CII RT-DCC-01 Research Topics



**University of Colorado Boulder**

**University of Texas at Austin**

**January 11, 2018**

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# Overview

Through the efforts of Phase I, RT-DCC-01 developed 29 potential research topics. Phase II involves prioritizing the topics in order to develop a research roadmap with the intention that if the topics were researched and developed that the comprehensive implementation could double productivity. Please read each topic and reread them again in attempts to become as familiar with each topic as possible. During our next meeting in Boulder on January 23rd and 24th, you will be asked to prioritize each topic on a series of metrics. As you review each topic, begin considering how you might rate each topic according to each of the following metrics.

**Unit Rate**: As a labor productivity measure, unit rates are defined by the equation: . This is a common measure used to measure the productivity of specific construction tasks and activities and is utilized in many project labor reports. ***How would each topic relatively improve construction tasks and activities’ unit rates?***

**Direct Work Rate**: Collected through activity analyses or work sampling studies, direct work rate is the percentage of time that a craft worker spends in the act of either exerting physical effort to perform an activity or of physically assisting in these activities. Direct work often involves the installation of materials, but it also includes the physical effort of support groups. Direct work rate can often be referred to as “tool time” or “wrench time”. ***How would each topic relatively improve craft workers’ direct work rate?***

**Feasibility to Create**: Each of the following topics will require a level of research to develop the concept to the point where it could be implemented in the industry. RT-DCC-01 has been charged with developing a five-year research slate for the DCC. It is possible that some topics may require only a one-year research topic while other topics may require multiple years. ***How feasible is it to create the technology or process considering available resources?***

**Feasible to Implement**: Once a topic has been researched and developed, effort is still required for any company to implement a new technology or process on any of its projects. For example, some topics may involve retraining a workforce, new contractual relationships among project stakeholders, and investment in new equipment to name just a few examples. ***How feasible would it be for each topic to be implemented on most downstream and chemical sector projects?***

**Long-term Longevity**: The longevity of any process or technology can be thought of as its lifecycle. Once a concept goes through its innovation and commercialization stages, it then proceeds through diffusion where the process or technology becomes adopted and used. The final stage is often referred to as the substitution stage, when the process or technology declines in use and ends in eventual extension, due to replacement by other processes and technologies. Many characteristics can prolong the diffusion stage, such as a technology’s adaptability to different type of projects and design. ***How sustainable and adaptable is each proposed topic to future changes? How useful will each topic be to different types of projects in the downstream and chemicals sector?***

CII RT-DCC-01 Research Topics

01 Goodrum

# Use of 3D Printing Beyond Engineering and Design

The use of 3D printing to develop scaled physical models of engineering design is being used to convey design concepts for client presentations. It is also being used for task planning among construction crews, especially for activities involving complex spatial operations. However, 3D printing technology has potential to transform other project phases, including construction and operations and maintenance. Large scale 3D printers and additive manufacturing have the capability of using construction raw materials (e.g. concrete, metals, and high-density plastics) to develop full scale assemblies (e.g. wall sections) and facility parts (e.g. gaskets and valves). Agencies such as the National Aeronautics and Space Administration have begun examining how 3D printers can be used to develop on-demand supply chain solutions to provide needed tools and parts. The entertainment industry has also been using 3D printing technology to develop full scale audio animatronics and different aspects of set design. The purpose of the proposed research is to explore how 3D printing can be used beyond engineering and design and as a potential new process for construction and to help support a facility during operations and maintenance. 3D printing has broad potential, ranging from small scale and standardized components to large-scale customized components.

02 Caldas

# Increasing the Use of Advanced Work Packaging

Advanced Work Packaging (AWP) promotes a disciplined approach for project planning and communicating project scope from conception to turnover. The deliberate engineering and construction management practices required in AWP are essential to improving craft labor productivity and predictability. By supporting more precise and detailed planning, AWP holds the promise of fundamentally transforming the capital project delivery process and providing significant productivity benefits. Case study results showed a strong relationship between AWP implementation and higher project performance, compared to traditional planning and execution processes. Even though AWP became a CII Best Practice in 2015, its use among companies in the downstream and chemicals sector is still limited. This project would identify the barriers to using AWP and how to remove them.

03 Hallowell

# Utilization of Artificial Intelligence to Improve Construction Execution

Artificial intelligence (AI) has begun to see rapid implementation across industries, ranging from driverless vehicles to children’s toys. AI has potentially broad application to improve construction execution as large datasets can be used to optimize construction sequencing, monitoring, predictive analytics, and adaptation to unexpected changes, to name a few. AI can be achieved, for example, by customizing machine learning algorithms that are able to predict outcomes based on latent patterns that would require enormous efforts from humans to recognize them. Additionally, optimization of construction planning may be achieved using cognitive computing and neural networks.

This topic would involve exploration of the many AI strategies being implemented across industries to identify high-reward opportunities. The team may also explore how existing AI may be leveraged and adapted for near-term construction applications and how customized AI can be used to make radical changes in future operations.

04 Goodrum

# Advancing Parametric Design through Artificial Intelligence

Too often, construction crafts are forced to build a project with imperfect design information. From the craft perspective, the challenges are not necessarily related to design decisions made during preliminary design, although there is always room for optimizing a design. Rather, craft workers are impacted from missing, conflicted, and erroneous information developed during detailed design when the focus of design is the development of construction documents. Building information modeling made significant gains in reducing conflicts in drawings. Clash detection reduces spatial conflicts across multiple building systems, and a designer only has to enter a dimension once on a model for it to appear in multiple sheets of a blueprint. Parametric design is already being used to automate aspects of design; for example, some systems allow a designer to define the centerline of a proposed pipe, then the system generates the inside and outside diameter of the pipe along with the required pipe hangers. However, the accuracy and consistency of information is still subject to human error. Other fields, such as medicine and software development, have learned how to leverage artificial intelligence to reduce human error. For example, future medical information systems are being designed to help ensure that a prescribed medical treatment matches a patient’s needs and is compatible with the patient’s medical background before treatment is provided. How can artificial intelligence be utilized to improve the automation of design so that future design systems not only generate an optimized design but also ensure that the precise information is provided on the construction documents to help ensure construction crews can install the system on the first attempt every time?

05 Goodrum

# Workforce 2030: Recruiting the Next Generation of Construction Craft Workers and Beyond

There is a prolonged shortage of construction craft workers, and the average age of construction craft workers is increasing significantly as a result. While there is much that can be done to better utilize the existing workforce (e.g. multiskilling, automation, modularization and prefabrication), these solutions still hinge on the ability of the industry to attract the next generation of construction craft workers. Traditional industry recruiting strategies focus on the prospects of career growth and high wages among the construction trades, however there is growing evidence that other job characteristics are even more important to the future workforce, such as the opportunity to improve society and the physical act of building something. The construction industry is not alone in competing for the next workforce generation. Other industries, like manufacturing, are increasingly focusing on how to better communicate the work they do to better recruit the next generation in addition to communicating the career pathways including the education and training required to enter those industries. In construction, the career pathways often differ for each construction trade in terms of the years of training and types of certifications required. How can the construction industry better recruit the next generation of construction craft workers? The average age of the first-year trainee in many craft training and apprentice programs is in the late twenties when it should be closer to 18, so how do we close the gap? This research would include large scale surveys to understand attitudes, opinions, and other barriers to entering the construction workforce, as well as designing and testing interventions to reduce those barriers.

06 Goodrum

# Redefining how we Train the Next Generation of Construction Craft Workers

Rebuilding the U.S. construction workforce requires us to reexamine how we train the next generation of construction craft workers. There are outstanding formal craft training programs throughout North America, but how do we increase their exposure to more individuals? How do we better prepare students beginning in secondary education to be both career and college ready in order to be more successful when they enter a formal construction craft training program? Is it possible to expand apprenticeship and other craft training opportunities beginning in high schools and would this have a positive effect on an individual’s career path? How do we expand the apprenticeships and other work-based training programs? Finally, how do we better measure the number of qualified craft workers so that as a nation we can better direct the necessary resources to expand craft training where needed? The project may evaluate how the clients and contractors can collaborate to boldly pool resources for the development of targeted training programs, which could have dramatic long-term returns on those investments.

07 Sears

# Beyond Hand Tools: The Use of Exoskeletons and other forms of Body Augmentation to Better Equip the Way Construction is done

Humans have been experimenting with various forms of body augmentation for centuries. In fact, if clothing is considered a form of body augmentation, then many researchers believe that we’ve been doing so for at least 100,000 years. In the 1700s, eyeglasses were invented for improving vision, and today we have contact lenses, pacemakers, hearing aids, wheelchairs, prosthetics, and orthodontics. It is also not unreasonable to classify Personal Protective Equipment (PPE) as a form of body augmentation. Traditional body augmentation has sought to protect body parts from extreme conditions or to repair broken body parts, but today, new technologies are beginning to *enhance* the human body. Militaries are developing exoskeletons to enhance the endurance and strength of their soldiers (Wehner 2017), and companies like Sarcos Robotics are developing similar, powered exoskeleton suits for industrial applications (“Sarcos Guardian XO” 2017). Ekso Bionics’ passive exoskeleton allows a craft worker to hold a 40-pound tool overhead, nonstop for hours at a time (Rogers 2017).

This project should explore the many aspects of the human body that could be augmented and improve performance, safety, and worker wellbeing. In addition to exoskeletons, other forms of augmentation could include, for example, body cameras that allow for the study of the movements of individual workers and search for inefficiencies, and smart contact lenses that provide augmented reality vision, allowing them to see through walls, or see bright flashing lights around safety hazards. The project should explore the various forms of body augmentation that exist today, as well as body augmenting devices currently under development, and identify ways in which these technologies may be used to improve construction productivity or improve construction productivity data collection.

08 Caldas

# Redefining the Owner and Contractor Relation to Promote Innovation

Owners and contractors increasingly question the effectiveness of current project delivery and contracting strategies, since many projects don’t meet their cost and schedule performance, and often do not achieve the desired results for all stakeholders. These frustrations include misalignment of expectations, incomplete hand-offs between phases, ineffective project organization, change orders, and claims. Recently, innovative project delivery strategies, such as Integrated Project Delivery (IPD), have been proposed to improve stakeholder alignment, coordination, and collaboration. This study would analyze innovative project delivery strategies and contracting methods aimed at redefining owner and contractor relationships, increasing collaboration, and promoting better project outcomes. This may include, but is not limited to, innovative project delivery strategies, contracting methods, shared investments, and shared incentives.

09 Caldas

# Real-Time Data Collection and Analysis of Construction Activities for Productivity Improvement

Advances in information technologies, computing, and sensing have created new opportunities for collecting and analyzing activity-level productivity data in real-time. These technologies can be used to enhance many tasks aimed at supporting productivity improvement efforts, such as automated labor productivity assessment, rework reporting, and real-time tracking of commodity utilization, among others. Examples of these technologies include RFID, drones, and video cameras, among others. This project would identify the technologies with higher productivity improvement potential and define appropriate implementation strategies. Potential benefits include reduced control cycles, increased ability to gather leading indicators of productivity performance, and improved capability for proactive identification and mitigation of productivity barriers.

10 Sears

# Unlocking the Productivity Paradox through Big Data Collaboration

The construction industry tends to keep trade secrets and protect proprietary information that is perceived to promote competitive advantage.. For example, it is not uncommon for a dozen competing contractors to prepare their own quantity takeoffs for the exact same scope of designed work, and it would be very surprising to find any collaboration among such contractors regarding estimation accuracy. This culture of secrecy also extends into engineering design, where companies seek to protect their investments in R&D through intellectual property. In other industries such as the tech industry, it often seems that no sooner has one company developed a new product or process than another company has reverse-engineered the product or process. This phenomenon may partially explain why, in 2014, after several years of ever-escalating litigation, Google and Apple agreed to drop all of their patent lawsuits against one another (Kopytoff 2014). Also in 2014, Tesla declared that they would “not initiate patent lawsuits against anyone who, in good faith, wants to use [their] technology.” Tesla’s words for doing this were that it was, “in the spirit of the open source movement, for the advancement of electric vehicle technology” (Musk 2014).

The proposed project should investigate whether constituent companies of the construction industry truly receive unique competitive advantages from proprietary information, processes, and technologies, or whether efficiencies can be realized through the sharing of certain pieces of information. The project could explore where sharing of proprietary information could yield dramatic efficiencies in the industry, how risks associated with sharing of proprietary information could be mitigated, and specific forums where sharing could occur.

11 Van Boven

# Understanding the Barriers in Racial and Gender Diversity in the U.S. Construction Workforce and Developing Pathways to overcome them.

Limited workforce of U.S. construction workers is a major barrier to productivity. Restricted workforce limits diversity of ideas, increases turnover, and increases employment costs. One means of increasing the size and quality of the workforce would be to increase its ethnic and gender diversity. Yet, many women and ethnic minorities may be reluctant to join a workforce if they experience and perceive discrimination, prejudice, and sexism, among other construction workers. An important research agenda is (a) to examine the prevalence of perceived (and real) prevalence of prejudicial attitudes regarding racial and gender diversity in the construction workforce, (b) to develop and test interventions to reduce perceived (and real) prejudice surrounding racial and gender diversity, and (c) to test communication strategies targeting a more diverse workforce. The study may also explore how other industries have broken traditional barriers and how the construction industry can make itself more attractive to traditionally under-represented groups.

12 Goodrum

# One Facility, Multiple Companies: Utilizing Facility Parks to Improve Capital Efficiency

The U.S. manufacturing industry works on the paradigm that companies primarily build and operate the facilities in which their products are made. There are instances where multiple companies operate in a single manufacturing facilities and within the same battery limit. Primarily, this appears to occur because of corporate mergers and acquisitions. This topic examines a new business model where a facility is designed to purposely support multiple companies, where each company would purposefully share infrastructures and industrial enterprises. How could this model improve capital efficiency for a company to develop a new product if the cost of building or renovating an existing facility is dramatically reduced? One global example of this model is the Marl Chemical Park, located in Marl, Germany (<http://www.chemiepark-marl.de/cms/cpm/en/Pages/default.aspx>). This facility hosts thirteen different companies, and its focus is the conversion of petrochemical raw materials (e.g. benzene and propylene) into derived products. Within this facility, there are companies who operate their production lines with their own companies, but there are also companies whose operations are conducted by the host company.

The proposed work will formalize the concept of facility parks and better understand if this model could transform capital efficiency within the downstream and chemicals sectors. Research questions include, but not limited to: could this model work in the sector, what could be the impact to capital efficiency if implemented, and what the challenges that need to be overcome if the model was implemented widely.

13 Caldas

# Improving Craft Productivity by Providing Engineering Data to the Field at the Right Time and in the Right Format

CII RT 327 studied innovative delivery methods of information to the crafts. The team considered how engineering information has traditionally been received by craft professionals in industrial construction, measured the impact of new delivery methods based on craft professionals’ recommendations, and discovered significant improvements in productivity. Based upon guidance received during six large participatory meetings, RT-327 chose to field-test the productivity of two innovative delivery methods: two-sided isometric plans (includes a 2D isometric drawing on one side and a 3D model view on the other), and isometric plans supplemented with a three-dimensional physical model. The field-testing demonstrated productivity and accuracy gains during trials conducted with skilled pipefitters. Pipefitters provided with 3D information during experiments performed their work faster and with fewer errors compared to pipefitters that were not. This project would expand the study of innovative information delivery methods to include other recent advanced technologies, such as augmented and mixed reality devices.

14 Caldas

# Automated Materials Replenishment for Construction

Materials, equipment, and tools should be available to craft workers at the workplace when needed in order to ensure timely completion of construction activities. New technologies have the potential to automate some materials management functions and facilitate the delivery of materials, equipment, and tools to the work face. Examples of these technologies include Amazon Dash, which allows manufacturers to add a physical button or auto-detection capability to their devices to reorder supplies from Amazon when necessary. There is a need to study the construction productivity improvement potential of such technologies. In addition to automated material requisition, other conceivable applications include real-time material status update, automated inventory control, robotic warehouse management, and enhanced supply chain integration. This project could involve field tests or simulations to verify the benefit and impact of implementating these technologies.

15 Hallowell

# Improving Craft Productivity through Competition

Competition is a known motivator in occupational environments. Adding competitive elements to the work environment (i.e., gamification) involves providing employees with real-time feedback on various aspects of their performance in relation to performance of their co-workers. This is known to improve motivation and job satisfaction, which in-turn improves long-term work performance. Some manufacturing organizations have shown productivity improvement using ‘flight paths’ that monitor performance against a benchmark in real-time using large visual displays. Results indicate that such feedback devices not only improve pace through social incentives but also can be used to improve production flow if both lower and upper limits are set.

This project could explore how gamification, leaderboards, and ‘flight paths’ could be designed to enhance motivation and work satisfaction. The team is encouraged to leverage knowledge of human factors (e.g., psychology, sociology) when designing a study. The team is also encouraged to ensure that test leaderboards are sufficiently broad so that all desired outcomes (e.g., productivity, safety, and quality) are simultaneously monitored and incentivized and so that production flow is optimized, rather than sub-optimization of single crews or workers.

16 Hallowell

# Developing Innovation Climates that Promote, Fund, and Foster Transformative Innovations

Construction innovation requires two main ingredients: (1) generation of new ideas and (2) an environment that encourages innovative ideas to be shared and implemented. In order for innovations to thrive in the capital projects industry, organizations must strategically design systems to promote implementation of new ideas. This could include rewards and recognition of idea generators, innovation champions, funding for innovation pilot-testing, meaningful projections of return on investment, and others. In short, innovations need an environment where potentially successful innovations can thrive. This also involves combating traditional resistance to change and potentially establishing innovation funds on projects.

This project would consider how an innovation climate may be defined, measured, and improved. The study may involve assessments of how recent innovations have thrived and why others have failed. The fate of potential innovations from a worker or operator’s perspective could be of interest. The research team should consider the results of past innovation research funded by CII and the Charles Pankow Foundation.

17 Goodrum

# Innovation Testbeds: Reducing Risk in Expanding the Productivity Frontier

A future swarm of advanced technologies and theories offer potential of significantly improving construction productivity; however, there is significant risk in their implementation. Among other factors, much of the risk lies in uncertainty regarding an innovation’s effectiveness, reliability, and ease of use. To offset this risk, innovation test beds have been used for other industries to conduct rigorous, objective, transparent, replicable, and scientifically based testing of new theories, tools, and technologies (NIST 2015). The proposed research will create an innovation test bed to develop and empirically validate future technologies and theories in order to improve an innovation’s likelihood of significantly construction productivity. The testbed should be carefully validated so that simulation and testing on the testbed produce valid and reliable productivity improvement forecasts.

18 Sears

# Utilization of Sharing Economy Systems to Improve the Utilization of Available Resources

Sharing economy systems are a rather recent phenomenon, and they are disrupting industries as varied as the hotel industry, the taxi cab industry, and the banking industry. One common thread in these systems is that they tend to break down the barriers to to improve the utilization of resources For example, to become a taxi cab driver in many cities around the world, an individual may have to: obtain a taxi driver’s license, purchase a taxi medallion (which may cost hundreds of thousands of dollars), purchase a taxi cab, have a location to store their taxi cab when not in use, complete a defensive driving course, attend a taxi school,pass required exams, and/or possess a social security card. The decision to become a “cabbie” often requires a substantial time and financial commitment. On the other hand, companies like Uber and Lyft have removed many of the barriers that cabbies face and have permitted a broad population to be compensated for ridesharing services. The upfront time and cost required to get started as an Uber or Lyft driver is relatively minimal, which allows prospective drivers to “try it out” and see if they like the work. Drivers are free to choose their own hours, they don’t have to quit their “day-jobs” if they have them, and if they don’t like driving then they can quit with little to no notice.

While there are resources that are unique to each project, for example plans and specifications to build a project, there are common resources necessary for most every project, such as labor, equipment, and some materials. The proposed project will develop a sharing economy platform for connecting construction companies to utilize available resources, let it be individuals who are seeking short-term construction work employment, available machinery, and surplus materials. This project would require a dramatic re-thinking of the constraints associated with traditional supply chains. For example with respect to labor, the project may explore how the traditional barriers to entry in the construction industry may be overcome, how safety and skills training could be promoted with a more transient workforce, and how the tacit knowledge of senior construction personnel can be managed and preserved.

19 Caldas

# Systems Approach to Improving Capital Efficiency

Capital efficiency is a measure of a company’s ability to select, deploy, and manage capital investments that maximize shareholder value. Previous studies have identified the elements of capital efficiency. For instance, PwC (2017) proposed the following 12 elements of capital efficiency: strategic review, capital agility, delivery & execution, value performance, portfolio optimization, resource balancing, corporate strategy, finance strategy, budgeting authority, capital processes, investment options, and value measurement. This project would identify and verify the applicability of these elements to the downstream and chemicals sector. In addition, it would formalize a systems approach to better manage these elements, analyze their dependencies, and improve capital efficiency throughout the entire asset lifecycle.

20 Hallowell

# Improving Assets’ Productivity through Life Cycle Assessment

Organizations invest in capital projects to enhance the long-term financial sustainability and competitiveness of the organization. Research has shown that the total cost of operation of a facility (TCO) significantly outweighs the first-cost of a facility. Therefore, when considering productivity improvements, organizations should consider how actions improve not only efficiency and productivity in the construction phase, but also how actions in design and construction ultimately influence the lifecycle output of an asset and the total cost of operating the asset. Such a project may consider how actions taken during construction impact lifecycle productivity, where productivity is considered from an operational standpoint. The implications of design and construction actions can be considered over a much longer timeframe. Assessment of the productivity of a facility may drive business value, which is CII’s core function.

The team may consider how investments in design and construction of a facility have lifecycle impacts on facility operation, and how optimization of critical success factors may change as focus shifts from the construction phase to the lifecycle of the asset.

21 Hallowell

# Improving Productivity through Design: Use of Standardization and Modularization

Modularization, industrialization, and standardization of construction may have dramatic impacts on the efficacy of capital project delivery. For example, standardizing asset modules across companies, building them off-site in a controlled facility, and using robotics to manufacture components may have dramatic impacts (both positive and negative) on cost, quality, productivity, and safety. Standardization, modularization, and industrialization have all been considered in isolation in CII-funded studies. However, potential combinations of these techniques have yet to be explored in depth. Further, dramatic standardization of componentry may have dramatic results. For example, limiting bolt sizes to only three options on a facility may increase cost if a unit is considered in isolation; however, improvements in reliability, efficiency, and quality may far outweigh the additional costs. Such a project may consider the current barriers to dramatic standardization and modularization; the collaboration that would be required among facility investors, product manufacturers, and constructors; the need (or lack thereof) of proprietary or unique componentry; and short- and long-term options for standardization that have the potential to yield the greatest returns on investment. This project may involve developing strategies to break traditional barriers associated with standard practice. The team should consider the previous work conducted by CII and study the success (or lack thereof) in other industries like shipbuilding, automotive, and aerospace.

22 Caldas

# Leveraging Advancements in Materials and Equipment Technology to Improve Productivity

Previous research examined the impact that technological advances in materials and equipment had on construction labor productivity. Activities experiencing an improvement in equipment characteristics related to amplification of human energy, level of control, functional range, and information processing had at least twice as great of an improvement in labor productivity than activities experiencing no improvement in these technology factors. Likewise, it was found that activities experiencing advancements in materials associated with modularization, reduction in unit weight, and installation flexibility encountered at least twice the improvement in labor productivity compared to those activities with no likewise material improvements. Therefore, there is an opportunity to leverage advances in materials and equipment technology to improve productivity. The goal of this study would be to identify and test technologies with higher productivity improvement potential and assess their benefits, implementation challenges, and expected productivity gains.

23 Caldas

# Streamlining the Project Development Process to Accelerate Delivery

CII defines Front End Planning as “the essential process of developing sufficient strategic information with which owners can address risk and make decisions to commit resources in order to maximize the potential for a successful project.” Front End Planning is implemented using a phase-gate process, which divides the project development process into distinct phases, separated by decision gates. At each decision gate, project continuation is decided by an individual or group based on information available at the time, including the business case, risk analysis, cost estimates, schedule and resource requirements, among others. The phase-gate approach requires project teams to follow formal processes and produce several deliverables to support the decisions made at each gate, which can cause delays in the delivery of certain projects. This project would investigate methods to streamline the project development process and make it more adaptable to specific project characteristics, such as size and type.

24 Sears

# Improving Predictive Analyses to Proactively Improve Productivity

In recent years, construction safety scientists have used leading indicators to make predictions about the likelihood of injurious events occurring. In many cases, these predicted events are constrained to a particular time and location, because they are the result of a combination of leading indicators that happened to coincide. Construction managers are then able to use these insights to reduce their risk of an injurious event by shifting activities to occur at different times or locations. Can we apply this same approach to construction productivity? What if episodic drops in productivity were studied in the way that injurious events currently are? For example, research may identify critical lifts as a productivity leading indicator. One productivity expert recently explained that productivity often grinds to a halt at the time and location of a critical lift. Workers in the area of a critical lift see the lift being made and they stop to watch. The expert has observed this behavior, but stated that often nothing is done to prevent it. The proposed work will explore construction productivity through the lens of leading indicators and seek to identify the activities and combinations of activities that tend to precede drops in productivity. Advancements in predictive analytics and forecasting should be explored to relate potential predictors to actual outcomes. This study should be approached empirically.

25 Hallowell

# Fostering Productivity Cultures

Safety culture and climate has received great attention in the safety community. Organizations have clear safety goals and visions, dedicated programs to ensuring safe and reliable operations, and a genuine focus on operational excellence as it relates to safety. Organizations even employ dedicated safety personnel whose job is solely to ensure safe work practices and form site-specific safety plans. The implementation of such programs has had dramatic impacts on safety performance, with recordable injury rate improvements of over 200% since the 1990s.

This project could explore how practices employed to achieve a safety culture and safety performance could be translated to practices for productivity improvement. For example, the study could explore the following, among others:

* Safety manager → productivity manager
* Job hazard analysis → Job productivity analysis
* Site-specific safety programs → site-specific productivity practices
* Zero-injury goal → Zero-rework goal
* Safety Incentive Programs → Productivity incentive programs
* Safety training → Productivity training

The composite of these activities fosters a culture of safety, where safety is constantly considered, planned, incentivized, and recognized. Without compromising safety, this project could consider how analogs to safety programs could help to drive a culture of productivity and ultimately double productivity in the same way that injury rates have been halved.

26 Goodrum

# Defining Unit Rate Productivity Measures for Construction

There is a great deal of uncertainty on whether construction productivity is improving or declining. At the industry level, the uncertainty is related to a host of factors such as the heterogeneous output of the industry, changes in the quality of the built facility, and long-term concerns regarding the accuracy of construction inflation indices. At the project level where productivity is often measured through unit rates, different codes of accounts across different projects and companies often make comparison of unit rates across a sample of projects and over time difficult. Without addressing these issues, current efforts of describing productivity trends run risks of misallocating precious resources. The proposed project would examine how construction productivity can be accurately measured through unit rates across projects and how these measures could ultimately be used to describe industry performance. Precise and transparent measures will significantly improve the long-term productivity by clearly identifying areas requiring improvement and other areas of gains that may yield valuable lessons learned.

27 Hallowell

# Enhancing Productivity through Effective Safety Management

Organizations invest immense time and resources in safety management. Over the years, organizations have incrementally added safety activities, paperwork, policies, training, and self-regulation. For example, job hazard analyses began as a strategy for non-routine, high-risk work. However, construction safety experts have begun to express concerns that the individuals tasked with implementing safety practices are becoming overwhelmed with safety forms and paperwork, either because their organization has implemented too many safety procedures, or because the same procedures are implemented so frequently that they become redundant. Today, many organization require a job hazard analysis for every job, even repetitive, routine, and low-risk work. As a result, workers become desensitized to the importance of such activities, even for non-routine, high-risk work. Safety may have reached the point where the paperwork and burden is so great that workers have become desensitized even to core practices.

This project could explore areas of safety waste and how safety programs can be revisited to find efficiencies. In other words, the team could explore situations like the job hazard analysis where, in some cases, “less is more.” The team could investigate redundancies, how the quantity/frequency of safety activities impacts the quality of their implementation, and what safety elements are critical to or unnecessary for the development and sustenance of a safety culture. The team could consider a brief history of safety programs to investigate how the safety burden has changed over time and potential diminishing returns.

28 Goodrum

# Developing the Next Generation of Frontline Supervisors

Foremen and superintendents serve critical roles in a project’s performance in providing direct supervision of construction crews, ensuring that each crew has the resources it needs to do work, and serving as mentors to construction craft workers. Running parallel to the shortage of construction craft workers, a shortage of frontline supervisors is occurring as well. The development of new technologies (e.g. mobile information technology), processes, and construction methods is changing the resources and expectations to be imposed on future frontline supervisors. The proposed research will identify how to develop frontline supervisors to meet these future needs but also how to attract a diverse new generation of frontline supervisors in order to help provide clearer career pathways for future generations of a more diverse construction craft workforce. The project could explore the investments in training and advancement programs needed and the expected returns on those investments.

29 Sears

# Improving Engineering and Construction Collaboration through Mixed Reality

Mixed reality devices are becoming part of the construction process. However, their use is often limited to marketing or communicating visually with owners, and they are seldom used by craft workers in the field. Building Information Models are a critical component of these devices. One limitation of BIM models today is that they are often only developed for final deliverables; they are a representation of the final product. In the future, we may see mixed reality used with a series of BIM models. When a mixed reality device user walks a greenfield construction site for the first time, they may only see lines that represent the limits of clearing and grubbing. After clearing and grubbing is complete, they may switch to the next model that displays the limits of excavations. Next, they might switch to a foundation model, and when foundations are complete, they may move to a 1:1 floorplan model. That is, a model that shows the layout of walls, but nothing vertical. One can envision additional models that might include items like formwork or scaffolding, and then, of course, the final model.

Another limitation of BIM models today is that a single BIM model is typically developed for an entire project. Having a single BIM model allows many designers to collaborate within the same 3D space, but it also creates unwieldy, large files that require special hardware, software, and technical expertise to navigate. Mixed reality devices are partially removing these barriers by allowing users to wear a headset and navigate through a model by either moving their bodies or by pointing and clicking a simple handheld device. However, even if a craft worker manages to successfully navigate through a BIM model, they may find that the details that they were searching for are simply not included in the model. Alternatively, if work planners were to include specific, separate assembly BIM models in a craft worker’s work package, then all a craft worker would need to do is slip on a mixed reality headset, choose a work package number, and then instantly they would be presented with the virtual information that the work planner felt was paramount to the successful completion of the work package. The virtual information might include BIM models, animations, vendor installation videos, etc.

These are a couple examples of how collaboration between designers and constructors can be improved through the use of mixed reality. The proposed work will examine the use of mixed reality on a broader scale and seek to identify use cases in which collaboration can be enhanced between: multiple designers, multiple constructors, designers and product manufacturers, designers and owners, and of course, designers and constructors.