CONSTRUCTION 4.0 – DIGITAL TRANSFORMATION OF ONE OF THE OLDEST INDUSTRIES

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ABSTRACT: *In the early 2010s, the German industry started their reform and revival under the keyword "Industrie Vier Punkt Null". The European Union's strategies adopted most of the ideas and member states followed. The European construction industry too stared to explore how to benefit from it. In this review paper, we explain the ideas behind Industry 4.0. We present aspects of Industry 4.0: what it means for the customer, business and industry as a whole. Based on that framework we analysed the potentials of Industry 4.0 in the construction industry and where – due to some specifics of the industry – construction is actually ahead in adopting the Industry 4.0 concepts.*

Key words: *industrial policy, Industry 4.0, Construction 4.0, Building Information Modelling (BIM), cyber-physical systems*

JEL classification: M15

DOI: 10.15458/ebr.92

1 INTRODUCTION

Construction was one of the first users of information and communication technologies (ICT), starting in the 1970s with structural analysis programs (Fenves, Logcher, & Mauch, 1965). In the 1980s, computer graphics began with the computerization of engineering drawing (Duhovnik, 1984). In Slovenia, the trends were followed in the 1980s, when first domestic programs for structural analysis (Marolt, 1981) were created at the IKPIR Institute. In the 1990s, construction informatics became an independent science-research discipline within the construction industry (Turk, 2006).

In the first years of this century, the first commercial solutions for one of the most pressing problems of construction informatics emerged – structured information exchange on construction products. The software for Building Information Modeling (BIM) started to replace Computer Aided Design (CAD) and Drafting (CADD). Because all ICT solutions in the field of construction in one way or another process data, BIM became a central concept and a topic of many research directions (Eastman, Teicholz, Sacks, & Liston, 2011).

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After centuries of a *drawn line* being the basic information unit for presenting information in engineering, it was replaced by a digital object which (in the construction context) can also be interpreted by a computer.

Today, structured information work is well supported by commercial software and is becoming a part of the usual practice in architecture and construction; countries are beginning to legally require the use of this increasingly mature technology (EU BIM Task Group, 2017).

This development followed a similar path to the one of all other industries and professions. It began with the introduction of generic software (e.g., word processing, spreadsheets, and in our case, CAD software) that can be used for a number of different purposes and is not limited to one particular application. Enterprise information systems backed by relational databases and higher-level frameworks emerged soon after in order to support well defined repetitive processes (Romero & Vernadat, 2016). However, a human has been an interface between information systems and events in the material world. It was mostly through human intervention that information was entered into information systems. And it was a human action – based on the analysis done digitally – that made a difference in the material world.

Nevertheless, a number of technologies, mostly those fitting under the keyword "Internet of Everything", started to change that. It meant that the "real" world was beginning to be equipped with sensors and controllers that would provide a human-free interface between the real and the digital. The stage was set for a change. The change came under the heading of Industry 4.0.

In this paper we ask and answer the following questions:

- What is Industry 4.0?
- How to interpret the principles of Industry 4.0 in construction?
- Where does the building industry already have the characteristics of Industry 4.0 and where are the biggest setbacks compared to other industries?

The paper starts with a background and discussion on the Industry 4.0 through the lens of historical development, technological building blocks and its characteristics. Next, we place those findings in the context of the construction industry. We will argue that the principles of Industry 4.0 can already be found in the construction industry with some of them (such as production of the one-of-a-kind products and processes) being the foundation of the industry from the start. The paper ends with a discussion and conclusions.

2 INDUSTRY 4.0

Industry 4.0 can be explained in terms of historical evolution from Industry 1.0 to Industry 3.0:

- Industry 1.0 - **mechanization**. It was initiated by the introduction of energy production from water sources and steam power as a source of (mechanical) energy production. This transition from agrarian and rural towards European industrial society took place in the late 18th century (Balasingham, 2016) and was based on three natural resources: coal, iron and waterways (Sharman, 2017). The development of steam engines had an affect not only on heavy industries, such as iron and textile industry, but also on transportation, communication and other economic activities (Rifkin, 2016). Nevertheless, the key resource remained the labour – a machine assisted labour (von Tunzelmann, 2003).

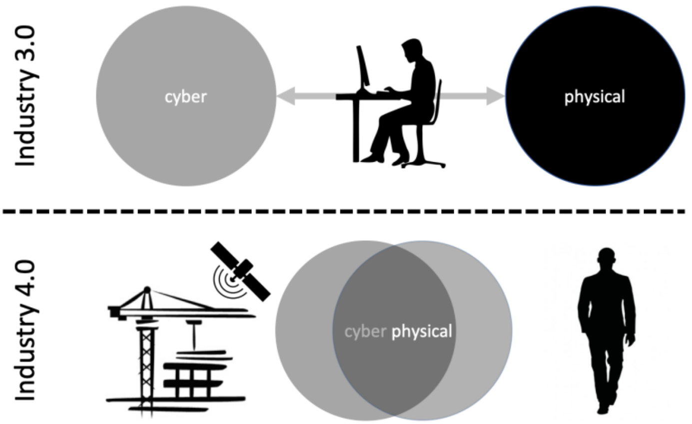
- Industry 2.0 - **electrification**. Rifkin (2016) argues that electricity (instead of oil and coal) as primary source of energy matured at the turn of the 20th century to create an infrastructure for the second industrial revolution. This enabled electrically powered mass production of goods (Industrie 4.0 Working Group, 2013) or, in other words, serial production. Production processes became relatively easy, resulting in mass productivity of labour-assisted machinery (von Tunzelmann, 2003) and consequently in an establishment of the social middle class with economic welfare (Balasingham, 2016).

- Industry 3.0 - **automation**. Despite the first computers being built in 1930s, it took several decades (from transistors to programming languages and integrated circuits) before they became more powerful and more reliable but small and easy enough to be manageable (Sharman, 2018). The tipping point came during the 1970s with the introduction of computerization into existing serial production, digitally supported design and numerically controlled machines. Due to the fact that computers played a major role within the transition from an industrial nation towards an information society it was also named the digital revolution (Balasingham, 2016). It enabled an IT-based manufacturing automation (Preuveneers & Ilie-Zudor, 2017).

The idea of Industry 4.0 was introduced at the beginning of this decade in Germany as a strategic response to the competition brought to the German industry by the accelerated industrialization of Asia. It was later adopted by the European Union as an umbrella concept for activities leading to the modernization of European industry with the goal to maintain its global competitiveness in the 21st century:

- Industry 4.0 - **networking**. Industry 4.0 appeared at the beginning of the 21st century. Its essential building blocks are cyber-physical systems or, in other words, networking of the material world. It is a mashup of cyber and physical systems and describes the "*organization of production processes based on technology and devices autonomously communicating with each other along the value chain*" (Smit, Kreutzer, Moeller, & Carlberg, 2016). Technologically, Industry 4.0 works with virtual digital copy of the real world. It is based on the building blocks of the modern digital world, such as the Internet of Things (IoT), Big Data, the Internet of Services, Smart Factories and Advanced Manufacturing. The essential difference with the automation of Industry 3.0 is that at first there used to be a human mediator between the real and the digital world (see Figure 1) who entered the information on the computer, read computer printouts and guided the events in the material world. (FIEC, 2015a) used simple terms and described Industry 4.0 as the digitalization of industry in general.

Figure 1: *The difference between the third and the fourth wave of the industrial revolution*



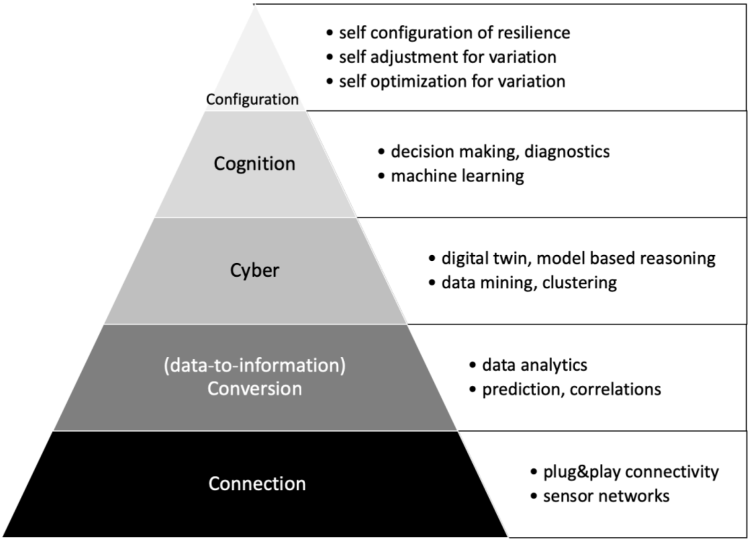
As observed by von Tunzelmann (2003), all industrial revolutions are associated with relatively slow productivity growth during their technological development stage. This is on one hand a signal of the saturation of the existing technology and, on the other, the immaturity of the new. The extent of application is very narrow and the cost of development very high. Among the expected consequences of Industry 4.0 are the usual increase in productivity, better use of resources, and higher quality of products. And there are some not so usual goals, such as significantly higher flexibility of products - serial production, where the size of the series is as low as one. Industry 4.0 is the subject of a number of national and European strategies (Santos, Mehrsai, Barros, Araújo, & Ares, 2017) and has its own chapter in the Horizon 2020 research program and the like.

2.1 Cyber-physical systems

The key technological concept of Industry 4.0 is cyber physical systems. A cyber-physical system is a system with a seamless automatic connection between the material world and smart digital components, capable of perceiving, directing and controlling the physical world. Jazdi (2014) noted that unlike the traditional embedded systems, designed as stand-alone devices, the focus of cyber-physical systems of Industry 4.0 is on networking several devices. Santos et al. (2017) describe cyber-physical systems as an extension of embedded systems bridging "*the physical and digital worlds by integrating complex information processing from multiple and networked physical elements*" (people, sensors, equipment, machinery, etc.).

Lee, Bagheri, and Kao (2015) observe that, in general, a cyber-physical system has two main functional components: (1) advanced connectivity, and (2) intelligent data management, analytics and computational capability. Based on this abstract guideline, a 5C (Connection, Conversion, Computation, Cognition, and Configuration, see Figure 2) architecture for implementation purposes was introduced (Muhuri, Shukla, & Abraham, 2019).

Figure 2: *Five levels of cyber-physical systems*



Source: Lee et al. (2015).

The proposed architecture defines a construction of cyber-physical system from the initial data acquisition through analytics to the final value creation on five different levels (Lee et al., 2015):

1. The level of **smart connections**. It includes "plug & play" devices, independent communications and sensor networks. Data acquisition and transfer within selected devices using standardized protocols has to be as straightforward as possible in order for this level to perform in accordance with expectations (Lee et al., 2015).

2. The level of **data-to-information** conversion. At this level, we find services based on data collected at Level 1 which are being processed and used for forecasts, correlations, statistics, and management to support decision-making.

3. The **cyber** level. It acts as a central information hub within this stack (Lee et al., 2015). The key concept for this level is the digital twin, digital representation of an object that exists or will exist in the physical world. When the data collected at the level of smart connections and analyzed at the data-to-information conversion level is placed in the context of the advanced data mining model, interconnections, simulations and analytics become real and useful.

4. The **cognition** level. Learning can take a step further and exploit artificial intelligence technologies to make advanced decisions, diagnostics and machine learning. It is assumed that a plurality of data that cannot be processed using traditional methods will need to be analyzed with machine learning, since the extent and diversity of data would be simply too great for the analysis to be handled manually by people writing algorithms.

5. The **configuration** level. This can lead to autonomous, smart, (self) learned and automatic configuration of cyber systems that can intelligently respond to environmental changes and user requirements. Lee et al. (2015) see it as the feedback from cyber space to physical space that acts as supervisory control to make machines self-configure and self-adaptive. To summarize, the material world shows the behavior of smart, adaptable, biological systems.

All levels combined will have a significant impact on the improvements to the industrial processes involved in manufacturing, engineering, life cycle management and wider (Industrie 4.0 Working Group, 2013).

Despite cyber-physical systems being on the very edge of the current technological development, the logical next phase is already being discussed – cyber-physical production systems. They will continue to blur boundaries between the real world and the virtual world in a way that smart products will be capable of planning, controlling and optimizing their own production processes without or with minimal human intervention (Preuveneers & Ilie-Zudor, 2017). They are expected to be the key aspect in the growth of sustainable manufacturing systems (Muhuri et al., 2019).

2.2 Technological building blocks

There is no clear consensus on the key technologies for the Industry 4.0 among researchers (Vaidya, Ambad, & Bhosle, 2018; Erboz, 2017; Chiarello, Trivelli, Bonaccorsi, & Fantoni, 2018; Santos et al., 2017). The numbers vary based on the researchers' point of view and their understanding of Industry 4.0. From our (engineering) point of view, the technological base for Industry 4.0 includes six pillars:

1. **Internet of People (IoP)**. A radically new Internet paradigm where people are not seen only as end users but rather as active elements of the Internet (Conti, Passarella, & Das, 2017). This paradigm exploits legacy Internet services to achieve connectivity on a global-scale linking users, suppliers, designers, manufacturers, etc. into a homogeneous whole.

2. **Internet of Things (IoT)**. IoT technologies are enabling seamless interoperability and advanced connectivity between the physical and cyber world with potential benefits in various applications, including smart homes, smart buildings, smart cities and others (Faheem et al., 2018). The vision is to connect everything that is complicated enough to be connected via the switch to the Internet and can be routed from the Internet. To summarize: all that is important is going to be equipped with smart sensors that are detecting what is happening around them in real time.

3. **Robotization** and other forms of **computer-aided manufacturing (CAM)**. It can translate digital information into design (for example by mounting, adding – digital printing or removing) of the material world. The German Industrie 4.0 Working Group (2013) named this new concept a smart factory, as it facilitates fundamental improvements to the before-known industrial processes.

4. **Digital twin**. The cyber-physical system being a core component of the Industry 4.0 needs the digital twin as the representation of the physical object for the development, analysis and control of the production process (Uhlemann, Lehmann, & Steinhilper, 2017). Digital twin is a digital replica, a cyber model of its physical opponent.

5. **Cognitive computing**. This is an umbrella term for a stack of technologies including big data, machine learning, cognitive algorithms and artificial intelligence. It tries to simulate human thought processes in the computer model – using the digital twin described above. Conti et al. (2017) illustrated that cognitive computing is replicating

(in the cyber world) the way users are analyzing and managing data in the physical world.

6. **Computer cloud**. Information and communication technology (ICT) infrastructure provides warehousing, processing and communication services as a service, similarly as people are paying for running water, electricity, heating. Virtualization of hardware and networks makes it possible to effectively access the appropriate capabilities, to ensure privacy, security, resilience, etc. Cloud based systems act as platforms enabling Industry 4.0 partners better integration (Erboz, 2017), providing a range of services to the smart factories of the future to integrate better manufacturing and logistics processes (Marques, Agostinho, Zacharewicz, & Jardim-Gonçalves, 2017) and inevitably lead to cloud manufacturing (Smit et al., 2016).

2.3 Characteristics from the user's perspective

From the user’s perspective, Industry 4.0 products have some special features that distinguish them from products made earlier. In the first place, these products are characterized by the fact that they are tailored to the individual. Consumers have already become accustomed to the services that came up with Web 2.0 (Klinc, Turk, & Dolenc, 2009) and are tailor-made for an individual (such as Facebook or Google services). Moreover, industrial products are still considered to be serial, that is, the same for all and everyone. Due to the automated transfer of information between the material and digital world, Industry 4.0 would considerably lower the price of the production of unique items and some early examples of the future are already hitting the market – body scans and custom tailoring, biological drugs based on the individual’s DNA, custom shoes based on the digital replica of the foot, etc. Torn and Vaneker (2019) noted that “*this flexibility of production processes to fabricate products with a high level of customization is similar to the one from the era of crafts manufacturing*”.

Industry 4.0 products are smart (Nunes, Pereira, & Alves, 2017). Products, such as mobile phones, cars, or home appliances, are already an indispensable part of the modern world, but now they will become "smart". This means that the car will, on the basis of data from different sensors and surroundings, adapt itself automatically to the conditions on the road and thus save energy, and the coffee machine will start the preparation process by its own when its owner usually starts and thus shortening the waiting time. Buildings will also be smart as they will "decide" when it is time to heat, open or close windows, or, depending on the current number of people in the building, how much elevators will be sent to the higher floors.

Industry 4.0 products are also (or mainly) connected. This means they communicate with each other: the car communicates with the road that communicates with the traffic lights which communicates with other cars and other smart products.

2.4 Characteristics from the economy's point of view

From the perspective of the company or industry, Industry 4.0 brings a shift from products to services and capital expenditure to operational expenditure. There is no more marketing, for example, for excavators, there are offers for digging services instead. Following the example of consumer platforms (such as Uber or AirBnB), there are industry platforms for mediation between providers and consumers. (Data) Business models where the company markets intellectual property, e.g., knowledge of how to manage a building, project design solutions, and the like, are emerging.

Santos et al. (2017) expect Industry 4.0 to "*influence paradigm shifts that are going to change the landscape of the European Manufacturing*" that is expected "*to achieve a growth from 15% to 20% by 2030 if it performs the digitization of their value chains*".

From the perspective of the AEC industry as a whole, digitalization is not limited to individual stages of design and construction, but digitizes the entire value chain from design through manufacturing to maintenance and the use of the product. Value chains (of data, processes and knowledge) can therefore be integrated.

3 CONSTRUCTION 4.0

When introducing highly innovative concepts embracing the state-of-the-art technologies into the traditional heavy industry, it is important to note that the construction industry is one of the lowest R&D intensity sectors despite being one of the most important industry sectors. Similarly, labour productivity in AEC has declined, while it almost doubled in other industries during the same period (Oesterreich & Teuteberg, 2016). Oesterreich and Teuteberg (2016) list and explain a number of structural problems within the industry that resulted in poor figures stated above: (1) the complexity of construction projects, (2) uncertainty over tangible and intangible constraints within the individual project, (3) highly fragmented supply chain, (4) short-term thinking as a result of the temporary nature of construction projects, and (5) rigid culture, resistant to changes.

Nevertheless, in the case of Construction 4.0 it is about exploiting the potentials caused by the massive digitization of information and material processes and large amounts of data in digital form that various sensors, cameras, builders and users give about building objects and the already built environment. Research agendas arise in the academic (Oesterreich & Teuteberg, 2016) as well as the industrial environment the AEC industry is co-shaping (FIEC, 2017).

3.1 Digitalisation of the construction industry

The European construction industry federation (FIEC, 2015a) wrote in its manifesto: "***Construction 4.0*** *is our branch of Industry 4.0. We use this term to refer to the digitalisation of the construction industry*."

Construction industry is known to be slow in implementing new technologies (Klinc et al., 2009; Klinc, Turk, & Dolenc, 2010), although there is an awareness that digital technologies are and will eventually transform the industry dealing with the built environment (Salamak & Januszka, 2018). The digitalisation of construction has many aspects of advanced processes and technologies, including (FIEC, 2015b):

- Industrial production (prefabrication, automation, 3D printing, etc.).
- Robotics (for performing repetitive and/or dangerous processes, use of drones for surveying, etc.).
- Digitally controlled building sites (equipment with sensors, inter-connected machines and processes leading to more fluid, faster construction with less errors, BIM, etc.).

It has to be noted though that the AEC industry is approaching Industry 4.0 from a different direction than others. Construction 4.0 is closing in the pattern for mass-production of the consumer-specific products (which is one of the goals of Industry 4.0) not from the state of mass and serial production but seeks opportunities for industrialization and repetition of manufacturing and maintaining ever-unique products. Construction has always been dealing with the production of unique, one-of-a-kind products and never had true examples of serial production within the sole scope of the construction processes. The AEC approach to producing goods could be seen as craft production on a massive scale, the product being either a sky-scraper, bridge or a family house traditionally. The main goal of the industry is therefore industrialization of production of unique products, which is quite different from other industries where the goal is customization of production of industrialized products. By digitizing value chains, dynamic and non-static value chains can become as effective as static value chains in classical industries.

Despite clear advantages of embracing digitalisation with a clear goal of bringing the construction industry up to date, Oesterreich and Teuteberg (2016) summarize a number of challenges that have to be taken into account when assessing the readiness for digital transformation (see Table 1).

Table 1: *Challenges of Industry 4.0 for the construction industry in the context of the PESTEL framework's perspective*

Challenge	perspective					
	P	**E**	**S**	**T**	**E**	**L**
Hesitation to adopt	*					
High implementation cost		*				
Organisational and process changes		*				
Need for enhanced skills			*			
Knowledge management			*			
Acceptance			*			
Lack of standards and reference architectures				*		
Higher requirements for computing equipment				*		
Data security and data protection				*		
Enhancements of existing communication networks				*		
Regulatory compliance						*
Legal and contractual uncertainty						*

P - Political, E - Economic, S - Social, T - Technological, E - Environmental, L - Legal

Source: Oesterreich & Teuteberg, 2016.

Most of the findings coincide with general recommendations for increasing the digital maturity of (Slovenian, but are also applicable widely) companies (Erjavec, Manfreda, Jaklič, & Štemberger, 2018):

- Digital competences of companies' employees need to be enhanced by developing skills on the cross-section of information technologies and business.
- Being a business initiative provided by the information technology, it is beneficial to assign accountable business roles to ICT personnel.
- It is important to develop and build an organizational culture, appropriate for successful digital transformation.
- It is necessary to strengthen and accelerate the development of the appropriate institutional environment.

3.2 Cyber-physical systems in construction

Following the research in the field of construction informatics in the last decade, it seems that most of the innovation in the construction industry is focused around BIM. That is why it is important to place stress on the statement of the European Construction Industry Federation (FIEC, 2015a) that wrote: "*BIM is central to Construction 4.0 but it* *is not the only element. Crucially, BIM can change the construction industry and facilitate Construction 4.0*."

Being an important part and the core of the massive change construction industry is facing it is interesting to see that there is no uniform definition of what BIM is. Relying again on the expertise of the European Construction Industry Federation (FIEC, 2015a), one can read that "***BIM** means various things depending on the context: Building Information Modelling, Building Information Model or Building Information Management. Other terms are also sometimes used*." Among the before mentioned other terms the one that perfectly captures the principle and the soul of the concept emerged recently: *Better Information Management*. From the context of Industry 4.0, BIM was perfectly described by Cerovšek (2011): "*A **BIM Model** is a digital representation of an actual building for project communication over the whole building-project life cycle*."

Examples from the AEC industry are found on all five levels of cyber-physical systems:

- At the level of **connectivity**, buildings, infrastructure objects, roads and other engineering facilities presenting the built environment have most probably been equipped with sensors for measuring, for example, temperatures, moisture, traffic volume, displacements, forces, voltages, and the like.

- At the level of data-to-information **conversion**, many of the collected data is already being analyzed resulting in computer made stochastic decisions based on raw sensor data, e.g., opening of traffic lanes based on the traffic volume, closing of the tunnel based on the speed of vehicles inside it, warnings based on displacement of the foundations, etc.

- The **cyber** level is the one that stands out the most from the AEC industry's point of view. The building information model provides a framework that is the basis for analysis, inference, design, planning and maintaining, and is the AEC industry’s instance of the digital twin.

- The most work has to be done on the **cognition** level in the field of machine learning and deduction even though some applications are already present. Effective prediction of traffic density based on the data obtained from sensor networks is one of them.

- The **configuration** level. At the level of (auto)configuration and autonomous systems, autonomous solutions for automatic adaptation of systems to certain influences that neutralize adverse consequences have been known for some time. Examples may be smart buildings or self-configurable objects that actively learn how to respond to energy needs, wind or earthquakes, traffic, etc. Lourenco, Roffel, and Narasimhan (2009) presented one such example, an automatic adjustment of high buildings to the wind load where self-adaptable system minimizes the oscillation frequency by using a movable ballast.

All described solutions are created at the level of the islands of cybernetization. Unified platforms for Construction 4.0 that provide technical infrastructure to services, together with a single market for applications and services, as well as an effective way to connect providers and consumers in the sense of enterprise-to-enterprise (B2B), are still in development.

3.3 Readiness of the construction industry for the principles of Industry 4.0

It can be argued that construction already is Industry 4.0, as they share many similarities:

- From the perspective of the consumer there are no significant differences since construction products (buildings, facilities, infrastructure) have always been adapted to the requirements of the investor, standards, conventions, location and similar, and were always unique. As a result, smart buildings and smart cities are being development.

- From the business perspective, project work in construction is an example of a dynamic, project-organized Hollywood economy. Construction factories and construction sites 4.0 have even more potential, with the greatest impact on construction costs and schedules as well as improved work processes and security.

- From the technological perspective, the construction industry had digital twins before the term was coined. BIM, Asset Information Models (AIM) and Geographic Information Systems (GIS) are all digital duplicates of their physical counterparts.

Nevertheless, Salamak, and Januszka (2018) argue that further digitalisation is the reason why the AEC industry is interesting, as there are many opportunities for profit by lowering the cost throughout the whole life cycle (from design to demolition). The most important opportunities were gathered by Oesterreich and Teuteberg (2016) and are presented in Table 2.

Table 2: *Benefits of Industry 4.0 for the construction industry in the context of the PESTEL framework's perspective*

Benefits	perspective					
	P	E	S	T	E	L
Cost savings		*				
Time savings		*				
On-time and on-budget delivery		*				
Improving quality		*				
Improving collaboration and communication		*				
Improving customer relationship		*				
Enhancing safety			*			
Improving the image of the industry			*			
Improving sustainability					*	

P - Political, E - Economic, S - Social, T - Technological, E - Environmental, L - Legal

Source: Oesterreich & Teuteberg, 2016.

4 DISCUSSION AND CONCLUSION

Having stated that cyber-physical systems are the key ingredient of Industry 4.0 and Construction 4.0, one first needs to acknowledge there is no other industry being more physical than construction and creating more volume of products or products that would pane larger areas. The entire built environment, all the infrastructure, is an area of interest for Construction 4.0. It is a big task for the construction industry with a huge impact on the life, work and leisure environment of humanity. Industry 4.0 is therefore a major challenge for the construction industry. The challenge is even bigger considering the low innovation culture in construction and the demographics of the business – few business leaders and a vast majority of small and medium enterprises with very different technological maturity.

The challenge is also to shift the industry from business models, where the product is of a material nature, to information and digital products, data and intellectual business models. The construction industry faces competition from other engineering professions for the primacy in integrating the digital and the material. Yet, the digital is just a layer of technology over what builders have been providing for centuries. The essential functions of places to live, places to work, or infrastructure to travel are not changing – just the technology to deliver the function is. Therefore, we are convinced that Construction 4.0 should be brought about by the construction industry and not by others that would develop a layer of digital over the "real".

The contribution of this paper to the corpus of knowledge is the harmonisation of the key principles of Industry 4.0 with the characteristics and specifics of the construction industry that were put into the context of Construction 4.0. In the end, we must also admit that Industry 4.0 is to some extent also a buzzword and a marketing gimmick – something that may not warrant a serious scientific analysis. Yet, sometimes it is important to give a name to a number of different but related developments. Names and concepts are an important motivator. With Construction 4.0 we are getting an umbrella concept for many of the technologies that interdisciplinary teams of researchers for construction, computer science, mechanical engineering, economics and social science – to name just the main ones – will be developing for years to come.

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