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Understanding the implications of digitisation and automation in the context of Industry 4.0: A triangulation approach and elements of a research agenda for the construction industry

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ABSTRACT

In recent years, Industry 4.0 has been introduced as a popular term to describe the trend towards digitisation and automation of the manufacturing environment. Despite its potential benefits in terms of improvements in productivity and quality, this concept has not gained much attention in the construction industry. This development is founded in the fact that the far-reaching implications of the increasingly digitised and automated manufacturing environment are still widely unknown. Against this backdrop, the primary objective of this paper is to explore the state of the art as well as the state of practice of Industry 4.0 relating technologies in the construction industry by pointing out the political, economic, social, technological, environmental and legal implications of its adoption. In this context, we present the results of our triangulation approach, which consists of a comprehensive systematic literature review and case study research, by illustrating a PESTEL framework and a value chain model. Additionally, we provide recommendations for further research within a research agenda.

Contents

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1. Introduction and motivation

Nowadays, the visionary idea of Industry 4.0 or other synonyms like Smart Manufacturing, Smart Production or Industrial Internet, to name a few, have been promoted steadily by different actors to describe the trend towards digitisation, automation and the increasing use of ICT in the manufacturing environment. As a result, funding programs and research initiatives are raised by the government of several countries as part of their effort to gain or maintain global leadership in the manufacturing industries [1,pp. 69–70]. In this context, the term Industry 4.0 comprises a variety of technologies to enable the development of a digital and automated manufacturing environment as well as the digitisation of the value chain [2,3]. This results in improvements in product quality and a decrease of time-to-market as well as improvements in enterprise performance [4].

Despite the provided benefits, companies from the construction industry have not managed to integrate these innovative technologies to keep up with their counterparts from the automotive or mechanical engineering sector [5]. However, there exist many challenges specific to the construction industry that must be taken into account. For example, the entire construction value chain is highly affected by tight collaborations with customers, subcontractors and other stakeholders. Hence, construction projects are site-based, complex and individual undertakings which require a higher level of specialist knowledge. Furthermore, the construction industry sector consists of a high amount of small and medium-sized enterprises with limited capabilities for investments in new technologies [5].

As stated so far, the lack of innovation and technological progress in the construction industry is going hand in hand with the underinvestment for research and development (R&D). According to the 2015 EU R&D Scoreboard, the construction & materials industry is amongst the lowest R&D intensity sectors with less than 1% of net sales [6,p. 9]. These findings are surprising, judging from the fact that the construction industry is one of the major contributors to employment and economy of each country [5]. Given these circumstances, there is definitely a need for further research, as construction companies are facing increasing challenges through globally economic competition, resulting in thin profit margins and limited R&D investments [5]. In this context, the following research questions arise:

- Research question 1: Which technologies are currently associated with the concept of Industry 4.0 in the construction industry?
- Research question 2: What is the current state of the art of these technologies in the construction industry?
- Research question 3: Which technologies have already been adopted by companies of the construction industry in the recent years?
- Research question 4: Which far-reaching implications does the digitisation and automation of the construction environment entail for future research?

Based on these questions, the primary objective of this article is to fill a gap in literature by providing a comprehensive overview of the currently researched and adopted Industry 4.0 relating technologies in the specific environment of the construction industry. The remainder of this paper is organized as follows. The multifaceted concept of Industry 4.0 and the economic impact of the construction industry are presented in Section 2. In Section 3, we use a triangulation approach for data collection in order to provide comprehensive results. First, we intend to derive a definition of Industry 4.0 for construction in Section 3.1 by carrying out a systematic literature review and applying a content analysis. Subsequently, we build on this derived definition to identify scientific and practical literature and to explore the state of the art in Section 3.2. Additionally, we perform a case study research by using multiple case studies for the purpose of exploring the state of practice in construction companies in Section 3.3. Section 4 contains the results from the systematic literature review as well as the results from the case study research, resulting in a data triangulation and the development of a research agenda in Section 5. Finally, conclusions and a final outlook will be provided in Section 6.

2. Industry 4.0 in the construction industry

Recently, Industry 4.0 is being introduced as a popular term to describe the trend for the increasing use of information and automation technologies in the manufacturing environment [1,p. 76]. To clarify this term at the outset, we present the following definition prior to starting the analysis. Subsequently, we describe the impact of the construction industry as a part of nation's economy.

2.1. The concept of Industry 4.0

In comparison to many other traditional manufacturing concepts like Advanced Manufacturing or Lean Production which has been widely established in the scientific literature, Industry 4.0 can be identified as a term which is mainly used in the popular science in different contexts [4]. Developed by the German Federal Government to promote its High-tech strategy, this multifaceted term comprises a variety of interdisciplinary concepts without a clear distinction [2]. It has often been used as a synonym for the planned 4th Industrial Revolution by pointing out its huge technological potential, comparable to technical innovations which led to the first industrial revolutions: (1) the field of mechanisation, (2) the use of electricity and (3) the beginning of digitisation [2].

From the technical point of view, Industry 4.0 can be described as the increasing digitisation and automation of the manufacturing environment as well as the creation of a digital value chain to enable the communication between products and their environment and business partners [2,3]. As a result, simultaneous planning of products and production processes leads to improvements in product quality and decrease time-to-market [4]. As