Influence of automated building construction systems on vocational education and training

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Abstract

Robotic systems are increasingly becoming a relevant factor for so-called "made to order" production, as is the case in the construction industry. The aim of this contribution is to provide a basis for a cross-disciplinary discussion on the topic of robotics in the construction industry, in which both technical issues regarding the technical challenges of robotics in the construction industry and how automated building construction can be practically addressed in education and training. Based on case studies and lab experiments, the authors investigated upcoming transformations in shell production by comparing the conventional construction process with proposed processes involving cable-driven parallel robots. The focus is on bricklaying and working methods for the installation of pre-fabricated elements. Based on the prospective changes in construction the impact on vocational education and training will be discussed and influences in current educational frameworks based on automation and robotics will be introduced.

Keywords –

automated building construction, cable-driven parallel robot, bricklaying, site logistics, human-machine interaction, social effect, technology dissemination, vocational education and training, VET

1 Introduction

The Internet of Things and Building Information Modeling (BIM), which has already been used in some construction organizations, are two major areas of digitization in the construction industry [1]. Due to the increasing digitalization in the context of industry 4.0 and the current increasing spread of BIM in the construction industry as well as the constantly growing technical possibilities and the increasing computing power, the application and use of automated building construction systems is currently being pushed forward. Such systems can ultimately include both digital planning and autonomous construction of a building. The changes resulting from digitization will create new jobs, change existing ones, or make existing ones disappear [2]. In the context of this article, the study by Dengler and Matthes (2015) deserves to be considered. The authors discuss which professions could (partially) be replaced today due to the current state of digitalization. It should be emphasized that the current status of digitalization has a similarly high substitutability potential for assistant and specialist occupations. The study concludes that the ongoing digitalization process should be taken more into account in the training of skilled workers in order to counteract the loss of professional groups [3]. It does not deal with the question of whether only a shift in the areas of activity in the occupational groups takes place through digitalization and to what extent possibilities can be created with which the occupational groups can be supported or to what extent current training standards would have to be adapted. This paper aims to provide a first qualitative basis to answer these questions in the context of vocational education and training (VET) in the construction industry. It is not the aim to present new curricula for VET in this field, because setting up new curricula involves a lot of red tape which in turn costs a lot of time. Developments in automation and robotics are currently happening very fast, and therefore the construction industry needs solutions that can be implemented within a short period of time. Therefore, at this stage, the authors are more interested in identifying how new requirements from automation and robotics can be integrated into existing ordinances and framework curricula on short notice. Preferably directly at vocational schools or at the workplace.

2 Methodology

Based on an existing prototype of a cable-driven parallel robot at the University of Duisburg-Essen, the authors used for this research a) simulations and data analysis, b) qualitative case study, c) comparative analysis. The authors carried out analyses regarding the operation of the cable-driven parallel robot within the body shell construction. Based on this, possible influences on existing material and work processes up to changes in the construction site layout are identified (detailed results are published in [4][5][6]).

Consequences for VET are derived from technology, work organization, tasks and responsibilities, work environment and safety, materials management and site logistics. Based on the (partially) new boundary conditions identified in this way, general influences on the technical personnel are worked out in a qualitative analysis and the effects on the field of activity are illustrated exemplarily within the following three occupational profiles.

1: Construction equipment operator - Currently, this occupational group is responsible for the operation and maintenance of construction equipment. It is assumed that this profession will take over the operation of an automated building construction system in the future.

2: Bricklayer - This professional group is massively influenced by the use of an automated building construction system due to a shift of work in their activity areas. In order to counteract the loss of this professional group, it is assumed that further qualification is necessary and advisable.

3: Draftsmen - This professional group is involved in the conception and planning of a building project from an early stage. By using the BIM method draftsmen can have one or more of the following roles depending on their qualification, project size and responsibility: BIM author, BIM user, BIM coordinator. Due to the use of automated building construction systems, the (digital) construction drawings, especially for execution, must be aligned to the use within such a system.

The results of the analysis are compared with the corresponding ordinances and framework curricula of the professions selected as examples, to identify points of contact in relevant learning fields. Finally, it proposes options for the implementation of these options in construction technology education, which could already be implemented in the current situation at the educational institutions (e.g. VET schools).

3 Changes on the construction site using the example of a cable-driven parallel robot

The development of cable-driven parallel robots allows to create large manipulators that even cover the volume of a construction site [4]. It first carries out masonry works, later on other trades, partially autonomously in the structural work. As the cable-driven robot is covering the volume of a complete masonry building, it is potentially suitable for a wide range of construction processes and thus a superior concept to currently existing specialized systems like bricklaying robots. Therefore, the cable robot technology might have a broader impact on the automation of nearly all construction steps and serves as an example of future automated construction and the potential changes in the involved professions. Since December 2016 we are using a demonstrator with the dimensions L/W/H = 12.0 m/1.5 m/5.0 m which is able to assemble bricks into simple wall panels. The capabilities of the prototype will be continuously expanded in the planned follow-up projects, e. g. with automated mortar application (e.g. high-performance adhesives).

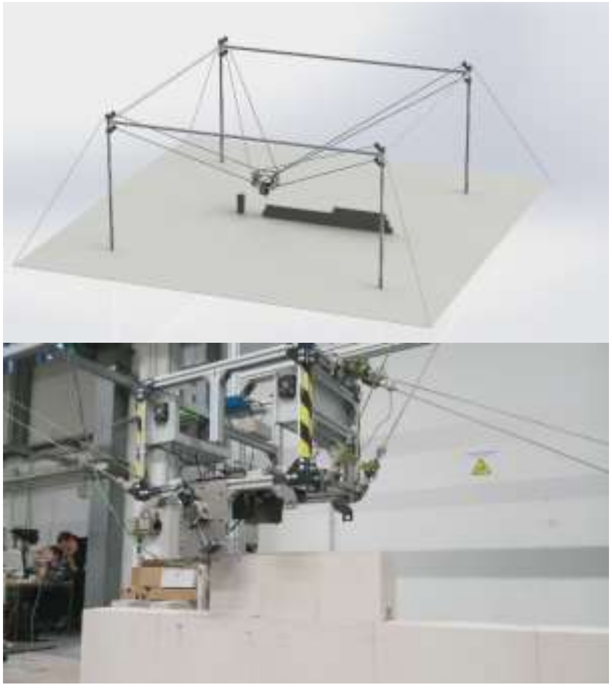

Figure 1. Cable-driven parallel robot for brickwork construction (upper illustration [5], illustration below own picture)

Figure 1 shows the desired long-term concept and a detail of the retractor of the current prototype. The prototype can already be used to investigate many interdisciplinary research questions. Due to the increasing digitalization, the construction industry is changing. Current buzzwords include Industry 4.0, Cloud Computing and Building Information Modeling (BIM). To assess the effects on VET, the changes resulting from the use of a cable-driven parallel robot in brickwork construction are identified below and significant adaptations to the construction site are derived from this. In principle, it must be stated that an automated building construction system is highly sensitive concerning the working process. Changes are common on construction projects and disruptive to labor productivity, in turn leading to increased costs and delayed projects [7][8]. Hence, early recognition of change is important, especially in automated processes. Faulty process sequences or wrong materials, which people must compensate (until now), lead to immediate downtimes during automated building construction. The construction process of the entire shell will be interrupted in the event of disturbances and additional (high) costs will be incurred.

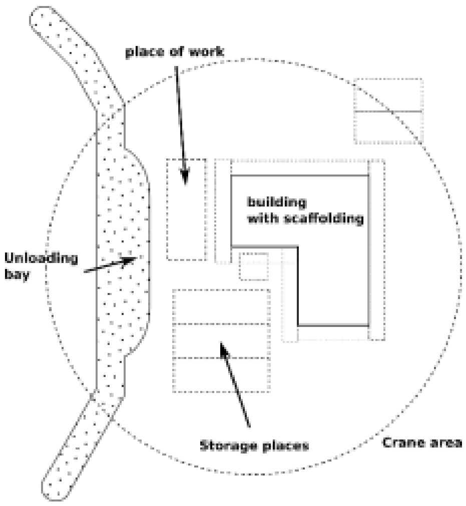

Figure 2. Example of a current construction site layout (based on [6])

Figure 2 shows an example of a current construction site layout without a cable-driven parallel robot and Figure 3 an exemplary construction site with a cable-driven parallel robot. Without a cable-driven parallel robot, a classic layout with tower crane, material storage areas, workshop, scaffolding and construction road is displayed. The construction site with a cable-driven parallel robot (Figure 3) is divided into 3 zones. Zone 1 is the material delivery zone. Here, trucks with the required materials arrive and are unloaded by forklift trucks. Zone 2 is the so-called pre-zone. The materials are stored here and pre-assembled into processable units for the robot. Zone 3 is the working area of the robot. Here, the construction process is largely autonomous. The personnel should not enter this zone while the robot is running as there is a considerable risk of injury. High loads are transported at speeds of several meters per second (the prototype currently transports 6-DF sand-lime bricks at a speed of approx. 0.5 m/s, the current maximum speed is approx. 4.0 m/s). For further details of the technical background of the cable-driven parallel robot refer to [6].

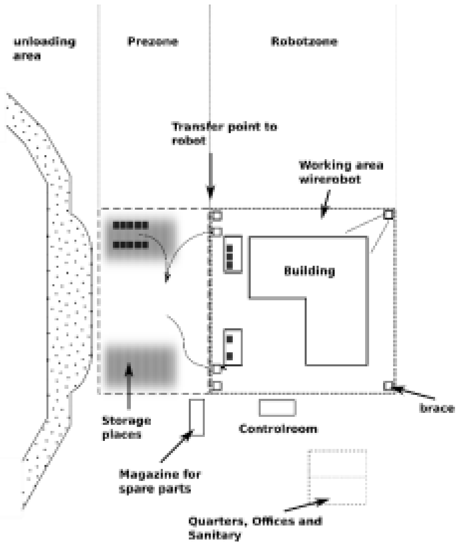

Figure 3. Changes on the construction site (based on [6])

4 Effects on the considered professions

Six different dimensions are considered to assess the effects on the technical personnel:

A: Collaborative working - Change of cooperation through interconnected working towards collaboration.

B: Support through technology- Support of many work steps by (partially) automated systems.

C: Modified construction processes - Changes in processes and office workflows, both in planning and by the introduction of ICT and robotics, especially in execution on the construction site.

D: Interaction with machines - Additional employment in man - machine and machine - machine interaction. The latter must be monitored by humans.

E: Virtual working - Increasing visualization of virtual objects in the real world.

F: Overflow of data - Increasing data must be handled, also in manual work processes.

The dimensions show, that there will be a shift from originally increasingly executive work towards cooperation and collaboration through interconnected working. Besides the other dimensions, which are mainly related to information and communication technology (ICT) issues, the first dimension takes foremost the social effect of automation and robotics into account and therefore the impact of automation on individual and collective level of human interaction. Hence, it investigates mainly the social outcomes of the innovation processes introduced by building automation in construction and workers re-skills effects. These effects are an important influencing part of the human capital, which is one of the basic factors of economic growth in the information, knowledge-based economy as its level of usage determines the innovation component [9]. The influence of automation on social aspects has been addressed since the 1930s (e.g. [10]) and has also become a relevant topic in the ICT community in the 1960s (e.g. [11],[12]) as well as in qualification and training of workers in the 1970s (e.g. [13]), probably driven by the beginning of the personal computer era with the founding of companies such as Apple, Microsoft and others. Nevertheless, the influence of automation in the construction industry seems to be predominantly discussed on technical and economic levels. Even if social aspects impact the whole social structures and changes working culture (e.g. on construction sites or in design teams) this paper deals as a first step mainly with direct changes and impacts on an individual level in exemplary professions. To be able to examine the effects on VET in a first step, the occupational profiles selected exemplary are identified on the basis of the essential activities and influences are localized in the context of automated building construction. The dimensions A-F are related to their effects on the following highlighted fields of activity of the considered occupational profiles ([14],[15],[16]), which are influenced in particular using an automated building construction system.

1: Construction equipment operator - **Set up construction machinery (cm); operate; transport and maintain cm**; carry out repair work on cm; observe safety and environmental regulations; **operate stationary equipment**

2: Bricklayer - **Execute preparatory work**; carry out scaffolding, formwork, erection of scaffolding, formwork, **structures and parts of buildings**; **produce masonry**; produce interior and exterior plaster; install insulation and insulation materials; erect lightweight walls; produce screeds and floor coverings; refine masonry; **produce exterior wall coverings**; carry out demolition and piling work; **operate, maintain and service construction machinery and equipment for building construction**; **quality check of the work carried out**; create measurement of finished work for billing.

3: Draftsmen - **Planning and coordinating work processes; preparing construction drawings for construction planning and execution**; carrying out surveying work; preparing documentation and drawings for presentations; **participating in the preparation of tender documents**; working out building applications in compliance with construction regulations; calculating simple static proofs; preparing accounting drawings and contributing to construction accounts.

As already shown in Figure 2, the construction site layout in particular will significantly change the field of activity of construction machinery operators. This includes the modification of construction processes and the interaction with machines. Recent developments show that construction machines with assistance systems and machine controls are increasingly being used [17]. In earthworks, for example, GPS data and inclination sensors are used to control the guidance of the excavator bucket along a digital terrain model. Other assistance systems, some with 3D control, make it easier, for example, to produce an exact level in road construction. Additionally, there are developments in surveillance, inspection and analysis of the construction progress [18], in the fabrication of wooden structures [19][20][21][22] and steel construction [23][24], too. Current research is also concerned with the unification of real and digital worlds (Augmented Reality Technologies [25][26][27]). To prevent existing underground pipelines and cables from being damaged during the excavation work, they are faded into a display or data glasses, for example. The use of these technologies is increasingly changing the way construction machines are operated on site as well as the planning of their deployment. Hence, the operation of an automated building construction system represents a further change in machine control and is therefore one of the most massive changes which includes almost all considered dimensions. The same applies to the operation of stationary systems. In contrast, transport is also subject to change. However, these are not to be assumed to the same extent as the other activities considered. Overall, it can be stated that in the dimensions "modified construction processes" and "interaction with machines" the strongest influences are to be expected. Since this paper looks at the effects of automated building construction on VET in the light of automated building construction using a cable-driven parallel robot, it is obvious that masonry construction will have a variety of effects. This means that the preparation as well as the construction of the building or parts of it and in particular the construction of masonry is influenced by almost all considered dimensions. A special focus will also be given to the examination of the executed quality. In the future, the bricklayer will be given the task of checking the performance and quality provided by the automated building construction system in a qualified manner and, if necessary, of adapting it by hand. Moreover, it will be necessary to understand, plan and organize the automated production process. Due to the sensitivity of the automated building construction system in the building process (everything depends on the faultless operation of the robot as the leading device), decisions must be made directly on site. Therefore, it is evident that in this field of activity more dispositive work has to be carried out and that, as a result, more and more management tasks will be assigned to this field. In the field of activity of draughtsmen a general approach seems to make sense, since this professional group is involved in the conception and planning of a building project from an early stage. Already in 1986, a modernization of the training content regarding computer-aided drawing and design was implemented in the reorganization of training according to the Vocational Training Act. Other technological innovations in electronic data processing (EDP), such as the incorporation of modern ICT, were included in 2002. Although the above-mentioned amendments go further than in the other two occupational groups considered, further changes can be expected in the observed dimensions. Since, for example, the BIM method considers the project ideally as a multi-professional and collaboratively planned building within its lifecycle, the planning and coordination of work processes is influenced by all dimensions. Due to the use of automated building construction systems, the (digital) construction drawings, especially for execution, must be aligned to the use within such a system for both the construction itself and the validation of the plans regarding the faultless implementation on the building site (e.g. operational aspects as well as data exchange and security issues). This presupposes that knowledge about the changed building processes during the practical implementation of the building construction must be available. The validation of the planning is done advantageously in a virtual building model. In addition, it should be pointed out that technical support for the preparation of tender documents is already integrated in a collaborative manner and therefore an ever-increasing amount of data has to be organized.

4.1 Intermediate results

Based on the qualitative analysis carried out, it can be concluded that the dimension "modified construction processes" has the greatest influence on the considered occupational profiles, followed by the dimensions "collaborative working" and "support through technology". On average, when comparing the considered occupational profiles, the highest influence of an automated building construction system is identified in the group of draftsmen, followed by bricklayers and construction machine operators. Nevertheless, the professional field of bricklayers will experience one of the most massive upheavals through automated building construction systems. For the construction machine operators, it could be assumed that the operation of the new technology could be handled in a similar way as it is currently the case with GPS-controlled construction equipment, for example, in which an introduction/ training takes place. On the other hand, however, it must be noted that an automated building construction system is a comparatively complex system whose operation and maintenance will probably require more far-reaching skills.

5 Consequences for VET

The results of the qualitative analysis are compared with the corresponding ordinances and framework curricula of the professions selected as examples. The German directives on training are structured in specific learning fields (LF) which were examined one by one to identify points of interest. As already introduced above, there is a lot of research on innovations in building construction regarding the use of assistance systems for construction equipment, but these new trends and developments have not yet been incorporated into any amended ordinance or the framework curriculum, especially in the profession of construction equipment operators. Using the example of construction equipment operators [28], five connecting points can be identified in the corresponding learning fields on which the use of an automated building construction system would have an influence leading to additional learning objectives.

LF 1: Setting up a construction site

Knowing automated workflows and processes, ability to plan and evaluate parking and traffic areas for automated building construction.

LF 2: Building a masonry wall

Ability to plan construction of masonry with automation technology (especially planning and checking of relocation plans).

LF 7: Handling of electrical systems

Understand the basic interrelationships and safety in automated electrical systems, integrate data and adapt programming if necessary.

LF 8: Maintenance of engines

Know the tasks and functions of automated technologies.

LF 9: Maintenance of trackside trolleys

Knowledge and ability to implement maintenance and servicing of automated technologies.

In LF 1, further learning objectives must be defined which deal with the changed workflows and processes. Because the construction site layout is fundamentally modified, it is important to be able to plan and evaluate parking and traffic areas for automated building construction. The production of masonry using automation technology should be addressed in LF 2. In this context, it is particularly important to follow on from the already known implementation plans, since the correct planning of an installation sequence is also an essential success factor for the rapid construction of the building when it comes to the automated building construction. When handling electrical systems in LF 7, construction equipment operators should be familiar with the basic interrelationships and safety aspects of automated electrical systems and should be able to integrate the corresponding data into the system.

Furthermore, it makes sense to be able to adapt programming on site, if necessary, as well as to know the tasks and effects of automated technologies in LF 8, and to know and to be able to implement maintenance and servicing of automated technologies to avoid or minimize longer downtimes (LF 9). For bricklayer [29] the modified workflows and processes resulting from the changed construction site layout leads to additional learning objectives similar to construction equipment operation.

LF 1: Setting up a construction site

Similar to construction equipment operator

LF 3: Building a wall of a single-shell building structure, knowledge of the basics of robot-compatible brickwork, e. g. wall connections and masonry connections and the ability to carry them out (e. g. for adaptation and repair work).

LF 7: Masonry walls of a single-layer

Ability to plan, test and optimize masonry of large formats for automatic construction (as a new installation technique), ability to work with digital layouts

LF 16: Fabrication of special wall components

Knowledge about measures for adjusting irregular masonry constructions (e. g. angled brickwork) and ability to implement it manually.

In relation to the specific handicraft activity, LF 3 should deal with the basics of robot-compatible execution of masonry in order to gain knowledge about wall connections and wall integrations which have to be implemented in the context of adaptation and repair work during the construction process. In addition, the bricklayers should be able to plan, test and optimize the masonry made of large-format masonry for automation (as a new installation technique). For this reason, it is recommended to work with digital installation plans in LF 7. As not every brickwork geometry can be created when using an automated building construction system, measures for the adjustment of irregular brickwork constructions (e. g. angled brickwork) should be known in LF 16 as well as the manual implementation in the context of an automated construction site should be taught. With reference to the automated construction site, the group of draftsmen [30] have six essential points of contact.

LF1: Participation in construction planning

Knowledge of data organization and data management in relation to collaboration platforms, planning and implementing data storage

LF 3+4: Development/ planning of foundation

Ability to create 3D/xD models for automated execution and validate third-party models.

LF 5: Planning a basement

Knowledge of the fundamentals of robot-compatible brickwork execution, creating, testing and optimizing installation plans for automated execution.

LF 10a: Preparation of a building permits application

Knowledge about data exchange between different stakeholders, ability to plan and implement data exchange strategies for automated execution, validate data, identify interface problems and propose countermeasures.

LF 11a: Designing an exterior wall

Ability to design external wall constructions for automated execution.

Due to the expected increase in digitally generated and processed data, important aspects that need to be addressed already arise in LF 1. Here, draftsmen should know forms of modelling and design, data organization and data management regarding collaboration platforms as active (and in practice to a large extent responsible) persons. Here, basic types of data transfer, information flows and interfaces should already be addressed to be able to plan and implement data storage and security strategies in practice. In LF 3 and 4, it is possible to extend digital modelling to automated building construction and implement it using practical examples. Furthermore, draughtsmen should be able to understand foreign models and validate their content. In this case, similar to the previous professional profiles, it is also imperative to know the fundamentals of robot-compatible brickwork execution and to have the ability to create, check and optimize installation plans for automated execution. This can be addressed in LF 5. Following on LF 1, the planning and implementation of data exchange strategies for automated execution, the technical validation of data as well as the identification and, if necessary, the first steps to solve interface problems should be considered when creating a building application (LF 10A). Finally, in learning field 11A, the automated execution can also be considered as a topic in the design of an outer wall construction.

6 Conclusion

This study shows that the use of an automated building construction system will lead to far-reaching changes in the entire work organization in the socio-technical field. The investigation provides a first ground for increased consideration of social aspects due to building automation in construction in a variety of areas. It is strongly recommended to conduct further investigations on the social impact of automation and robotics in construction in the social and psychological spheres on different sub-topics and levels. Such research is essential to avoid the development of a parallel and in a long term incompatible workforce. Indications for this are given through current research and development work, which shows that companies are increasingly considering how they can (fully) automate their work, which will lead to further significant changes in all areas of the construction industry in a relatively short period of time. For example, the object-related construction work is almost exclusively carried out by the automated system in the future, which will lead to the following positive causal relationships:

The productivity of the execution performance is increased by the automated building construction system. At the same time, this reduces the physical workload of the site personnel. This in turn leads to an increase in the physiological motivation of the workforce. Furthermore, the changed working conditions lead to more safety at work, which in turn will increase psychological motivation. In addition, the entire construction site organization has to be rethought, both at operational and management level. This means, for example, that tasks, responsibilities and competencies will be transformed due to changed work processes.

The examination of the potential changes within the operative production factors shows that there will be a shift from the executive work on the building itself towards dispositive work (planning, management and organization). The changed roles mean that skilled workers must acquire additional skills, competences and responsibilities as well. As a result, the training concepts and content in VET must be adapted to the new circumstances. The curricula for the operative construction staff must be redesigned in order to increase dispositive work. This paper gives some indications about additional learning objectives related to recent learning fields of existing regulations. To achieve a comprehensive understanding of technology and new working methods, further topics must be included in the curricula, depending on the characteristics of the specific occupation. These are topics from the ICT field as well as management. Although current ordinances or framework curricula do not yet cover such effects in terms of content, it should already be possible to address further learning objectives within the existing learning environments that are necessary for the profession in terms of content and methodology. The results of this study are intended to provide guidance in this respect.

The analysis carried out shows that the incorporation of automated building construction into the various learning fields of the considered occupational profiles appears potentially possible. As the amendment of training guidelines cannot be achieved at short notice, the authors are currently examining options which can be implemented immediately in the current situation in VET schools and companies to address the additional learning objectives independent of existing regulations. First promising approaches are (ICT-supported) group-oriented teaching/learning projects, across-school projects in cooperation with companies or even game-based concepts.

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