Computer-Assisted Technologies: Reduce Safety, Health and Ergonomic Exposures on Construction Worksites and Improve Project Quality and Efficiency
An Overview

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Abstract: Computer -Assisted Technologies (C-AT) have been evolving at least since 1960's and were initially applied to the automotive industry in the US and other countries. Application of C-AT to construction processes and equipment has emerged more recently and is expected to continue evolving for the foreseeable future. This paper will briefly discuss seven C-AT examples and their potential impact on reducing Safety, Health and Ergonomic exposures on construction worksites and improving the quality and efficiency of the construction process. The C-AT examples in construction discussed are: Robotic Systems (RS) and Wearables; Additive Manufacturing (AM) – 3D Printing; Layered Manufacturing (LM); Rapid Prototyping (RP); Virtual Reality (VR); Building Information Modeling (BIM); and Internet of Things (IoT).

Keywords: Robotic Systems – Wearables, Additive – Layered Manufacturing, Rapid Prototyping, Virtual Reality, Building Information Modeling, Internet of Things

1. Introduction/Background

Since the 1960's, the workforce in the United States has experienced significant physical, psychophysical and demographic changes. For example, Cutler (2003) reported the sedentary life style in the US has contributed to the average weight of the US population increasing from 168 lbs to 181 lbs (males) and 142 lbs to 152 lbs (females). He also reported the average Body Mass Index (BMI) for both males and females increased from 25 to 27. Dr. J.A. Davidson (2019) reported that "71% of Americans ages 17-24 do not meet qualification or military service". Ciriello (2001) observed a potential psychophysical reduction in the Maximum Acceptable Weight (MAW) workers were willing to lift/lower so he replicated the psychophysical studies of the 1970s-80s that resulted in the Liberty Mutual Research Guidelines aka "Snook Tables". Ciriello (2008 & 2011) found the MAW decreased to 69% for males and 67% for females. If validated by additional research, the authors believe the "set points" of ergonomics assessment tools such as the Load Constant (LC) of NIOSH's Revised Lifting Equation may need to be lowered from 51 lbs (ideal) to 35 lbs. The demographics of US workers are also changing i.e. workforce is aging and the male/female participation rate is narrowing. Toossi (2012) reported the % of workers age 65+ in 1990 was 8.6%, 13.8% in 2010 and projected it would be 19.2% in 2020. U.S. BLS (2017) reported by 2030, all "baby boomers" will be over 65. Toossi (2012) reported the workforce participation rate in 1960 was 80% (males) and 40%

(females). U.S. BLS (2016) reported the male to female workforce participation rate narrowed to 69% (males) and 57% (females). Recent business news reported more jobs are available than are qualified workers available to fill them. For example, American Welding Society reported by 2030 there will be "200,000 unfilled welding jobs". The authors believe C-AT will help meet the challenges of the current and future workforce including construction.

Some examples and applications of the computer-assisted technologies in the construction industry are discussed below.

Example 1: Robotic Systems (RS) - Tele & Computer Operated, Human Controlled

Palmer (2019) described the characteristics of human controlled and computer operated drones and their uses in the construction industry. Small drones used by the public cost a few hundred dollars whereas medium size drones used in construction cost $10,000 – 20,000 and are capable of carrying 50 lbs with 1 mm optic resolution, horizontal speed of 45 mph and maximum altitude of 16,000 feet. Typical construction applications include 2D & 3D "progress surveys" of construction sites; inventory monitoring of materials, equipment, personnel; GPS Site Mapping e.g. 20 acres in 10 minutes vs 10 days mapping manually; "roof top" delivery of small tools and materials <50lbs; after hours security surveillance; inspection of towers/tanks/pipelines/powerlines. Drones perform these tasks safer, faster and with greater precision than workers can perform them manually.

Grayson (2015) described how drones map the elevations of a roadbed and the data is then programmed into driverless dozers. The authors believe while autonomous construction equipment may reduce equipment "down time" and the need for equipment operators but it creates increased challenges for Safety Professionals to understand and preplan Risk Reduction Strategies (RRS) into the construction process.

Human Controlled Force-Multiplying Robotic Systems (Sarcos) can leverage human capabilities so physical tasks such as lifting can be performed with little exertion but more speed and accuracy. Their Robotic Inspection Tools can also perform "crawling" tasks into unstructured environments that are too small or unsafe for workers. Other examples of Computer Operated Robotic Systems include the Semi-Automated Masonry (SAM) that can lay 3000 bricks per day without error vs 1000 bricks/day by human bricklayer. The envelop in which SAM operates is protected by presence-sensing laser system. The robot from In Situ Fabrication and Mesh Mould (Swiss NCCR) can measure, cut and weld to create rebar mesh foundations and walls.

Example 2: Wearables - Simple, Exoskeleton, Exosuit

Novotny (2018 & 2019) described "simple" construction wearables such as cooling vests and heating jackets. These enable workers to perform tasks longer in environments that pose heat or cold stress without cooling tents, warming sheds or interchange of workers. Richardson (2017) provided a listings of "wearable" devices including those that provide real-time data of workers' location, atmospheric monitoring, workers' vitals such as fatigue factors and two way communications. Exoskeletons and Exosuits enable work in awkward positions such as overhead or cramped quarters inaccessible to equipment and increase a worker's lifting capacity >100 lbs (Sarcos). NIOSH (2017) reported while exoskeletons increase work quality and productivity with decreased work and fatigue, they may increase chest pressure, fall exposure due shift in center of gravity and other exposures.

Example 3: Additive Manufacturing (AM) – 3D Printing

Keating (2017) described one form of additive manufacturing that begins with a 3D Printer "printing" a styro-foam mold which is then filled robotically with a solid material such as concrete. An early version of this process was Insulted Concrete Blocks (ICB) which were positioned manually, inserted with rebar and then filled with concrete. Kusisto (2019) reported a concrete home can be "3D printed" for 30% less than traditional construction methods. Bendix (2019) reported a San Francisco based company called ICON has a 3D printer called Vulcan II that can print a 600-800 sq. ft. house in 24 hours for less than $4,000 and only requires a few workers to operate it.

Example 4: Layered Manufacturing (LM) aka Freeform Construction

EPSRC described layered manufacturing as the process of "depositing" layers of reactive material such as Portland Cement over other reactive materials for bonding. This process is sometimes call "freeform construction". LM began around 1997 and is still evolving. For example, Contour Crafting of layered material began around 2004 and Concrete Printing is currently under development. The cost, quality and safety of these methods are still being research.

Example 5: Rapid Prototyping (RP)

According to The Manufacturer (2017), the construction industry began to use rapid prototyping in the 1980s and it is becoming the "standard way" builders and engineers show design ideas by displaying physical models created by 3D Printers. This enables all levels of constructors to identify and solve design problems faster and more accurately resulting in design and construction costs less than the traditional 2D blueprint drawings. The reported benefits of RP are: fewer mistakes thus better quality construction; less wasted materials thus lower construction costs, improved time-line management of the construction schedule and better coordination of subcontractor activities resulting in a safer work area for all trades.

Example 6: Virtual Environments – Virtual Reality (VR) & Building Information Modeling (BIM)

Virtual environments for safety learning are a combination of virtual machine monitors, hardware platforms and visualization formats. Virtual Reality uses the user's vision, sound, haptic (touch), smell and taste with often real-time interactions of computer interfaces. Building Information Modeling is the construction industry's digital innovation that enables users to explore all areas of the construction project (Kassem, 2017). VR significantly improves users' understanding, recall and application (Rolando, 2019). Xie (2018) reported the benefits of VR include: allows trainees to experience role play in a safe and controlled environment; explores decision outcomes without risk to themselves or equipment; visualizes invisible characteristics such as temperature, air quality, chemical exposure levels, etc.; shows possible results for better thought and decision making process.

Example 7: Smart Working Environment – Internet of Things (IoT)

The Internet of Things refers to the connectivity of the totality of information and services that are available over the internet. Some construction examples (Burger, 2018) would be drones or cameras that monitor jobsite security without onsite personnel, sensors that record/report equipment performance and maintenance issues so repairs are completed before damage occurs, heating/cooling/lighting remotely controlled by distant smart phones saves travel time and energy costs , real-time personal monitoring devices reduce injury potential by alerting workers and stand-by personnel of a worker's changing physical or atmospheric conditions such as heat stress or toxic contaminant exposure. Albert (2018) estimated by 2020, 75 billion electronic devices will be connected over the internet. The IoT will provide information that will enhance the construction process through the development and application of artificial intelligence and machine learning including robotics and autonomous equipment.

2. Concluding Remarks

The physical, psychophysical and demographics of the United States general population and construction workforce will continue to change for the foreseeable future. Computer-Assisted Technology (C-AT) will continue to evolve and meet the challenges that result from these and other changes so worksites have reduced Safety, Health and Ergonomic exposures and the construction process results in higher quality and lower cost. The authors believe that Safety, Health and Ergonomic Professionals and Construction Engineering/Managment Professionals will need to also evolve so they have a greater understanding of these evolving technologies and the different exposures they pose to workers and the public so Risk Reduction Strategies (RRS) can be preplanned into future construction projects.

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