NAUKI INŻYNIERSKIE I TECHNOLOGIE ENGINEERING SCIENCES AND TECHNOLOGIES
2(29) • 2018

ISSN 2080-5985
e-ISSN 2449-9773

Tuğçe Sevil Yaman
Mersin University, Turkey
e-mail: tsevilyaman@mersin.edu.tr
ORCID: 0000-0001-9873-507X

EFFECTS OF THE 4TH INDUSTRIAL REVOLUTION ON CIVIL ENGINEERING WITH SPECIAL EMPHASIS ON STRUCTURAL ENGINEERING – THE CASE OF GERMANY

WPŁYW CZWARTEJ REWOLUCJI PRZEMYSŁOWEJ NA INŻYNIERIĘ LĄDOWĄ ZE SPECJALNYM NACISKIEM NA INŻYNIERIĘ BUDOWLANĄ – PRZYPADEK NIEMIEC

DOI: 10.15611/nit.2018.2.04

Summary: The 4th Industrial Revolution (Industry 4.0) was introduced in 2011 by Germany. Internationally, it stands for the digitization of industry. It was developed as a future project within the framework of the high-tech strategy. Germany has the opportunity to play an active role in shaping the 4th Industrial Revolution. To do so, new business models and considerable potential for optimization of production and logistics can be tapped. Digital technologies have also widely found their way into civil engineering. The object of the study was to investigate elaborately Industry 4.0, mainly by focusing on the state of digitization in civil engineering field. The developments in civil engineering area in Germany, especially in structural engineering, as a result of the challenging project Industry 4.0 which is characterized by strong individualization of products under conditions of highly flexible production were examined in this study. Potentials of digitization, digitization in construction sector, challenges of digitization were also discussed. Consequently, derived conclusions were reported.

Keywords: digital technologies, 4th Industrial Revolution, customized production, structural engineering.

Streszczenie: Czwarta rewolucja przemysłowa została wprowadzona w Niemczech w 2011 roku. Na forum międzynarodowym oznacza ona cyfryzację przemysłu. Została rozwinięta jako projekt przyszłościowy w ramach strategii wysokiej technologii. Niemcy mają możliwość odgrywania aktywnej roli w kształtowaniu czwartej rewolucji przemysłowej. Aby to osiągnąć, wykorzystuje się nowe modele biznesu i duży potencjał dla optymalizacji produkcji i logistyki. Wysokie technologie znalazły także szerokie zastosowanie w inżynierii lądowej. Tematem pracy jest szczegółowe zbadanie czwartej rewolucji przemysłowej z uwzględnieniem przede wszystkim stanu cyfryzacji w obszarze inżynierii lądowej. Artykuł podejmuje badanie jego rozwoju w Niemczech, przede wszystkim w inżynierii budowlanej, jako rezultat wymagającego projektu czwartej rewolucji przemysłowej, charakteryzującego się silną indywidualizacją produktów w warunkach bardzo elastycznej produkcji. W pracy pojawiają się problemy potencjału cyfryzacji, zjawiska cyfryzacji w sektorze budowlanym oraz wyzwań związanych z cyfryzacją. Artykuł kończą konkluzje.

Słowa kluczowe: technologie cyfryzacji, czwarta rewolucja przemysłowa, produkcja jednostkowa, inżynieria budowlana.

1. Introduction

New products and services which arise from splendid ideas are in demand worldwide and ensure people's prosperity and quality of life. In the digitization of production, particularly German small and medium-sized enterprises (SMEs) face great challenges. Impacts on these companies are far-reaching, i.e. networking of machinery, changed organizational structures, integration and qualification of employees in networked work processes, and IT solutions for protection of valuable company data. Therefore, Industry 4.0 penetrates the global value-added networks and drives new business models [Bundesministerium für Bildung und Forschung 2017].

Only an innovative country can offer its people quality of life and prosperity. That is why Germany invests more money in research and innovation than any other country in Europe. Thus, Germany makes decisive progress in key topics, such as Industry 4.0. Also, Germany supports financially modern education and training. More than every tenth product that is traded all over the world is obtained as a result of special research performed in Germany. Therefore, Germany is in line with the USA in terms of research performance and it is in a leading position worldwide [Bundesministerium für Bildung und Forschung 2018].

Industry 4.0 stands for the digital transformation in industry. That means, components independently communicate with the production plant and if necessary a repair or reorder of a material is arranged. Industry 4.0 is an intelligent network of people, machines, and industrial processes. After the steam engine, production line and computer, intelligent factories of the fourth industrial revolution are now in full swing. History of industrial revolutions is demonstrated in Fig. 1. Examples include the development of the first mechanical loom seen as the trigger of the first industrial revolution to the use of electronics in mass production. The Federal Ministry of Economic Affairs and Energy supports the economy in exploiting the potentials of the digital revolution. In Industry 4.0, the production intermeshes with the state-of-the-art information and communication technology. Thus, products are made according to individual customer requirements: sports shoes with customized sole and design chosen by customer or custom-fit and individually designed piece of furniture. So, Industry 4.0 makes it possible to produce individual pieces at the price of mass-produced goods also in top quality and cost-effectively. The technical bases for this are intelligent, digitally networked systems and production processes. Therefore, Industry 4.0 determines the entire life cycle of a product: from the initial idea, continuing through development, production, usage, and maintenance to recycling. Thus, in the factory of Industry 4.0, intelligent machines independently coordinate production processes, service robots support people in assembly work during heavy work, driverless transport vehicles take care autonomously of logistics and material flow. Nevertheless, networking does not only take place within intelligent factories, but also beyond companies and sector boundaries between various players in the economy: from medium-sized logistics companies to specialized technical service providers up to creative start-ups. Furthermore, IT support makes it possible to flexibly adapt processing stations to changing product mix. In doing so, capacity can be optimally utilized. In addition, automated analysis methods can also point out maintenance requirements and default risks [Bundesministerium für Wirtschaft und Energie 2018].

The goal of the project Industry 4.0 is an intelligent factory characterized by its adaptability and resource efficiency. To achieve this goal, manufacturing techniques are increasingly supported by computer science. Due to new technology, the industry is developing rapidly [Industrie-Wegweiser 2017].

Industry 4.0 has provided major changes in the global economy such as investment, consumption, growth, employment, and trade issues. Innovations resulted by Industry 4.0 greatly affected the growth and employment areas [Schwab 2016].

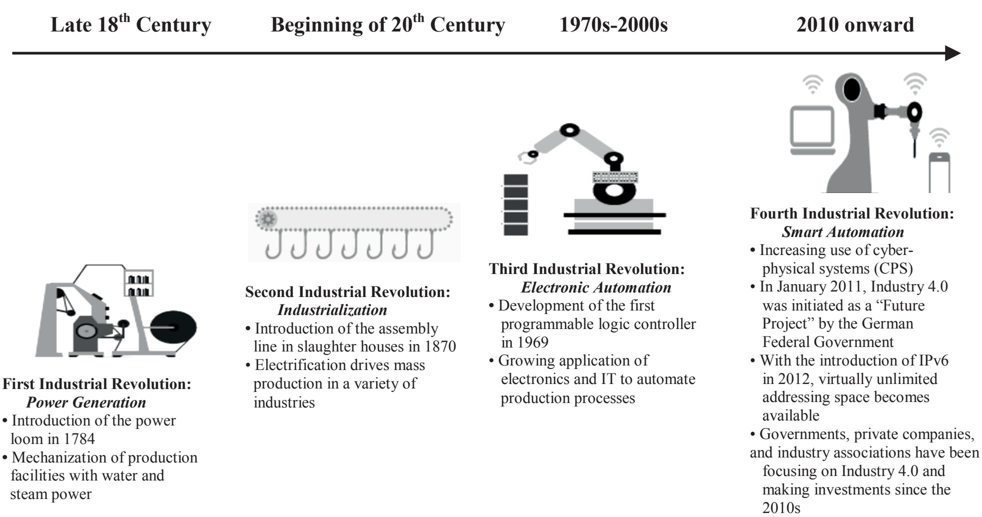


Fig. 1. History of industrial revolutions: industry evolution with key developments

Source: [Deloitte 2016].

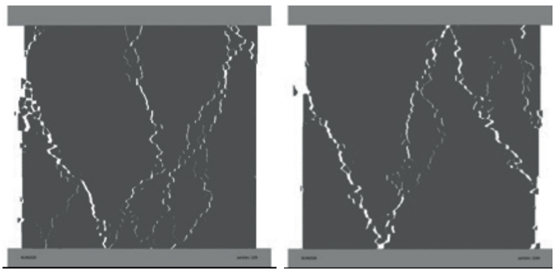
The objective of this study was to perform an in-depth investigation about Industry 4.0 and its implementation specially into civil engineering field. Topics were discussed particularly referring to the studies realized in Germany, since

Industry 4.0 project originated from this country. In the first part of the paper, Industry 4.0 concept is explained by giving its characteristics. Literature review on the research performed in Germany using this new technology in structural engineering field is presented in the second section. Potentials of digitization are demonstrated in the third part. Besides, digitization, particularly in construction sector, is examined in the fourth part of the paper. In the fifth section, challenges of digitization are mentioned. Eventually, derived conclusions are put forth in the final part.

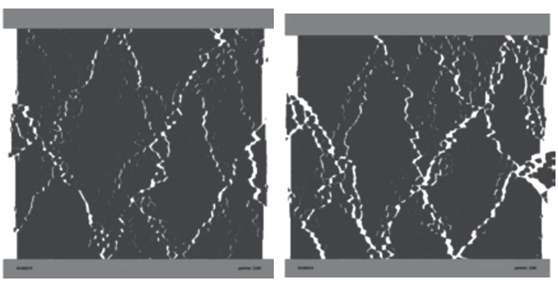
2. Literature review of studies using the new technology in structural engineering

German Research Foundation (Deutsche Forschungsgemeinschaft-DFG) supported the project titled 'Simulation of Concrete Failure Behavior with Discrete Elements' under the direction of Prof. Dr.-Ing. E.h. Manfred Curbach in the period between October 2013 and October 2017. The aim of the project was to analyze the concrete failure and fracture behavior including the crack evolution. The failure behavior of concrete was examined by applying a numerical simulation based on discrete element method (DEM). A discrete simulation was particularly suitable, because cracks were in-built parts of the simulation method. Thereby, the concrete specimen was represented by an ensemble of single particles. A discrete modeling approach differs fundamentally from a continuum-based method in that the equations of motion of single particles are kinematically independent and also discontinuities are inherent characteristic of the simulation method. In the numerical simulation, the concrete specimens were generated by the inclusion of a random function presenting statistical deviations of individual particles in terms of their positions in concrete. Also in the simulation, different particle generations with the same further parameters were calculated, similar to different specimens of the same charge in real experiments. Furthermore, exactly the same test specimens were loaded virtually several times once under low and once under high load levels. The possibility of loading until the failure of a specimen and also testing the same specimen many times under different conditions is an advantage of the numerical simulation compared to laboratory experiment. Crack patterns of the concrete specimens under low and high load levels are shown in Fig. 2. On one hand, it was observed that the crack patterns of varying representations of the same loading were principally similar, but different in the details of their particular crack locations. This is the same situation as in the laboratory experiment, where the cracks of two identical specimens are never exactly at the same positions. On the other hand, as Fig. 2 indicates, under high load levels the similarity of the crack patterns increases according to the low loading levels. Also, there is an increase in the number of the crack branches [Technische Universität Dresden 2017].

Beckmann et al. published a paper about their work after the completion of the project. They mentioned that a numerical simulation based on DEM for the investigation of concrete behavior under compression load was utilized in the research. Crack patterns, crack initiation, and damage evolution were studied. It was demonstrated that concrete behavior was more brittle for higher loading velocities than for lower velocities. Particle simulations and DEM simulations were found to be reasonable approaches for the numerical investigation of concrete behavior and crack propagation [Beckmann et al. 2018].



a) Low Load Level



b) High Load Level

Fig. 2. Crack patterns of concrete specimens under low and high load levels

Source: Technische Universität Dresden, 2017.

The project entitled ‘Strengthening of Plane Reinforced Concrete Elements against Impact from the Rear Side’ as a subproject of the Research Training Group GRK2250/1 (impact safety of structures made of mineral-bonded composites) has been funded by German Research Foundation (DFG) from May 2017 to April 2020. Steel fibers of various shapes and lengths were used to strengthen concrete elements. By the addition of steel fibers, much ductile failure behavior of concrete can be obtained. The next step in the current research is to use other types of fibers, such as plastics, for this purpose. Under pure static loads these new materials, i.e. plastics have no positive effect due to their creep tendency. However, the situation is different in case of dynamic loads, such as shock processes. Since such loads last only fractions of seconds, the negative creep properties of plastics are negligible. Thus, there is a very large field of application. Basically, these materials have already proven their suitability in impact scenarios, particularly in the form of rockfall nets made of plastics. The use of such materials as short fiber reinforcement in cement-based matrices, so-called strain-hardening cement-based composites, is a relatively new approach. Since the research project is quite comprehensive, 13 fellows from different institutes and disciplines have been conducting the research together [Technische Universität Dresden 2017].

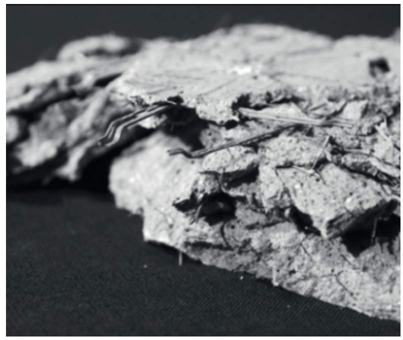


Fig. 3. Fragments of a specimen made of fiber reinforced concrete after impact testing at the accelerated drop tower facility

Source: [Technische Universität Dresden 2017].

This project deals with strengthening of the rear side of structures with cementitious-based composites. So far, tests were carried out with matrices to which short steel and polypropylene fibers were added. Thereby, different fiber content and fiber forms were used. The fact that addition of fibers is a properties-determining modification for the concrete matrix was also visible during specimen fabrication. With the blends of steel fibers very good flowable concrete was produced. By adding the same volume of polypropylene fibers, the concrete, however, became extremely stiff and consequently difficult to process. In the impact experiment, the fiber concrete mixtures showed a very fine behavior in terms of reduction of concrete splintering. The first experiments with the new fiber materials will be performed to investigate the efficiency of these materials under impact loads. These investigations should be done at the material and structural level [Technische Universität Dresden 2017].

Another important research project funded by German Research Foundation from September 2015 to May 2018 was the project entitled 'Experimental Investigation of Load Bearing Behavior of Textile Reinforced Concrete (TRC) under Uniaxial Compression'. The progressive development and spreading of innovative and resource-efficient composite TRC has resulted in many new fields of application. Relating thereto, there is a great demand for design models and material models to be used in computer-aided calculations and standardization. Basis for such models is the complete investigation of the load-bearing behavior of TRC. The first models have already been developed to test the behavior under tensile force, bending moment, lateral force, and torsional moment. However, load-bearing behavior of

TRC under compressive force is still less known. This specific material behavior is important mainly for the design of compression struts. To examine fundamentally the behavior of TRC under axial compression, a wide range of tests were conducted. Unreinforced and reinforced fine-grained concrete cubes of 40×40×40 mm^3 dimensions were used as test specimens. The experimental program included a wide range of parameters in which textile reinforcement orientation played an important role. The experiments on unreinforced and reinforced specimens prepared in 2016 focusing on hand-laminated specimens were enriched by including casted textile reinforced specimens to the experimental program. Thus, in addition to parameters such as mesh size, mesh spacing, and thickness of twine, further parameters were examined. Latter results were compared in terms of manufacturing method and concrete strength. Moreover, influence of different textile impregnations, in particular, rigid and flexible impregnation systems were compared by performing a last test series. From the gained insights, first general conclusions could be derived. To better clarify the load-bearing behavior and understand the mechanisms, there are still numerical simulations to be realized, e.g. to visualize the stress flow in test specimens at different inclination angles between the textiles and the loading direction. Based on model ideas for fractured rocks, a model for TRC was developed in order to predict the strengths for special inclinations of textile reinforcements [Technische Universität Dresden 2017].

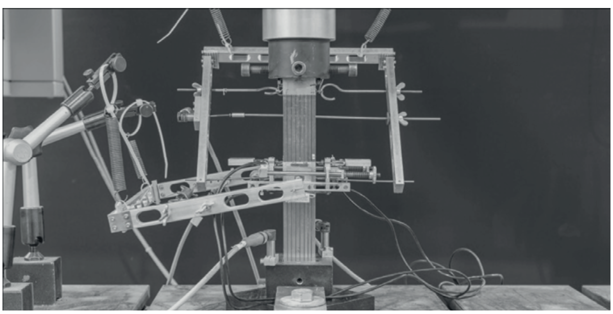


Fig. 4. Test setup including measurement instrument

Source: [Technische Universität Dresden 2017].

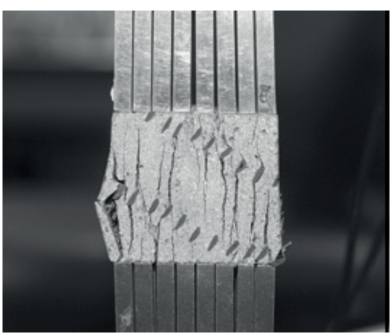


Fig. 5. Crack pattern of a TRC cube with inclined reinforcement layers

Source: [Technische Universität Dresden 2017].

Bochmann et al. wrote a paper as a basis for the aforementioned project to examine TRC behavior under compression. A literature review for concrete behavior under uniaxial and biaxial compression loading on structural discontinuities was presented. Also, mechanical models from rock mechanics were reviewed, since rock has natural planes of weakness that resemble a similar impact on load bearing behavior as artificial planes of weakness defined by fabric reinforcement in TRC [Bochmann et al. 2018].

There exists another project planned for the period from September 2017 to February 2020 entitled 'Fatigue Behavior of Carbon Reinforced Concrete (CRC) and Structural Elements Strengthened with CRC under Static and Cyclic Long-Term Load as Part of The Joint Research Project C3-V2.1 entitled 'Long-Term Behavior of CRC'. This project aims to reach a significantly longer life with CRC compared to conventional reinforced concrete with steel. In order to be sure about the service life of CRC for a variety of applications, comprehensive knowledge about the behavior of CRC under long-term and fatigue loading is required. To gain this knowledge, procedures have to be developed and tests have to be performed to understand the behavior of CRC under permanent load. For similar materials, such as reinforced concrete, partially TRC, and fiber reinforced plastics (FRP's) there are various approaches developed for test concepts and engineering models to estimate the long-term and fatigue behavior. However, transferability of these approaches to CRC is still to be verified. Within the scope of the C3-V2.1 project, long term tests were planned for both static and cyclic long term loads. It is possible to examine the material behavior of CRC by small-scale tests of different loading periods and number of load cycles under varying load levels and decisive exposures. The aim is to set up approaches to predict material behavior and to validate them using the test results. By experiments on building components under selected conditions, the applicability of the material behavior to structural components is to be validated. Transferability of the models to the structural behavior under cyclic or static long-term loads is to be examined. This approach should finally allow the prediction of the service life for indoor and outdoor applications in the field of strengthening, and new elements for varying material combinations, and the determination of the material application limits [Technische Universität Dresden 2017]. It can be seen from Fig. 6

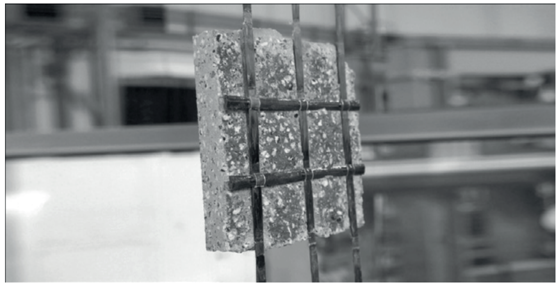


Fig. 6. View of a CRC specimen after test
Source: [Technische Universität Dresden 2017].

below that the textile component of the specimen lasts after the test even when the concrete part has already failed.

There are also other structural engineering departments in Germany such as the department of RWTH Aachen University which realizes projects involving digital technologies, e.g. ‘Thin-walled folded plate structures made of cement-based composite materials’. Textile-reinforced load-bearing structures enable the production of extremely thin-walled and slender concrete structures. To support all phases of the design and manufacturing process, a simulation platform was developed including the following tasks [RWTH Aachen University 2018]:

- form finding with the help of optimization approaches,
- modeling the shape via manufacturing apparatus,
- simulation of the structural behavior of the folded structure in its final configuration.

3. Potentials of digitization

Digitization is responsible for a profound social and technological change and it shapes entire life. The digital conversion requires rethinking of traditional business models and it also opens up great opportunities. The planning, construction, and operation of structures will also be mainly determined by digital transformation in the future. The creation of digital, virtual, and constantly synchronized structures’ models provides a holistic view of construction processes, methods, and technology. Such a cooperative working basis allows depicting the entire lifecycle of a construction project virtually and also recording and managing all important information from planning and implementation to operation, and also dismantling [Goger et al. 2017].

Winkelhake classified technologies for digitization solutions as IT solutions, which are cloud services, big data, mobile applications and apps, collaboration tools, and cognitive computing machine learning, Internet of Things (IoT), 3D printing, virtual and augmented reality, wearables, block chain, robotics, drones, nanotechnology, and gamification [Winkelhake 2018].

Buguin et al. stated in their report that the McKinsey Global Institute identified the 4th industrial revolution as the age of cyber physical systems which combine computation, networking, and physical processes and consists of countless technologies including mobile devices, IoT, artificial intelligence, robotics, cyber security, and 3D printing [Buguin et al. 2013].

Oesterreich and Teuteberg categorized Industry 4.0 technologies and concepts as building information modeling (BIM), IoT/internet of services (IoS), product-lifecycle-management, cloud computing, mobile computing, augmented reality/virtual reality, mixed reality, robotics, radio-frequency identification, big data, 3D-printing/additive manufacturing, smart factory, human-computer-interaction, modularization, cyber-physical systems/embedded systems [Oesterreich, Teuteberg 2016].

Accenture, one of the world's biggest consulting companies, investigated the top 500 companies in Germany utilizing a three pillar model consisting of digital strategy, digital offerings, and digital processes. The most significant improvement was found in digital processes. On one hand, digital strategy gave the intensity which corporate strategy uses as a decisive factor. On the other hand, the extents of strategic goals were determined by digitization. Digital offerings were used to evaluate products, solutions, and services. Also, the functions that companies use to address their customers were included in the evaluation. Digital processes were understood within the index as internal processes and applications. Accenture formed three fields of action categories and graded them depending on ratings from 4 (mostly digitized) to 1 (minimally digitized). The average values of each of the three fields formed the rates of those fields. Moreover, the average of these three calculated average values of each field formed the index value of digitization [Accenture 2015]. In total, the top 500 companies increased the index value by 9.8 percent from 2013 to 2014. The greatest progress was made in digital processes in which the index value rose 14.3 percent. For digital strategies, the improvement was 6.5 percent and for digital offerings it was 9.7 percent. Overall, the digitization level was described as the average of three characteristics as it can be observed from Fig. 7 which demonstrates the digitization of top 500 companies.

In a comparison of sectors, Accenture showed that there was a significant difference among industries. Sectors such as Information Technology (IT), Media/ Entertainment, and Telecommunications are at the top of the list. At the bottom of

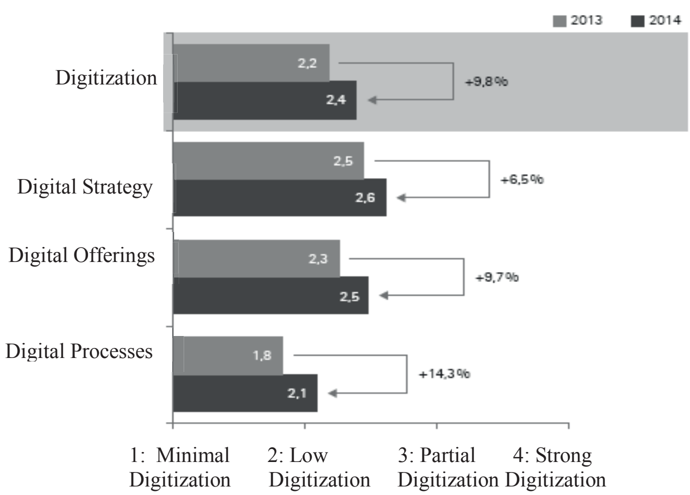


Fig. 7. Digitization of top 500 companies in Germany in 2013 and 2014

Source: [Accenture 2015].

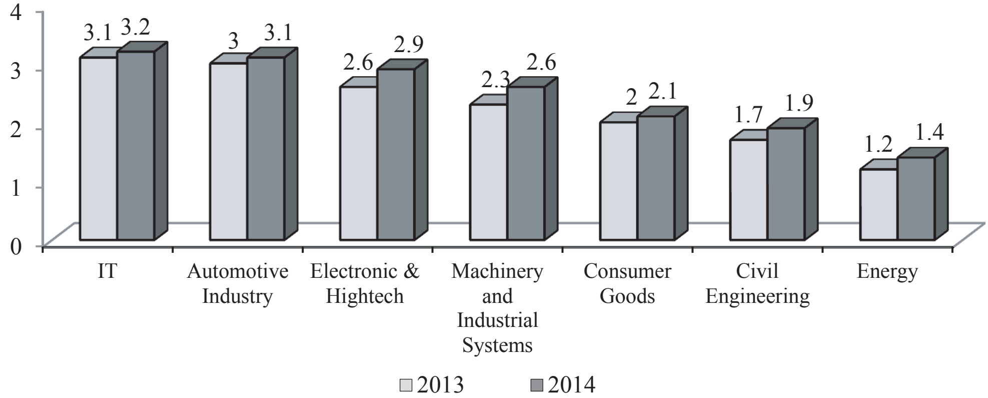


Fig. 8. Digitization levels of various sectors
Source : [Accenture 2015].

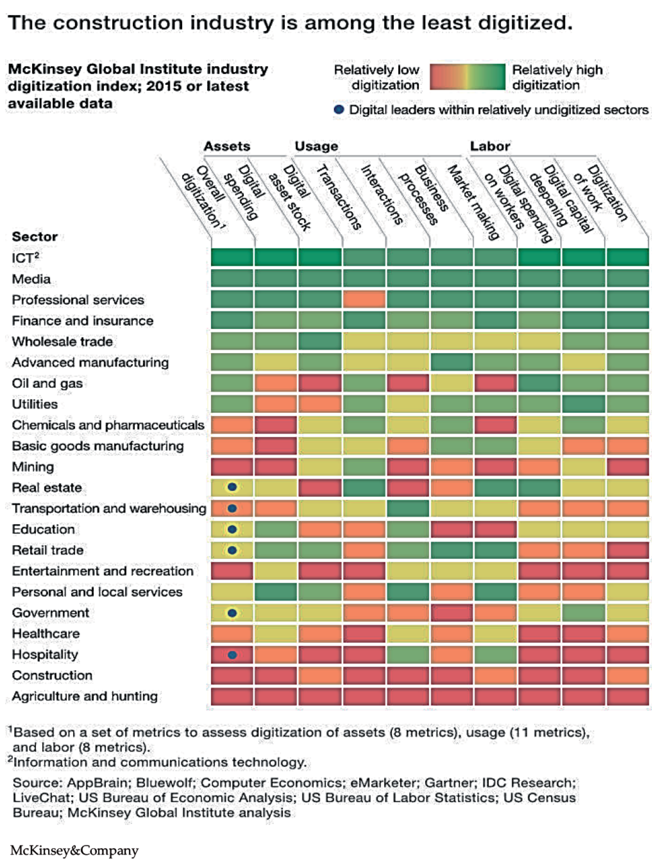


Fig. 9. Global industry digitization index
Source: [Davies 2018].

the list, energy and building sectors are located. In Fig. 8, the evaluation is done using a scale from 1 to 4. 1 stands for minimal digitization, 2 for low digitization, 3 for partial digitization, and 4 for strong digitization. Fig. 8 depicts that there is no sector which is strongly digitized. Even the IT sector did not reach the highest value of 4.

Finally, Accenture proposed six measures for successful digitization strategies:

1. Recognizing potentials for a company
2. Streamlining the processes for a company and if necessary taking measures
3. Having courage for new business models and innovative thinking
4. Building up new skills
5. Setting up rules
6. Creating financial resources

Davies presented a graphic demonstration of the digitization levels of different sectors prepared by Mc Kinsey Global Institute which is shown in Fig. 9. This figure indicates that the construction industry poorly developed in terms of computation and digitization [Davies 2018].

4. Digitization in construction sector

Sven Rogalski from the University of Applied Sciences in Darmstadt suggests that smarter site logistics are needed on a building site. He observed that construction employees spend about 30% of their working time on main tasks and the remaining 70% on transportation work, cleaning-up, rearranging as well as searching for materials or equipment. At this point, digital technology helps to manage time better by optimization such as the supply software which supports deliveries just-in-time and allows smart and interlinked construction machines to utilize their optimal capacity, e.g. excavator calls free truck when necessary as well as the location of machinery, products or material are determined by global positioning system or radio frequency identification. Autonomous machines such as drones or robots are used to measure and examine property, pipes, and channels as well as to monitor and to document construction progress and, additionally, to record construction defects. Furthermore, EU-Directive 2014 recommends the use of BIM as a criterion when public contracts are granted. Federal Ministry of Transport and Digital Infrastructure requires mandatory use of BIM in public infrastructure projects in Germany from 2020 onwards while corresponding regulations have already been applied in the UK, the Netherlands, Denmark, Finland, and Norway. Moreover, Rogalski suggests the usage of autonomous drone in development projects to detect facades. Another research approach on building site is the utilization of helmet camera for continuous recordings with the following characteristics [Rogalski 2017]:

- automatic face recognition and visual feedback,
- automatic location based on Global Positioning System (GPS) and Quick Response (QR) Code Data,
- continuous recording,

- real time merge and compression of visual recordings,
- automatic synchronization.

The advantage of continuous recordings with a helmet camera refers in particular to an actual situation without extra effort and the production of historical data about the progress on the building site. Another example for assisted working is floor tiler robot which satisfies sensor-supported requirements to measure the room, tiler dimension, and to consider the customer demands. The aims of assisted working such as tiler robot are [Rogalski 2017]:

- modernization of the craft or manual processes,
- constant involvement of the craftsman without replacing him/her,
- support and relief of the artisan by the use of industrial robots,
- minimization of highly physically demanding work,
- improvement of working ergonomics,
- improvement of quality and quantity of manual processes,
- enhancement of the processes in terms of predictability, controllability, monitoring ability, revisioning, and transparency.

Lunz thinks that the keyword Industry 4.0 opens up new digital opportunities such as efficiency improvements in manufacturing and management processes in the industry sector. Due to decentralized building sites, potentials have not been sufficiently exploited so far. There is a lack of transparency and communication in many areas. Furthermore, BIM gives an important impetus to the development of digitization on building sites. The survey entitled 'IT trends in the building industry', a joint project of BRZ Deutschland GmbH and the FOM University of Economics and Management showed that familiarity and application of the BIM method have increased significantly in the last four years. All phases on a building site are mapped with BIM in a digital model. The data model serves as a common basis for all project participants from development through planning and execution of building work up to administration, and usage. This model delivers information on the qualities, temporal course, costs of the construction, and operation in addition to 3D-presentation of all subsections. Thus, the determination of exact quantities and building times in all project phases from tender preparation to billing is possible. For example, time-consuming multiple entries on building sites become unnecessary and liquidity in building operations increases. Due to control in BIM model, a faster invoice approval and thus timely incoming payments are possible. However, the potential for success exists not only in the use of software-based solutions. The first starting point for optimization must always be in organizing the company and project processes as well as in the organization of the underlying data structures because unstructured processes do not automatically reach a goal oriented structure through digitization. Moreover, another example with high potential to increase the efficiency lies in digitized management of equipment and material. Basically by using and networking mobile terminals on the building site, recording and inspection processes are accelerated and less prone to errors. Thus, transition to digital processes on a building site saves time, costs, and also increases transparency. So, through digital workflows better operating force is reached. Modern business intelligence solutions provide up-to-date and valid information by linking all relevant project and company data from various data sources and consolidating them into meaningful decision-making bases to provide them in a demand-oriented, interactive, and mobile way. Moreover, according to an IT-trend study, 62% of the surveyed companies are familiar with virtual project rooms, although the technology is better known for building-planning companies than the construction firms. Virtual project rooms connect all participants in a building project across company boundaries via the internet. In view of the increasing usage of BIM, such project communication management systems will be increasingly used in the future. Their main goals are up-to-dateness of process, speed, documentation, transparency, legal security, and thus higher quality and cost savings in the building processes [Lunz 2016].

'Building Site 4.0' is an innovative mobile application for the building industry. By using this application architects, engineers, and building companies can record, document, link, retrieve, edit, and forward all processes locally via tablets or smartphones. In the past it was necessary to bring all building plans and files to the building site. With the new technology, there is no need for that. The users of 'Building Site 4.0' record the data directly on a building site by a few mouse clicks (e.g. deficiencies, disabilities, interruptions), mark them on the digital blueprint, and file the project-specific collected data including a photo and notes in the digital building file [Leben und Technik 2016].

One-third of the engineers surveyed said that digital transformation was already on their agenda and more than 70% recognized Industry 4.0 as an opportunity for their company. As an answer to the question what aspects offer a long-term development potential in civil engineering in Germany, 66% of the participants pointed out building efficiency, 49% maintenance of infrastructure, and 41% digital transformation. Almost all participants (nearly 90%) agreed that digitization improves the operation of buildings and facilities in terms of quality and completeness of asset documentation as well as making them more energy-efficient and cost-effective. About three-quarters of them associate digitization in the context of real estate and investments with the use of BIM. From the point of view of the participants, the greatest benefit of BIM was the generation of data that could be used in facility management [Verein Deutscher Ingenieure 2016].

In a research of the University of Duisburg/Essen, automated construction elements were defined [Karl et. al 2017]:

- Construction robots created by the ETH Zürich University:
  - a kind of mini excavator with a boom,
  - applicable to different levels,
  - limited span of the loom.
- Contour crafting is a computer-aided construction process for the construction of buildings:
  - most popular type at the present,
  - currently many projects worldwide.

- Robot arms:
  - famous from the automobile industry,
  - very accurate,
  - become massive and heavy in a short time,
  - high installation work.

According to Roland Berger Consulting Company, 93% of actors in the construction industry agree that the digitization will influence the whole processes. Less than 6% of the construction companies already use all digital planning tools and 100% of the building material companies believe that their potential for digitization has not fully exhausted yet. Digitization offers opportunities to increase the productivity for construction industry. Other sectors already profit from digitization along the entire value chain. However, the sector of civil engineering is still lagging behind. Only few actors have used the potential of digitization to solve problems. Four aspects help in the implementation of digitization. These aspects are important for all levels of value added chain. The fact that each of these four aspects can be applied at each level of the value added chain is crucial for demonstrating the great potential of digitization. The value added chain of actors of the civil engineering sector can be represented as follows [Berger 2016]:

- logistics: flow of goods, storage, and transport,
- procurement: purchase, supplier management, supplier evaluation,
- production/construction: production, quality management,
- marketing/sales: sales/dealer management,
- after sales/end-customer marketing: pull marketing, user support and services.

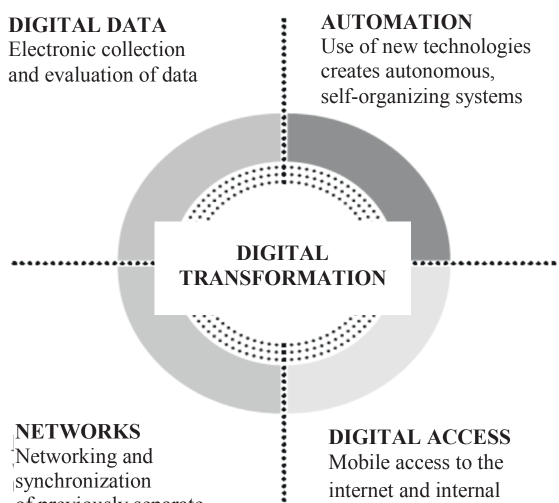


Fig. 10. Four aspects of digital transformation
Source: [Berger 2016].

In their research, Dallasega et al. focused on proximity in the supply chain in the construction sector. Construction supply chains were specially investigated, since the construction industry is project-driven and its supply chain partnerships are constantly changing. The efficiency of the optimization performed by Industry 4.0 concepts about the optimization of proximity between actors in the supply chain was examined. It was recognized that Industry 4.0 notions had significant effect on technological, organizational, geographical, and cognitive dimensions of proximity. Moreover, a framework was created to rate their utility to the construction supply chain. The applicability of the formed framework was proven by two case study companies and practical publications [Dallasega et al. 2018].

Construction projects are becoming increasingly complex. At the same time, cost and time pressure is rising as well as the expectations for quality. Thus, better methods and reduced complexity and costs are required to increase productivity as well as to guarantee quality. Companies face the challenge to decide which approaches are appropriate for them and how they can be implemented. Not considering digitization is not a good option. Recent developments in the civil engineering sector and other sectors show that the megatrend of digitization is unstoppable. Actors of the civil engineering sector who deal with the technical developments and ideas regarding feasibility along the whole value added chain have better chances to stand out from the competition. In addition, these companies increase their productivity and effectiveness by the application of digital methods [Berger 2016].

5. Challenges of digitization

In his paper Sommer points out that enterprises feel more or less prepared for Industry 4.0 depending on their size. Large companies are better prepared than small firms. Enterprises are eager to implement digitization, but the risks/obstacles reduce their readiness to Industry 4.0. Practical challenges that enterprises face are the following:

- insecurities, like data security or maturity of Industry 4.0 technologies should be reduced,
- the benefit of Industry 4.0 has to be transferred from vision level to reality level,
- investments in Industry 4.0 technologies should be encouraged by public funding in order to lower the barriers explicitly for SMEs,
- internal staff qualification and training courses should be given in schools and universities,
- SMEs have to be supported separately as they are less capable of coping with the financial, technological, and staffing challenges than large enterprises.

Sommer continues that SMEs are critical elements in the supplier network of large enterprises. The gap between the two enterprise categories must not be increased [Sommer 2015].

Dalenogare et al. mentioned in their article that the adoption of advanced technologies can be more challenging for emerging countries. Since their economies have been more concentrated on extraction and commercialization of commodities, companies in these countries are behind their counterparts in developed ones in the implementation of technology. Other factors such as information and communication technologies' infrastructure, culture, level of education, and economic and political instability can also interfere in the value perception and in the level of investments in advanced technologies [Dalenogare et al. 2018].

In his paper Kovacs analyzed Industry 4.0 by shifting towards more complexity-aware economics. In this analysis, he emphasized the major unintended negative consequences that are calling for cultivating governance in favour of structural change. He categorized the dark corners of Industry 4.0 as security-related uncertainty, unintended consequences of automation, distorting effects of measurement, and undesired results of neglecting contextual interactions [Kovacs 2018].

Caruso stressed that the consequences of digital revolution are mostly negative. He indicated that individualization of employment relationship, and also job insecurity and pressure for horizontal competition among workers exerted by companies, comprise a tendency to socialize production processes and to diffuse ownership of means of production. Furthermore, he stated that workers are induced to participate in formally horizontal decision-making processes, but the rhetorical invitation to actively participate is functional to reorganizing command methods and to a substantial verticalization of decision-making processes [Caruso 2017].

Pfeiffer and Suphan performed a study to improve the methods of studying relevant developments and to build a basis for the continuous and early reporting of qualitative change in firms and jobs using the large-scale research data in employment and occupations. Their paper is guided by the question whether the results of qualitative case studies, based on understanding of experience as dynamic, can be used to inform about the results of quantitative analyses of labour-market data that are based on understanding of experience as routine and static. They also tried to answer whether a combined approach can change the way of evaluation of the relationship between Industry 4.0 and work [Pfeiffer, Suphan 2015].

Eng et al. stated that an essential aspect of Industry 4.0 is the permanent and comprehensive availability of the data obtained. While the relevant measurement and analysis data are processed centrally and used for process control in a current process analytical technology system, in the future it will be possible to link the information procurement up to individual system components deepened and over the entire value chain. The biggest challenge is the meaningful processing, reduction, and presentation of data. If feasible solutions are to be found, there are enormous opportunities with regard to optimized process management, corrective interventions in the ongoing process, and ensuring permanent product quality. The availability of low cost sensor and chip technology also offers opportunities to increase product safety. Today's systems already check the expiration date and avoid confusion during usage, as well as the authenticity of the product. In the future, there will be further opportunities to prevent counterfeiting, organizing batch recall, managing complaints, and conducting long term investigations. New risk factors are because of their autonomy similar to the human employee and unnoticed mishandling of the cyber physical elements (CPE). The adequate qualification and the validation of the self-optimizing processes will be the biggest challenge in this area. At an early stage, the assessments of technological implications should take place and standards should be established. In the planning phase of a system, degrees of freedom and interfaces of the CPEs in the production process have to be clearly defined [Eng et al. 2016].

Oesterreich and Teuteberg defined the key aspects necessary for the implementation of Industry 4.0 as: horizontal integration through value networks, end-to-end digital integration of engineering across the entire value chain, and vertical integration and networked manufacturing systems. Besides these key features, they mentioned that several important factors for the adoption, such as IoT, Big Data and Cloud Computing, should also be considered. They pointed out that compared to the economic impact of the construction industry, investments in construction sector to research and development are relatively low. They also emphasized that labor productivity in construction industry had declined over the last decades. They listed the following structural problems that might be responsible for this inconsistency [Oesterreich, Teuteberg 2016]:

- Complexity: Construction projects are complex undertakings due to the high amount of interrelated processes, sub-processes and the high number of project participants involved.
- Uncertainty: As each construction project is a time-limited, site based unique work, there exists a lack of complete specification for processes and sub-processes and uniformity of materials, work and teams at the construction site.
- Fragmented supply chain: Another characteristics is the high fragmentation in the supply chain in terms of a high amount of SMEs with undifferentiated products and services and limited capabilities for investments in new technologies.
- Short-term thinking: The decentralized organization of construction companies as well as the temporary nature of the construction projects are an obstacle for innovation.
- Culture: The construction industry is known for its strong and rigid culture and also its strong resistance to changes.

6. Conclusions

The aim of Industry 4.0 project is to create an intelligent factory which is defined by its adaptability and resource efficiency. To achieve this purpose, manufacturing techniques have been supported by computer science. Due to this new technology, the industry is developing very fast.

The purpose of this paper was to do research to comprehensively examine Industry 4.0 which is related to the digitization of production processes in the industry. The study was mainly concentrated on the status of digitization in civil engineering area. Since the 4th Industrial Revolution was introduced by Germany, the research on structural engineering performed in this country using these new technologies was presented in the paper.

The fourth Industrial Revolution ‘Industrie 4.0’ driven by the German Federal Government gave Germany the opportunity to play an active role in shaping and developing new products such as ‘Building Site 4.0’ to maintain more productive and simple working on the construction site. Digital technologies have also been used in structural engineering.

Literature survey shows that German universities perform a great amount of research projects supported by German Research Foundation in which digitization enables to do those projects accurately. Technische Universität Dresden and RWTH Aachen University are becoming apparent with their contemporary and innovative projects. They use simulation platforms, simulation of structural behavior, optimization processes via new technologies, and digital technologies linking them to other tools to reach better results. The digital conversion requires rethinking traditional business models and it also opens up great opportunities. The planning, construction, and operation of buildings will also be mainly determined by digital transformation in the future.

According to Accenture, sectors such as IT, media/entertainment, and telecommunications are at the top of the list of sectors that mostly use digitization in their work. At the bottom of the list, energy and building sectors are positioned. In 2014 IT reached a digitization value of 3.2 out of 4 and construction sector a value of just 1.9. The lowest value of 1.4 of digitization was seen in the energy sector.

According to the global industry digitization index prepared by McKinsey Global Institute in 2015, the construction industry is among the least digitized industries. It dropped behind in following the pattern of computation and digitization.

Digital technologies help to manage time better by optimization such as supply software which supports deliveries just-in-time and allows smart and interlinked construction machines to use their optimal capacity. Using digital technologies saves working time and application of creative tools helps in optimizing performance and quality of construction stages.

BIM gives an important impetus to the development of digitization for constructions. Federal Ministry of Transport and Digital Infrastructure requires mandatory use of BIM in public infrastructure projects in Germany from 2020 onwards. All phases on a building site are mapped with BIM in a digital model. The data model serves as a common basis for all participants from development through planning and execution of building work up to administration, and usage.

Furthermore, ‘Building Site 4.0’ is an innovative mobile application for the construction industry. By using this application architects, engineers, and building firms are able to record, document, link, retrieve, edit, and forward all processes locally by their tablets or smartphones.

The paper showed that digitization and application of new technology opens up new opportunities to realize the work in a more organized and more efficient manner on a building site. Industry 4.0 would enable to optimize processes and link devices to finish tasks rapidly. Furthermore, the findings of the study showed that there has been a significant development from 2011 onwards regarding digitization in construction sector, but the progresses are still not as fast as in other sectors. Consequently, there is still a lack in the application intensity of digitization in civil engineering sector.

However, there exist important challenges which should seriously be considered and resolved in order to benefit fully from the enormous opportunities offered by the smart revolution Industry 4.0.

SMEs face some obstacles in implementing digitization. These challenges should be eliminated, since SMEs are vital components in the supplier network of large enterprises.

Moreover, companies in emerging countries are less successful in the implementation of technology. Information technologies' infrastructure, culture, level of education, and economic and political instability can affect the value recognition and investments in leading-edge technologies.

Challenges of digitization include uncertainty related to security, negative results of automation, distorting effects of measurement, undesired consequences of neglecting contextual interactions, individualization of employment relationship, job insecurity, and pressure applied to workers for horizontal competition. In addition, proper processing, reduction, presentation of data, as well as adequate qualification and validation of self-optimizing processes are among significant challenges.

Specially for construction industry, investments in research and development are quite low despite the economic importance of this sector. Additionally, labor productivity in construction industry has decreased over years. The inconsistency may be caused by complexity, uncertainty, fragmented supply chain, short-term thinking, and culture.

These major challenges should be overcome to achieve the highest performance from the intelligent network attained by the 4th Industrial Revolution.

References

Accenture, 2015, *Mut, anders zu denken: Digitalisierungsstrategien der deutschen Top500*, http://www.accenture.com/_acnmedia/Accenture/Conversion-Assets/DotCom/Documents/Local/de-de/PDF_3/Accenture-Deutschlands-Top500.pdf, (07.04.2019).

Beckmann B., Schicktanz K., Curbach M., 2018, *Discrete element simulation of concrete fracture and crack evolution statistically varying properties of concrete specimens*, Beton- und Stahlbetonbau, vol. 113, no. S2, pp. 91-95.

Berger R., 2016, *Digitalisierung der Bauwirtschaft – Der europäische Weg zu "Construction 4.0"*, http://www.rolandberger.com/publications/publication_pdf/roland_berger_digitalisierung_bauwirtschaft_final.pdf (07.04.2019).

Bochmann J., Curbach M., Jesse F., 2018, *Influence of artificial discontinuities in concrete under compression load — a literature review*, Structural Concrete, vol. 19, no. 2, pp. 559-567.

Buguin J., Dobbs R., Bisson P., Marrs A., 2013, *Disruptive technologies: advances that will transform life, business, and the global economy*, McKinsey Global Institute, San Francisco, CA, USA.

Bundesministerium für Bildung und Forschung, 2017, Industrie 4.0 – Innovationen für die Produktion von Morgen, http://www.bmbf.de/pub/Industrie_4.0.pdf (07.04.2019).

Bundesministerium für Bildung und Forschung, 2018, Bundesbericht Forschung und Innovation 2018 – Forschungs- und innovationspolitische Ziele und Massnahmen, http://www.bmbf.de/pub/Bufi_2018_Hauptband.pdf (07.04.2019).

Bundesministerium für Wirtschaft und Energie, 2018, Digitale Transformation in der Industrie, https://www.bmwi.de/Redaktion/DE/Dossier/industrie-40.html (07.04.2019).

Caruso L., 2017, *Digital innovation and the fourth industrial revolution: epochal social changes?*, AI & Soc, vol. 33, pp. 379-392.

Dalengare L.S., Benitez G.B., Ayala N.F., Frank A.G., 2018, *The expected contribution of industry 4.0 technologies for industrial performance*, International Journal of Production Economics, vol. 204, pp. 383-394.

Dallasega P., Rauch E., Linder C., 2018, *Industry 4.0 as an enabler of proximity for construction supply chains: A systematic literature review*, Computers in Industry, vol. 99, pp. 205-225.

Davies J., 2018, *Smart contract operating project networks: Using integrated functionality for improving workflow, transparency, and easier collaboration*, Thesis, Via University College, Denmark.

Deloitte, 2016, Industry 4.0 and manufacturing ecosystems – exploring the world of connected enterprises, https://www2.deloitte.com/content/dam/insights/us/articles/manufacturing-ecosystems-exploring-world-connected-enterprises/DUP_2898_Industry4.0ManufacturingEcosystems.pdf (07.04.2019).

Eng M., Wittmann U., Kappeler S., 2016, *Industrie 4.0: Chancen, Herausforderungen und Grenzen Future Pharma Fab*, Swiss Pharma 38, 2016, Nr. 2, http://www.swisscleanroomconcept.ch/UserFiles/File/FirmenNews/MW%20Industries/M%2BW%20Industrie%204.0.pdf (07.04.2019).

Goger G., Piskernik M., Urban H., 2017, *Studie: Potenziale der Digitalisierung im Bauwesen*, http://nachhaltigwirtschaften.at/resources/nw_pdf/schriftenreihe/201802_Studie-Potenziale-der-Digitalisierung.pdf (07.04.2019).

Industrie-Wegweiser, 2017, *Beispiele für Industrie 4.0*, http://industrie-wegweiser.de/industrie-4-0/ (07.04.2019).

Karl C.K., Spengler A. J., 2017*, Industrie 4.0 in der Bauwirtschaft – Einfluss der automatisierten Gebäudeerstellung auf die gewerbliche Berufsbildung, Hochschultage 2017*, http://www.berufsbildung.nrw.de/cms/upload/hochschultage-bk/2017praesentationen/FT03-4_Karl_Sprengler.pdf (07.04.2019).

Kovacs O., 2018, *The dark corners of industry 4.0 – grounding economic governance 2.0*, Technology in Society, vol. 55, pp. 140-145.

Leben und Technik, 2016, *App Spezial- Innovative mobile Anwendungen für die Bauwirtschaft*, http://www.zukunftstechnologien.info/technik-und-wirtschaft/bauwirtschaft/app-spezial?utmsource=arrow&utm_medium=next (07.04.2019).

Lunz J., 2016, *Chancen der Digitalisierung für die Baubranche*, http://www.zukunftstechnologien.info/technik-und-wirtschaft/bauwirtschaft/chancen-der-digitalisierung-fuer-die-baubranche (07.04.2019).

Oesterreich T.D., Teuteberg F., 2016, *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*, Computers in Industry, vol. 83, pp. 121-139.

Pfeiffer S., Suphan A., 2015, *The labouring capacity index: Living labouring capacity and experience as resources on the road to industry 4.0*, Working Paper 2015 #2, University of Hohenheim, Germany, http://www.sabine-pfeiffer.de/files/downloads/2015-PfeifferSuphan-EN.pdf (07.04.2019).

Rogalski S., 2017, *Digitalisierung im Bauwesen – Trends & Chancen*, http://www.hawtech.de/fileadmin/HAWtech-Dateien/HAWtech_Mitteilungen/Tagung_2017_H1.6_Rogalski.pdf (07.04.2019).
RWTH Aachen University, 2018, Lehrstuhl und Institut für Massivbau, https://www.imb.rwth-aachen.de/forschung/abgeschlossene-projekte/8-duennwandige-faltwerke (07.04.2019).
Schwab K., 2016, *The fourth industrial revolution, by Klaus Schwab*, World Economic Forum, Geneva.
Sommer L., 2015, *Industrial revolution – Industry 4.0: Are German manufacturing SMEs the first victims of this revolution?*, Journal of Industrial Engineering and Management, vol. 8, no. 5, pp. 1512-1532.
Technische Universität Dresden, 2017, Institut für Massivbau, Jahresbericht 2017, http://tu-dresden.de/bu/bauingenieurwesen/imb/ressourcen/dateien/forschung/publikationen/jahresberichte/Jahresbericht2017_WEB.pdf?lang=en (07.04.2019).
Verein Deutscher Ingenieure, 2016, *Digitale Transformation im Bauwesen*, http://www.i40-magazin.de/allgemein/digitale-transformation-im-bauwesen/ (07.04.2019).
Winkelhake U., 2018, *Technologies for digitisation solutions*, *The Digital Transformation of the Automotive Industry: Catalysts, Roadmap, Practice*, Springer International Publishing, New York.