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Evolution of Automated & Autonomous Machines & Equipment in Construction: An Overview

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Extended Abstract: The construction industry is a major economic driver of the U.S. economy but suffers from numerous inefficiencies and low productivity. The North American construction market was valued at around USD 2.1 trillion in 2021, and the market is projected to grow at about 4.84% during the 2022-2027 period (Mordor Intelligence, 2022). The Construction Industry Institute TM (2022) reports non-construction industries have been applying digital technologies for decades, but these technologies have only recently been applied to construction machines and equipment to improve project cost, scheduling, quality, safety. and overall productivity.

In this paper, we provide an overview of the evolution Automated & Autonomous Machines and Equipment (AAM&&) in Construction. It provides a glimpse of how, when and where construction AAM&E emerged and provides a few examples of their benefits and challenges.

The market for autonomous construction equipment globally is expected to grow from $9.47 billion in 2020 to $15.13 billion by 2025 with projected annual growth rate of 10.0 – 11.1%. The major manufacturers of autonomous construction equipment are Komatsu Ltd., Caterpillar Inc., Hitachi Construction Machinery Co., Volvo Construction Equipment, Built Robotics Inc., Cyngn, Royal Truck & Equipment, Case Construction Equipment, Deere and Company. These companies are focused on using technology such as automation and robotics to address the shortage of heavy equipment operators as well as improving project quality and cost effectiveness. For example, San Francisco based Built Robotics builds robotic upgrade kits for common construction equipment such as excavators, bulldozers and skid steers. In 2019, Mortenson Construction who is a top-20 U.S. based builder/developer partnered Built Robotics to deploy its proprietary software and multilayer safety systems to ensure safe operations on its renewable energy projects and other projects in North America (Research and Markets, 2021; Alderton, 2021).

Early examples of Japan's mechanized construction equipment are: Kobe Steel's 1930 electric shovel (Kobelco, 2022); Komatsu's 1943 Bulldozer (Kikkisworkshop, 2022); Hitachi's 1965 hydraulic excavator (Hitachi, 2022). Around 1990, Japan's manufacturers developed and commercialized semi-automatic hydraulic excavators (Morikawa and Otsuki, 2020).

In the late 1980s, Japan released the Field Management Software (FMS) for mines. This became Komatsu's autonomous platform for heavy construction & mining equipment and began its first testing in 1990. Komatsu's first commercial deployment was in Chile in 2007. In 2008, another autonomous system was launched in Western Australia's iron ore mining operation where workers operated autonomous mining vehicles remotely from Perth, Australia more than 1,200 kilometers away (Jurgens 2021). From 2015 to 2018, the fleet of autonomous mining dump trucks expanded from 69 to 130 at 6 fully autonomous sites and by 2020, Komatsu had 251 autonomous mining trucks with a perfect safety record. By 2021,

Komatsu deployed its first fleet of fully autonomous water trucks and deployed an automated blast-hole drill allowing a single remote operator to control multiple drill rigs. In 2013, Komatsu introduced the world's first dozer with fully automatic blade control and in 2016 they deployed autonomous mining trucks in North America (Jurgens 2021; Alderton 2021).

Caterpillar has been investing in autonomous mining trucks for decades. It ran its first two prototype autonomous mining trucks from 1994 to 1995 at a Texas limestone quarry. In February 2022, Caterpillar announced its fleet of autonomous haul trucks which reached 500 worldwide operating 24/7 on 3 continents, hauling more than 4 billion tons, traveling more the 145 million kilometers with improved performance and safety over those with operators (Caterpillar, 2022).

In 2017, Volvo Construction Equipment unveiled its prototype of an autonomous, battery-electric quarry load carrier with the prediction of 95% reduction in carbon emissions and 25% reduction in ownership cost. Addition autonomous, battery-electric prototype quarry equipment includes electric hybrid wheel loaders and grid-connected excavators (Volvo, 2017). Volvo (2021) reports the benefits this prototype include:

- increased energy efficiency due to the electric drivetrain and innovative design,
- lower emissions due to the battery-powered driveline,
- increased safety:
  - starting with a fenced/confined area for the autonomous operations,
  - redundant stop systems,
  - traffic management system which secures right traffic flow,
  - obstacle detection system combining LIDAR (light detection and ranging) and RADAR (radio detection and ranging) sensors,
  - real-time video stream from the front of the machine,
  - text-based safety screen to alert site workers of its movement to left, right or reverse,
  - live stream communication where the remote operation can make eye contact with pedestrians and workers to minimize misunderstandings,
- increased productivity due to the combination of automation, electrification and connectivity.

John Deere (2021) unveiled Precision Construction as its smart technology solution for its construction customers. The suite of technology solutions focuses on maximizing uptime and productivity. However, we believe that there are multifaceted challenges of AAM&E applications in construction. The construction sector is one of the core economic contributors in the nation, but has been suffered from copious inefficiencies and truncated productivity. Even though digital technologies (e.g., sensors, drones, real-time video stream, etc.) have been more utilized in the construction fields, the AAM&E applications (e.g., robotics, automated or autonomous vehicles) have been receiving relatively little attention from the construction stakeholders. For instance, the construction factors which limit the adoption of automation in construction included contractor-side economic cost (e.g., high initial capital investments to adopt robotics or automation), client-side economic cost (e.g., reduction of public or government infra-structure spending), technical/work-culture concerns (e.g., unproven effectiveness or immature technology), and weak business case (e.g., return on investment or cost-benefit analysis) (Delgado et al. 2019; Morrison, 2020).

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