ARTICLE IN PRESS
ISTRUC-00024; No of Pages 10
Structures xxx (2015) xxx–xxx
Contents lists available at ScienceDirect
Structures
journal homepage: http://www.elsevier.com/locate/structures

Automating measurement process to improve quality management for piping fabrication

Mahdi Safa [a,*], Arash Shahi [a], Mohammad Nahangi [a], Carl Haas [a], Hamid Noori [b]

[a] Department of Civil and Environmental Engineering, University of Waterloo, 200 University Avenue West, Waterloo, Ontario, N2L 3G1, Canada
[b] School of Business & Economics, Wilfrid Laurier University, 75 University Avenue West, Waterloo, Ontario, N2L 3C5, Canada

ARTICLE INFO

Article history:
Received 3 June 2014
Received in revised form 26 February 2015
Accepted 11 March 2015
Available online xxxx

Keywords:
Construction quality assurance
Piping fabrication
Staged-fabrication
3D imaging technologies
Optimization
Handheld laser scanner
Photogrammetry

ABSTRACT

Addressing deficiencies and defects that occur during construction projects, particularly in piping fabrication, is costly and time consuming. The current quality management process associated with piping fabrication has a number of limitations, resulting primarily from human error and lack of consistency. This research therefore introduces an automated process for construction quality management that employs automated technologies for detecting defects, to contribute to the existing body of knowledge. The system relies on piping construction data collected with the use of photogrammetry and laser scanning, which are then used as a means of comparing the work actually performed to that designed. The developed three-station quality management model has the potential to decrease the overall cost of a project by reducing the fabrication rework required as well as by avoiding costly and time-consuming site assembly realignments, which are often caused by defects in the fabrication and delivery processes.

1. Introduction

In construction, a quality assurance (QA) system refers to the method by which owners and contractors use systematic quantitative and qualitative measurements to ensure adequate confidence that a product, process, or service will conform to contract requirements [1,2]. Given the dynamic construction environment, failure to achieve adequate quality levels in construction processes has long been an obstacle to the delivery of projects on time and on budget. Effective improvements in the quality assurance systems associated with construction processes therefore offer significant promise [3–5]. Construction projects are characterized by their one-off nature, with consequent inherent lack of standardization and an extreme number of changes in product design details over the lifecycle of a project [6–9]. In addition, current QA processes primarily involve paper forms and manual human operations, which are inaccurate, time-consuming, expensive, and labor intensive [10–12]. The associated problems may cause delays in completion of the project and may trigger claims by the owner and other parties [13]. The new technologies offer potential advantages to the currently used manual systems by using less process time and having a smaller footprint and features beyond the restrictions of traditional measuring devices [14].

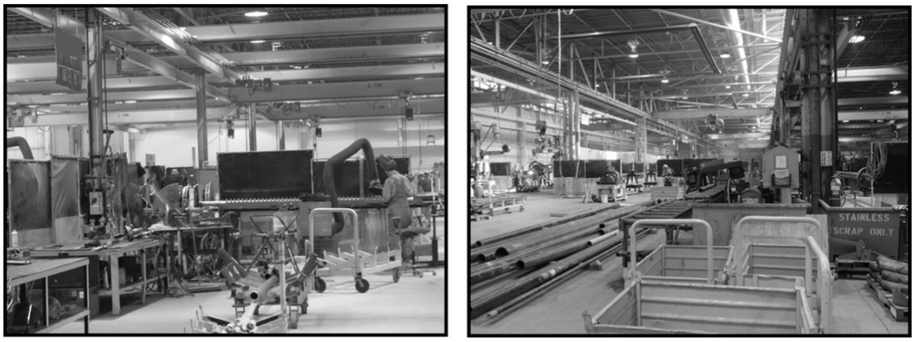
Despite the increasing attention this area of research has been receiving in the literature, developing an applicable project-wide model (a framework) for the piping spools measurement control process is still novel. While, the theoretical aspects of developing a new automated quality measurement model are evolving, the debates over more specific and often practical applications remain somewhat inconclusive. Whereas, many organizations collect quality data such as defect rates, error rates, and rework rate for piping fabrication, a project-wide automated measurement process has not been defined. Hence, we introduce an automated measurement framework to improve the process of identifying inspection (measurement) goals, inspection planning, as-built data acquisition, and defect detection in different phases of a project. We discuss the validation of this formalism based on different project studies.

The scope of the research presented in this paper was limited to the development of a QA model of the built dimensional quality of prefabricated pipe spools and pipe modules that have been produced using a staged-fabrication process. The application of staged-fabrication techniques has resulted in a profound change in the construction industry worldwide [15–18]. Prefabrication can be defined as "a manufacturing process, generally taking place at a specialized facility, in which various materials are joined to form a component part of a final installation" [19]. Any component that is manufactured offsite and is not a complete system can be considered prefabricated, including pipe spools and pipe modules (Fig. 1). Benefits include improved quality, enhanced design, reduced project time, and less

* Corresponding author at: Postdoctoral Fellow and Research Assistant, Department of Civil and Environmental Engineering, University of Waterloo, Waterloo, Ontario, Canada N2L 3G1.

http://dx.doi.org/10.1016/j.istruc.2015.03.003
2352-0124/

Please cite this article as: Safa M, et al, Automating measurement process to improve quality management for piping fabrication, Structures (2015), http://dx.doi.org/10.1016/j.istruc.2015.03.003



(a) (b)

Fig. 1. (a, b) Views of a piping fabrication shop in Ontario, Canada.

reliance on site labor. For some projects, these benefits come with increased costs, which could, however, be minimized in the future, as the construction industry becomes more familiar with the technology [20].

Modularization and prefabrication represent aspects of a trend toward staged fabrication that has been developing in the construction industry in Canada and the US over the past few decades. Improved productivity is a key driver for the use of staged fabrication [21]. In addition, conditions (supply chain) in Canada and in many other parts of the world necessitate modular design and staged fabrication across nationally and sometimes globally distributed supply chains. Examples include pipe modules that are fabricated in places such as Edmonton, Hamilton, and Cambridge, and then shipped to Fort McMurray, energy projects in Toronto, or oil fields off the east coast. Most staged fabrication occurs offsite. Offsite fabrication provides cheaper, safer, more sustainable, and higher quality construction components because of controlled conditions, more thorough quality control, and less construction waste [22]. While the use of staged fabrication is increasing in all construction sectors, this paper focuses on solutions to particular technical problems in order to improve the quality management system associated with the staged fabrication of piping assemblies in the industrial construction sector.

2. Background

Successful transportation and delivery of staged fabrication materials have always been a key challenge. In spite of recent substantial advances in modularization and prefabrication and the use of an extra 10% to 20% of structural material for bracing and supporting modules, significant damage still occurs during shipment, requiring rework after arrival at the site: an undesirable secondary effect. Other factors that lead to rework and increased costs are fabrication errors and inaccuracies, which are due mostly to human interaction and challenging material behaviors in the fabrication process. The Construction Industry Institute (CII) has reported that the cost of rework as of 2001, and the annual cost was approximately US $ 15 billion [23]. Defects frequently become evident during the construction phase, which is costly for both the contractors and the owners. It has been estimated that approximately 10% of the cost of construction rework is caused by delays in detecting the defects [24,25]. Timely and accurate quality management practices can hence save money and expedite project schedules. Current approaches for measurement quality control on piping fabrication and installation are not as effective as they could be in identifying defects early in the construction process. As a result, defects can go undetected until later phases of construction or even to the maintenance phase. It was reported by the Construction Industry Institute in 2003 that 13.3% of all fabricated pipe spools in the industrial sector required rework (CII, 2003).

Addressing deviations due to fabrication errors and shipping damage requires an automated, integrated, and continuous inspection and quality control management system. Combining 3D imaging with 3D design information opens up a wide range of potential solutions. Applying this technique for automating the measurement process of QA provides project management with an outstanding opportunity for visualization of the as-built point cloud data, which needs to be properly registered with the as-planned point cloud [26]. The feasibility of the use of these technologies has been the subject of numerous research studies involving the analysis of construction progress and other computer vision and construction management applications [27–42]. Such tools make it is possible to automate tasks related to quality control and quality assessment, including (1) the automated quality assessment of fabricated assemblies, (2) the remote identification of exceeded tolerances, and (3) the remote and continuous quality control of assemblies as they are being fabricated. Solving these problems and automating these tasks will reduce the risk of fabrication errors and thus decrease project cost as well as enhance schedule and productivity performance.

Technical sensing devices that provide 3D information have been used for a variety of engineering tasks, including acquiring data from construction sites. Technologies such as global positioning systems (GPS), ultra wideband (UWB) tags, total stations, digital photos to be used in digital photogrammetry, and terrestrial laser scanners have been investigated for use in the extraction of as-built information for monitoring and control processes. The ability to compare the built status detected by sensing technologies within a framework that contains information about any object in the field at any time facilitates the assessment of construction performance. The following

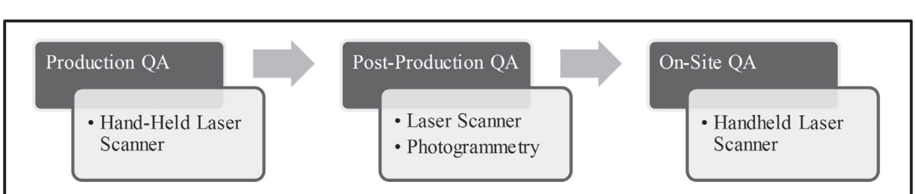


Fig. 2. Components of the QA processes for fabricated pipe spools.

Please cite this article as: Safa M, et al, Automating measurement process to improve quality management for piping fabrication, Structures (2015), http://dx.doi.org/10.1016/j.istruc.2015.03.003