AN EVALUATION OF ACTOR NETWORK THEORY AND THE EFFECT OF GOVERNMENT POLICY IN A UK CASE STUDY

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By

Erika Heupel

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On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

ADVISOR
Catherine D. Baritaud, Department of Engineering and Society

ACTOR NETWORK THEORY IN GRAPHENE ENHANCED CONCRETE INNOVATION PROJECTS

Cement is the primary component of concrete, the most extensively used material in the construction industry. Due to its high strength and durability, it is employed in countless applications of infrastructure such as buildings, bridges, dams, sidewalks, roadways, and tunnels. Though concrete is the most abundant manufactured substance, it is among the most environmentally destructive. Its production is responsible for 8% of global annual carbon dioxide emissions (Zamora-Castro et al., 2021). Additionally, in many urban areas, pre-existing infrastructure is nearing the end of its service life and requires renovation or replacement. To maintain public safety, modern technologies are driving the development of ultrahigh performance construction materials (Dimov, et al., 2018).

In order to keep up with the growing global demands of concrete, graphene nanoplatelet (GNP) additives are a viable alternative that could lessen the carbon footprint of concrete. For this reason, the technical project will conduct experimental testing of GNPs, small graphene particles, in concrete mixes. Research indicates that graphene in concrete requires less cement while maintaining the same building load specifications, leading to better durability, mechanical strengths, and sustainability (Dimov et al., 2018). This technical project is tightly coupled with the STS research, which will examine the construction industry and actors working to lessen the amount of carbon dioxide produced by construction. This can be viewed through the lens of Actor Network Theory (ANT) developed by Bruno Latour, Michel Callon and John Law, in order to link technology and its processes to social dynamics. Through a case study approach, the research question will ask: How can government sustainability policy foster the implementation of low carbon technologies in the construction industry, and what other actors are involved to achieve this? The technical portion of the project will be mentored by Osman Ozbulut, in the

department of Engineering Systems and Environment. The other team member is Andrew LeBoeuf. The STS portion of the project will be advised by Catherine Baritaud in the department of Engineering and Society.

CLIMATE CHANGE AND INFRASTRUCTURE

A concrete mix is composed of cement, water, fine aggregate, coarse aggregate, additives, and admixtures. Traditional concrete mainly relies on Portland cement, a mixture of limestone and clay. To be effectively used as the main hydraulic binder, it is heated in a kiln at 1,500°C. This process is extremely energy intensive and releases large quantities of carbon dioxide into the atmosphere (Zamora-Castro et al., 2021). Therefore, lessening the amount of cement in concrete or finding an alternative in infrastructure developments would slow the effects of climate change. On a global scale, greenhouse gas emissions have increased an average 5% per year, through cement production alone (Kurad et al., 2017). Just in 2020, theUnited States' consumption of cement was nearly 102 million tons, which has been steadily increasing over the last decade (Garside, 2021). These staggering quantities of cement are largely unknown by the general public.

To negate the carbon dioxide effects of expanding, more complex construction, we must first examine its industry and policies. Infrastructure systems are the backbones of the socioeconomic development of a community so its maintenance and investment are critical (Das et al., 2020). Specifically in the U.S, there is a heightened need for renovation, repair and replacement due to a crisis of degrading infrastructure. The latest report card from the American Society of Civil Engineers (ASCE) evaluated U.S infrastructure at a C minus (Russonello, 2021). Furthermore, ASCE has estimated that its maintenance will require an investment of up to 3.5%

of US GDP (Das et al, 2020). Though cities and states have made efforts to invest in new infrastructure and infrastructure technology, transformational investment has been lackluster until Biden's $1.5 trillion 'Moving Forward Act' that proposes a federal investment in infrastructure (Russonello, 2021). Although this investment by Congress is imperative, the need for rebuilding and renovations will only exacerbate climate change, likely resulting in an increase in carbon dioxide emissions by 200 million tons (Dell, 2021). Unless new sustainable measures are taken, the American public cannot rebuild, without greatly adding to the climate change problem.

ACTOR NETWORK THEORY IN CONSTRUCTION PRACTICE

COMMON ACTORS

According to Actor Network Theory (ANT) developed by Bruno Latour, Michel Callon and John Law, a technology's success is dependent on a mobilization of actors that will either limit or broaden its implementation (Jolivet & Heiskanen, 2010). Particularly in construction, innovations require the mobilization of multiple resources and actors. Common actors of the industry are the owner, architects, designers, engineers, contractors, subcontractors, material suppliers, research and educational institutes. But outside of construction, actions are necessary from government policy-makers and its constituents to guide a sustainable market.

Consequently, there must be collaboration among these various parties to be "restorative and regenerative by intention and design" (Hossain et.al., 2020, para. 1). Outlined in Figure 1 on page 4, the technology transfer of graphene-enhanced concrete and other similar sustainable building innovations are framed within this network to emphasize that relationships can help or

hinder its adaptation. Overall, the ANT sociotechnical perspective is particularly useful for studying green innovation to highlight the paths that adjust or affirm these technologies.

Fig. 1: Representation of the connectivity of actors in the construction industry, in conjunction with the technology transfer model. This demonstrates the groups and paths that influence sustainable building technology innovation. (Heupel, 2022).

DEMANDS FOR IMPLEMENTING GREEN TECHNOLOGY AND INDUSTRY BARRIERS

When it comes to government policy, many infrastructure projects are funded through tax revenue, so the public holds a key voice. The demand for energy-efficient, sustainable property has drastically increased among end-users, government regulators, and real estate investors. According to the Institute for Market Transformation and Appraisal Institute, the "value of energy efficiency and sustainability is rising and becoming more definitive" due to "evolving social and cultural priorities, [and] increased public awareness" (Bozorgi, 2015, p.1). This suggests that sustainability has become a standard for defining economic value in buildings and a desirable trait in communities and neighborhoods.

However, a main barrier relates to the term sustainability itself. One challenge for sustainable development is the absence of a quantitative global definition for sustainable infrastructure. Transferring the principles of sustainable development into the construction sector requires a "change of paradigm," and this transfer is challenged by the fact that there is "no universally accepted definition and no unique solution for sustainable buildings" (Passer, et al., 2015, p. 1). So as the perception of what comprises a sustainable building and green technology continues to shift, this can be based on the location of a project. In addition, there is a lack of research on how to conduct sustainability in construction and how innovation in sustainable building actually unfolds (Havenvid, et al., 2019).

Other barriers to adopting green technology are linked to the inner workings of the construction industry, since it is often "blamed for being inefficient, non-sustainable compared to other sectors" (Egmond, 2019, para.1). Cultural change is slow due to limited investment in innovation, the reluctance of professionals, inadequate senior level buy-in, the lack of immediate proven benefits, unwillingness from organizations to assume more risk, and the transient nature

of supply chains and project teams (Shahzad, et al., 2021). Many construction innovations are considered to be a response to external needs, particularly those of the client, rather than an internal demand by the industry (Harty, 2008). Due to this focus on the client and managing costs, construction status quo tends to focus on profitability before environmental protection.

Despite the many actors involved in the industry, sustainable achievements have not been far-reaching at the internal level. So simply relying on public awareness and the initiatives of corporations will not help tackle the global carbon emissions crisis. For this reason, the goal of the research is to analyze a case study that exhibits how policy can apply to sustainable building technology. Coincidentally, while beginning technical research on graphene-enhanced concrete, the first application of graphene concrete had been successfully poured in England. This inspired a U.K. focused case study regarding its government sustainability policies and the various actors involved in the project.

UK GREEN POLICY AND ITS EFFECT ON ACTORS IN SUSTAINABLE BUILDING PROJECTS

NET ZERO BUILD BACK GREENER PLAN

In 2019, the UK passed a law to end its contribution to global warming by 2050 with a net zero target and is legally bound to decarbonize all sectors of their economy by that year ("UK becomes first," 2019). According to the 'Net Zero Build Back Greener' plan, prime minister Boris Johnson declared to "lead the world in ending our contribution to climate change" so that "green tech becomes the global norm" ("Net Zero Strategy," 2021, p.8). The government aims to support this through the next decade by exploring policy measures across different sectors. In the report, opportunities that have been identified in the construction include:

1. Reporting on embodied carbon in buildings and infrastructure to explore a maximum level for new builds in the future

2. Reducing embodied carbon by way of material substitution where appropriate

3. Using green engineering-based approaches, including "new ways of making concrete" ("Net Zero Strategy," 2021, p. 15).

To help with these opportunities, since 2019, the government has devoted money to initiatives that help construction industry stakeholders meet sustainability agenda and expand their green portfolios. According to the government, backing research with funding will allow the UK to gain a competitive edge in the latest low carbon products ("UK's path", 2021). During 2021 alone, an investment of £500 million was allocated to develop net zero technologies, bringing the grand total of research funding to £1.5 billion within the last two years ("UK's path", 2021). By funding green technology in construction, the UK government remains a focal actor, and then enables other actors in research, development and engineering to participate in the 'build back greener' goal.

CONCRETENE PROJECT

A project that has benefited from the major investments and advocacy from the government is a graphene cement application. A graphene concrete slab, dubbed as 'Concretene' was engineered for sustainability and formed the foundations of a new gym in Amesbury, England (Lavars, 2021). The project was a joint venture conducted by the construction firm Nationwide Engineering and scientists at the University of Manchester. The engineers and researchers found that the addition of graphene strengthened the product by 30% compared to standard concrete, requiring less material and thus, reduced its carbon footprint ("Concretene", 2021). Other actors involved in the success of the project were structural engineers at HBPW Consulting, the National Graphene Institute (NGI) and the Graphene Engineering Innovation

Center (GEIC). Many of these partnerships and industrialization processes were made possible due to investments from the NGI and GEIC at Manchester (Mertens, 2021). In fact, NGI, had received £38 million in funding from the UK Government and the European Regional Development Fund (National Graphene Institute, n.d.).

Moreover, the UK government is continuing relations with Nationwide Engineering for future projects. Nationwide Engineering has three five-year ventures with Network Rail, owned by the UK Government Department for Transport, and two seven-year contracts with Government Crown commercial building ("Concretene", 2021). Specifically, Network Rail plans to reduce CO2 emissions in the next four years, so there is the potential to use graphene concrete in this area of infrastructure ("Concretene", 2021). Through government funding and partnership, actors involved in 'Concretene' are able to become leaders of sustainable innovation, and legitimize their work as helping the public by connecting it back to green policy.

Ultimately, UK regulatory policies plays an important role in shaping the direction of innovation and change in the construction sector. And in response, firms in the UK have assisted their green targets. Adapted from Havenvid, et. al., (2019), this innovation push and pull stems from regulations and standards as shown in Figure 2 on page 9. Although national policy does not openly create the innovations, they "set up economic frames like funding bodies, in which innovation is attainable." (Havenvid, et al., 2019, p. 265). Since UK policy and its subsequent funding has now set sustainable agenda as attainable, firms, investors, and researchers can be more ambitious in making decarbonization possible.

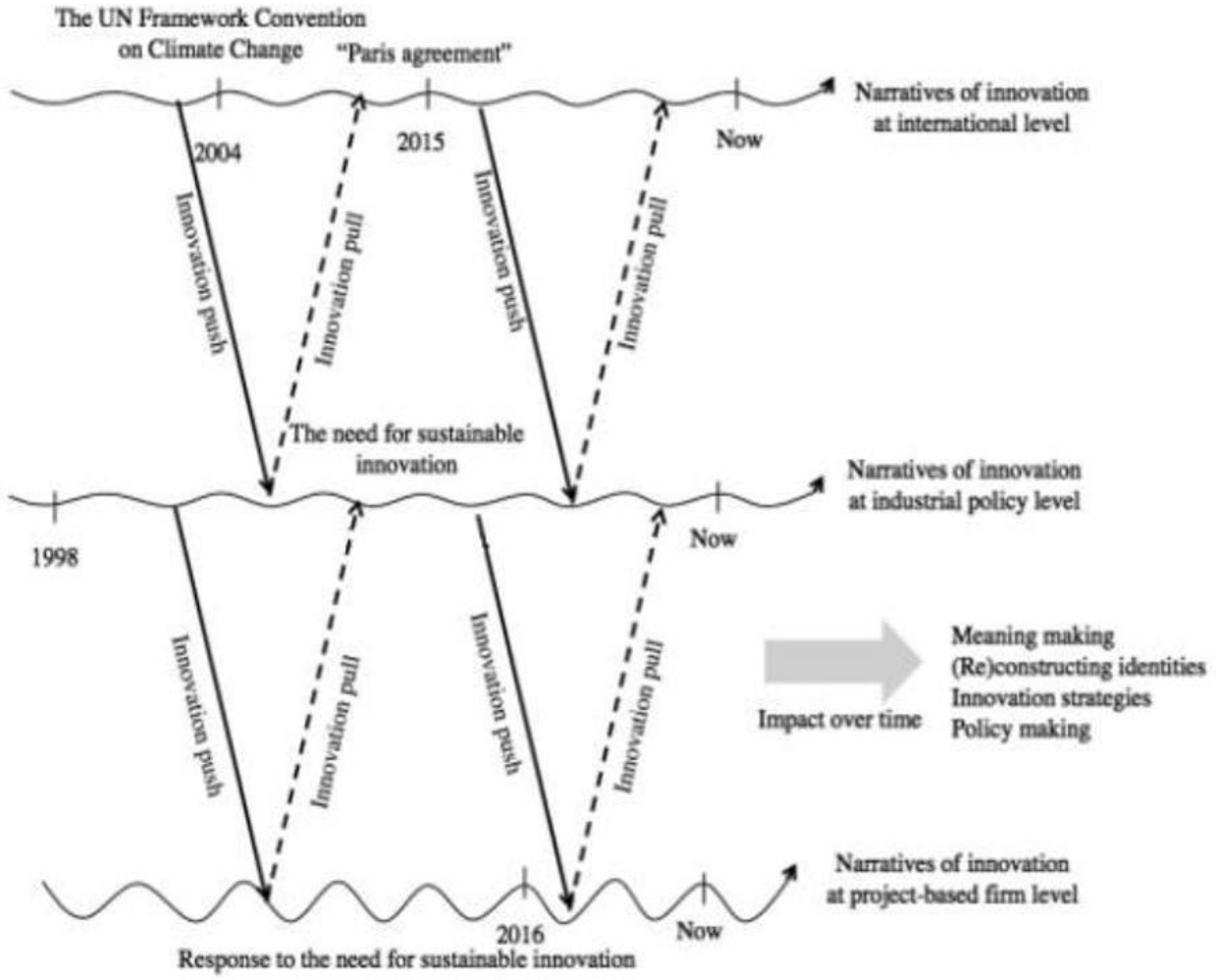

Fig. 2: Innovation push and pull exemplified by international climate change moments, like UN Framework Convention and the Paris Agreement that later impacted UK Net zero construction sustainability (Adapted by Erika Heupel (2022) from Havenvid, et al. (2019).

DRIVING SUSTAINABLE ACHIEVEMENTS THROUGH POLICY

Though innovation and technological development can help push for environmental preservation, with directives or funding from the government, construction enterprises can be compelled to be more environmentally responsible as an entire industry. The UK's 'Build Back Greener' plan and the Concretene case study highlights the government's involvement in

facilitating necessary sociotechnical connections related to sustainable construction such as research, partnerships and the promise of future projects. Overall, as more policy actors begin to focus on low-carbon, energy-efficient industries towards 2050, in response, engineers and construction firms must be ready to incorporate solutions that address climate change challenges. For this reason, UK efforts may be a key example for the United States to consider since Biden has vowed to launch a government effort to cut carbon pollution in half by 2030 and to reach net-zero emissions by 2050 (Dennis and Joselow, 2022). Although there are a multitude of interactions needed to construct a green and sustainable construction sector, the precedent demonstrated by the UK and the mobilization of its actors is a step towards combating climate change that can be followed by other governments across the world.

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