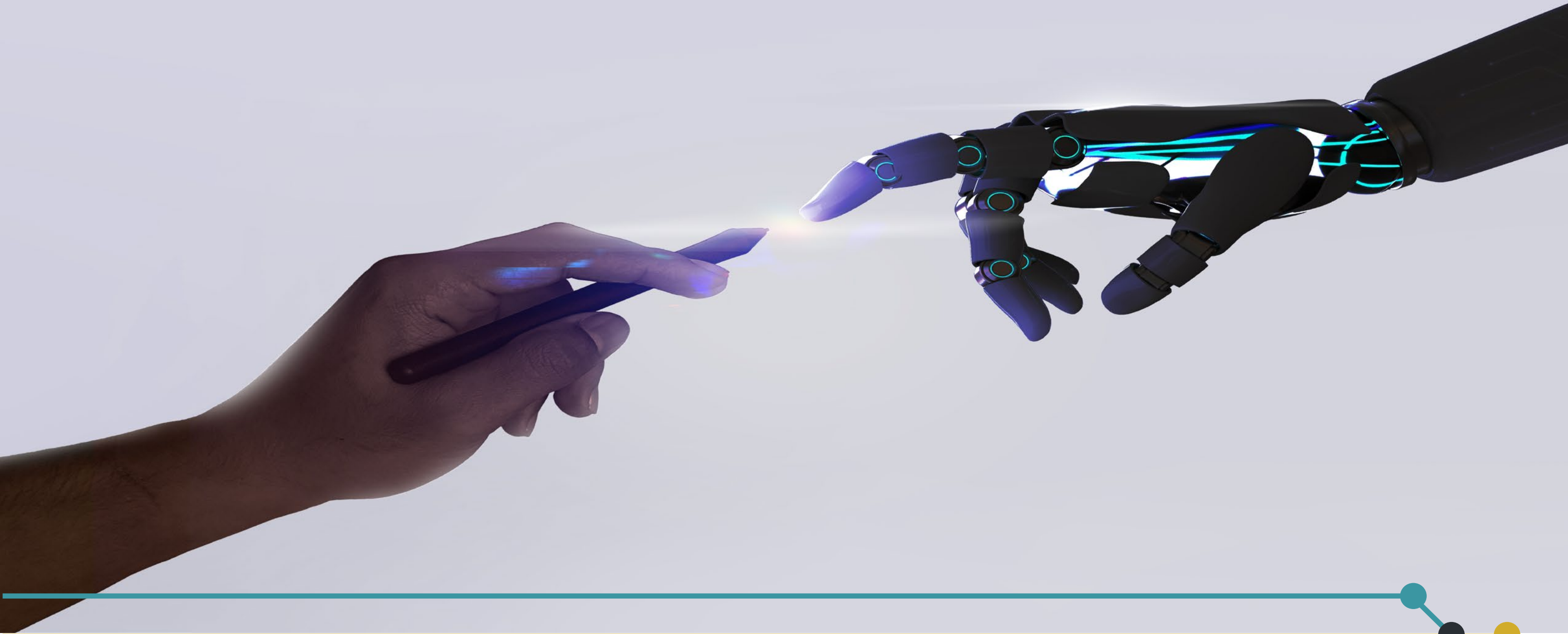

Increased complexity in risk mitigation and failure analysis

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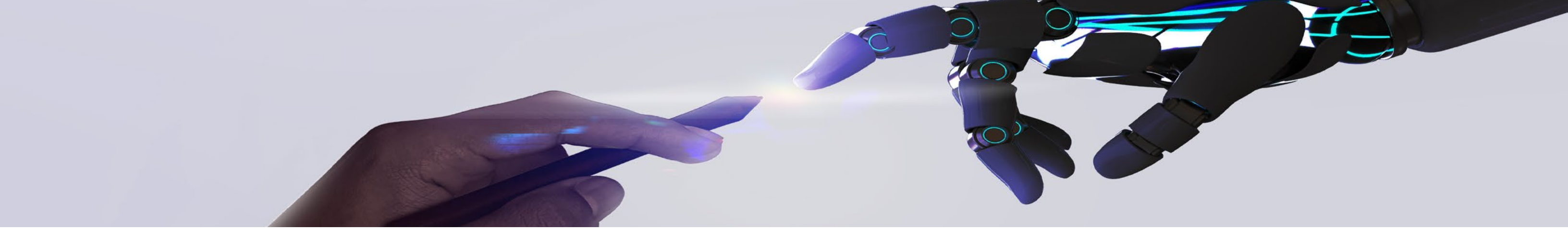
One of my all-time favorite and most revered mentors taught me that all difficulties in physics occur at interfaces – think hot-cold, wet-dry, dissimilar metals, plastics-metals, insulators-conductors, and software-hardware. The list can go on almost indefinitely as we conjure up failures from our own professional and conceptual experiences. Yet, despite the dichotomy, I love working with these complex interfaces and anticipating, investigating, and resolving the inherent challenges.

If I had to make a sweeping statement about expert witness work, I would say the interface is more of a three-fold interface, not a dual interface as I described above. In this industry, we work at the intersection of legal, business, and technical issues. Our jobs as technical professionals are dedicated to excellence and integrity, but we must understand how to frame our work and work product in the legal and business realms for our clients who need answers that matter to their work paradigms.

This three-fold interface is endlessly fascinating and very complex. Let’s use large, complicated construction as a hypothetical example for our discussion. Construction can and does involve contract law, insurance law, construction law, and building codes. It may also involve tort law with respect to supply chains and products.



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Governments and subcontractors must follow and adhere to many standards, and many authorities having jurisdiction (AHJs) must be consulted to get permits and permissions signed off during construction. Risk registers must be designed and tended to regularly, along with certified and qualified personnel from various disciplines, including civil engineering, structural engineering, mechanical engineering, electrical and electronics engineering, architecture, and many varieties of project managers, construction managers, and quality inspectors.

Evolving Complexity in Construction

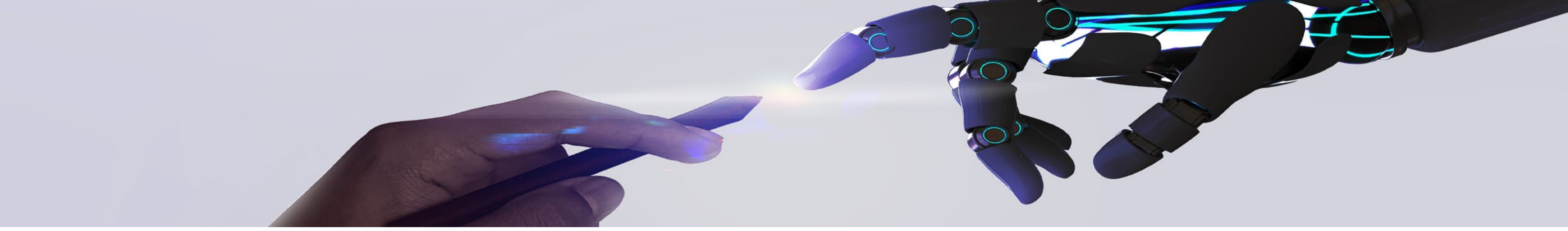
Construction is ancient in the history of the world, but the increased complexity we face is not. Only a few decades ago, contracts, government directives, permit requirements, and communications were much simpler. Heavy equipment drivers and operators communicated with hand signals, handshakes sealed deals, and paper contracts were filed and recorded in filing cabinets inside brick-and-mortar buildings. Architects and engineers stood at their desks and used drafting templates and mechanical pencils to render blueprints and design drawings on vellum, with wooden pegs and spacers for the floorplans and structural layouts. It was relatively straightforward to sort out which company and which human to contact if something went wrong.

Introduction of new technology

Let’s consider the era when computer-aided drafting (CAD) was introduced, adopted, and became the norm. The advent of CAD turned drafting tables into beautiful pieces of design history. This new technology added more layers of complexity to the design and revision phases of projects. It also led to questions such as who is responsible for construction delays when the entire design has been rendered in third-party CAD software, and who is “supposed to” pay for the cost overruns of a misplaced structural member?

Is the accountable party the responsible engineer who worked with and signed the plan drawings, the CAD draftsperson, or the software engineer who coded the CAD scaling algorithms? Or perhaps the responsibility falls to the third-party organization that trained the draftspersons and architects on the software program? Maybe a software patch or code revision fixed one thing but broke something else in the core code – it happens.

Quality testers may not catch this issue if they only test for additional features, assuming the core code is still functioning to specification. When that happens, you can sometimes reload an existing finished drawing, and the placement will be slightly offset from how the original layout was designed. Should the field quality inspector have caught this on the drawings and returned it to the construction manager to send back to the engineering teams? Who pays for schedule delays and extra time spent on drawings that have already been signed and sealed? It becomes complicated when you add in technology.



Mismatches at critical interfaces

One of the most important elements to recognize and perform risk analysis on, within the complex interfaces between established construction practices and new technology, is the mismatch in product lifecycles. A very simple example of this considerable mismatch is the expected lifecycle of a front-end loader compared to the expected lifecycle of the electronic control the operator uses to control the drive train, direction, and lift-and-lower degrees. Heavy equipment can last for many decades while being used on difficult terrain and/or in severe weather conditions.

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Electronics have intrinsic vulnerabilities to temperature and humidity fluctuations, as well as to shock, vibration, and intermittent power surges. Therefore, the increase in electronics we see built into everything on construction sites – from personal protective equipment (PPE) to measuring equipment, handheld devices, and heavy equipment – must be carefully considered during design and manufacturing, especially during field use and maintenance. There may not be a work order or a precedent in equipment yards to stock a dozen extra front-end loader controller cards or to designate a controlled environment where sensitive electronic cards can be stored. Risk is even higher without training.

A look to the future – Programmable robots and autonomous vehicles

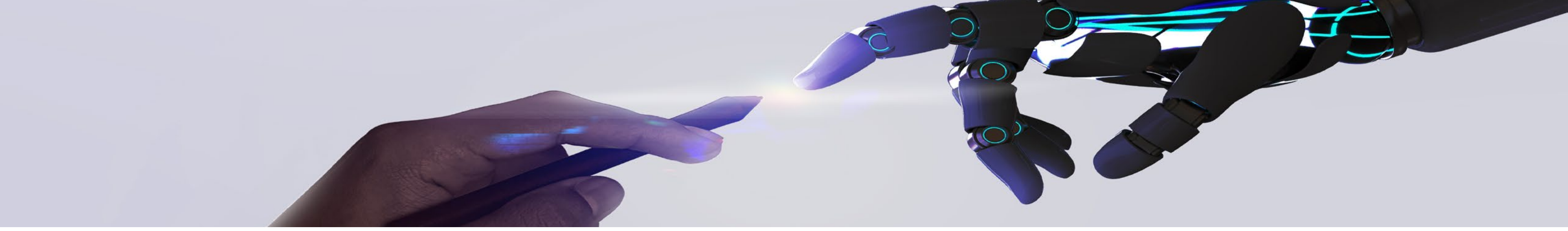
To gain some real-world insight into the complex interfaces between today’s construction practices and tomorrow’s new technology, let’s contemplate a hypothetical situation for a moment.

A glance into the world of high-tech construction

Imagine using a fleet of multipurpose, mostly autonomous vehicles and programmable robots to compensate for a lack of skilled construction labor. Theoretically, this scenario is a wonderful solution. Autonomous vehicles and programmable robots don’t get tired and don’t need breaks (if maintenance cycles are longer than work shifts), and they can work in inclement weather and low-light conditions that humans find dangerous or cannot tolerate.

Now imagine a fictitious project in which these programmable robots make the bricks used to construct the entry door to a new building. Once the bricks have been fired, cooled, and cleaned, the robots do the “heavy lifting,” stacking the bricks to the pallet sizes needed to fill a transport vehicle with the optimal load.

Next, the autonomous transport vehicle backs up to the loading dock, where a programmable robotic forklift loads the pallets onto the truck bed, lashing them at stability points with proper, measured pressure, weight, and balance for the average speed of the truck’s trip to the construction site.



The autonomous transport vehicle is programmed to drive from the brick-making factory to the site during the most efficient time of day, even if that happens to be 1 AM, because the on-site robot will be there to unload the truck and record all interactions and operations for the construction management database of events.

Once the pallets of bricks are unloaded at the optimal point on the construction site, the human foreperson programs a shuttlebot to transport the bricks to the bricklaying robot arm, which then lays the bricks in the pattern specified by the architect and programmed into the robot arm by the programmer. A human either mixes or supervises the mixture of mortar because some judgment must be used for appropriate combinations and slump for the bricks.

The machine that mixes the mortar would have to have intrinsic chemistry measurements and be cleaned frequently, so it is too expensive for this project. The bricklaying robot arm is precise and accurate and does the work in about one-eighth of the time it would take a three-person bricklaying crew. When the masonry work is completed, the robotic arm is packed onto its pallet, secured, and driven to the next job by the mortar mixing attendant and the arm programmer, so it can stay busy for the third-party company that subcontracts it to building sites nationwide.

This technology solves so much, doesn't it? It reduces both construction time and costs. Labor rates are lower, and people are not calling in sick. There are no weekend or overnight stalls in the workflow. This is a perfect-world, hypothetical, theoretical exercise. What happens when we consider real-world risk and responsibility in this chain of work steps?

Mixing traditional construction with high-tech

Risk considerations

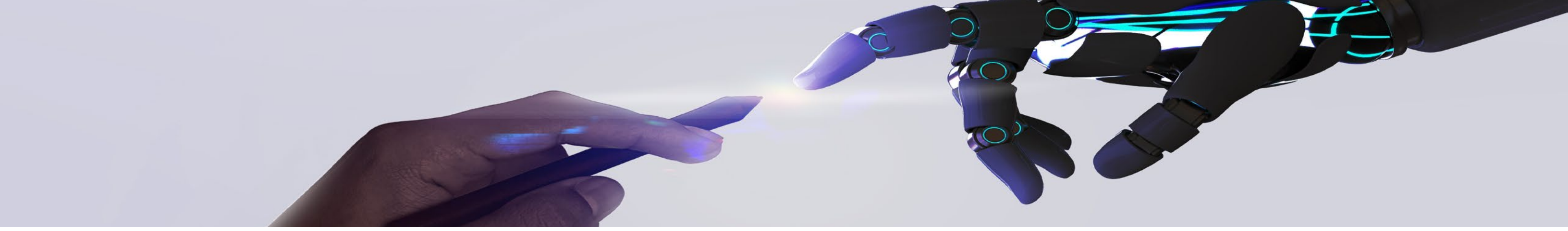
Contracts between prime, subprime, and equipment rental companies have long been an integral part of the construction industry. If an earth mover, for instance, breaks on site due to a particularly rocky debris field that was unknown prior to the start of work and construction is delayed for a week, how do we move on? How do we ensure the responsibility falls to the appropriate party or parties for remedy and remediation?

That depends largely on the governing contracts. The contract outlining the terms of a construction project, including the project scope and how to handle unforeseen issues, may be dictated by government regulations, insurance law, construction law, the AHJs, and fully executed legal agreements between the parties.

Further, construction contracts tend to include terms that are open to interpretation, such as "substantial completion" before payment, and specifications on which equipment and phases must or shall have insurance coverage. Unfortunately, in the case of the latter, underwriters do not always understand the complex systems that they insure. They may not have the time or statistics at their fingertips to project how often robotic brick-laying machines fail or the severity of the failure effects. Using standard boilerplate for policies may not cover the nuances of newly designed construction robots, which leaves claims open to interpretation, mediation, or litigation to solve language disputes. As a result, ambiguous language must be negotiated by the relevant parties and by counsel as the contract is being developed.

Considerations for failure analysis

Now, let's examine what may happen when a project that implements high-tech machines fails. Imagine this scenario occurs after the hypothetical chain of events outlined above.



Not long after the new building opens, the brick entryway wall collapses and injures a resident. Several years ago, failure analysis would have involved questioning witnesses who may have been present at the time of the incident, reading the quality inspection reports as the bricklayers built the wall to specifications, interviewing the bricklayers, and obtaining the bricklayers' design drawings and labor records. We would have also asked for the construction management logs that were part of the program management requirements to assist us in determining whether a design defect, a brick manufacturing defect, or an installation defect caused the wall to prematurely age and fall.

In the past, this would've been a laborious, multidisciplinary process involving a team of architects, civil engineers, structural engineers, and mechanical engineers. This team would have to evaluate any damage that may have occurred to the bricks during transport (due to shock and vibration) or while the bricks were on site. Material engineers would be able to determine the stability and brittleness of the bricks and constituent materials in the mortar. Forensic construction managers would be able to identify whether the collapse was due to a subcontractor mistake or a schedule acceleration that caused cutting corners, and forensic accountants would be able to calculate business damages. An examination of the contracts could show responsibility, potentially, with interpretation by counsel.

Increased Complexity – Advantages and Disadvantages

When we fast-forward to our hypothetical example, using multiple programmable robots and an autonomous delivery vehicle, we see that there are many more elements to examine. These elements include data communications, cloud storage and retrieval of data, security policies for transferred and transmitted data, computer algorithms and code, mechatronics, electromechanical components, electronics for control-feedback loops, and human designers and programmers who are computer, robotics, and autonomous vehicle high-tech workers, not construction specialists.

In summary, failure analysis projects become much more costly, in both time and money, when high-tech is added to a traditional industry, even if the above example is extreme in the present-day state of automation in the construction industry. Anticipating and mitigating risk and determining what went wrong, why, and who is responsible in the event of a failure are only a few of the many factors to consider when bringing high-tech to the construction site.

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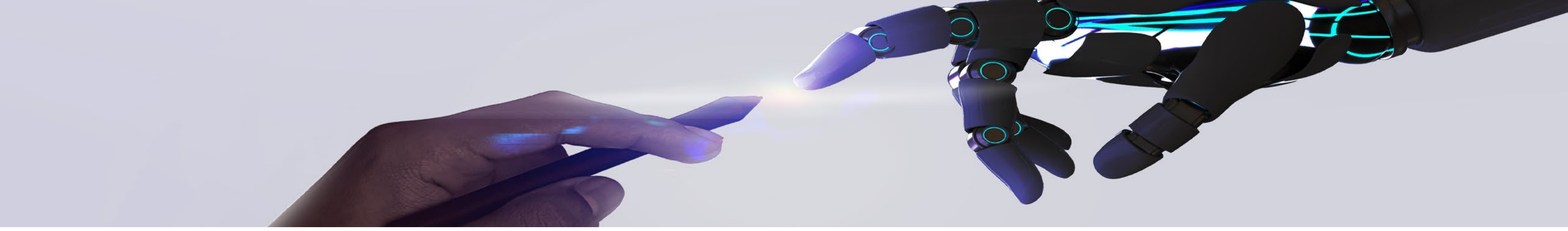
Professionals from the three-fold interface of business, law, and forensic technical services must continue to work together toward the common goal of refining traditional understanding of the industry so narratives included in contract language are refined at the same pace as developing technology used in the field. We must mitigate risks and incidents from the beginning of projects, even as early as the bid solicitation phase, and learn to write different requirements, responsibilities, and terms and conditions in our contracts, including those with subcontractors and equipment and materials providers.



Contingency funds must be set aside at higher dollar amounts as we add new technology on-site in case electronic components fail or a robot failure must be investigated and remediated. No matter what is decided, scrap or salvage, it is always more expensive when there is a mismatch between the product lifecycles of heavy equipment and the electronic and electrical parts.

We must learn about new supply chains and considerations for products that may seem out of context for the traditional industries we are accustomed to analyzing. We must also learn to hire and integrate people with different skill sets into the contracts and risk teams that we form within the framework of business, legal, and engineering teams.

As a failure analysis engineer and expert witness, my own work increasingly consists of educating myself on how to best communicate with professionals and laypersons who need to understand my findings and results clearly and concisely. Informing business and legal clients of the causes of delays, cost overruns, and physical product and materials failures due to high-tech additions in their fields can help strengthen our three-fold interface, providing clients with data that is useful at the beginning of projects, not just when failures occur.

About the author

Karen Rayment is a Director at HKA with more than 20 years of experience. Licensed as a professional engineer in eight states, Karen has been appointed as an engineering expert on over 50 occasions. She has testified as an expert in litigation (including delivering concurrent evidence) related to intellectual property and other matters in U.S. civil courts and acted as an expert in professional liability cases for medical malpractice and electrical and electronic products liability disputes.

Karen has designed experiments, performed hands-on testing and failure analysis of consumer and commercial products, validated and verified prototype products, and troubleshot product design, manufacturing, and safety issues. Her experience also includes providing support on product investigations and hazard and safety analysis studies for the U.S. Food and Drug Administration (FDA), U.S. Consumer Product Safety Commission (CPSC), Health Canada, the European Union (EU) Commission, and the UK Ministry for Industry and Innovation.

Karen holds an MBA in Global Strategic Management from California State University, an MS in Electrical Engineering from San Francisco State University, and a BS in Electrical Engineering and Computer Sciences from the University of California, Berkeley. She is a Project Management Professional and a Certified Fire and Explosion Investigator.

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