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IQP Future of Construction

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Construction Innovation In The Year 2030

IQP Final Report

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An Interactive Qualifying Project Report

Submitted to the Faculty of

Worcester Polytechnic Institute

In partial fulfillment of the requirements for the Degree of Bachelor

by

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This report is the product of an education program, and is intended to serve as partial documentation for the evaluation of academic achievement. The report should not be construed as a working document by the reader.
Abstract

This project identifies and investigates which areas of the construction industry are in the most need for innovation and advancement. The study takes into account the opinions of industry experts and current industry trends to identify and analyze what innovative products or technologies are viable and will have the greatest impact on the industry. A proposal was created as a result of the findings of the study to help guide Skanska in pursuit of future innovation.
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Executive Summary

The goal of this project is to identify areas in need of improvement and innovation in the construction industry and then identify actionable ways to correct and improve these areas. To successfully accomplish our project goal, we established five objectives to guide us. The objectives were as follows:

**Objective 1:** Identify the shortcomings of the construction industry.

**Objective 2:** Consult industry experts in order to identify the most important areas of focus within the industry.

**Objective 3:** Seek out opinions of industry representatives within each area of focus in order to identify potential innovations.

**Objective 4:** Compile the results and identify which innovations are feasible based off of findings

**Objective 5:** Make a recommendation for innovations to pursue.

To accomplish these objectives, we first conducted our own independent research into the construction industry. We then summarized the research into a presentation to be delivered to an expert panel at Skanska to receive feedback. The expert panel contained a wide range of Skanska employees ranging from structural engineers, material engineers, and crane operators, among others. At the end of this presentation, the initial innovative ideas previously determined had coalesced into more tangible ones because of the expert panel’s reviews. Unfortunately, our list still contained too many viable options, and we were forced to cut it down further. To reduce the list to a more manageable form and keep the ideas with the most potential, we created a survey
for the expert panel. We chose to keep the survey as short as possible to increase the effectiveness and generate more responses, as our research showed this was the most effective way to entice responses.

The survey narrowed our areas of interest down to four main areas: concrete, fireproofing, supply chain visibility, and robotics. We then set out to research these topics further and create a firm knowledge base to head into our more interactive investigation methods. We interviewed many experts from the industry who were leaders in their respective fields. We spoke with salespeople and engineers from national and international manufacturers, suppliers, and union executives. We were also able to interview some on-site contractors and compare their information to other interviews we conducted as well as gain a different perspective on the topics and ideas we developed. We had the opportunity to visit construction sites in the Boston area and see firsthand how our innovative ideas could be implemented in the field.

In our survey, in addition to asking experts to rank their preferences for areas to innovate, we also asked the expert panel to explain the reasoning behind their ranking decision. While examining the data we found common themes to focus on across all four areas. With the four themes of safety, efficiency, environmental and societal impacts in mind, we focused on identifying innovative technologies and concepts in our four areas.

We created lists of potential industry leaders to contact about the state of the industry and seek their opinions about where it could go. We obtained contacts from our sponsor representatives at Skanska as well as WPI. Through these connections, we were able to get in contact with these representatives. Once in contact, we were able to plan either phone or personal interviews with the experts.
Our interview questions were fairly open ended and heavily geared toward the conceptual and the future of the industry. We would create a list of questions, conduct the interview, and then meet after to discuss, compare notes, and then condense them into a single document. We planned to conduct mostly phone interviews, along with a few in-person interviews. These interviews would shape our ideas as well as further our understanding of the industry.

We also planned out a series of site visits to two Skanska projects as well as the Autodesk Innovation studio. These visits allowed us to see the industry as it presently is, as well as what is coming next. This understanding would allow us to anticipate how our ideas would work and be accepted on site in a practical environment. Additionally, we could speak with project managers and contractors for feedback and information. We approached these visits similarly to our interviews. Beforehand we made note of who we wanted to speak to and what we wanted to see, and afterward, we discussed the visit and noted key elements or information.

As a result of all of the construction site visits, the expert interviews, and the independent research, we formulated final proposals for innovative technologies and concepts for the company to pursue. Each of our four areas of focus has multiple viable innovations for the company to pursue. While keeping the four themes of safety, efficiency, environmental and societal impacts in mind, we identified numerous innovative ideas. In the area of concrete, we have five innovations.

**Additive Manufacturing**

Additive manufacturing is essentially similar to a large scale concrete 3D printer. A gantry with a nozzle is set up and a thick concrete slurry is pumped to it, and as the nozzle moves, it lays layers of concrete for the desired structure. The concrete mixture is typically
viscous in nature, but still able to flow as it is poured. The mix needs to flow to place it and then harden and gain strength to support the additional layers. The benefits of this system are that it eliminates the time required to set up forms. It also allows for shapes and designs to be made that would otherwise be difficult or impossible to create with a traditional form.

Additive manufacturing has limitations as well, however. The main limitation of 3D printing is that it requires a entirely new pouring infrastructure compared to traditional concrete. The 3D printing concrete system requires the erection of a gantry that will allow for the concrete to be pumped to the higher floors of the structure. However once the gantry is in place, the concrete pouring can proceed at a faster pace.

**SpeedCore Construction**

In large commercial construction, building structures are usually built around a steel reinforced concrete core. However, this technique can often be very costly and time-consuming. Because concrete requires time for it to cure, construction speed is slowed. Although, more often than not, this required time is accounted for in scheduling, the construction timeline can be drastically shortened by altering this process.

Unlike traditional concrete core construction, SpeedCore is a modular core construction system comprised mainly of steel plates sandwiched around concrete. The modular design allows for the steel plate structure of the core to be built offsite a floor at a time and trucked to the site over the road. At the site, the modular sections can then be lifted into place and filled with concrete. The core is faster to build itself because the cross-tied steel plates are able to bear the structural load of the floors above as the infilled concrete cures. This allows floors of buildings
to be erected much faster without the wait time associated with concrete. SpeedCore amounts to significant time savings in larger structures, or buildings over ten stories.

**CO₂ Cured Concrete**

Carbon cured concrete is another innovative advancement for concrete construction. This new type of concrete is silicate-based and has a low-calcium content. What further sets this concrete apart from typical mixes is the fact that it gains strength through carbonation instead of hydration. That is instead of using water to cause a chemical reaction in the mix, this concrete absorbs ambient CO₂ which causes a reaction similar to typical Portland cement which hardens the substance. However, the bonds created in the carbonation reaction are stronger than the bonds formed in conventional concrete. It significantly reduces the carbon impact of traditional Portland cement based concrete.

**Geopolymer Concrete**

Geopolymer concrete (GPC) is an eco-friendly alternative to conventional Portland cement concrete. Also known as alkali-activated cement, geopolymer cement is made by combining waste materials like fly ash and ground granulated blast furnace slag (GGBS), both byproducts of other industries. Fly ash, a byproduct of the thermal power industry, and GGBS, a byproduct of the steel industry, are recycled as sources of silicon and aluminum. The silicon and aluminum along with some aggregates are then added with an alkaline activating solution to polymerize the materials into molecular chains to create a hardened binder.

**Active Support Construction**

Active support construction uses kinetic energy to remain stable and allows for far more massive scales of construction than traditional concrete. An active support structure would use a
closed loop system in the center to launch particles through a tube via electromagnets. This motion anchored in the center of the structure adds an incredible amount of stability. Unfortunately, the biggest deterrent to this technology today is the cost.

**Fireproofing**

Fireproofing technology is an old technology that, despite some minor improvements over its history, has remained relatively unchanged. Since the introduction of spray application, fireproofing has not seen any innovation, yet the technology still faces a number of issues. Fireproofing is often susceptible to damage even on-site, and is not strong enough to withstand transport when applied as a substrate. These issues lead to a lot of on site work, and often repairs. The greatest obstacle fireproofing technology faces is the bond strength of the material. By strengthening the bonds between the substance’s molecules, durability can drastically be improved. As a result, the aforementioned issues can be addressed. Fireproofing bond strength improvements would also allow for pre-application of the fireproofing material to the substrate, thereby reducing costs and eliminating risks to those onsite from overspray as minimal field application will be necessary. Additionally, fireproofing could be combined with other insulation to reduce labor and material thickness requirements.

**Robotics**

Robotics allow for faster, stronger, more precise tooling than humans can produce. These innovations will help humans to create better cheaper structures in the future. The first innovation is flexible parts. They are inexpensive, faster to create, and capable of reducing the robotic production costs. They also can achieve 3 degrees of freedom in movement with only two articulating mechanisms.
Robotics are also increasing safety by allowing for kickback sensors in tools. The reduction in cost for the sensors and the supporting network allow for a less expensive system. So far, the systems have only been tested in handheld saws but the methods can be applied to nearly any tool. Robotics can also be used for onsite materials handling. As artificial intelligence improves, robots are becoming increasingly able to navigate difficult jobsite terrain and intelligently deliver the correct product to the correct area. A robot similar to this was in the early stages of development at the Autodesk innovation studio, and this type of technology could be used to facilitate widespread innovation.

Another possibility we explored was an autonomous spud wrench. This device would climb a vertical I-beam to assist in setting beams in construction. According the experts we surveyed this process is one of the most dangerous aspects of ironwork and such a device would greatly reduce the risk of injury or death by allowing the ironworker to stay on a more stable platform before setting the beam into place. The autonomous spud wrench would also do all of the alignment between the bolt holes, much like a worker might use a spud wrench today to align the holes. This would allow the worker to focus just on installing the bolts and keeping a footing while the “spud wrench” gave a strong handhold and kept the beam steady for the worker.

While meeting with Ironworker Local 7 executives, we shared our idea with them. They were not receptive, but they provided our team with a alternative suggestion that they view as a safer, more inclusive tool for their industry: a smart, autonomous safety harness and attachment point. The Local 7 executives described a tool that would climb just above the worker, allowing for near limitless climbing, and eliminating the need for tackle to be attached to a structure or beam before it is erected. The robot would increase safety by having less slack than a normal
harness tether, meaning in the event of a slip the worker would have less shock imparted on their body, and would have a lesser radius on the tether, meaning they’ll swing less and won’t reach the same speed in the fall. Additionally, they believe a smart, fall sensing, retracting tether would further increase safety. This would allow the worker more movement, especially laterally off the I-beam that the robot is climbing. In the event of a fall, the robot would retract the tether to shorten the radius, thus lessening the forces achieved in a fall and reducing the distance a worker could swing and potentially hit other workers, structures, or other objects that could injure themselves.

Supply Chain Visibility

Supply chain management needs an interconnected network to succeed. To realize the potential of a network of that caliber it must be used from raw materials to final construction. An Ideal software tool would manage all aspects of the site from delivery tracking, crew management and assignment, storage and sorting of materials to top level updates. This would allow for a cohesive and efficient jobsite which contains little to no delays and completes the projects faster by eliminating the time delays caused by human error. Similar to other examples of supply chain automation the time and money saving from such a system would be substantial as a large percentage of time is wasted in mismanagement and miscommunication on the job site, with the help of a tracking system and supply chain software planning can be streamlined and thus help reduce time waste. This technology further ties into precision tracking, while in the past object recognition could only be slowly run on images now with better algorithms we can run it on live video feeds and recognize objects which the neural net was trained to detect using data sets. If the accuracy and precision of such object detection can be further increased, these
types of software can allow for inexpensive and easy to set up object and people tracking which can be used to then manage supply chains.

Conclusion

The construction industry as a whole is in need of innovation and advancement. Its inability to rid itself of complacent practices and techniques has caused the industry to become stagnant and resistive to innovation. In the four construction areas that were selected for in depth research, including concrete, fireproofing, supply chain visibility, and robotics, the need of innovation is especially present. The opportunities for innovation in each of these areas are very broad and encompass many aspects of each process, but each innovation has proven to address many themes of focus that were also identified as important drivers for innovation by our expert panel. These themes ultimately were identified to be safety, efficiency, environment, and societal impact.
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I. Introduction

This study explored possible innovative technologies that could impact the future of the construction industry. There is great potential for future innovation in the field of construction. However, the construction industry has become stagnant in a world where technology is driving other industries forward. Because of this, construction has fallen behind and now is looking for innovative ways to progress and keep up with the times. Innovation is a wide concept which seeks improvements in processes, equipment, and technologies. In the field of construction, innovation is not straightforward, despite the importance of this sector in the development of society.

There are currently many obstacles preventing construction from pursuing innovation. The construction industry is a multi-billion dollar industry which has a lot to gain from innovation but also has a lot to lose. The risk of failure in construction is often very great as well as the risk to the workers involved. Safety is a great concern on job sites and often can discourage the pursuit of innovation as it introduces uncertainty to a job site. Furthermore, the complexity of the construction industry itself can often discourage innovation. The industry is very complex. With each construction site’s uniqueness, the risk averse nature of the industry, the adopted resistive culture, and great potential of liability, the construction industry often avoids change. As a result, innovation across the industry is difficult to achieve, or even pursue. A stigma surrounds the industry that the current processes are working, so why change it. Together, these factors discourage innovation and cause the production and efficiency issues associated with construction today.
The goal of our project was to identify innovative solutions to pursue in the construction industry. To do so, we established objectives in order to achieve our goal. First, we sought to identify which areas of construction were in the greatest need of innovation. From there, we consulted industry experts to gather information on specific issues within the areas of construction. We then conducted independent research and sought the opinions of industry representatives to identify innovative solutions to the issues surrounding specific areas of construction. This project was sponsored by Skanska US which, as a result of the project, may seek to pursue a recommended innovation for future implementation.
II. Background

This purpose of this project is to look ahead into the future of the construction industry and some possible innovations to come. In order to do so, research was conducted to understand the issues that affect growth and innovation in the construction industry. In this chapter we present how the construction industry has grown stagnant and is facing a number of obstacles preventing its growth. To fully understand the scope and underlying factors of the problem, this chapter reviews the construction industry, the challenges that it faces, and the possibility of innovation in the industry, specifically in the four areas of concrete, fireproofing, supply chain visibility, and robotics.

1. The Construction Industry and its Challenges

Historically, the construction industry is slow to innovate and find new technologies to progress itself further (Hall, 2019). The consistent demand keeps the industry moving forward, so why risk the pursuit of new technologies if demand can be kept up with using current methods. The old English idiom “if it’s not broke, don’t fix it” describes the situation perfectly. Why would the stakeholders of such an industry pursue a change in a system that works and face a potential risk of failure? The risk involved in construction is always great, however, innovation could potentially lessen or eliminate the risks and dangers of construction (Balfour Beatty, 2017). Innovations in the industry could result in fewer instances of higher construction costs, dangerous work environments, and slow-moving production.
The construction industry has been slow to innovate because of four main contributing factors associated with advancement: financial risk, safety, industry complexity, and the culture. The industry is more often risk-averse when it comes to innovative technologies. Consequences of failure run high, and could be very costly. Construction is a multi-billion dollar industry, specifically in the commercial property and infrastructure development sectors of construction. Millions of dollars are invested into each of these large-scale megaprojects, so the risk of failure is great (Hall, 2019). This risk averse nature tends to drive the industry away from change, and often innovation as a result (Hall, 2019).

The risk of failure in the industry is not only just costly, but it also increases the safety risk due to the unknown nature of innovation. Safety is another large contributing factor to the slow progress of construction. Job sites are hectic and safety needs to be of utmost importance. There are nearly 6.5 million people at work across over 250,000 construction sites that span the United States alone on any given day (Occupational Safety and Health Administration, 2017). Workers safety is held above all other aspects of construction, but the job sites are still dangerous and accidents do happen. In 2017, there were 4,674 worker fatalities in the private industry, this includes the restaurants, businesses, and construction among others (Occupational Safety and Health Administration, 2017). Out of those deaths, about 21% were from construction accidents (Occupational Safety and Health Administration, 2017). In other words, one in five worker deaths in this year were in construction. This fatal injury rate on job sites is much higher than the other industries included in the private sector (Occupational Safety and Health Administration, 2017). The increase of safety risk and financial loss associated with the risk of failure continue to slow pace of innovation in the industry, however, they are not the only contributing factors.
The construction industry in itself is another contributor to the slow pace of innovation. The nature of the industry is so complex and time-consuming that progress is naturally slower. Across the hundreds of thousands of job sites, every site is different in some way. Whether it is the environment, the materials in use, or the location each individual site is different. This means strategies and approaches used on one job cannot be applied in the same way to another. This, in turn, causes a slowdown of the industry’s progress. The industry is beginning to fall behind, as the rest of the world progresses construction is being left behind. The CEO of a new modular style construction company called FullStack Modular, Roger Krulak, notes how absurd it is that construction is so far behind other industries (Hall 2019). When in reality, because of the constant demand, it should be at the forefront of innovation. In a 2017 report from Mace Group, a global consultancy and construction firm, Steve Hughes describes the problem:

“For many years, the poor practices prevalent in the construction industry have hindered our productivity performance. Inadequate design processes, poor project management, insufficiently skilled labor and underinvestment in digitization, innovation, and capital are all parts of the problem (Hughes 2017).”

Historically, the construction industry has only reinvested 2% of its revenue on research and development (Hall 2019). In other words, in the past only a small fraction of the industry’s total revenue has funded innovation. Recently, however, the industry is being forced to keep up. Due to increasing external pressure from an advancing society, the industry has started to make innovation a much greater priority. Within the last two years, construction technology has been allocated billions of dollars in investment. There are many factors causing this sudden change.
More and more, companies are now being forced to look towards innovative technologies, software, and processes to solve the many issues the industry is facing currently (Hall 2019). The construction industry under extensive pressure to innovate and search for new solutions to the challenges it now faces. The construction industry is facing challenges in the areas of safety, cost, sustainability, materials, and labor. These challenges are putting pressure on the industry and are forcing those involved to address them.

Safety is of great concern on a construction site. Job sites are often dangerous due to the immense size of the buildings as falls and accidents with materials are prevalent. Although fatal accidents are seldom, they still occur (Occupational Safety and Health Administration 2017). In fact, according to the Occupational Safety and Health Administration, more commonly known as OSHA, fatal injuries have decreased in recent years, but are far from being eliminated. As mentioned earlier in 2017, there were 971 deaths in the construction industry (Occupational Safety and Health Administration 2017). This makes up almost a quarter (21%) of the total number of deaths to workers in the private sector in the same calendar year (Occupational Safety and Health Administration 2017). Moreover, almost 50% of the deaths in construction were due to falls or being struck by an object (Occupational Safety and Health Administration 2017). In a perfect world, this would not be a concern, but the world is not perfect and accidents happen. However, that does not mean that society has to accept this fact. More and more research is being conducted with safety in mind. The goal is to eliminate, or get as close to eliminating, fatal accidents on job sites. Even though in the past safety has, in part, limited innovation, today it is a main driving factor for the industry to innovate improve the safety of workers and others on every job site.
Another main contributor to the pressure to innovate is staying competitive. Competition in today’s construction market is fierce. To beat their competitors, companies must cut their costs lower than the competition while maintaining similar or better service. Today, expenses are becoming exorbitant. In New York City, building costs are among the highest in the entire world (Hall 2019). The New York City construction industry alone spent around $62 billion last year alone (Hall 2019). New York is not unique in this either, building costs everywhere have increased. Land prices and cost of materials are also on the rise. According to the Association of General Contractors of America, the AGC, over the past year, 2017, the average cost of construction materials is up 7.4%. Diesel fuel, steel piping and tubing, asphalt mixtures, and aluminum products are among the variety of construction products that have contributed to the large year-over-year cost increases (AGC 2018). The construction industry needs to remain competitive, and therefore there is a need to promote innovation from within and to adopt technologies which will contribute to reducing cost and staying competitive.

Among cost and safety, the environment is becoming a growing concern surrounding the construction industry. Sustainable practices in construction have always been sought after, especially regarding materials. These practices are becoming more of a necessity rather than a desire, however. Resources throughout the globe are growing scarce, but one of the most devastating impacts on construction is sand. Sand seems like a limitless resource, but the evidence is now showing that it is dwindling rapidly. In construction, sand is a major component for concrete. And as the need for construction materials throughout the world grows, supplies are shrinking. Sand and gravel are the most extracted materials in the world by weight, and since these materials are created through thousands of years of erosion, demand is beginning to
outstrip supply (Gabbatiss 2017). The United Nations estimated in 2012 that nearly 30 billion tons of these materials were used to make concrete. That is enough to construct a wall 27m high by 27m wide around the equator (Gabbatiss 2017). The scarcity has, in turn, caused the prices of these materials to skyrocket. In fact, according to Josh Gabbatiss of the Independent, the value of sand in the US has increased almost six-fold in the last 25 years. In the past five years, extraction has increased by 24%. Material scarcity has and will continue to push for innovation in the industry.

Another key contributor to the push for innovation in construction is labor. Recently, the industry has been battling a shrinking labor pool. Over the past couple of years, the labor workforce has steadily decreased (Hall 2019). Not only is the workforce growing scarce the overall productivity has become stagnant. Krulak, CEO of FullStack Modular, described the situation by saying “labor is not keeping pace with demand. Almost every construction project isn’t on time or on a budget (Hall 2019).” Levels of productivity in construction have plateaued in recent years. Over the last decade, output per worker has remained flat in construction, whereas in industries that have embraced innovation like the service and manufacturing industries output per worker has increased by 30 and 50 percent, respectively (Hughes 2017). Krulak later went on to say that situations like these are the things that are driving the industry towards solutions (Hall 2019). That is exactly what is happening. The shortage of labor and stagnant production rates are forcing research into assistive technologies to help increase productivity and efficiency on job sites.

The world is progressing forward, and the construction industry needs to innovate to keep up. The industry as a whole will benefit from innovation. Our project, however, will focus in on
four areas of construction that are being impacted by technology and innovations currently and will continue to be innovated over the next few decades. The areas of fireproofing on job sites, concrete, supply chain within the job site, and robotics on the job site will be our focus, but they are not the only areas of construction that will see innovation in the coming years. The entire industry is evolving and will continue to do so. The overall outlook for construction is positive. Modern technologies will make the future of construction safer, more efficient, and more effective (Hall 2019).

2. **Fireproofing**

Fireproofing has remained nearly unchanged since it was patented over 40 years ago. The formula in the 1970’s patent has only seen one revision when a 2009 building code revision necessitated a higher bond strength, but the properties that prevent the spread of fire and much of the makeup, application, and appearance remains unchanged over the last 40 years. Fireproofing is applied on site by contractors, often multiple times as plans are changed or errors are corrected. The fireproofing on site is lengthy, as we discovered from meeting with contractors on site, and there is little that has been done to speed the process up and make the job easier for the contractors. The material is delicate, not able to be worked around easily, and presents a unique challenge as the material is applied the same as it was 40 years ago. According to a source the field is ripe for innovation and almost anything would be a welcome change. Thinner more durable materials would save on materials and installation costs, add up to weight and space savings over the entirety of a structure, and combinations with other materials or needs could satisfy similar requirements, such as acoustic or aesthetic needs.
3. The Issues of Concrete and its Modern Applications

Concrete is a product made from cement, sand, and aggregate. The aggregate adds strength and volume, however in construction applications additional reinforcement is necessary in the form of rebar. Concrete is used for foundations, as well as structure in certain buildings. The most common cement used in construction today is Portland cement, a hydraulic cement, meaning it requires water for the chemical reaction that causes the cement to set. Often, mixes are also supplemented with additives that help change the characteristics and behavior of concrete such as setting, flow, strength gain, freeze-thaw durability, and flow. When initially mixed, concrete’s properties are similar to thick pudding, as it is plastic and malleable, but as the mixture cures through a chemical reaction known as hydration the material gains both strength and durability as it hardens. This process takes time; the American Concrete Institute recognizes 28 days as the typical timetable for concrete to reach significant strength, significant strength being approximately 75 to 90 percent strength (ACI, 2019). 100% cured concrete never occurs in the field unless the mix is put under controlled conditions. Although, in some instances, concrete can take longer to cure or cure faster depending on the mix additives.

The hydration process causes issues with cold weather construction, and requires more energy, labor, materials, and tools to work with at even fairly mild temperatures- the reactions necessary will not occur below 40 degrees. Currently, concrete suppliers can make the mix with hotter water to keep the mix from freezing, but even still the mixture needs to be kept warm through the use of heaters, warming blankets, and other techniques while it sets. This increases time, costs, and creates more emissions. This means that construction time, costs, and emissions
are significantly increased in the winter in colder climates. This causes concern in people across a wide variety of interests and improvement is needed here to advance the construction industry.

Higher strength concrete capable of reaching higher strengths in shorter curing times is also currently available with today’s technology (Shah, Gohil, Chavda, & Khediya, 2015). Commonly known as high performance concrete, or HPC, these mixes typically cost more than normal concrete, sometimes as much as 16% more (Shah, Gohil, Chavda, & Khediya, 2015). HPC, however, still is not a long term solution to Portland cement based concrete, as it still requires curing time.

Another issue associated with concrete is that it often has one of the largest impacts on the environment out of the entire construction process. Concrete has a very energy intensive process (Gabattis, 2017). Most of the energy is put into the cement, a key component of concrete. The cement industry contributes between five and seven percent of the global carbon dioxide pollution yearly (AGG, 2017). Thus, many companies are focusing on ways to create more sustainable concrete.

Additionally, cement is still mostly poured by hand into hand assembled on-site forms. Robotics, 3D printing, and prefabricated forms (in the context of building cores) are being studied, tested, or used. These all reduce waste and time, which helps the planet, the industry, and the environment, and consumers. Concrete is a vital component of every structure, forming the foundation of houses, sheds, skyscrapers, sidewalks, and most of every developed piece of land in the world. Improvements in this industry would have worldwide economic impacts.
4. **Supply Chain**

The supply chain is the sequence of processes involved in the production and distribution of a commodity. For construction this involves ordering and delivery of products, assigning of crews and the order in which construction processes happen on the work site. In the past this was done manually on paper or whiteboards, people shared information over emails or phones to coordinate the schedule. With the advent of the information age, new technologies and software are being tested to allow for smoother, more optimized work flows. This has become a force on the construction industry, those who can have the fastest, most efficient supply chains save the most money (Anders, 2010). Cost efficiency is often a large issue in the construction industry. This is often caused by time mismanagement, communication delays, and repetitive processes. In the end, with technology bridging the gap, it is within the construction industry's grasp to streamline their supply chains with only their own hesitation stopping them from moving forward (Ruben, 2000).

5. **Robotics**

In the past robotics was limited by computer hardware and sensors. As hardware and software improve so do sensors and motors. This essentially means that robots now are capable of far more precise and complex tasks, leading to them being more capable of movement and automation (Robotplatform, 2019). This allows for a faster and safer way to build, putting pressure on the construction industry to innovate or be left behind. Traditionally basic sensors like an infrared sensor or a color sensor were fed to software which then processed the data and gave instructions to the motors which then moved the robot (AG, 2019). One of the biggest
limiters of past robots was battery density. While current batteries are slightly better than they were in the past it's still not a big enough improvement to meet the requirements for some robots (Sprague, 2015). Heavy load bearing robots take a lot of energy as such they either need to be connected to an external power supply or recharge often, reducing their life as the battery cycles (Spotnitz, 2003).

6. **Opportunity for Improvement**

The progression of the construction industry is very atypical and is often dependent on a number of exterior variables. Advancements are typically brought on by changes in technology, policies, or processes. These could be a new piece of equipment aimed at cutting production time, a new safety standard aimed at creating a safer work environment, or a new sustainable process with materials aimed at cutting down waste. Technological advancements often provide the greatest opportunity for improvement in the construction industry, as they frequently lead to changes in the latter areas of safety and process efficiency. Technology is constantly driving all different types of industries, but until recently the construction industry has maintained stagnancy and avoided it. Historically, the construction industry is slow to adapt and change due to its longstanding traditions, but with pressure to speed up production while maintaining safety, the industry has been forced to succumb to change (Heigl, 2018).

7. **Skanska**

Skanska is one of the major stakeholders of the construction industry, especially in large commercial and infrastructure development. Skanska is a Swedish based construction company that has been in business for over 125 years. Today, Skanska is one of the largest construction
and development companies in the U.S., serving a broad range of clients across the commercial property development and infrastructure development sectors. They work on a number of different types of jobs including those in transportation, power, industrial, education, sports, and commercial. They specialize in larger facilities like office buildings, shopping centers, logistics properties, roads, hospitals, and schools. Some of their past projects in the northeastern United States include Metlife Stadium (home of the New York Jets and Giants franchises), dormitories for Hult University’s campus in Cambridge, MA, and a recreational center for Boston University. The company’s mission is to contribute to society through their work. At Skanska, they want to “build for a better society” (Skansa 2019), and that is why they are looking to push for change and continue to be at the forefront of the pursuit for innovation in the construction industry.
III. Methodology

In order to successfully identify future innovations in the construction industry, our group needed to establish methods by which we would accomplish the end goals of the project. The procedure to conduct this project was a multi-step process with many distinct techniques that helped reach our project objectives. The objectives of this project were to:

**Objective 1:** Identify the shortcomings of the construction industry.

**Objective 2:** Consult industry experts in order to identify the most important areas of focus within the industry.

**Objective 3:** Seek out opinions of industry representatives within each area of focus in order to identify potential innovations.

**Objective 4:** Compile the results and identify which innovations are feasible based on findings

**Objective 5:** Make recommendation for innovations to pursue.

These objectives were the main focuses we sought to accomplish throughout the report. This chapter outlines the strategy and process followed in order to attain the project goals and to achieve the desired outcomes. It provides a guide to how the goal was met, what objectives were set, what methods were used to complete the objectives, and finally how those objectives accomplish the project goal.

The research strategy is based on the posing of key questions aimed at answering the focus question of the project: “What is the construction industry going to look like in the coming decades?” To further narrow this broad research question, the group thought it best to pursue a
particular sector of the construction industry. The sector of interest was the large commercial and infrastructure development sector. We wanted to know “what are viable innovations in the large commercial and infrastructure sectors of the construction industry in the coming decades?”

1. Survey and Expert Panel

After doing some basic research on the topic of construction and reviewing the information we gained from the background, it was decided that an expert panel would be needed to clarify, verify and expand on our selection. In order to collect that information we first started with extensive research, and then brainstormed. Using these methods a list of construction topics was created and then a feasibility analysis was conducted reduce the extensive list. This analysis listed out the potential topics, the advantages and obstacles associated with each technology, and the potential timelines for each topic (Pouliquen, 1970). These were then analyzed and the ones found to be too out of reach or found to have too long of a timeline were discarded (Justis, 1979). The remaining topics were compiled into a presentation to be delivered to an expert panel at Skanska to get the potential real-world applications of these ideas. The expert panel contained a wide range of Skanska experts ranging from structural engineers, material engineers, crane operators and many more. The format for the expert panel was derived from various documents and was oriented towards a diversity of experts to get a wide range of feedback for our topics (Waltz, 2015).

The format of the presentation was set in such a way that each topic presented had its own discussion which was noted down in both a audio recording and hand written notes by two people for future review. Each topic had its potential advantages and disadvantages listed and
orated throughout the presentation. Then prompting questions were asked and the expert panel
started the topic review in which the experts and the interviewer discussed the current topic on
screen and its possible applications, drawbacks and advantages, this was then repeated for the
next topic, similar to the structure of our feasibility analysis (Young, 1970).

At the end of this presentation, the rough ideas determined prior to the presentation had
coalesced into more tangible ones because of the expert panel’s reviews. The problems and
advantages associated with each topic were much more clearly highlighted and had been given
context by the experts. Unfortunately, even with this elimination method, our list still contained
too many viable options, and we were forced to cut it down further. To thin the list to a more
manageable form and keep the ideas with the most potential we set out to create a survey for our
expert panel. The survey format was kept short and to the point, this was done as to convince
more people to fill it out. The survey was designed from several guides and was intended for a
specific target group, as such, the survey was only 2-3 minutes long (Dillman, 2006); this was
because our research had shown that surveys at this length were answered far more frequently
(Vannette, 2014). For the different technologies to choose from, we went with a ranking system
for the first question, this was so that we could clearly see trends within the picks and it also let
us clearly define the key technologies that stood out (Appendix C). The surveyor could rank
from best to worst using either numbers with one being the best and the total number of options
being the worst. An alternative sorting method that was available was simply dragging and
dropping the topics to their preferred order. The rankings were kept to a minimum of 4 which
was selected after discussion with the project team, Skanska and the project advisor, as such 4
topics was the agreed-upon limit for the reach of the IQP project.
Each idea listed in the ranking first had its main title and then a subtitle containing a more detailed description. This was done as some topics had the same major heading but a different minor description, it also allowed the reader to more easily distinguish between the listings. The second question was a text field to give optional feedback on their previous picks or elaborate on any new ideas. This was done to give the survey takers the freedom to add new information if they saw fit or elaborate on their top picks in a more detailed manner (Division of Instructional Innovation, 2007).

The methods used in our survey process varied but together they netted us a lot of informational data which when analyzed got us our four final topics. Overall the methods used in the survey and expert panel served as the bedrock for our project, providing a solid foundation for us to build upon.

2. **Construction and Informational Site Visits**

To see where and how some of these options could be realized, as well as further our understanding of the need for innovation, we visited multiple Skanska projects in the Boston area as well as an informational site. The site visits would allow us to see various stages of completion of a project and the sundry trades and operations involved. While on the sites we would strive to grasp a general working of the sites, the culture, organization, etc, as these were key to the viability, structure, and deployment of any innovations. The informational site would give us a first-hand look at the organizational and technological innovations in the current industry.
Our prime goal in visiting the sites was to observe and understand both the culture on site and the technology being employed on job sites today. This would both shape our future conclusions by showing current innovations and help us to understand what was and was not viable, as well as see areas lacking technology, innovation, efficiency, and safety.

Focusing on certain areas we identified from the survey results would allow us to make the most efficient use of our site visits. We knew ironworking, fireproofing, supply chain, and concrete would be our main focus on all of our site visits, and this allowed us to plan out questions. We also planned to make our hosts aware of our areas of interest in order to make sure we saw as much as possible of them on our visits.

In addition to touring the sites and speaking with the Skanska team on-site, we also planned to conduct quick interviews onsite with professionals in the industry. We would quickly determine their wants, needs, and initial reaction to our suggestions in order to gain real-world labor feedback from who would ultimately work with the outputs of the projects we would eventually propose. The professionals we planned to interview on site were either union laborers or union supervisors, employed by a subcontractor to Skanska, and because of this we had to plan to be quick, simple, non-intrusive, and non-threatening.

In addition to the construction site visits, we also planned to visit the Autodesk Innovation Studio in Boston, Massachusetts. The Innovation Studio is a workshop for industry professionals and students to work in collaboration with the newest technologies. This allows these key contributors to familiarize themselves with these technologies and promote their acceptance to further advance the construction industry. While in the studio, we hoped to witness some of the newest ideas in construction across all fields. They range from purely physical
technologies like 3D printers and CNC welders to the pure design and planning technologies, as well as technologies that bridge the gap, some spanning the entire length of a project from conceptualization to final assembly.

While the Autodesk Innovation Studio contained new technology in almost every aspect of construction the areas the pertained most to our ideas were in the supply chain management field. The Studio visit would allow us to see the other end of the tools we would see in previous site visits. At construction sites, we would see the outputs of the planning and supply chain tools. At Autodesk, we would see first-hand as architects and engineers input data and designs into these programs and used them to plan the project.

3. Interviews with Industry Experts

Another method we used to gather data was through interviews with industry experts and everyday contributors. The purpose of conducting interviews with the concrete, robotics, supply chain visibility, and fireproofing industry representatives was to gain first-hand knowledge and expert opinions pertaining to our research questions. Each interview had four distinct goals. These goals were to determine what the current practices are, understand the issues with the current practices, receive the expert's opinion on what innovations they believe are going to become relevant in the future, and discuss the advancements their company is currently pursuing. We chose to set each interview up to mimic the General Interview Guide Approach as laid out by Carter McNamara in his book. This structure allowed us to best extract the information we were looking for, while also allowing a degree of freedom to veer from the traditional structure to ask follow-ups and productive tangents (McNamara, 2006). We interviewed nine representatives
from eight different companies and organizations. This list was compiled through industry research which allowed us to identify key players in each area of focus. Interviews often also led to more leads and contacts for future interviews. Often getting the opportunity for an interview was difficult as scheduling was an issue. However, we continued reaching out for interviews until we had sufficient information and results to make our recommendations. A complete list of companies can be found in Table 1.

Table 1: List of Interviewed Companies and their Fields

<table>
<thead>
<tr>
<th>Source</th>
<th>Area of Focus</th>
</tr>
</thead>
<tbody>
<tr>
<td>GCP Applied Technologies</td>
<td>Fireproofing, Concrete</td>
</tr>
<tr>
<td>WPI Robotics Department</td>
<td>Robotics</td>
</tr>
<tr>
<td>Milwaukee Tool</td>
<td>Supply Chain Visibility, Robotics</td>
</tr>
<tr>
<td>Subcontractors (On Site)</td>
<td>Supply Chain Visibility, Concrete, Fireproofing</td>
</tr>
<tr>
<td>Local 7 Ironworkers Union</td>
<td>Supply Chain Visibility, Concrete, Fireproofing, Robotics</td>
</tr>
<tr>
<td>Autodesk Innovation Studio</td>
<td>Robotics, Supply Chain Visibility</td>
</tr>
<tr>
<td>Skanska Project Manager</td>
<td>Supply Chain Visibility, Fireproofing, Concrete</td>
</tr>
</tbody>
</table>

Prior to each interview, our team met to develop and solidify the questions we were to ask during the session. Each interview had the same overarching goals, as stated above, which led to standard questions asked of each representative. As an example, each interview began with “What is your current role?” and ended with “Where do you think technology within the company is going?” We chose this approach to first engage the respondent by avoiding jumping directly into the content as recommended by McNamara (McNamara, 2006). This allowed the
respondents to become involved in the interview from the start. The sequence of the interviews also followed a chronological flow; we approached the interviews by first asking about the present and then leading into the future. This makes the interview easier on the respondent as it is typically easier to talk about work in the present than work in the past or future (McNamara, 2006). Our questions were written in such a way to provoke open ended responses from our interviewees. A complete list of the standard interview questions can be found in the Appendix.

During our team meetings, we also created specific questions for each individual which aligned with our overall goals. The interviews took place either on the phone or at company sites with at least two group members present, most often all three were present. When necessary, during the interview structure would change and become more conversational. We would do this to further indulge in a topic or point that the respondent had made. Group members were assigned an area of focus, Treksh focused on robotics and supply chain visibility and Connor and Tyler focused on concrete and fireproofing. Depending on the field of expertise of interviewee was a part of, the corresponding representative within our team facilitated the interview. One group member was responsible for electronically transcribing interview answers while the other member acted as a secondary note taker. Following the interview, the group met to compile all notes into a single document, where key points were identified. During these meetings, in order to determine which points were the key takeaways from each interview, the group reviewed what was discussed throughout the interview. A consensus was then reached between each of the group members resulting in which points or ideas were important to take out of each interview.

The interview method had four major limitations which could have potentially impacted the quality of our results. The first two limitations are related to the physical structure of the
interview process. Interview settings varied between each session, five interviews were conducted over the phone, and four interviews were face to face on site. This is a limitation because questions and responses could be more easily misconstrued through phone interviews, due to technological issues, than in person. We also experienced that our on-site interviews lasted significantly longer than the phone interviews; on-site interviews averaged to about an hour while the average phone interviews were about 20 minutes. In person interviewees were more inclined to provide additional information than phone interviewees who simply provided information specific to our questions. The next limitation of our interview procedure was the conduction and compilation of our interviews and notes. The interviews were conducted by a different group member depending on the content area; this is a limitation because each group member has an accent or approach which may prompt more or less conversation and extraction of information. Additionally, after the completion of an interview, notes were also not reviewed in a consistent manner. The notes were compiled a number of days after each interview rather than directly after the session. This may have resulted in a loss of or misinterpretation of information. The following two limitations related to the industry representatives. When asked about technologies or techniques their companies would be pursuing in the near future, many representatives were hesitant to reveal that information. It was a concern of theirs to maintain proprietary information in order to remain competitive in their respective fields.
IV. Results

1. Introduction

Our research investigated four main areas of the construction industry. These areas of focus were centered around advancements in the fields of concrete, fireproofing, supply chain visibility, and robotics. These areas were selected through our consultation with a panel of industry experts, as discussed in the methods. Initially, the expert panel brainstormed and developed a more comprehensive list of areas to pursue innovation within the construction industry. A full list of the ideas generated by the panel can be found in the Appendix D. As defined in the Methodology section, an objective of our project was to identify the most important areas of construction in need of innovation. Focusing on this objective, we conducted a survey of experts. The survey resulted in the selection of the four areas of focus as described above. From our background research, we could see that these areas could benefit from additional innovation. This early conclusion would be later reinforced in our research and interviews.

In our survey, we also asked the expert panel to explain the reasoning behind their ranking decision. As a result, using the survey data, which can be found on the next page (Figure 1), we were able to identify certain themes to focus our improvements on within each area in. As we worked through our research, it continued to be more apparent that these four areas of construction were in need of improvement. The experts recommended investigating how to make areas safer. Safety is a significant concern across the industry, and improving the safety of job sites is a top priority.
Figure 1: Graph of survey results
Another theme that was frequently chosen by the experts was efficiency. The overall efficiency of a project could mean many things. Cost effectiveness is a primary concern for any company, whether it be cutting material costs, cutting production time, or increasing overall production rate, is going to have a great effect on the bottom line. Additionally, more efficient construction means faster construction, which decreases costs further, satisfies the customer and improves relations with neighboring sites by decreasing construction time.

Environmental impact reductions also came up with a high frequency in the survey results. More and more companies are shifting their focus to more sustainable practices. No longer is it just acceptable to produce quality designs, it is now an objective for construction companies to seek to be more sustainable in their operations.

The societal impact was another theme that was identified with high recurrence. This impact focuses its objective to promote more jobs, improve the lives of the employees, and generally be able to create a more positive impact on society. Our research showed that many of the viable innovations in each area of focus within the construction industry addressed these themes and are capable of making a real impact on the industry in the future.

2. Area of Focus: Concrete

Concrete is a crucial part of the construction industry, especially in commercial and infrastructure development sector. Concrete is used structurally throughout many building designs and foundations. Due to its durability, strength, and relatively low cost, concrete is the backbone of many projects. Concrete is such an important component to many construction projects, however, there are many issues with the current concrete practices. As presented in the
previous chapters, these concerns often come in the areas of job site safety, production efficiency, environmental impact, and societal impact. Due to this, the industry is in the process of innovation and there are a number of viable ideas capable of addressing these concerns.

A. Safety

As presented earlier, safety is a significant concern in the construction industry. Although, concrete does not pose a large threat to workers safety on a jobsite, it can still have an impact. Currently, construction sites attempt to block off concrete pouring site and use warnings to alert workers of wet concrete. These actions are typically enough to prevent any accidents, but the longer the concrete construction operation, which includes forming, pouring and curing, the higher the chances for accidents to occur. Therefore, reducing the length of these operations, will significantly reduce the chances of accidents and even fatalities. Innovation to concrete’s process and makeup could make these areas on sites safer, as there is a need to reduce curing times, or eliminate them altogether. In turn, this would reduce the threat of safety that these concrete sites pose on construction sites.

On February 21, 2019, we had the opportunity to tour a construction site of a dormitory for the Hult International School of Business located in Cambridge, MA. This construction project was in the final stages, meaning that all the structural components were erected and the building was enclosed. However, on site we were still able to see a site where concrete was being poured. With a lot of work being conducted by many different subcontractors, the fresh concrete became a potential danger to the workers on the site. As precaution, the workers had posted caution signs and warning tape to warn others of the fresh concrete. The warnings worked as no
accidents happened as a result, but this hazard could be avoided with an advancement in concrete’s current practices.

For the future of concrete, a need to expedite the curing process, or even eliminate it, has to be addressed. If an advancement in this area is found, one small aspect of construction safety could be eliminated. Although, concrete safety is not much of an issue on construction sites, eliminating it by lowering concrete curing times will make a difference. Construction sites will be safer as a result, which allows for focus to be placed on much more pressing safety matters.

B. Efficiency

Operational efficiency describes a company’s ability to deliver products or services in the most cost-effective way possible, while maintaining quality (Construction World, 2018). Concrete operational efficiency is accomplished by making sure that through its production waste is minimized, including excess materials, defects and overproduction. Reducing idle times for its employees can also help to increase efficiency. The ultimate goal of operational efficiency is to lower costs, without compromising productivity and profit. A main issue with the operational efficiency of concrete in construction today is the timeline associated with the material’s curing process. Concrete curing requires time for the material to gain enough strength before additional load bearing activities can proceed. This time requirement is often accounted for when the project schedule is created, but if the curing process could be accelerated or even eliminated, then construction could proceed much faster. Currently, there is a need in the industry to accelerate the concrete construction operation or find alternatives to replace this process.
Currently, there is a push for improvement on cure times. There is a focus on different additives used to achieve a shortened curing process while maintaining strength. Other sectors of the construction industry are already working on finding mix additives to hasten the curing process. Through an interview with industry representative Bob Hoopes, we learned that the Department of Transportation has implemented a technique known as “Fast Track Paving” within the last couple of years (Hoopes, B. (2019, April 20). Phone Interview). This technique allows the crews to pave new roads in a shorter period of time. The DOT’s fast track paving technique is currently used for both highway paving and bridge decks. “Fast Track” is capable of achieving high strength relatively quickly as well. In fact, the mixes are now capable of achieving 3500 psi in 30 hours and 6000 psi in 3 days, which is a much higher level of strength faster than typical Portland cement (Hoopes, B. (2019, April 20). Phone Interview). As mentioned earlier, HPC or high performance concrete is capable of higher strengths faster, but is still insufficient and can be improved. In order to have a higher concrete operational efficiency, there is still a need to shorten, or eliminate, the time required for the concrete to cure.

Another way concrete curing time on site is being addressed is through prefabricated concrete features. Prefabrication concrete is another means of creating a more efficient production, which has become more popular in recent years on smaller projects. During a site visit of a recreational center being built for Boston College, we were able to see prefab concrete being used as part of the project. Prefab concrete is capable of being produced off-site and then transported and erected according to design. At this site, the outside concrete paneling of the building along with some archways were all precast concrete. Figure 2 shows an image of a precast concrete wall being erected. The precast nature of these features allows for curing times
to be skipped on site. In turn, the use of prefabricated concrete can save on project delivery time by reducing the time scheduled for concrete, which includes constructing the forms, concrete pouring, curing, and removing the forms. This solution has limitations, and still does not fully solve the issue of concrete operational efficiency. On our site visit, we had the opportunity to speak with a project manager dealing with the prefabbed concrete panels. Precast concrete needs to be made to the exact design, any slight change in dimension renders the panel useless until the dimension is corrected (Simon, J. (January 30, 2019). Personal Interview). This can lead to project delays and hurt the operational efficiency of the entire project.

Figure 2 - A precast concrete wall being lifted into place

The current attempts to address the issues surrounding the operational efficiency of concrete are not sufficient. “Fast Track” paving and precast concrete help speed up production times of concrete use, however, they are not perfect. Even with these current technologies, there is still a need for improvement. “Fast Track” paving has proven to speed up the concrete curing process, but the curing process could be shortened further or even eliminated. Furthermore, while precast concrete eliminates on-site curing, the frequent corrections to the dimensions of the features adds unaccounted for delays into the equation and hurts the operational efficiency.
C. Environmental Impact

Construction projects around the world have a significant impact on our environment, both on a local and a global scale. Every stage of the construction process has a measurable environmental impact. As described in the Background section, concrete has a substantial impact on the environment. Thus, many companies are focusing on ways to create more sustainable concrete.

Concrete is also very sensitive to the environment. In fact, concrete curing times are drastically affected by ambient weather. Any time the ambient temperature dips below 40 degrees F, a heated environment is required for concrete curing. In the Northeast, specifically the New England area, this is especially true, as the weather here is typically colder than other parts of the country. During our visit to the Hult International School of Business in Cambridge, MA, we were able to see a dormitory building in the final stages of construction. Our visit was in February, so winter weather was a factor in construction. Even though the building was in its final stages, we came across a crew pouring concrete on the bottom floor of the building. Due to the cold weather, the crew had to make a temporary enclosure to help keep the concrete warm. The crew also had a heater in the area to keep the concrete at a suitable temperature to promote the curing process. Currently, this is the only true solution to wintering concrete. As a result, there is a need to address this and find a solution to winterize concrete or eliminate the curing process. In order to address this shortcoming, research is being conducted into additive materials to allow the concrete to cure at lower temperatures (Hoopes, B. (2019, April 20). Phone Interview). In turn, this innovation would allow production to be completed faster, even if the ambient temperature is too low for the curing process. Construction would also be much more
effective in the colder months by eliminating the need to set aside time and resources to allow
the concrete to be heated in order for curing to occur. The impact on the environment from the
process would also, in turn, be lessened. Under current practices emissions are increased for cold
weather because the concrete must be heated in order to cure.

Concrete’s effect on the environment is impactful and needs to be addressed. The current
attempts at solutions are insufficient and do not address the carbon footprint of the cement
industry. There is an immediate need to address these issues. A new concrete, one that requires
less energy to conceive, needs to be sought out. Furthermore, the issue of cold-curing concrete
also needs to be addressed. The current practices are inefficient and can be improved upon.

D. Societal Impact

The construction industry has a tremendous impact on society. In the commercial and
infrastructure development sector of construction, this is especially true. These projects have the
potential to bring about many social benefits to society. Hospitals and schools have immediate
beneficial impacts. Due to its importance in construction, concrete has the potential to shorten
the length of these projects and bring the finished project to the public faster. Concrete also has a
direct societal impact on the workers, subcontractors, and managers that populate the job sites.
Although, the societal impact of concrete is not a large concern, there is room for improvement.

We were able to see the societal impact of concrete on a jobsite and the workers first
hand. During our visit to the Hult Business School in Cambridge, we saw how the concrete
curing process has an effect on all of the rest of the job site. Although, the concrete pouring is
scheduled out and all the workers are aware of it, any corrections or alterations to plans can
cause some inconveniences. During this particular site visit, a repair on the on bottom floor
caused an inconvenience to other workers of different trades because of the location. The area where the concrete was being poured was blocked off and disrupted the flow of materials and workers to other areas of the site. Even though this mishap was unforeseen, it could have been avoided if the concrete was more adaptable or was able to cure in little to no time. This would have allowed the repair to be made in no time, while also allowing work on the rest of the site to continue as scheduled.

Socially, concrete can be improved to help make work easier for workers on site and its process can be improved to finish projects faster to benefit the public. Any reduction in construction time will increase project profits and will benefit the public sooner. On site, innovation to concrete will make work for the many workers across the different trade all working simultaneously on the project much more convenient. Because of these factors, there is a need to improve concrete in order to address the societal impact issues.

E. Discussion

As a result of the above findings, we have come up with a number of possible innovative ideas to help solve the issues of concrete in construction. The ideas described below are futuristic and some are not currently feasible with today’s technology. However, all of the following technologies have potential with further research and could have huge effects on the future of the construction industry.

Additive Manufacturing

The first innovative solution is concrete construction through the means of additive manufacturing. 3D printing is a possible solution to addressing production efficiency flaws surrounding concrete. It is an innovative technology that can be used to quicken the construction
process. 3D printing has evolved greatly over the past decade. From rapid prototyping to full-scale working cars, 3D printing has changed the way people are thinking about manufacturing. Figure 3 shows a residential home in the process of being printed.

![Figure 3 - 3D printing concrete homes (AGG, 2017)](image)

Now, 3D printing has made its way into the construction industry. The concrete used in this process is workable enough to be printed, while also being thick enough to hold itself up as the printing creates layers. 3D printing is fully capable of changing the way buildings are constructed from residential homes built in a day to apartment complexes built in a week. Typically, current construction techniques could take a few months to complete structures, 3D printing is capable of completing the same structures in a few days or weeks. Currently, experiments are being conducted, for example, a team at USC is working on a 3D printer which aims to build a whole house including electricity and plumbing in under 24 hours; in Amsterdam, a team of architects has constructed the Print Canal House, a micro house made using bio-based, renewable materials; while a Chinese company called WinSun claims already to be able to do it
at scale and affordably (Balfour Beatty, 2017). Furthermore, with 3D printing concrete, there is little to no waste produced as only the necessary amount of mix is poured. In this way, 3D printing saves countless hours on labor on site and form installations. In turn, this technology is capable of improving production efficiency and saving on the overall cost (Balfour Beatty, 2017). Another benefit of additive manufacturing is the ability to print more complex geometries, which opens the door to many more potential building designs (Gaget, 2018).

Additive manufacturing does, however, have its limitations. Similar to current pour methods, the 3D printed concrete would still require some time for curing. Although the typical mix is capable of being stacked on top of itself, time is still required for the concrete to reach a substantial strength level. Also, even though additive manufacturing eliminates the need for forms to be built, the system still requires a large gantry structure to support itself. The gantry allows the concrete to be pumped up to the nozzle where it is then printed from the nozzle as portrayed in Figure 3. However, once the gantry is in place the 3D printer can proceed. Despite these limitations, 3D printing concrete is a viable option for future projects and could potentially make extensive reductions to project completion times and, thus, increase efficiency.

**SpeedCore Construction**

In large commercial construction, meaning large office buildings and apartment complexes among others, building structures are built around a solid concrete core and reinforced with structural steel. Figure 4 shows a concrete core construction project being completed.
However, this technique can often be very costly and time-consuming. Due to required concrete curing times construction speed is slowed due to the added time required for the concrete to set and gain strength before proceeding to the next phase. The question is, could the core and surrounding structural components be built in parallel?

There is a new innovative technique, referred to as SpeedCore, that is currently in research and development. In an interview with leaders of the Local 7 Ironworkers Union out of Boston, MA, SpeedCore was discussed as a viable option that is capable of replacing standard concrete core design and construction (Local 7. (February 21, 2019). Personal Interview). This new design is set to be first implemented on the design of Seattle’s new Rainier Square site. Rainier Square Tower will forgo a typical high-rise core, which wraps a steel frame around a concrete core that has been reinforced with steel rebar. The tower will instead use the SpeedCore system which is a modular system of steel plates sandwiched with concrete. A boundary system is set up to shape the core, and then cross-tied plates are moved into place, and then filled onsite (AISC, 2019). According to the designers, this new design is capable of withstanding the design
wind and seismic loads that exist in Seattle. The composite shear wall core design allows SpeedCore to be built at a much faster rate (AISC, 2019). Furthermore, since the concrete is filled in on site between structurally sound steel plates, the surrounding structural components are able to be erected almost simultaneously as the core itself. Figure 5 shows a side-by-side of traditional concrete core construction and composite plate shear wall core construction 172 days into construction:

![Figure 5 - SpeedCore Construction (Right) vs. Traditional Concrete Core Construction (Left) (AISC, 2019)](https://www.youtube.com/watch?v=_joMFRHgwCg)

In a construction simulation of Seattle’s Rainier Square’s construction sequence, conducted by the American Society of Steel Construction, the building was built in just 377 days by using the SpeedCore technique. The traditional concrete core design took over a hundred days longer to complete, as construction lasted 489 days. Throughout the entire build simulation, the SpeedCore construction design is built much faster, and is ahead of the traditional concrete core construction simulation from day 1. A video showing the entire simulation is available here:

https://www.youtube.com/watch?v=_joMFRHgwCg

This new innovation is fully capable of increasing production efficiency and creating more cost-effective designs.
**CO₂ Cured Concrete**

Carbon cured concrete is another innovative advancement for concrete construction. This new type of concrete cures is silicate-based and has a low-calcium content. What further sets this concrete apart from typical mixes is the fact that it gains strength through carbonation instead of hydration. That is instead of using water to cause a chemical reaction in the mix, this concrete absorbs ambient CO₂ which causes a reaction similar to typical Portland cement which hardens the substance. However, the bonds created in the carbonation reaction are stronger than the bonds formed in conventional concrete. This technology is 50 years in the making, but not until recently has it been a commercially viable option (Solidia Technologies, 2018).

Concrete is the most widely used material in the world. Conventional concrete, which includes the use of cement, is the world’s 2nd largest CO₂ emitter (Solidia Technologies, 2008). Carbon sequestered concrete can reduce the carbon footprint of concrete by up to 70%, or about 1.5 gigatons of the world’s CO₂ emissions. Its creators believe that this concrete has the potential to further reduce this contribution in the future. This concrete has the potential to reduce this by more in the future. Water usage during the concrete mixing process is completely eliminated as well, avoiding the consumption of 3 trillion gallons of fresh water required by conventional concrete each year. That is enough water to fill 1 million Olympic swimming pools each year (Solidia Technologies, 2018).

This concrete is a durable replacement for conventional concrete that sequesters CO₂ during curing and can be designed for compressive strength, abrasion resistance and freeze-thaw cycling resilience that are equal to, or better than, that of conventional concrete. CO₂ curing concrete can be a substitute for any concrete application. CO₂ cured concrete is capable of
achieving 28-day strength in 24 hours (Solidia Technologies, 2018). Although, the carbonation curing process doesn’t eliminate the time requirement of concrete curing, it does shorten it. This innovative technology can, therefore, address issues concerning the efficiency of concrete construction, while also having a huge impact on the environmental impact. Carbon-curing concrete is currently available, but is not widely used. This concrete solution is a viable replacement for conventional concrete, and needs to be pursued. This innovation could have a great impact on the future of the construction industry.

**Geopolymer Concrete**

Another innovative solution to the issues surrounding concrete construction is geopolymer concrete. Geopolymer concrete (GPC) is an eco-friendly alternative to conventional Portland cement concrete. Also known as alkali-activated cement, geopolymer cement is made by combining waste materials like fly ash and ground granulated blast furnace slag (GGBS). Fly ash is a byproduct generated from thermal power plants and GGBS is waste generated from steel plants. Together these components are processed as sources of silicon and aluminum. The silicon and aluminum then added with an alkaline activating solution to polymerize the materials into molecular chains to create a hardened binder (Mishra, 2014). Figure 6 shows the typical components involved in creating geopolymer concrete.
Geopolymer concrete gains compressive strength rapidly and much faster to conventional concrete. In fact, after 24 hours GPC has achieved more than 25 MPa; after 28 days this concrete has achieved 60-70 MPa (Mishra, 2014). As a comparison, the high performance concrete currently used today is capable of achieving similar strength in 56 days (Shah, Gohil, Chavda, & Khediya, 2015). Geopolymer concrete may require some heat to initiate polymerization, but is capable of curing at room temperature.

Because of its strength capabilities, geopolymer concrete is capable of the same applications that cement concrete is used for currently. Although the technology of geopolymer concrete is fairly new, this concrete has been used for the construction of pavements, retaining walls, water tanks, and bridge decks (Mishra, 2014). However, GPC is not popularly used today in construction. In 2013, the world’s first structural building, The University of Queensland’s Global Change Institute was constructed using geopolymer concrete. The four-story building was built using three suspended geopolymer concrete floors involving 33 precast panels. This was the first successful use of this innovative concrete. Since then, this concrete has been used on other projects but has not gained much popularity. Able to solve the concrete’s issues of efficiency and
environmental impact, geopolymer concrete is a viable, eco-friendly option to replace current cement concrete that needs to be further researched to potentially have a great impact on construction moving forward.

**Active Support Construction**

Another possible solution to the issues surrounding concrete is through active support construction. Similar to SpeedCore, active support construction could be a replacement to traditional concrete core construction. The term active structure also refers to structures that, unlike traditional engineering structures (e.g., bridges, buildings), require constant motion and power input to remain stable (Khurana, 2009). The advantage of active structures is that they can be far more massive than a traditional static structure. An example of a active support structure would be a space fountain, a building that reaches into orbit.

A space fountain is a proposed form of structure extending into space that can extend to geostationary orbit, but does not rely on tensile strength for support (Hyde, 1985). Since such a tall tower is not capable of supporting its own weight using traditional construction materials, the structure relies on fast-moving pellets inside a vacuum sealed tube to keep it stable. The pellets are projected upward from the bottom of the tower and redirected back down once they reach the top, so that the force of redirection holds the top of the tower aloft. Figures 7 and 8 show simplified diagrams of this potential system.
The idea of space fountains is not new, the design was first proposed by Roderick A. Hyde in the early 1980s. An in depth functional operation description of the above system devised by Hyde is as follows:

“As the projectiles travel upward through the tower they are slowed down by electromagnetic drag devices that extract kinetic energy from the upgoing stream and turn it into electricity. As the projectiles are braked they also transfer some of their upward momentum to the tower structure, exerting a lifting force to support some of its weight. When the projectiles reach the station at the top of the tower they are turned around by a large bending
magnet. In the turnaround process they exert an upward force on the station at the top of the tower, keeping it levitated above the launch point.” (Hyde, 1985).

Active support structures have never been attempted. The technology has many risks associated due to its potential for catastrophic failure. A structure of this nature would also require extremely high energy input. It requires constant power input to make up energy losses and remain erect. The high energy content of the kinetic component of the structure also continually threatens to cause the collapse of the tower if the containment systems fail (Hyde, 1985).

In his initial design, however, Hyde included safety measures. Multiple projectile loops would be utilized to provide redundancy. This would allow for time to make repairs in the event of a loop failure. Furthermore, even if all of the tower’s power sources failed simultaneously, it would take a long time for the tower to fail. This is because the kinetic energy stored inside the projectile loop is much greater than the amount lost to inefficiencies. According to Hyde it would take many hours or days for the velocity of the particles to slow to the point of complete failure (Hyde, 1985). The fired particles require over three hours to complete one full loop. So, in the event of a total destruction of the loop, cutting the flow of projectiles completely, there would still be some time for evacuation.

Theoretically, the system is feasible and capable of creating sound structures. Practically, the concept of active support construction would first be used to build structures of comparative size to current structures. From there, structures could be extended to higher heights. Active support construction is truly a futuristic concept that could potentially be implemented. These
structures would allow for much more functional space within these building as much higher
heights could be reached. These structures also propose a unique solution to recurring issue of
deadweight in construction. Active support construction, although seemingly out of reach, could
be the next great innovation to the construction industry and have a tremendous impact on the
industry’s future.

3. Area of Focus: Fireproofing

Fireproofing is an important safety measure employed in buildings today, required by the
ICC code that serves as the basis of many US and international codes. Spray Fire Resistant
Material (SFRM) is a substance that is sprayed onto steel beams with a cement-like binder and is
a popular fireproofing. Figure 9 shows a steel beam coated in SFRM. Intumescent paint is
another fireproofing method employed today that swells up on contact with heat, becoming less
dense, and in certain types releasing chemicals that retard or cool the fire.
After speaking with fireproofing installers and industry representatives we came to a conclusion
best summed up by one of our sources: the industry is “ripe for innovation.” According to an
interviewee, fireproofing has not seen significant changes since the current spray technique was
patented in the 1970s (Boucher, C. February 14, 2014. Phone interview).
Through our direct observation of sites, we could see that the fireproofing sustains damage during regular use and construction and must be touched up, and even minor changes to plans require reapplication of the material. Fireproofing is also sprayed onto the surface on site which potentially releases contaminants into the air and surrounding area.

A. Safety

We spoke with ironworker union executives about the impacts fireproofing will have on their job. Ironworkers are used to dealing with bare beams and for a prefabricated fireproofing to work it needs to be thin and strong so that iron workers can work around it. It additionally must not be slippery. After this conversation, we explored the feasibility of a non-skid fireproofing coating. This potential innovation would both increase efficiency with pre-applying at least part of the coating and increase the safety for the workers. The non-skid would make it easier and
safer for ironworkers to climb and walk along beams during the erection of structural components during the early stages of a building’s construction. This would be a radical shift from the materials used today such as SFRM or intumescent paint. The materials are applied onsite, which may potentially expose many workers to overspray and increases the difficulty incurred with disposing of the waste.

B. Efficiency

After speaking with an industry professional from GCP Applied Technologies, speaking with a fireproofing contractor supervisor at the BC site, and touring sites, speaking with people working hands-on with the material, durability is a weak point of the fireproofing industry. The coatings frequently need to be reapplied during construction, as they get cut, scraped, worn, changes are made to the structure, or are damaged through other incidents. Durability improvements are needed to increase efficiency through both reduction in reapplication as well as increasing efficiency through the pre-application of fireproofing to materials. The bond strength and physical material durability need to be increased to make the material and industry more efficient. Increased durability will also help with reapplication down the road as regular wear on exposed fireproofing will be decreased. We saw on many of the site visits that fireproofing was worn away, or scarred from work and after speaking with both project managers and fireproofing installers it’s clear that it’s a regular and a lot of productivity, labor, and capital is spent redoing work due to the durability, or lack thereof, of the fireproofing materials used.

Additionally, experts suggested that the material could be combined with materials or suited to perform other duties as well such as acoustic or temperature insulation, or as design or
decorative element. This would again save more material. There would be less time needed for other installers, less material, and faster construction.

C. Environmental Impact

The lack of durability in fireproofing also has a significant environmental impact. Materials are discarded from the removal of the fireproofing and additional raw materials are required to replace it. Additionally, more energy is used to reapply it, the job continues longer which wastes more energy in construction.

Fireproofing does not bond well enough to the substrate to pre-apply and survive transport. If the material bond was strong enough to be applied in a manufacturing facility, the environmental impact would be lessened as well. Manufacturing facilities are better suited to reducing waste, applying more efficiently, and controlling emissions than an open environment in a building under construction. This would expose fewer chemicals and particles to the environment where construction is occurring and move them to a manufacturing facility where they can be handled better.

Additionally, combining fireproofing with another insulation would reduce waste created by a site and possibly use fewer materials. Many of the economic and efficiency benefits that could be achieved in the fireproofing industry also have a net positive effect on the environmental impact of the construction industry

D. Societal impact

The efficiency innovations keep neighboring property owners to the site happier because every increase in productivity and efficiency is less time the building is under construction. This
means less noise, less traffic, less dirt, and an overall better situation for both the client and the surrounding properties.

The reductions in emissions and particles in the air would have a positive effect on the workers and the neighbors to construction sites. The reduction in carbon footprint through more efficient application also has a positive effect on the world. Less energy expended for application, reapplication, and removing waste from the site also contributes to the overall health of the world.

E. Discussion

As laid out earlier, fireproofing would benefit from innovation focused on the binding strength of fireproofing materials. Fireproofing has shown that it is susceptible to damage even on-site, and is surely not strong enough to withstand transport applied to a substrate. Increasing the bond strength of fireproofing to the material below would reduce waste and raw material use to apply to damaged or worn areas. This reduces the environmental impact as well as making the project more economical. Furthermore, it’s a net societal impact because the job will be shorter.

The stronger bond of fireproofing would also allow for the pre-application of fireproofing to materials. Large prefabricated structures could be fireproofed in the manufacturing environment, saving time and space on-site. With a higher bond strength, intumescent paints could be applied to raw steel as well, reducing time and saving space on-site. Additionally, the paints could be applied with a non-skid texture in certain applications that would increase worker safety but without a material that bonds well enough to withstand the rigors of transport it is no feasible.
The pre-application of fireproofing in a manufacturing environment also has its own health & safety, environmental, and societal benefits. Application in a manufacturing facility allows for better air handling, reducing the exposure of other workers to the overspray and any chemicals produced by the fireproofing process. A manufacturing plant is also better suited to deal with waste and better avoids possibly exposing the environment to the waste. Runoff from site dumpsters can be damaging to the environment. A manufacturing facility is also likely to be more efficient than a mobile installation company, both with waste handling and with time and costs. Finally, the movement of tasks from the site to an offsite manufacturing plant keeps workers employed, but reduces the traffic and congestion on-site. Less vehicles, people, and material will need to be on a cramped urban or suburban site. This is better for the on-site employees as well as the neighboring community, while not eliminating jobs or otherwise harming workers.

Experts suggested that the material could be combined with materials or suited to perform other duties as well such as acoustic or temperature insulation, or as design or decorative element. This improves the industry in many of the same ways the other two innovations do: eliminating time, eliminating waste, and eliminating raw materials. This makes the project faster, more economical, and more environmentally friendly, which benefit the company, the contractors, the customer, the community, and the world as a whole.

4. Area of Focus: Supply Chain Visibility

Supply chain visibility, or SCV, is the ability of parts, components or products in transit to be tracked from the manufacturer to their final destination (Rouse, 2009). The goal of SCV is
to improve and strengthen the supply chain by making data readily available to all stakeholders, including the customer. SCV is becoming increasingly more important as certain parts of jobs are outsourced or subcontracted by the companies in charge. Due to the outsourced work, there is often a miscommunication which leads to loss of visibility and control between the two companies operations (Rouse, 2009). The issues with supply chain visibility are apparent on many job sites. In fact, at all of the sites that we visited, it became obvious to us that supply chain visibility and management was an area that would benefit by innovation. In interviewing site managers, we also learned that managing materials and tools was a main concern. Further steps could be taken to improve how these assets are organized and handled on job sites. Supply chain is a crucial part of the construction process, however, there are many issues related to the management and visibility. These areas of concern often fall into the areas of jobsite safety, production efficiency, environmental impact, and societal impact. Due to this, the construction industry is faced with a need to innovate and search for viable solutions.

A. Safety

Supply chain management on job sites is a very important contributor to the safety on job sites. SCV often has one of the greatest effects on the safety of job sites through the organization of materials and tools on site. Currently, not much is done to regulate the organization of equipment, tools, and materials. More often than not, these components are left in “the most convenient” area, however, this often results in a haphazard placement which poses a threat to workers safety. The threat to job site safety as a result of supply chain management is one that can easily be prevented. Innovation in this area could fulfill the need to find a solution to the organizational hazards often created by poor supply chain management practices.
During our site visit to the Hult International School of Business dormitory we were able to see the issues with supply chain management first hand. Similarly, at the Hult project site, materials and equipment were constantly shifting around the site with no clear visibility for all of the workers involved, meaning only those working directly with the materials or equipment had any idea of where they were located. This poses an issue. While talking with the site’s project manager, Bethany King, we realized that organization of certain tools and equipment is left up to the particular subcontractors (King, B. (February 21, 2019). Personal Interview). The organization of sites, or lack thereof, creates the potential for safety hazards. Piling materials and tools almost randomly creates safety hazards, both for fires as well as tripping or falling. In order to help create safer construction sites, better supply chain management is needed. There is a need for organizational software or clarity when it comes to supply chain management on job sites.

Supply chain management technology could help to mitigate human errors as well. As although, not very common, accidents do happen on sites. As pointed out earlier, according to OSHA, the construction industry accounts for almost a quarter of all fatal accidents in the private sector, far outnumbering the next closest industry. The risk of accidentally using the wrong material in the wrong situation can cause a series of hazards down the line. The use of a wrong material could cause a safety hazard or code violation, but this can be reduced when a system is put in place to correctly identify materials and locate them on the site. These concerns with the safety hazards created by poor management of the supply chain create a pressing need to address in order to make construction safer.
B. Efficiency

As described earlier in the background, the operational efficiency of a project is the ability to deliver a successful build in the most cost-effective way possible, while maintaining quality (Construction World, 2018). Supply chain operational efficiency is accomplished by making sure that waste is minimized, deliveries are on time and in the correct location, project scheduling is being met, and delays are minimized. Supply chain visibility great way to increase the efficiency of a project. Innovation in the process of supply chain visibility will be the most useful in increasing efficiency (Hoossainy, T. (February 15, 2019). Phone Interview.).

With little control by the construction company, materials overages send costs up the chain eventually inflating prices for the customer. Additionally, space onsite is wasted storing materials that could hold more workspace, office space, parking, or other uses that make or save money over materials storage. Figure 10 shows a site we visited which has poor organization of its buildings materials. Without a system in place, the company must let subcontractors stockpile material at the site, a common occurrence noted in our site visits. At each site, the project managers told us the same thing: “subcontractors are in charge of purchasing and tracking materials and keeping them in a designated area” (King, B. (February 21, 2019). Personal Interview). This represents an area where a supply chain tracking software or system could create value. With more advanced management, just in time delivery could boost efficiency and reduce storage costs and opportunity costs.
Better management also reduces loss. The company and its subcontractors are virtually powerless to identify delivery errors, loss, destruction, vandalism, pilferage, or theft without a system. Without being capable of identifying which materials should be on site and which are no longer there, it is difficult to correct the error. The current system of “you take care of it” costs the construction company and its customers in the long run.
Additionally with high level management tools at their disposal, project managers could reduce the amount of time trucks sit empty or waiting to be unloaded. Managers could avoid downtime, overlap, and other supply chain issues. Managers onsite reported scheduling unloads via a calendar from talking to subs and occasionally running into issues. Figure 11 shows a construction site’s whiteboard calendar system. This system is inefficient and incapable of keeping up in real time. Sometime subcontractors do not tell management of a delivery, or the delivery driver gets lost or delayed, and other communication issues delay work and tie up equipment. With a high-level management tool at their disposal managers would also be better suited to reduce impacts of higher level supply chain issues.

*Figure 11 - Example of a project schedule (Taken by us during site visits)*
C. Environmental Impact

Throughout our investigation, the environmental impact theme has tied closely in with the efficiency theme. Cutting waste, cutting energy used, cutting the time spent working all make for a greener construction industry. Many of the issues that plague the supply chain management sector are as much efficiency impacts as environmental impacts and the benefits espoused in the previous paragraphs on reducing waste directly reduce the environmental impact of the construction industry. When a project can store less material on site through just in time deliveries, there need be less disturbed area as well. In some cases, this reduced the impact on the local ecology and displaces less wildlife and destroys less natural vegetation.

D. Societal Impact

With better supply chain management there is less opportunities for work stoppages due to supply and product issues. This keeps employees paid, working, and happier. The project will also complete faster and the increased productivity will mean more can be accomplished in a similar time frame. This benefits the customer, the company, and the local community. Additionally the innovations in supply chain management now will be able to be used to build developing countries in the future. The benefits realized from modern technology in a skyscraper in Boston, for example, will also make it easier and cheaper to bring clean water to areas of Africa. However, these technology improvements will most likely be realized and developed in the private sector first.
E. Discussion

As a result of the above findings, we have come up with a number of possible innovative ideas to help solve the issues of supply chain visibility in construction. The ideas described below are futuristic and some are not currently feasible with today’s technology. However, all of the following technologies have potential with further research and could have huge effects on the future of the construction industry.

**Intuitive Interconnected Construction Scheduling**

Scheduling a construction project is no easy feat. This aspect of supply chain management is often the root of many issues. Construction scheduling software refers to a variety of programs to organize, assign, and forecast work on construction projects. Unfortunately by its very nature the industry is not very interconnected or standardised enough when it comes to the supply chain to implement truly interconnected networks to manage timetables and allocate tasks (Reymen, Hoezen, & Dewul, 2006).

We can still look at examples and research to see what impact this would have if such a system was implemented. One only needs to look to companies like Amazon who have mastered the supply chain, its delivery, supply and shipping are down to the second. This is because everything is managed by computer programs and humans are only consulted where needed, this practice optimised the flow of items so that very little time is wasted.

Packages do not spend much time in storage before they are shipped out because they arrive at the best time to depart as soon as possible. In fact there are large hub facilities which serve as a fast track to move product from one coast of the US to the other. While such a
implementation does not fully fit the construction industry we can still take inspiration and apply the parts that do work (Chiles & Dau, 2005).

From our data collection and research we saw that while there are many supply chain tools on the market for multiple of parts of the supply chain but they all specialize in those subsections, no software currently available truly merges the construction supply chain into one cohesive, efficient machine. An Ideal software tool would manage all aspects of the site from delivery tracking, crew management and assignment, storage and sorting of materials to top level updates. This would allow for a cohesive and efficient jobsite which contains little to no delays and completes the projects faster by eliminating the time delays caused by human error.

**Precision Tracking**

There are many new technologies which can cheaply track objects but they all have their downsides and problems (J. Han et al., 2014). From small RFID chips to advanced lidar sensors all of them face a few key challenges stopping their full implementation in the jobsite (L. Yang, J. Cao, W. Zhu, & S. Tang, 2015).

The first is range and penetration, the jobsite is a cluttered place as such signals will have a hard time keeping the entire site covered unless multiple tracking beacons were set up, this number would also have to be scaled up depending on the site size and the type of tracking method used (Amala, Ravichandrabu, & Spandana, 2017). Secondly the software needs to catalog all the items correctly so either they have to be tagged by the manufacturer or they have to be manually tagged once they arrive on the site. Lastly the sorting system on its own cannot shine, it needs a compatible supply chain software to use the data from the tracking sensors to make the work flow more efficient (Papadopoulos, Zamer, Gayialis, & Tatsiopoulos, 2016).
Similar to other examples of supply chain automation the time and money saving from such a system would be substantial as a large percentage of time is wasted in mismanagement and miscommunication on the job site, with the help of a tracking system and supply chain software planning can be streamlined and thus help reduce time wasted (Xu & Luo, 2014).

Overall if the construction industry can overcome the hurdles that come with implementing a live precision tracking system for both people and materials than in conjunction with a good software this technology has the potential to have great synergy with other supply chain tools.

**Photo Recognition**

This technology further ties into precision tracking, while in the past object recognition could only be slowly run on images now with better algorithms we can run it on live video feeds and recognize objects which the neural net was trained to detect using data sets (Shinde, Kothari, & Gupta, 2018).

YOLO is one such object recognition software that can detect and identify objects live from video based on the training data it was fed. Unfortunately even with such advances the object recognition is not precise enough to sort construction site objects and deliveries but if used in conjunction with precision tracking and scheduling software this can add another layer of data which can be setup with relatively cheap camera and a software.

If the accuracy and precision of such object detection can be further increased, these types of software can allow for cheap and easy to set up object and people tracking which can be used to than manage supply chains.
5. Area of Focus: Robotics

Construction often requires precision and skill to accomplish a safe, strong and durable structure. Historically, man has been more than capable of fulfilling such requirements but as structures become bigger and more complex they need more precise tools. Although the repetitive nature of building persists the need for precision and speed grows. As such due to the repetitive nature of the majority of tasks surrounding construction can be augmented by automated machines, or robots.

A. Safety

Construction workers endure many risks over the course of a job, these dangers can range from back injuries from heavy lifting to strikes by falling objects. These risks are mitigated using many existing practices but these risks can be reduced further by substituting humans with robots for high risk activities (Bhattacharjee & Ghosh, 2011).

In our meeting with Local 7 executives we shared a working proposal with them about an autonomous spud wrench, to assist in setting beams. However after discussion, the Local 7 executives indicated a different approach. They disliked our idea, but had something even better to propose. The executives expressed dissatisfaction with the current harness equipment. To scale a beam, they must attach a pulley to the top of a beam, place it, then scale the beam. If they slip and fall, they swing on the harness line, and could suffer serious harm, even if they aren’t falling to the ground.

Our site visits, one of which is shown in figure 12 showed us that robotics is currently underutilized in the field, the main problem is that the construction site is usually very chaotic
and messy as such a pre-generated map cannot be used for the robot and it must have on board sensors and computing if it needs to move across the changing construction site.

Figure 12 - Example of a cluttered construction site in the Boston area

(Taken on our site visit to Boston College)
The ironworkers saw a way to incorporate our previous idea with a safer, more useful alternative in a robotic harness attachment. As described to us, a climbing robot would be most useful as an anchor for a worker’s harness, climbing just a foot above him as to minimize slack and therefore fall distance. Additionally it could recognize a fall and reel in the harness to further minimize the length of the pendulum during a fall. This strategy would greatly improve safety for iron workers.

This is just one application, another is, tools can also be enhanced with sensors and automatic shut offs to minimize the risk from tool blowbacks. Because of the relatively cheap Inertial and Orientation sensors and their fast response times this alongside deep learning algorithms to determine trigger conditions can be universally applied to most hand held tools which can pose a danger to their user.

B. Efficiency

The technological advancements made in recent years allow for greater precision and less energy expenditure, this scales up such that the more automation is applied to a field the more it will benefit from this efficiency. This information was cultivated from interviews and discussions with robotics professors Carlo Pinciroli and Kenneth A. Stafford at WPI and other construction experts. Table 2 shows a table of the professionals that we spoke with along with their affiliations.
Table 2: List of Interviewees and their Affiliations

<table>
<thead>
<tr>
<th>Name</th>
<th>Affiliation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bethany King</td>
<td>Skanska</td>
</tr>
<tr>
<td>Jamie Simon</td>
<td>Skanska</td>
</tr>
<tr>
<td>Professor Guillermo F. Salazar</td>
<td>WPI Dep. of Civil Engineering</td>
</tr>
<tr>
<td>Professor Carlo Pincioli</td>
<td>WPI Dep. of Robotics Engineering</td>
</tr>
<tr>
<td>Professor Kenneth A. Stafford</td>
<td>WPI Dep. of Robotics Engineering</td>
</tr>
</tbody>
</table>

The Ironworkers union addressed that with the help of robots the time needed to perform repetitive tasks could be reduced as the work is streamlined to be more energy and time efficient. Figure 13 shows an example of repetitive tasks on a construction site, securing cross supports among the rafters. As an example that was brought up, the climbing anchor robot would save time when compared to manually attaching the safety hooks every time a new position is needed.

Site visits showed us that a lot of time delays, schedule mismatches and other problems often reduce the efficiency of construction, wasting both time and money. There are many factors that cause this, from miscommunications to traffic and imperfect planning. Compared to humans, robots can ignore a lot of these constraints and can work at the drop of a hat, they can directly be linked to planning software which can direct the work force together with the robots to streamline and optimize work schedules, deliveries and material storing.
C. Environmental Impact

From our site visits and research we observed that there is a lot of disposable items like plastics and waste wood produced from a construction project. This leads to undesirable environmental impact as most of the waste will either need to be recycled which is costly and energy intensive or simply go to a landfill (Arshad, Qasim, Thaheem, & Gabriel, 2018).

Robots used in precise applications are relatively costly and precise constructs. Furthermore, their parts are specialized and they have nearly no disposable items in their construction. However, because of their precise nature they also produce less waste material during repetitive processes, unlike most construction equipment in use today. Similarly, as most
if not all robots run on electricity, robots themselves, potentially, have much smaller carbon footprints compared to most current machines in use. As electricity is transitioning to cleaner sources like solar and wind, the more robotics is implemented, we can expect a decrease in waste energy produced by construction.

Our interviews indicated that although the environmental impact caused by waste products that can be eliminated by automation with robotics is relatively minor compared to the global waste, any improvements towards reducing waste is important.

D. Societal Impact

As more automation and robots are introduced into the industry we will see the costs of construction go down, though this is likely to be a slow process and with current technology and building methods, in the various types of build sites too much automation is impossible.

As prices go down more infrastructure development will be possible in developing countries accelerating construction worldwide. Automation makes prices go down and thus makes commodities and services more widely available, this can be seen in many industries which have slowly integrated robots into their industries (International Federation of Robotics, 2018).

E. Discussion

Through our findings, as presented above, we were able to identify a number of possible innovative ideas to help solve the issues of robotics in construction. The ideas described below are futuristic, but most are actually feasible with today’s technology. All of the following
technologies, however, have potential with further research and could have huge effects on the future of the construction industry.

**Flexible parts**

Traditionally flexibility in parts has been known to be bad though this view is now changing with new advances in the field of flexible or compliant mechanisms (Chen & Howell, 2018). There are many benefits to using these compliant mechanisms, to start with they are easily mass producible as they are essentially made of poured materials that can be sliced in accordance with a template to increase production speeds. Because of the materials they are made of and the low cost of production these mechanisms are vastly less expensive to their alternatives (Nelson et al., 2016). Figures 14 and 15 show an example of a compliant mechanism in the form of a switch. Switches like this can be easily mass produced and scaled to have tremendous impacts on robotic electrical components by replacing the current switches.

![Compliant Mechanism: Switch #1](Compliantmechanisms.byu.edu, 2019)
Another advantage is their reliability, because these mechanisms are made of a single cast; they do not contain rivets, joints and other such structures which would result in bend and tear of the mechanisms. Because of this new types of mechanisms can be created which are more efficient, as an example we can look at the three degrees of freedom motor mount which previously required three motors but as a compliant mechanism only requires two for a full range of movement (Aten, Zirbel, Jensen, & Howell, 2011). Figure 16 shows an example of such a compliant mechanism. This particular mechanism was used to stabilize the robotic thrusters of a NASA spaceship. Again, mechanisms are capable of replacing previously complex and expensive components of robots.
Another example is the traditional spring, usually springs need be maintained and are quite hard to make to exact specifications, increasing their cost. With compliant mechanisms you can get a reliable spring force to your custom specifications, thus allowing cheap and exact force vectors for your compliant mechanism spring (Yu, Howell, Lusk, Yue, & He, 2005). Figure 17 and 18 shows a compliant spring mechanism.
Overall these mechanisms have a vast array of uses which have only been researched for the past few years, as such they have the potential to act as a catalyst for a new string of breakthrough in robotics and thus automation.

**Sensors to prevent kickback**

As sensor technology becomes cheaper and self-learning algorithms become better we hit a breaking point where it is extremely inexpensive to include automatic sensor based cutoffs controlled by a machine learning algorithm. This research is very elementary and only just emerging but it holds potential to increase the safety of tools by an order of magnitude. This has only been tested on handheld saws but the basic method can be applied to nearly any tool (Lantern LLC, 2019). Figure 19 shows a saw equipped with a sensor that automatically shut the saw down when kickback occurred.
Figure 19 - Saw equipped with a kickback sensor (Lantern LLC, 2019)

The initial tests use a nine axis accelerometer, a gyroscope and a magnetometer, the data from these sensors from hundreds of normal uses fed into a neural net which learns detect kickback and stop the saw as soon as a kickback event as seen in figure 19 is detected. Normally human reaction times are simply not fast enough and even when they are human instincts might not always let go of the machine trigger instead grab on tighter, keeping it turned on; but with the sensors constantly reading your user data the neural network can within milliseconds, detect dangerous behavior, and turn the machine off, preventing an accident. A video demonstration of this technology in action is available here: https://www.youtube.com/watch?v=OdW7vhYYSdM

These advancements hold a lot of potential as small sensors become cheaper and software for detecting potential accidents becomes more and more accurate we reach a tipping point where it becomes practical for all tools to include this safety feature.
Automated Material Movement System

As new breakthroughs in supply chains happen we are forced to create and design better robots to keep up. This was the case in Ports of Auckland in New Zealand. The port of Auckland is stuck in the middle of a rapidly expanding city with no land to reclaim and no way to expand out to sea as such to meet the growing shipments in the cramped space of the bay they had to innovate to keep up. Part of this plan are their hundred-ton autonomous robots guided by nanosecond-precision tracking, as depicted in Figure 20.

These robots are extremely heavy duty as such to prevent accidents they have a multitude of safeties build in, live tracking, laser sensor based automatic shut offs and a human handler keeping an eye on the pathing to prevent collisions. The key part that allows all these to work is the localized location tracking grid, three sensor arrays in the bay, at all times, triangulate and keep track of the location and orientation of the fleet of autonomous robots, this allows for the needed nanosecond precision which allows these robots to load and unload shipping containers on a automated, optimized schedules.
Figure 20 - Port of Auckland autonomous cargo transports (The Hundred-Tonne Robots That Help Keep New Zealand Running, 2019)

Perhaps even more importantly this is a rare testbed for autonomous vehicles and humans working together. Figure 21 shows a human-operated vehicle working among the autonomous ones. Where on one side of the ports human drivers load and unload containers from ships these autonomous carriers than take these containers and autonomously sort and stack them. Because human drivers are faster at unloading ships and those ships have different storage configurations, autonomous systems do not work well here on the contrary where humans need further input and more time to sort and stack the containers is where the robots shine cutting down on both costs and time.
One can easily imagine such robots carries pallets instead of shipping container, moving around a busy construction site, optimizing and automating the flow of large deliveries to the job site. Moreover, with humans and such robots working in conjunction on what they respectively excel at time and money savings are further increased. But this is still a very rigid system and there are many challenges that need to be overcome.

**Skanska Proposal**

The following chapter is another result of the report. As mentioned earlier, our group worked with the support of Skanska throughout the process. As a result the report culminated into two proposals for different innovative technologies. Below is the proposal submitted to Skanska:
Construction Innovation In The Year 2030:
Innovation Proposal of
The Autonomous Spud Wrench
&
The Autonomous Harness

Prepared for: Skanska US (Boston)
Prepared by: Tyler Marsh
             Treksh Marwaha
             Connor Murphy
Today’s construction sites are full of many perils and as designs grow more vast and complex many more are introduced. Safety on these sites sometimes is overlooked as project efficiency and cost-effectiveness take higher regard. As a result, one of the most prevalent concerns with the construction industry today is safety. The Occupational Safety and Health Administration, better known as OSHA, estimates that there are nearly 6.5 million people working on construction sites nationwide each day. The safety of these workers needs to be of utmost importance. In recent years, regulations have been implemented to help increase workplace safety, especially on construction sites. However, accidents do still happen. According to a 2017 report from OSHA, across the private industry, there were 4,674 worker fatalities. The private industry includes restaurants, businesses, and construction among others. Out of those deaths, about 21% were from construction accidents alone. In other words, one in five worker deaths in 2017 were in construction-related accidents. This fatal injury rate on job sites is much higher than the other industries included in the private sector. Furthermore, almost half of the fatal accidents associated with construction were from falls or being struck by an object. These falls typically occur during one of the most dangerous times in construction: erection of the structural steel.

Possibly one of the most dangerous tasks on construction sites is setting and erecting the structural steel, according to experts from The Local 7 Ironworkers Union. This feat is still done by hand, starting with the very first beam on the leading edge. This puts workers in a very unstable situation. As the worker must balance on the beam while using a tool known as a spud wrench to align the bolt holes on both the column and the I-beam. Workers are required to wear the appropriate safety harnesses, but even these fail on occasion. A product that could automate
this process or assist the man in some way would greatly reduce the risk of injury, or death, to workers while setting the structural steel.

1. **The Autonomous Spud Wrench**

We are proposing two similar, but different products that have not yet been implemented into the industry. Both innovations aim to make this key aspect of construction much safer for workers. The first of the two innovative products is what we are calling an “Autonomous Spud Wrench.” This product aims to fully automate the setting of structural steel beams in the early stages of construction. By automating this process, humans can be removed from a very dangerous situation. In turn, this will greatly reduce the threats to workers safety on construction sites.

The Autonomous Spud Wrench (ASW) would climb a vertical I-beam column to assist in setting beams in construction. Once the robot reached the appropriate spot on the column it would then operate as a robotic spud wrench by aligning the bolt holes of both the column and the beam. By taking care of this dangerous task and providing the human worker a much sturdier platform to stand on, the leading edge beam can be placed much more safely. With the ASW, all the human worker needs to do is attach the bolts themselves.

We believe that this product can be brought to fruition through WPI’s MQP process. As there are many components working together in such a machine (robotic systems, mechanical systems, electrical systems), we think that this project may be best accomplished through interdisciplinary teams or a multitude of teams working in tandem. A project of this nature would require students with some robotic engineering backgrounds, mechanical engineering backgrounds, and civil engineering backgrounds among others. Although this may take multiple
teams working in tandem, we believe it will have a huge impact on today’s construction processes.

The scope of the MQP would cover the complete design of the machine, a prototype, and testing. The design of the machine would have to take into account the many regulations and standards enforced by OSHA while also maintaining its effectiveness. With WPI’s resources and Skanska’s support, a prototype for an ASW is feasible. Furthermore, with the connection of both supporters, proper testing would also be feasible. In order to create an effective product, all of these facets of design must be taken into account. We do not foresee this project being completed in just one project cycle, or a year. Instead, we believe that many iterations will need to be passed and tested in order to reach a final viable design. Since no real product such as this exists today, as far as we are aware, this work could pioneer a substantially impactful innovation. We believe the Autonomous Spud Wrench is a very viable innovation that, when developed, will have an immediate impact on the construction industry.

2. The Autonomous Safety Harness

The second innovation proposal is very similar to the Autonomous Spud Wrench in that the focus of this product is to eliminate the threat posed by erecting the leading edge beams. Unlike the Autonomous Spud Wrench, Autonomous Safety Harness (ASH), as we call it, would not take the work from the human, but would instead give him or her a safer environment to work in. ASH aims to replace the current safety harnesses that protect construction workers. Our safety harness systems are applicable in many more situations as well. Instead of being specialized in only beam placement as the ASW was, the Autonomous Safety Harness could be
used throughout the job site at any stage where there is a risk of falling. Thus, this product would have an immediate improvement in worker safety on construction sites.

While meeting with executives of the Local 7 Ironworkers Union, we shared our idea of the Autonomous Spud Wrench with them. They were not found of taking work out of the worker's hands. Instead of shooting the idea down, however, the executives offered an idea of an alternative to our I-beam climbing robotic spud wrench. The executives suggested a more inclusive tool to help make the industry safer: a smart, automated harness. Our smart harness would operate similar to our spud wrench, in that the harness would climb beams or columns above the worker to ensure his or her safety in the event of a fall. With an automated harness moving with the worker, near limitless mobility is achievable on a construction site, while maintaining assured safety. Thus eliminating the need for ropes and cables to be attached to a structure or beam before it is erected.

Another feature of our smart harness is that the robot would operate with sensors to ensure that the worker would always be within the correct range to limit slack in the line. This means that in the event of a fall, a worker would have less shock imparted on their body as a result. The worker would also have a smaller radius of motion on the tether. Additionally, the sensors on the robotic harness would also then sense the sudden change in force on the system and begin to slowly retract the worker until he or she was safely back on a stable platform. Altogether, these features would allow workers much more freedom to move throughout the construction site, while maintaining safety.

Again, we believe that an MQP would be a great way to develop an innovation such as this. Like in our spud wrench, there would be many different components working collectively to
operate the product. As before, we believe a multi-team approach is the best way to tackle the
design and building of this product. The development of a product of this nature would be a
substantial undertaking and would likely take multiple iterations to create a successful prototype.

As with the Autonomous Spud Wrench, the scope of the MQP would cover the complete
design of the machine, a prototype, and testing. The harness design would have to take into
account the many regulations and standards enforced by OSHA while also maintaining its
effectiveness. Unlike our spud wrench proposal, which is very open-ended, we envision our
smart harness small in stature and easily transported about the construction site. We believe in
order for the harness to effectively replace the current harness and tether system, the design of
our smart harness needs to be mobile and easy to use. We foresee the device being carried
alongside the worker and simply attached to an overhead column or beam, where the robotic
system would then initiate and follow the worker as he or she worked.

With WPI’s resources and Skanska’s support, we can viably create and test a functioning
prototype smart harness. In order to create an effective product, all of the facets of design must
be taken into account, for instance, the device’s ability to be transportable, its capability of
supporting required loads, and its ability to be easily implemented on construction sites. We
foresee this project taking at least a couple of project cycles, as we think iterative designs might
be best to achieve what we believe is possible. Furthermore, we would recommend possibly
bringing in the Local 7 Union to provide expertise on the matter. They could bring a number of
resources to the table to help with testing prototypes. Since no harnesses such as this exist today,
as far as we are aware, this work will explore a new frontier. We believe our smart, automated
harness will be a substantially impactful innovation and needs to be further pursued.
V. Summary of Our Findings

Through our project, we have found a myriad of innovations in four areas that address the themes of safety, efficiency, environmental impact, and social impact. They address concrete, fireproofing, supply chain management, and robotics.

Concrete Innovations

Additive manufacturing is essentially concrete 3D printing. A gantry is set up with a moveable nozzle and concrete is pumped into the nozzle. The concrete is kept in a thick firm slurry, so that it will hold it’s shape and harden enough by the next pass that it will keep it’s shape under the weight of the building wall. This technique eliminated the need for forms, and eliminates the time spend setting them up. It also allows for shapes to be created that are otherwise impossible with a traditional form. Once the gantry is built, it also allows for faster paced pouring than traditional forms.

Speedcore construction is a prefabricated core construction technique that builds the steel core form structure offsite with all necessary hardware and reinforcement pre attached so that it can be set into place and filled with concrete on-site, to form a stronger core and speed the process of construction. The steel structure is able to bear weight as the concrete cures which means the process can be accelerated.

CO2 cure concrete cures with a carbon dioxide reaction. The concrete absorbs ambient CO2 as it hardens, forming stronger bonds than portland based cement’s hydrocarbon bonds. It also reduces the carbon footprint of concrete by offsetting emissions.
In a similar trend, geopolymer concrete uses byproducts of other industries as components to create greener concrete. It recycles these byproducts into a hardened binder.

Active support construction uses kinetic energy to keep a structure stable. It is a concept that utilizes a closed loop and electromagnets to circle particles or weights in order to stabilize the surrounding building.

**Fireproofing**

Our fireproofing innovation centers around one concept and a corollary to it. Fireproofing routinely sustains damage onsite and is clearly not strong enough to withstand greater rigors. However with a binding strength improvement, pre-fabrication of fireproofing materials would allow for numerous savings as well as benefits to the workers and surrounding environment. It would make it easier to reduce and manage waste and emissions.

**Robotics**

Robotics allow for faster, stronger, more precise construction than humans are capable of. They allow for cheaper and safer construction in many areas. Innovations such as flexible parts are making robots even cheaper by being easy to produce and requiring less moving parts. They are also making construction safer through kickback sensors that prevent injuries. Additionally robots can handle tasks like materials handling, making the craftsman’s job easier. Lastly, an autonomous safety harness could prove to be a lifesaving innovation, reducing falls, injuries, and damage while also allowing for easier, freer movement for workers tomorrow than they have today.

**Supply Chain Visibility**
Our research ideas concerning SCV showed great promise, out of all our ideas it is much easier to implement because most of the challenges concern software which can be rapidly prototyped and improved. As tracking becomes cheaper and easier and we find better use of the data from such sensors using neural networks and algorithms, using them make workflows more efficient and convenient to analyse. Supply chain plays an important role in the construction industry and innovations such as object recognition, cheap object or people tracking and optimizing softwares can help drive the industry forward, reducing costs and increasing time efficiency.

VI. Conclusion

The Construction Innovation Interactive Qualifying Project sought out to answer the leading focus question: “What will the construction industry look like in the year 2030?” By the end of this project, this focus question was answered within the context of the study and produced a detailed proposal of all studied technologies in terms of their applicability to the construction industry.

We used a multitude of methods to collect data and then analyze it to select the appropriate ideas for innovation. In determining which technologies were the best, we first consulted a panel of industry experts in order to identify which sectors of construction needed advancement. The experts pointed us in the direction of four specific areas of construction. These areas consisted of concrete, fireproofing, supply chain visibility, and robotics. The accumulation
of the results in all of these categories allowed for a proposal of specific innovative solutions to the current problems surrounding the construction industry.

The research done in this project reflects the current moment in time. Technology advancements are unpredictable and innovations surge and seize at random moments in time. The results of this project reflect the current data as well as both current and foreseeable innovative technologies that are applicable to the four areas of construction, as described above. The opportunities for innovation in each of these areas are very broad and encompass many aspects of each process, but each innovation has proven to address many themes of focus that were also identified as important drivers for innovation by our expert panel. These themes ultimately were identified to be safety, efficiency, environment, and societal impact. All of our proposed solutions are capable of fulfilling the needs in each of the areas. Although some may need more research to make the innovation more applicable, all of the innovative ideas are capable of having a real impact on the future of the construction industry.

The construction industry as a whole is in need of innovation and advancement. Its inability to rid itself of complacent practices and techniques has caused the industry to become stagnant and resistive to innovation. There are many technologies that hold promise to revolutionize the construction industry, however, the ones proposed are the most viable and impact worthy. It is only a matter of time before one or more of these innovative ideas succeed. That is why we recommend further research into our proposed technologies. We believe that this will best be accomplished through the use of a future Major Qualifying Project or a graduate research project. In doing so, the selected innovation will be the sole focus of the project and implementation could possibly be achieved. Projects like these could have longstanding
implications for the future of the construction industry, as we are on the cusp of innovation that will change construction forever and bring great revival to the stagnant industry.
References


Division of Instructional Innovation and Assessment(2007), The University of Texas at Austin. “Guidelines for Maximizing Response Rates.” Instructional Assessment Resources.


Appendix A: List of Interview Questions

- What is your current role within your company?
- Do you have an area of expertise that you specialize in or oversee?
- What are the current processes that your company implements when working to complete a job as efficiently as possible?
- How successful are these processes?
- What limitations, if any, do you see with the current processes?
- Have you noticed any areas of improvement, whether it is with the tools, processes, techniques or the products themselves?
- Are you currently looking to improve on any of your techniques, processes, or products?
- When on a job site how do you typically communicate with PMs and subcontractors?
- How do you see the role of robotics affecting your sector of the industry?
- Where do you think the technology within your company is going?
- Are you aware of any upcoming innovations in your field?
- Where do you see the construction industry moving towards in the coming years?
- Where do you see your company’s field in the coming years?
Appendix B: Complete List of Interviews

- Craig Boucher- GCP Applied Technologies
  - Spray on Fireproofing
- Bob Hoopes- GCP Applied Technologies
  - Concrete
- Tauhira Hoosainy- Milwaukee Tool
  - Supply Chain Visibility
- Local 7 Ironworkers Union
  - Supply chain visibility, concrete, fireproofing, robotics
- Subcontractors- On site of Skanska build site
  - Concrete, supply chain visibility, fireproofing
- Professor ___ - Robotics Department WPI
  - Robotics
- Catherine Rose- AutoDesk Innovation Studio
  - Robotics
- Project Manager Elizabeth King- On site of Skanska build site (Hult Dormitories)
  - Fireproofing, concrete, supply chain visibility
- Project Manager Jamie Simon- On site of Skanska build site (Boston College Rec Center)
  - Fireproofing, concrete, supply chain visibility
Appendix C: Survey Results

Survey Response Analysis

https://www.surveymonkey.com/results/SM-6RG5M6H3V/
Appendix D: Complete List of Generated Ideas

- Idea: RFID Chips to Sort Materials
- Idea: Live Camera Feeds for Cranes/Radio Directors
- Idea: Safety Harnesses / Hooks
- Idea: Self-Healing Concrete
- Idea: RFID Chips to Sort Materials
- Idea: Thinner Fireproofing
- Idea: Robots Installing Steel
- Idea: Thinner Fireproofing: Fireproofing / Acoustic rating in one application
- Idea: Live Camera Feeds for Cranes/Radio Directors
- Idea: 3D Printing
- Idea: Animals/Swarm Robots
- Idea: Safety Harnesses / Hooks
- Idea: Thinner Fireproofing
- Idea: Optimization Simulation Software
- Idea: Optimization Simulation Software
- Idea: Water Absorbent Buildings
- Idea: Safety Harnesses / Hooks
- Idea: Live Camera Feeds for Cranes/Radio Directors
- Idea: Live Camera Feeds for Cranes/Radio Directors
- Idea: Robots Installing Steel
- Idea: 3d Printing
- Idea: Underground Buildings
- Idea: Animals/Swarm Robots
- Idea: Animals/Swarm Robots
- Idea: Repetitive Robots