Properties[4-6]	Enhanced Functionality[6]	Development Timescale[10]
Steel Coating	Nano-polymer bonds to material surface, eliminates oxidation.	Steel coated with nano-polymer has higher resistance to corrosion.	2007 - 2016
Glass Coating	Titanium dioxide film affixed to surface of glass.	Decomposes organic materials upon contact which self-cleans glass surface.	2007 – 2012
Ceramics	Carbon nano-tubes or other nano-tube based materials are grown through bottom up approach to form nano-structured ceramics.	Improved resistance to stress, increased strength and flexibility. Reduced deterioration. Less volume and weight. Surfaces can conduct electricity.	2012 – 2026
Concrete Strengthening	Carbon nano-tubes are mixed into the concrete replacing steel rebar.	Improved strength and reduced thickness. Less volume and weight v. strength.	2012 – 2026
Insulation	Nano-pores of air or nitrogen are created within gels or polymers	Efficiency increase due to high surface-to-volume ratio. Reduced toxics and non-renewables.	2007 - 2016

Introduction

Innovations in building construction have profoundly changed our urban environment. More recently, these innovations have occurred through the challenges presented by urban planners and city building codes coupled with scientific advances, which enabled architects to affect design and usability changes. The construction industry's supply chain structure coupled with push vs. pull innovation dynamics has come under scrutiny as being atypical, inefficient, and underfunded [1-4]. The nanotechnology innovation models depict a dynamic flow of information through a highly-constrained, yet well-funded and supported system. Consequently, predictions from within the construction industry herald a coming nanotechnology revolution [1,4]. Thus, novel discoveries within diverse disciplines, such as materials science, electronics and electrical engineering, chemistry, and physics, have positioned nanotechnology as the 21st century enabler of innovation in construction[5,6]. However, there has been little work to-date on the current governance regime that may allow nanotechnology to emerge as a game changing technology within this sector.

Research Questions

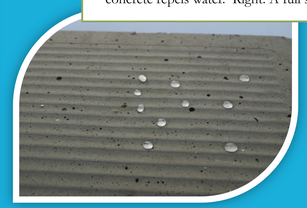
〉 *Can we develop a system-based model of innovation which addresses the rising use of nanotechnology in the building construction industry?*

〉 *Can governance actors and their interactions be aligned with this system?*

〉 *How can guiding principles from anticipatory governance and sustainability foster responsible innovation?*

NEWER APPLICATIONS

Concrete using advancements in nanotechnology deters water absorption and is therefore less hospital to microbes, thereby improving product quality and longevity. Left: Broken nanotechnology enabled concrete repels water. Right: A full slab.



Conclusion

Assessing innovation models, governance frameworks and the development of nano-enabled applications in a disconnected manner ignores critical relationships between these three components. Our research proposes a contextualized research approach grounded within the construction sector against which models of innovation, governance and technological development can be assessed. Coupling bibliometric and interview data will produce quantitative results that can be enriched with qualitative narratives.

References

1. Bartos, P. J. M. (2009). *Nanotechnology in Construction: A Roadmap for Development.* (Z. Bittnar, Peter J. M. Bartos, J. Němeček, V. Šmilauer, & J. Zeman, Eds.) *Construction Materials* (pp. 1-14). Berlin, Heidelberg: Springer.
2. Blayse, A.M., and K. Manley. 2004. "Key influences on construction innovation." *Construction Innovation* 4(3):143-154. Slaughter. (1998)
3. Pinkse, J., & Dommisse, M. (2009). Overcoming barriers to sustainability: an explanation of residential builders' reluctance to adopt clean technologies. *Business Strategy and the Environment*, *18*(8), 515-527.
4. Zhu, W., Bartos, M., & Parro, A. (2004). Application of nanotechnology in construction Summary of a state-of-the-art report. *Materials and Structures*, *37*(273), 649-658.
5. Andersen, M., Sanden, B., and Palmberg, C. (2010). *Green Nanotechnology in Nordic Construction Eco-innovation Strategies and Dynamics in Nordic Window Value Chains*. Oslo, Norway.
6. Lee, J., Mahendra, S., and Alvarez, P.J.J. (2010). Nanomaterials in the construction industry: a review of their applications and environmental health and safety considerations. *ACS Nano* 4(7): 3580-90.
7. von Hippel, E. (1988). *Sources of Innovation*. Oxford University Press: New York.
8. Robinson, D. (2009). Co-evolutionary scenarios: An application to prospecting futures of the responsible development of nanotechnology. *Technology Forecasting & Social Change*, 76 (9), 1222-1239.
9. Brem, A., & Voigt, K.-I. (2009). Integration of market pull and technology push in the corporate front end and innovation management – Insights from the German software industry. *Technovation*, *29* (5), 351-367.
10. Bartos, P.J. (2006). Nanotechnology in construction: a roadmap for development. Proceedings of ACI Session on Nanotechnology of Concrete: Recent Developments and Future Perspectives. Nov. 7, 2006. Denver, CO.
11. Rafols, I., Zwanenberg, M.M. Nightingale, P., and Smith, (2011). Missing links in nanomaterials governance: bringing industrial dynamics and downstream policies into view. *The Journal of Technology Transfer*. Published On-line. February 9, 2011.
12. Wiek, A. and Foley, R.W. "Assessing nanotechnology innovation through anticipatory governance and sustainability." Working Paper. 2011
13. Karinen, R., & Guston, D.H. (2007). Toward anticipatory governance: the experience with nanotechnology. Soc. Sciences, 27 (4), 217-232.
14. Gibson, Robert B. 2006. "Sustainability assessment: basic components of a practical approach." *Impact Assessment and Project Appraisal* 24(3):170-182.

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