Construction and Climate Change; Challenges and Opportunities: A Case Study of the Northeast U.S.

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Abstract. The Northeast megalopolis of the United States, which covers a high-density corridor from Washington, D.C., north to Boston, is one of the most developed environments in the world. It contains a gigantic, complicated, and intertwined network of supporting infrastructure with average score of D+, hence requiring substantial rehabilitation and renewal. The 2020 North American Construction report forecasted a CAGR of 8.4% by 2024 despite the pandemic. The pace of growth will recover from 2021 onwards as the ongoing infrastructure investments and smart city projects will add momentum for the region’s construction industry. On the other hand, climate change impacts are underway across the globe and the Northeast of the U.S. is not an exception. Populations and aging infrastructures that they depend on, are highly vulnerable to climate hazards including heat waves, as well as flooding due to a combination of sea level rise, storm surge, and extreme precipitation events.

In this study, future projections of climate change in the Northeast of the U.S. were used to explore their potential impacts on construction industry including but not limited to safety of workforce, selection of building materials and their lifecycle, logistics, scheduling, costs, and insurance. The challenges and opportunities that construction industry faces under climate change were also covered. Later, the feedback loop between the construction and climate change were discussed as well as how sustainable construction practices could mitigate climate change impacts while providing safety for construction workforce. Finally, this paper focuses on resilience, buildings carbon footprint, green infrastructure, sustainability, and a prototype decision-support tool for construction projects to better manage weather risk from contract to project completion, known as Climate-i Construction, and how construction industry can benefit from them under 21st century changing climate.

1. Background
Climate change is a global phenomenon which disturbs all aspects of human lives. These range from rising temperatures, higher sea levels, and more frequent extreme weather events. The result of these changes is rippled throughout all aspects of the environment. The durations and start of seasons are shifting with greater periods on change introducing less stable environmental conditions (NASA, n.d.). The largest changes to seasons are with winters becoming shorter, and spring is becoming longer. As the overall temperatures rise, so are the ocean’s temperatures (Dupigny-Giroux, 2018). This warmer water allows for more intense coastal storms with greater frequency. An additional result of a warmer climate is that it produces storms with less predictability and with incidence and intensity, impacting
all aspects of daily activities (USGCRP, 2018). Climate change impacts reach all regions of the Earth, with the influences within each region unique to that region-specific characteristics.

Climate change has global implications which when looked at regionally, provide more insight into the effects. The Northeastern Region of the United States is facing specific threats because of climate change. The rising temperatures are occurring at a faster rate than other regions in the world (Dupigny-Giroux, 2018). The area is experiencing warmer winters and hotter summers. The warmer winters are resulting in shifting snow rain lines further north. The hotter summers are particularly concerning as this highly populated region is experiencing large scale urban heat island effects within the previously mild summer cities (Dupigny-Giroux, 2018). This historical trend of mild summer leaves the impacted areas with limited existing ability to lessen the heat. The major urban areas within this region are coastal and built on filled in wetlands. As a result of being near sea, these cities are directly affected by raising sea levels (City of Boston, 2018). The rising sea levels are compounded by an increase in precipitation of 70% from 1985 to 2012. As the rain has increased, flooding has been one of the prominently felt consequences of climate change (US EPA, 2016).

2. Introduction

2.1. Areas being Affected

Climate change has a tangible impact on the physical environment which in turn put the construction sites and the individuals working there at elevated risks for mishaps and incidents. Within the construction industry, climate change has had a direct effect on the increases in overall ambient temperature of jobsites around the country, the duration and intensity of the seasons, the predictability and ferocity of storms. As many construction professionals spend large portions of their shift in either a combination of indoors and outdoors space or entirely outdoors, a rise in ambient air temperature illustrates a significant risk for these workers who often perform activities with a heavy level of exertion (Schulte et al., 2016). Natural disasters can have devastating effects on jobsites and the personnel who are there. Financial losses from natural disasters in the United States have risen from $528 billion from the years of 1981-1990, to an astounding $1,230 billion between 2001-2010 (Kunreuther et al., 2008). This 230 percent increase in losses due to natural catastrophes over the period of this study does not account for the loss of life that has occurred. From 1992-2006 there were (62) floods, (72) hurricanes, and (80) wildfires that resulted in fatalities. While these fatalities were among multiple industries and not solely related to the construction industry, construction did make up a significant amount of these fatalities with restoration activities related to post hurricane reconstruction accounting for (72) deaths alone (Schulte et al., 2016). Climate change brings with it dangerous and destructive forces that continue to elevate the danger level on jobsites and to the employees working there.

Inclement weather and even rare disastrous storms are not uniquely new to the construction industry as every project is subject to the climate and geographical risk of the site's location. Where once there was insurance to stave off significant losses due to weather related setbacks, climate change is also altering the very fabric of certain financial institutions which used to insulate the construction industry from these losses. Insurance companies have always faced a guessing game, but they thrived on the ability to predict when and where disaster would strike. Climate change is altering the game as the frequency and severity of these storms are on the rise. Climate change is on a trajectory to cause a collapse across multiple financial institution, which will in turn void the way in which insurers are able to calculate the risks associated with these projects (Sagatom Saha & Brody Viney, 2020). If insurers are no longer willing to take on the risks associated with climate change, then there will be deep financial consequences as all players in the industry absorb this immense cost.

2.2. Material Availability/New Building Materials

As the construction industry reacts to climate change, there is the expectation that materials will change to reduce construction industry’s contribution to the GHGs (Greenhouse Gas) emissions. Some of the ways are through utilizing green materials, low carbon concrete, and sourcing locally. These
categories fall within a broader net called embodied carbon. Embodied carbon is the sum of carbon emissions from the extraction, fabrication, transportation, and erection of construction materials on a structure (Kotch, 2020). This is similar in concept to operational carbon output, except this includes the carbon from the start of a materials life to the time it is placed in the structure. Measuring the carbon output from the manufacturing, transportation, and construction phase of a material will help in the selection of materials by selecting truly beneficial products (Building Transparency, n.d.). This practice allows for the entire process to be looked at for an overall reduction in emissions.

Concrete is a large contributor to the carbon emission in construction with cement production being the main culprit contributing 8% of the carbon dioxide (CO₂) emissions globally (Rodgers, 2018). Low carbon concrete is an emerging solution to reducing concrete’s emissions. This is done in a variety of methods of including other products to reduce the required amounts of cement in the concrete mix and in some places, using more efficient methods to mix concrete. Some of the materials used are waste by-products from other manufacturing activities such as fly ash or steel slag (Emerson, 2020). Another methodology is to sequester CO₂ and insert it into concrete. Blue Plant uses this idea to create aggregate from CO₂ emissions as well as recycling concrete to use as aggregate (Blue Plant, n.d.). As the focus turns to monitoring and reducing emissions, using products which incorporate recycled and lower emissions will become paramount.

2.3. Impacts on Cost and Schedule
When the effects of climate change culminate into large destructive natural disasters, the construction industry is always at the forefront of institutions most directly affected. Natural disasters effects on the construction industry are twofold as not only do these storms have direct effects by damaging projects that are in progress, but they create damage to already existing roads, utilities, and other infrastructure which in turn need to be repaired (Apurva et al., 2020). These disasters also have an indirect effect on the industry as they create issues with the industries’ supply chain that can impact anticipated delivery dates of the project which in turn can lead to cost overruns. Post natural disaster, the combination of several contributing factors such as disruption to basic utility services, stark increases in demand of skilled labour, and massive material price escalation all compounded to increase the duration and cost of the project (Apurva et al., 2020).

2.4. Type of Design and Projects
Climate change is affecting both new construction as well as renovations. One aspect that is most affected is the sustainability design principles being incorporated into new designs. These sustainability features include water conservation, high-efficiency mechanical units, using environmentally sustainable products, optimizing operation and maintenance practices, choosing appropriate building site, and enhancing the indoor air quality (GSA, 2021). New construction incorporates resiliency features in the design which should be implemented in planned renovations as they are a crucial opportunity to upgrade the existing structures to cope with the predicted climatic conditions of the future. These resiliency additions range from planning to incorporate flood barriers to increased ventilation to deal with the predicted extended periods of high temperatures (Button, 2018). Buildings are not alone in the effort to incorporate resiliency and sustainability features into the structure, infrastructure is also an active participant in combating the impacts of climate change (MassDOT, 2021). Infrastructure is particularly unique as the project can transverse multiple regions such as coastal and inland regions. The areas each have specific concerns such as flooding or fire. To better understand where the risks lie with climate change, vulnerability studies need to be conducted to determine the associated risks with their location.

2.5. Current Critical Infrastructure
Vulnerability studies are extremely critical in the determination of where limited money and time are spent by state transportation departments to protect critical infrastructure assets. These studies identify the key assets for moving people and commerce around the northeast region of the United States which are most at risk from the effects of climate change. The Massachusetts Department of
Transportation (MassDOT) has been active in assessing the infrastructure and has been taking action to upgrade the resilience of the state’s transportation assets (MassDOT, 2021). With many major facilities within the Boston area being on the water such as Logan International Airport, major port operations for petroleum, and entire sections of the city are at major risk of becoming submerged within the end of the century without action (City of Boston Environmental Department, n.d.; MassDOT, 2021). An example of this would be the subway stop at the Aquarium in Boston. This location is having permanent flood gate systems erected around four access points to prevent flooding as flooding has occurred multiple times in the past and is part of the larger Blue Line Harbor Tunnel Infrastructure Improvements project (MBTA, n.d.). Boston is not alone in having to implement climate change responsive projects, other major cities within the northeast have also followed suit.

New York City (NYC) is currently facing the same concerns over a changing climate as Boston. New York City and Boston are or have looked at the creation of large-scale flood barriers to head off storm surges from storms such as Hurricane Sandy. These structures would seal off the harbours during extreme weather events (Hilburg, 2018; Sustainable Solutions Lab, 2018). While these ambitious projects may not be feasible or may take decades to become reality, but smaller projects are still occurring. NYC is currently working to ensure their stormwater management system can function in future conditions. This includes looking at current and future high tide, sea levels, and precipitation to ensure their systems can still effectively drain. Previously, only in the worst conditions failures were occurring but with increased rain events along with higher tides and sea level, the current systems cannot drain the water due to undersized pipes and the outlets below high tides (Mayor’s Office of Resiliency, 2021). In addition to upgrading the city’s ability to drain runoff, other projects are looking at protecting low lying areas of the city. One such project is named The Big U, which is located on the Lower East Side of NYC (Rebuild By Design, n.d.). The large undertaking is proposed to provide flood protection barriers, improve stormwater drainage, and elevated open space along the waterfront (East Side Coastal Resiliency Staff, n.d.). This project is like many other projects in other major coastal cities within the Northeast region providing upgrades to existing shorelines to protect coastal populations.

In addition to rising sea levels, coastal and all urban areas are facing a specific threat from the increasing temperatures. With an ever-increasing number of days above 90 degrees Fahrenheit, the urban heat island effect is a major threat to vulnerable communities (City of Boston, 2018). This heat effect occurs in areas with more concrete, asphalt, and steel, which absorb heat and are areas that tend to have less natural vegetation which help dissipate the heat (BWSC Staff, n.d.). The simple and logical fix would be to create more green space within urban areas. While this is feasible in areas of new development, in areas already heavily developed the feasibility decreases drastically. Possible ways to reduce urban heat islands is to incorporate green design into infrastructure projects, increase urban vegetation, green roofs, and most importantly conduct studies to determine where this work needs to occur within a city (EPA, 2020). Boston uses the term urban forest when referring to the city’s trees, which are maintained in part to help cool the city (BWSC Staff, n.d.). In some cities within the Northeast, tax credits are being offered for the construction of green roofs. Philadelphia and NYC are among the cities that are offering these incentives to build green roofs to help cool and green the cities (Department of Revenue, 2019; Mayor’s Office of Resiliency, 2021). As cities explore the threat of urban heat islands, the risks to human health are present and the strain of the mass use of air conditioning on the electrical grid is apparent (City of Boston, 2018).

3. Current Solutions

3.1. Legislation Changes and New Building Codes
The construction industry is not known to be the most reactive industry to implement change. With the introduction of stricter building codes by municipalities, which better protect structures from new 100-year storm data, change within the industry is being enacted. Research looking into 100-year storm events shows and predicts the higher frequency of large-scale storm events. This includes storms with increased precipitation in shorter periods of time (Massachusetts Climate Adaptation Partnership,
The studies which present this type of information feeds into policy throughout the Northeast region. NYC has enacted local law 97, which is one of the most ambitious laws of its type (Urban Green, 2021). This law establishes restrictions of GHG emissions for buildings over 25,000 square feet (Sajip, 2021). If these constraints are not met, the owners of the buildings are imposed fines. These fines are motivating renovation projects to meet the emission standards. Boston has enacted zoning code article 37 which incorporates green building and climate resiliency into the building code. This requires major buildings to reach a certifiable level with Leadership in Energy and Environmental Design (LEED). This code offers guidance and requests information on the buildings to determine what risks there are and what measures are in the design to protect the buildings from the impacts of climate change (BPDA, n.d.). Building departments are not alone in introducing or providing guidelines to produce resilient buildings within the construction industry.

Nongovernmental organizations have also played a role in combating climate change. LEED part of the U.S. Green Building Council (USGBC) has different levels of ratings which correlate with how “green” the building is. LEED has numerous different building categories, which range from new construction, renovations, operations, and maintenance (USGBC, n.d.). These are rank at different levels such as certified, silver, gold, platinum, and zero (USGBC, n.d.). LEED Zero is similar to that of Passive House Institute US (PHIUS), where the mission is to certify and provide goals for buildings to meet. The goals are to create homes and buildings which are net zero (USGBC, n.d.; PHIUS, n.d.). Net zero refers to a building that uses, over a course of a year, a net zero electricity and water. LEED and PHIUS both have different standards and levels with PHIUS originating with homes growing into commercial buildings with LEED focusing on commercial and growing in residential (USGBC, n.d.; PHIUS, n.d.). The organizations provide a symbol for the owners to express their role in protecting the environment and following the social responsibility trend of being environmentally aware.

### 3.2. What Companies Are Doing to Overcome New Legislation (Private Sector)

With new laws and regulations being introduced to the construction industry as well as new third-party authorities on the subject matter such as USGBC, firms operating in the private sector are being held to the highest standards of sustainability and resiliency when designing new projects. The construction industry represents a huge player in the United States’ contribution to climate change as buildings are responsible for 39% of CO2 emissions, 41% of all U.S. energy usage, and 73% electricity usage (Ahn et al., 2016). In 2007, Boston updated Article 37 of its zoning code to ensure there is a minimum green building standards that all new projects must reach as well as requiring developers to integrate consideration for current and future climate conditions into a formal resiliency checklist (BPDA, n.d.). Designers, developers, and contractors have all become acutely aware of the policies created by the United States Green Building Council. While the USGBC is the official third-party organization that oversees and regulates the standards for Leadership in Energy and Environmental Design (LEED), there are certain alternatives to LEED such as the Green Globes Levels that are overseen by the Green Building Initiation. These types of certifications which have become greatly sought after as they represent an understanding of the responsibility developers have to the community as well as attractive tax benefits. Being able to classify a building as a LEED certified building, provides advantages to the marketability of the product and brand, can create better work and living environments, and reduce negative ecological impacts as well as reducing carbon emissions (DeLisle et al., 2013). To deliver the highest quality and least environmentally impactful product, projects are heavily integrating all members of the construction team to design and deliver the foremost environmentally conscious building. Developers are implementing a wide array of green systems into the design wherever they can to achieve the highest level of certification. These systems include reuse of existing structure, high efficiency envelop systems, smart energy management systems, renewable energy (solar, geothermal HC/energy pile, fuel cell), rainwater utilization systems, natural ventilation and daylighting, and roof & wall greening (Ahn et al., 2016).

### 3.3. New Technologies

The construction industry use of heavy equipment is a symbolic picture of the industry. The use of fossil fuelled equipment adds to the emissions that the industry release annually. To counter these
emissions, electrical heavy equipment is being experimented with. Caterpillar has created an all-electric 26-ton excavator, which is the first one of its size (Lambert, 2019). Caterpillar is not alone in the electrified equipment push. Volvo as well as other large manufacturers are working on releasing all electric equipment as well (Volvo, n.d.; Raczon, 2020). In addition to making electric power equipment, many companies are now offering remote controlled equipment as well (Caterpillar, n.d.). These new technologies help keep workers safe and fight climate change. The widespread use of all electric equipment is lagging, which is preventing the large-scale manufacturing of these machines.

Technology is not limited to upgrading currently used equipment but is also on pace to provide a replacement for human labour. Robotics has advanced and continues to do so at a rapid pace. While increasingly higher temperatures affect human labour, robots can operate without any effect. While climate change may not be a predominate force spurring the creation of these robots, it does provide another benefit for them. For instance, Advance Construction Robotics manufactures automation tools designed for tying and placing rebar on horizontal planes (Advance Construction Robotics, n.d.). Drones are another tool being used to increase productivity in all aspects of construction, ranging from inspections, surveying, mapping, progress walk throughs, and trials are being done to use drones to complete tasks such as painting (Knight, 2020). As technology advances so will the use of robotics, as the benefits of increased productivity, ability to work in extreme conditions, and cost reduction their application will become desirable.

4. Moving Forward
Not only are the current effects of climate change here to stay, but as the construction industry looks to the future the evidence suggests that there will be future climate related issues that will compound with the current problems that will need to be identified, analysed, and accounted for in future design. Ensuring that the projects that are being constructed, are on the forefront in terms of resiliency are critical factors for both designers and developers. As greener technologies become available and green building become the industry standard, the starting point for many of these projects begins adapting the project delivery method. While traditional design-bid-build (DBB) method was the staple process by which projects use to be constructed, changing technologies, and ever evolving legislation that defines green construction call for all team members to communicate and be more involved. The first step in creating a resilient building is implementing an integrated construction process (ICP) and using integrated project delivery (IPD) method. IPD ensures that all major team members in the construction process are collaborating and supporting each other to successfully integrate the necessary technologies and meet the criteria of the regulatory administrations to be considered green and resilient projects (Ahn et al., 2016). Ensuring that all project team members are capable of delivering the desired product is essential to projects success.

Changes in municipal regulation and third-party certification requirements can have adverse impacts on a project. Throughout the Northeast many cities and towns have organized committees and regulating authorities to investigate, report, and regulate policies in regard to climate change. In Boston, Article 37 of the zoning code also created the Interagency Green Building Committee (IGBC) which is responsible for ensuring that projects comply with the cities policies towards resiliency and green buildings. Currently the City of Boston requires that projects consider the potential impacts of the results of climate change such as extreme heat, extreme precipitation, rising sea levels, etc. and provide a framework for how these buildings will combat these issues (BPDA, n.d.). New York city has also taken action to bring resiliency regarding their stormwater and sewer systems to the forefront of construction issues. Local Law 172 required the city identify which areas of the city are most susceptible to flooding and the NYC Green Infrastructure Program is offering grants for new or redevelopment properties that comply with the stormwater retention program and that incorporate green infrastructure into their projects (NYC Stormwater Resiliency Plan, 2021). In addition to the governing laws and legislation, projects must also consider the requirements set forth by the USGBC to attain the agreed upon LEED certification. Projects must be innovative and utilize green technologies in their design. Project teams must collaborate to deliver the most desirable green product. Incorporating innovations such as enhanced energy efficient HVAC and water usage, use of green material and resources, improved indoor environment, and capitalizing on the existing site and
its proximity to transportation all need to be taken into consideration (USGBC, n.d.). Project teams need to continue pushing the envelope of green building innovation to ensure that they continually stay ahead of the curve and to ensure that their projects are compliant with the local regulations.

Understanding the changes that are occurring with the climate and being able to better predict the location and degree to which severe storms will affect an area is also an important aspect of the future of resiliency. Looking ahead to only the rising sea level, it is estimated that by 2070 as many as 150 million people worldwide could be adversely affected by rising sea levels, and the Northeast with its many highly populated coastal cities will be at elevated risk (Yang et al., 2020). Early warning systems that can better predict and notify individuals in the affected area of a severe impending storm would be critical to ensure adequate preparations can be made.

In addition to new technologies that incorporate early warning systems, incorporating new strategic building designs can play a large factor in preventing damage to critical building systems. Designing modern buildings with electrical, HVAC, and mechanical equipment on upper floors as opposed to their traditional location in basements and other below grade areas helps protect against critical equipment failure in the event of disasters striking (USGBC, n.d.). In situations where flooding either already happens consistently or is expected to occur regularly with the rise in frequency of storms, some owners will have to consider abandoning the lowest floor entirely. This option comes with a heavy loss of opportunity as abandoning an entire floor limits the projects usable space. However, abandoning the lowest floor does have a large window of effectiveness as this method can be utilized with little to no additional maintenance cost for up to 50 years, and the method has been proven to be highly effective at mitigating damage to the rest of the property. While not as drastic as abandoning the entire first floor of the project, elevating the buildings first floor can be an appropriate option in certain situations. By elevating the lowest floor, teams can mitigate damage to building elements and still retain use of the first floor. This option also is not without trade off as it limits the square footage of the first floor and there is potential that storms could still damage portions of the first floor if it is a severe storm (FEMA, 2015).

5. Conclusion
Climate change is an imminent multi-faceted concern that encompasses a large array of industries and will continue to evolve as the extent of this force is continuously explored and researched. In its current capacity climate change has already had a direct impact on the construction industry. Climate change has impacted all aspects of a construction projects from the type and sources of building materials to the equipment and methods used in the physical construction, to the planning and designing of future projects with the intent of minimizing climate changes effects. Like the construction industry, climate change is a numbers game and being at the forefront of climate change, innovation and resiliency projects can effectively strategies and minimizes its adverse effects while simultaneously delivering a superior and greener product.

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