AUTOMATION CONSIDERATION DURING PROJECT DESIGN

by

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ABSTRACT:

Automation as pertaining to the construction industry is the use of mechanical and electronic means to achieve automatic operation or control to reduce potential exposure, time, or effort while maintaining or improving quality. Contractors utilize automated technologies on projects as a means of saving cost, reducing project durations, improving quality and consistency, and gaining other related project benefits. Communication between the constructor and designer of the construction means and methods to be used is often limited as a result of contractual relationships and competitive bidding requirements. This commonly leads the designer to assume conventional construction equipment will be implemented rather than specialized automated technologies. For this and other reasons, designer consideration in a project's design of the use of automated construction technologies is limited. This paper describes a study to investigate the ability of designers to consider the use of automated construction technologies in the design of a project. The study identifies design practices that facilitate the implementation of automated technologies and exposes barriers, within both the design process and the overall project development process, to the consideration of automation in the design. The findings of the study can be used when one is considering the implementation of construction automation technologies during the design process.

KEYWORDS: automation, design, construction, constructability, equipment, robotics

1. INTRODUCTION:

Over the past few decades, improvements to productivity in the construction industry have been insignificant compared with other industries. Productivity improvements in other industries, especially manufacturing, have stemmed to a large extent from the effective implementation of new technologies. The introduction of new technologies in the construction industry to fully automate the building process has been limited. The same is true for heavy/highway construction. The construction industry remains a craft-oriented and labor-intensive industry with minimal automation of tasks.

The lack of automation in the construction industry can be attributed to many factors. One of the hurdles to automating the construction process is the design of a project. That is, the design of a facility inhibits both the use of available automated equipment during construction and the successful development of new automated equipment. Furthermore, the capabilities of automated equipment are constrained by the physical aspects of the design. Minor modifications to designs can potentially enhance the use of automation and lead to increased construction productivity.

This topic was the focus of a research study to investigate the design practices that facilitate construction automation. This paper describes the study efforts along with identified design practices that enable construction automation and barriers to designing for automation that were exposed.

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2. RESEARCH METHODOLOGY:

The goal of the research study was to improve the ability to prepare designs that facilitate the use of automated technologies in construction work. Designing for construction addresses the constructability of a project and, in this case, a subset of a project's overall constructability - "automation constructability". To meet this goal, the research effort included two objectives. The first objective was to develop and accumulate recommended design practices which, when implemented, enhance the ability to automate construction activities. The recommended practices reflect the capabilities and limitations of current automated technologies and the application of current design practices. Secondly, barriers to the use of automated technologies in the construction process as a result of design features, methods, and deliverables were identified. Knowledge of the barriers provides additional guidance in both the planning and design processes.

Literature accessible through libraries and the World Wide Web was reviewed to determine relevant automated technologies available to the construction industry. This includes technologies which were under research and development, but when ready would be available to the construction industry. Automated technologies were found world wide and filtered based on relative potential for use in the United States construction industry. Technologies were categorized according to the finished product which they are used to create.

To determine industry usage of automated technologies, a survey was sent to the top five hundred contractors as ranked by Engineering News Record (ENR). Companies were asked to respond to several specific questions concerning industry perception, benefits, barriers, etc. of implementing automated technologies. The survey included several questions specifically written to determine whether constructors found value in implementing automated technologies.

Additional information was obtained through interviews of industry personnel. Contractors, designers, fabricators and personnel in other industries were interviewed. Standardized interviews were conducted through structured questions concerning the benefits, barriers, and limitations of automated technologies.

The contractor interviews were conducted from the perspective of both the project manager and equipment operator. Careful considerations were made to obtain a range of companies, based on annual revenue. Design firms were selected based on the type of designs produced and employee count was used to determine their relative size. Fabricators were also interviewed to get another perspective concerning automation. Interviews with fabricators were based on the grouping of technologies available to constructors and the potential for influence by the fabricator. Recognizing that automation exists in many other industries, interviews of personnel in other industries were also conducted to include information concerning how well other industries have come to include automated technologies.

3. RESULTS:

The survey of top contractors provided a list of available automated technologies and questioned whether each firm uses the technologies, has considered using the technologies, would recommend using the technologies to others, and if there is a perceived value in developing the technology. The survey intent was to determine or attempt to quantify the level of automated technology use by the industry. The survey revealed that there is a strong prevalence in concrete and masonry construction of automated mobile screeding, rebar bending, and concrete surface treatment. In addition, responses suggest that there is value in developing further

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technologies for automating reinforcing cage fabrication for beams and columns, and for mobile bricklaying. Excavation and demolition responses indicate that remote control soil compaction is used exceedingly more than other technologies within the category. Automated dump trucks and global positioning system (GPS) aided excavation appear to be highly considered applications for implementation, but with little or no actual implementation. One such implementation has proven to reduce cost by thirty percent through the use of automated trenching and pipe placement (Lee, Lorene, and Bernold 1988). Inspection and surveying activities show strong prevalence of robotic pipe inspection; otherwise technologies have not yet been greatly implemented for these tasks. For structural steel construction, metal welding and cutting systems are widely used and are recommended to other industry members. Also, robotic welders are implemented extensively amongst industry members. Lastly, material and asset management technologies appear to have developmental value amongst industry members.

Interview surveys consisted of questions concerning best practices, barriers, and changes to the design process or project design. The following summarizes the survey results.

3.1 Contractor: PM & Equipment Operators

According to project managers, over seventy percent of contractors interviewed use some form of automated technology in construction and over seventy five percent have considered the use of automated technologies. Also, implementation is attributed predominately to cost, followed by production, and then quality. Equipment operators perceive production, cost, and quality as benefits of automation and have found through experience that production, cost, schedule, and quality are benefits of implementation. Project managers are unified in agreement that having constructors and designers working together to define automated technologies that needed to be developed would be of value.

3.2 Designer:

The survey results indicate that designers typically do not formally consider construction automation, but when it is considered, the decision is based predominately on cost and quality. Responses also suggest that not many designers are aware of the automated technologies available to contractors, nor does there seem to exist any reference material for individuals seeking information concerning automated technologies and design. While no resources may commonly be used at this time, it should be noted that there exists a website where designers can go to gain information concerning emerging construction technologies (www.new-technologies.org/ECT/Index.html).

3.3 Fabricator:

According to the fabricators interviewed, design for automation is based on cost and quality, followed by productivity and safety. Similar issues to those mentioned previously arise in the fabrication of products and again there is a great deal of value placed on the communication between the designer and the manufacturer/fabricator.

3.4 Best Practices

Accumulated from the literature review and surveys were recommended design practices to facilitate the use of automation during construction. The practices can be categorized as project-related and industry-wide. Project-related recommended practices are as follows:

- Conduct constructability reviews that incorporate consideration of construction automation.
- Standardize building elements.

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- "In order to optimize the use of automated technology, it is important that design principles based on the technology are considered (Howe, 1998)."
- Provide adequate clearance for automated technologies to operate.
- Prioritize design objectives (cost, quality, safety, etc.) and compare design alternatives.
- Use electronic documents and make them available to the contractor.
- Consider the capabilities and limitations of the automated technologies. Table 1 provides examples of design practices related to various construction activities in which automated technologies and equipment are notably evident.

With respect to the construction industry as a whole, it was recommended that the technologies be marketed to designers and owners. Primarily the technology manufacturers would undertake this with assistance from constructors. Many designers and owners simply do not have enough exposure to projects that implement automated technologies and, due to this aspect, there is no benefit acknowledgement concerning implementation of automated technologies. Such marketing efforts would expose the designers and owners to the capabilities and benefits of construction automation.

3.5 Barriers

The study revealed numerous barriers to the consideration of construction automation in the design phase. As with the recommended design practices, the barriers can be separated into those that exist at the project level and those are present industry-wide. Project-level barriers are as follows:

- Automated technology capabilities are limited and create tremendous costs when contractors attempt to match project variability with automated equipment variability.
- Frequent changes/advances in the technologies. Technological advancement and improved design occur rapidly and many users cannot keep up with the changes.
- The cost of owning and operating automated technologies.
- A lack of standard design elements. Repetitious elements are likely to lead to greater utilization of automated technologies.
- "No two sites present the same problems, and a layout suitable for one site maybe quite unsuitable for another (Cusack 1994)."
- A lack of consideration of the construction phase by the designer, due to the means and methods residing with the constructor.

Other barriers exist that are not necessarily applicable to a specific project, but are representative of the nature and structure of the construction industry. These industry-wide barriers are as follows:

- Designers typically have limited construction experience. There should be pre-construction consulting between the designer and constructor concerning cost saving construction methods.
- Designers typically have limited knowledge of automated technologies. There should exist consulting between designers and constructors concerning automated technology availability and potential implementation.
- Designers typically have limited knowledge of the design practices, which facilitate the use of the automated construction technologies.
- A general lack of designer interest in considering automated technologies in their designs.

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- The structure of, and the roles associated with, the traditional design-bid-build contracting method. Barriers exist which limit the amount of pre-construction consulting and communication that can occur.
- The traditional roles and responsibilities of the designer. Traditionally the means and methods of construction have been the responsibility of the constructor. Consequently, a designer's ability to influence the implementation of construction methods has gone unused or unrecognized.
- Resistance to change from the commonly used design practices.
- Some designers view change as high risk, because there exists a level of uncertainty and untested consequences. Particularly risk associated with implementing automation.
- Conflict of interest on public projects when contractors are brought in during design. Publicly funded projects are required to be competitively bid, limiting the pre-construction communication between constructors and designers.
- Lack of reference material available for designers to use for consulting.

4. EXAMPLE OF AUTOMATION BENEFITS

The benefits of construction automation, and the design impacts on the use of construction automation, can be illustrated using a past project on which a concrete extruder was utilized. The project, located near Clackamas, Oregon, involved the construction of a freeway overpass. Nearly three thousand feet of MSE retaining wall rails were constructed during the two-year project duration, but not all of the railing was extruded. The only railing that was extruded was railing attached to wall "H". Wall H is over 2000 feet long and the extruder contractor completed the wall in two days. Although wall H contained the longest stretch of railing, there were other opportunities to utilize an extruder. Railing extending along another wall, wall "P", and onto the bridge itself, was less than 1000 feet in length and took the bridge contractor over three weeks to complete. Working crews for both walls were relative in size. The railing along wall P and the bridge was not extruded, but could have been. The extruder contractor pointed out that the railing on wall H had a vertical back and curved face, allowing for optimal utilization of their extruder, while the wall P and bridge railing did not. Also, there was a height difference between the railing on wall P and the bridge railing. Although attached, the height transition added to the overall cost of extruding. Since the wall P and bridge railing was under three hundred feet and required a change in shape configuration, the extruder contractor could not competitively compete against conventional construction methods. Also, the railing on wall P and the bridge had two vertical faces, which magnifies any inconsistency and adds to the cost of using an extruder. The extruder contractor added that having at least one curved face helps to reduce visibility of inconsistencies to the human eye.

5. CONCLUSIONS:

Implementation of automated technologies can be greatly affected through the design process when consideration is given to the contractor's opportunities for automation applications. This is made feasible through fluid communication between the constructor and designer. This communication should optimally take place during the design phase. If the designer is not already knowledgeable about the construction means and methods to be used, it is beneficial if the constructor conveys the means and methods for constructing the project to the designer and at a minimum provides some evidence of the automated technologies being considered for implementation. In addition, owners need to perceive the construction process in its entirety, starting from the architect/designer and

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completing in the hands of the constructor. By holding each entity accountable for cost, quality, and safety, owners can indirectly influence the driver for designers to incorporate designs that will lead to potential cost saving automation and increased project safety.

6. RECOMMENDATIONS:

Designers and constructors are encouraged to take a non-adversarial approach to communication and information exchange with digital documentation and plans, as well as intentions for methods of construction and project follow through, on the behalf of the designer. Lastly, constructors and designers are encouraged to develop business relationships with one another that foster competitive, low cost, high quality, safe projects and in doing this automation implementation can be better achieved.

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Table 1. Example Design Practices to Facilitate Construction Automation

Automation Category	Example Design Practices
Concrete Finishing	▪ Tighter specifications for grade, slope, and smoothness. ▪ Long continuous paving with constant slope. ▪ Keep floor utilities together, not spread out. ▪ Pour constrained to machine width; no perpendicular curvature. ▪ Eliminate mid-slab protrusions.
Concrete Reinforcement Fabrication and Placement	▪ Use repetitive sizes throughout building for columns, beams (i.e. Revise reinforcing and/or concrete strength in lieu of changing member size.). ▪ Use round columns vs. square columns. ▪ Conducive standards for local iron manufacture facility. ▪ Control degree of architectural variability.
Earthmoving/ Excavation	▪ Digital copy of existing surface profile. ▪ Uniformly sloped grading plans with well-defined break-lines. ▪ Precise standards for locating underground utilities effectively. ▪ Depths conducive to the use of automated equipment. (Stronger pipe doesn't get buried as deep, so automation implementation may balance or lower costs through increased productivity)

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Soil Compaction	▪ Allow for adequate width of equipment. ▪ Use backfill material conducive to the equipment. ▪ Adjust trench slopes to slope range of equipment. ▪ Adjust lift specifications to allow clearance for perpendicular objects. (Pipes, Shoring supports, etc.)
Site & Structure Inspection	▪ Level surface or platform free from obstacles. ▪ Visibility between equipment and operator.
Pipe Fab. & Inst.	▪ Accessibility of welders by leaving two feet between connections and joints.
Structural Steel Fab. & Inst.	▪ Use of Object Based Design process so that design documents can be used to detail and fabricate material.
Material Tracking	▪ Specifications for use of barcode labels. ▪ Industry Standardization of technology. ▪ Design with more interchangeable sequences of work. ▪ Specifications for required participation.

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