Managing Earthwork Construction Business Institutions Applying Industry 4.0 Relating Technologies – The Case of German SMEs

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ABSTRACT

The interest in Industry 4.0 relating technology in earthwork construction is increasing and continues to gain more and more in popularity. Earthwork contractors have begun to think about alternative and innovative ways to increase productivity by applying new ICT technologies. In this context they try e.g. to utilize sensors, software and information and communication tools to improve processes and to reduce workforce and total costs at the same time. However, as with many innovations, there exist companies that have not invested in these technologies yet. The objective of this paper is to investigate in technologies associated with Industry 4.0 and their potential future application-possibilities in the field of earthwork construction. Therefore, this paper conducted an in-depth literature review of relevant Industry 4.0 technology topics. Additionally, semi-structured interviews among German earthwork industry experts were conducted, which revealed several insights regarding benefits, challenges and barriers of managing relevant technologies.

Keywords: Industry 4.0, Earthwork Construction, Technology Management, Information and Communication Technology

INTRODUCTION

Traditionally the construction industry is not perceived as being among the most innovative industry branches. The earthwork construction sector with its excavators and bulldozers would not appear to have much in common with digitization at first glance. And in fact, earthwork construction itself has lagged in digitization for years. But they are currently undergoing the same digital disruption that has already hit several other industry branches (World Economic Forum, 2016). In becoming increasingly connected and automated, new technology should enable low-skilled operators to work more efficiently in the nearby future. Since the adoption of BIM (Building Information Modelling) is progressing and its implementation gets pushed through governments initiatives and several contracting entities, the interest in smart connected heavy machinery will accelerate (Singh, 2007; Kelp & Kaufman, 2017). However, little is known about the full role of Industry 4.0 relating technology within the application field of earthwork construction and its potential for facing future challenges in terms of increasing competition and the lack of skilled workforce. For that reason, the main objective of this study is to examine how Industry 4.0 relating technologies are capable for earthwork construction and to what extent they may affect the earthwork construction environment. Therefore, a literature research was conducted first, using Google Scholar and several databases such as ASCE, EMERALD and ASCE, to determine the latest developments of Industry 4.0 relating technologies in the field of earthwork construction. Therefore, search keywords like Industry 4.0,
earthwork construction, earthmoving machines, earthmoving equipment, machine guidance systems, innovations, productivity, connected machines, big data, smart sensors and process optimization were involved in the articles searched. Where it was considered meaningful for reasons of plausibility some additional papers were included in the research. After collecting the latest academic contributions, an analysis was performed to classify the main areas of interest. It is acknowledged that the review focuses on Industry 4.0 technologies, having a closer look on smart technologies applied on earthmoving machines and within earthwork construction in a narrower sense. In addition to the literature review, semi-structured interviews among German construction experts were applied. The interviews should reveal further insights regarding the companies’ experiences on the technologies described and into their impacts on earthwork construction. Therefore, several questions were outworked to experience the participant’s assessments. In a final step, the results from the literature review and the interviews were brought together and synthesized, to determine the future trends. The aim is to predict future developments and to provide a direction for future research.

LITERATURE REVIEW: INDUSTRY 4.0 RELATING TECHNOLOGIES

Machine Guidance Based Site Control Technology (SCT)

Today, several types of earthmoving machines are available with different automation configuration levels, allowing operators to operate more efficiently. In contrast to existing methods, conventional survey stakes are redundant, because today’s machine guidance systems are based on 3D design and real-time measurement information. This automated machines, minimize the need for surveyors to stake out and continually check the grading work. This greatly speeds up the process and adds accuracy, because the machine matches the model. The current state-of-practice are systems with automatic blade or cutting-edge bucket control (Seo, Lee, Cassule, & Moon, 2015). Albeit, extensive research has been conducted, a fully autonomous system for a mobile earthmoving machine such as a bulldozer, excavator, motor-grader or roller has yet not been applied on a real construction site (Dadhich, Bodin, & Andersson, 2016). Thus, the current state-of-practice comprises just semi-automated machines, using sophisticated design software to direct the operations with a high level of precision. In this context, Dadhich et al. (2016) investigated in the key challenges of automating earthmoving machines, stating that more research and more industrial support is necessary to speed up the process towards fully autonomous machine solutions. The advantages are apparent, considering the lack of skilled operators and the impacts on productivity and cost savings. Accordingly, several case studies show, that machine guidance systems are feasible for productivity gains between 5% to 270% and cost savings in the range of 10% to 70% depending on various external contribution factors (Jonasson, Dunston, Ahmed, & Hamilton, 2000; Aoalsteinsson, 2008; Higgins, 2009; Forrestel, 2007; Caterpillar Inc., 2006; CTC & Associates LLC., 2015; Kirchbach, Zeeshan, & Tezel, 2015).

Smart Sensors and IoT

The Internet of Things (IoT) – also known as the Industrial Internet – is a technology that is likely to disrupt industry branches, enabling automatic communication and interaction among objects and the physical environment (Krotov, 2017). At a first glance, connected products are essentially not perceived as a breakthrough innovation in general, since industrial equipment has been supervised remotely in the past. However, the novelty originates from the IoT’s potential of widespread application as rates for data traffic have decreased, enabling a seamless connectivity and automated surveillance at acceptable cost (Saarikko, Westergren, & Blomquist, 2017). The functionality behind this is that the IoT makes objects sensed or controlled and thus implies a network paradigm of cyber-physical systems (CPS) that allow physical objects to connect with each other and to collect and exchange data through the internet protocol and wired or wireless networks (Kang, et al.; Chen & Chen, 2016). Regarding earthwork construction, IOT can collect or exchange data acquired from smart sensors mounted on earthmoving equipment (Caterpillar Inc., 2015). It is a core technology for
the realization of smart connected machines, enabling productivity analytics and predictive maintenance (Parpala & Iacob, 2017). Machine data, generated automatically through smart sensors, allows manufacturers and customers to analyze work patterns, to anticipate changes, and to monitor and to confirm whether a machine has achieved its desired productivity. They may also be able to identify patterns in machine maintenance before a machine experiences catastrophic failure or damage (Azar & Kamaat, 2017; Parpala & Iacob, 2017).

**Big Data**

The term "Big Data" is an important component of any company’s digitization strategy and is becoming increasingly important in civil engineering and earthwork construction. It describes datasets whose size exceeds the capacity and capability of traditional database software tools for capture, storage, processing and analysis. However, there is no exact measure to describe when a record is referred to as "Big Data". Literature describes "Big Data" based on the following 5 dimensions: data volume, data variety, data velocity, data reach and data variability. According to Kaplinski et al. (2016) “Big Data” technologies are new generation technologies and architectures which were designed to extract value from multivariate high-volume data sets efficiently by providing high speed capturing, discovering and analysis,” to enhance decision making (Kaplinsky, Koseleva, & Ropaite, 2016). As a result, "Big Data" is worthless if no technologies are available to extract valuable information from the data sets and illustrate it in a meaningful way. The increasing importance of “Big Data” in civil engineering is due to the new technologies and intelligent sensors that are available in today’s construction machines. They can generate enormous amounts of data, which can create significant competitive advantages when applying adequate analysis options. The manufacturing industry has followed “Big Data Analytics” approaches for many years, using data collection; processing and analysis to better understand irregularities within their production system. They range from the creation of automated daily reports to sophisticated predictive analyses requiring usage of data mining or advanced statistical tools. “Big Data” solutions are now also gaining increasing interest in the earthmoving machinery industry as an integral part of predictive maintenance management systems. (Santos, et al., 2015).

**Cloud Computing and BIM**

Cloud Computing builds the basis for providing access to a shared pool of configurable resources via the Internet and thus is they key enabling technology for BIM (Building Information Modelling). BIM facilitates a visualization of the construction design, allowing several project participants simultaneously to monitor the progress of a construction site (Bilal, et al., 2016). While the conventional BIM is intended for designing, creating, managing and sharing the whole lifecycle of a building, where process sequences usually can be predefined, the application of BIM technology to earthworks is a little bit more sophisticated, because irregular shapes (topography) and unforeseen object data (e.g. soil condition) must be considered (Moon & Seo, 2017). Because most construction projects entail earthwork phases, where data of both buildings and urban environment is required, there is a need in integrating both approaches, to visualize a site in its entirety (Roarty, 2015). However, BIM is usually applied in building construction and not very common in today’s earthwork projects (Tanoli, Raza, Lee, & Seo, 2017). However, regarding earthwork construction, BIM integrated technology will facilitate spatial data analysis and more effective and transparent earthwork calculations in the future (Kim, et al., 2015). Regarding the smart deployment of earthmoving machines on site, the basis therefore is always three-dimensional construction drawing data (Kim, et al., 2015; Tanoli, Raza, Lee, & Seo, 2017). However, BIM researches focusing on earthworks are still in its initial stage but are currently making advances. For instance, Moon & Seo (2017) developed a 3D earthwork BIM methodology, presenting a graphic simulation that can assist machine operators during excavation work. It combines software and hardware technologies to represent the actual excavator configuration in a three-dimensional virtual environment. (Moon & Seo, 2017).
METHODOLOGY

This study applies a qualitative research method to investigate in current barriers and opportunities of applying Industry 4.0 relating technologies to the management of small and medium sized construction enterprises acting in the field of earthwork construction. A qualitative research strategy is appropriate given the fact that the study intends to gain insights on how construction professionals manage their company applying Industry 4.0 relating technologies. Therefore a set of semi-structured interviews was carried out to collect valuable data. Following that a sample of ten German construction companies focusing on earthwork construction was constituted on the criteria of the existence of a formal, public discourse regarding the use of Industry 4.0 relating technologies. Afterwards the key people responsible for the companies’ management strategy were identified within these companies.

To get reliable data all interviewees were selected under the premise of the following requirements: a) to have experience in earthwork construction as a senior manager, b) to have management experience in earthwork construction of minimum 10 years, c) to be completely familiar with earthmoving machines and relating production techniques, c) have an understanding of Industry 4.0 relating technologies, d) less than 250 employees, e) to apply a minimum level of information and communication technology within their organization (e.g. CAD Software, Digital Terrain Models, Machine Guidance Systems, Mobile ICT Components, Local Area Network, Internet Access and E-Mail).

The interviews were based on the following main questions:

1. How do you estimate the relevance of Industry 4.0 related technology and its adoption to earthwork construction regarding the management of your company?
2. What are the problems and barriers of implementing Industry 4.0 related technology within your company and on site?
3. Can you describe an example of Industry 4.0 related technology which you already use?
4. Which associated technology would be promising in managing your company in the nearby future?

FINDINGS

Infrastructure Requirements

All interview participants pointed out that, before Industry 4.0 becomes relevant in earthwork, the necessary framework conditions must first be created by policymakers. In particular, access to high-speed internet also needs to be enabled on remote construction sites. Unlike in the manufacturing industry, construction sites are unique and are often located away from developed areas. As almost all technologies associated with Industry 4.0 are dependent on the internet and can only then function together as a complete system, most participants believe that earthwork will lag behind industry for a number of years. In addition, they note that the implementation of these technologies necessitates considerable capital expenses as well as the approval of employees. Since the construction sector has difficulty recruiting young talents familiar with new technology and largely has to fall back on an older personnel base, the acceptance, willingness to learn and a supposedly higher training expense for older employees represent additional limiting factors for implementation.

Construction Process Management

All interview participants already use machine guidance systems on various construction machines in their company. In line with the literature review, they also largely hold the view that these systems lead to cost savings on the construction site of between 10 and 70%. According to the participants,
the introduction of positioning and sensor systems as well as their integration with modern software in the new generation of construction machines represent a promising approach for the potential adaptation of the digital factory for the construction site. Besides the potential for cost savings and the optimization of processes, the systems create increased information transparency and thereby open up new means of communication (Kirchbach, Koskela, & Gehbauer, 2014, Kirchbach, Steuer & Gehbauer, 2013).

Autonomous construction machines are also conceivable in the near future – due to constant system developments and the interplay of automatically generated digital information by means of sensors. Examples mentioned include earth-moving compactors for soil compaction, bulldozers for levelling work and diggers for excavating construction pits.

**Supplier Side**

All participants report that they have different construction machine manufacturers in their fleet of machinery and, consequently, no compatibility with respect to the often supplied and integrated fleet management systems in particular. As the practical application of these technologies is based on the ability to exchange data between different manufacturers, it is necessary for OEMs to rethink their systems and sensors in order to make them compatible with each other using open interfaces. On the whole, it can be determined that initial efforts have been undertaken by manufacturers to digitalize earthwork. In this context, however, the project participants need to enter into close dialogue with each other in order to prevent the development of isolated solutions. Continued efforts should concentrate on developing a holistic approach that encompasses all work steps (and not just some work steps, as has so far been the case). Since a construction site often involves earthwork, building construction and civil engineering, an integration into BIM should also be considered. Thus, no ‘islands of automation’ should be created. Instead, existing approaches are to be combined, bundled into a single solution and further developed.

**Fleet Management & Predictive Maintenance**

The finding that the participants have not thus far utilized telematics systems intensively for their construction machines is primarily due to the fact that each manufacturer introduced its own software and different software interfaces were used which were not compatible. This prevented consistent data transfer – meaning users of mixed fleets had to log in to multiple interfaces or integrate additional hardware to access data. In turn, this resulted in more workload and additional costs and was not communicable to users, especially as many devices are already fitted with the components ex works. Another key point mentioned by the participants in this respect is the predictive maintenance of the machine fleet. This technique is already utilized in some areas – albeit to a limited extent. Although the technical basis already exists with IoT and smart sensors, here too there is insufficient will among manufacturers to standardize for full implementation. In 2016, the US association of fleet managers AEMP, the US construction machine manufacturers’ association AEM and the German representative body VDBUM agreed to a standard AEMP interface 2.0 for construction machines. Despite this positive approach, which resulted in the ISO standard 15143-3 in 2017, the current solutions on offer are not suitable for practical use. Here, the participants stated the possible reason for this is that the sales staff are only inadequately informed and largely are unaware of these agreements. This is likewise an indication that the manufacturers do not currently have the will to provide these technologies in a practicable manner.

**Workforce**

According to the opinion of most participants, the introduction of Industry 4.0 technologies in earthwork will also change the requirements on employee qualifications. The simplest work steps currently performed manually may be automated in future. For this reason, soft skills such as
organization, communication and decision-making will be required in future. Moreover, greater knowledge of software and programming will be necessary. It is already the case that construction machine technicians must be able to resolve basic programming and code errors independently. In the future, these requirements will increase further due to system complexity. This is increasingly leading to a need for interdisciplinary knowledge (mechanics, software and programming). Suitable and tailored training measures will also have to be developed and provided to this end. However, employees will also need to be open to technologies and place the necessary trust in themselves and management. The desire for continuous learning is a key requirement to keep pace with technological progress. The interview participants believe this will represent a major challenge for many of their colleagues, and hence one of the greatest barriers to the further development of their company.

Communication

Currently, various construction machine manufacturers and parts from the supplier industry are working on online cloud solutions that aim to create a suitable information platform on which relevant project information can be shown and accessed in real time. As a result, all construction participants, surveyors and project partners with internet-enabled devices, the office as well as all construction machines with 3D machine controls fitted with an internet-enabled modem should be able to provide and access relevant information at the same time. This solution approach should thus allow the office, all construction participants and the respective construction machines to communicate with each other directly on a secure, web-based portal. CAD machine data can thereby be accessed anytime and anywhere, allowing construction progress to be monitored continuously from the office. Thanks to this two-way communication, construction managers also have access to latest planning data all time. Without question, this solution approach would significantly simplify many working processes and minimize unnecessary journeys and working hours. In turn, this would lead to a reduction in costs and an increase in machine productivity. This two-way communication to and from the machines ensures that the machinery managers are always working with the updated CAD terrain models and planning data. Consequently, all project participants with access authorization to the portal would have an easy means of accessing relevant design files and all productivity information regarding construction sites and construction machines in real time. The site managers could thus save precious time on travelling to the construction site and, as a result, effectively manage the use of machines and site coordination from the office.

CONCLUSIONS AND FUTURE RESEARCH DIRECTIONS

This qualitative study examines and considers Industry 4.0 technologies in terms of their application and management in earthwork construction in Germany. The aim of this study is to investigate the opportunities, possible applications and barriers. Based on the data collected from interviews, the relevant key areas from the perspective of management are identified, systematically categorized and described. Due to the nature of qualitative studies, the results cannot be generalized or universalized. However, the results provide the basis for future research and open up new starting points. For instance, quantitative investigations could be conducted in the future to analyze the distribution of various technologies. Particularly, comparative research could provide interesting insight with respect to company size or company earnings. Future research should also consider the construction sector as a whole and examine the extent to which the presented technologies can be suitably implemented and combined throughout the entire value chain of construction. To this end, case studies could be prepared that encompass earthwork, civil engineering and building construction.
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