Innovation in construction: trends and obstructions of adoption and implementation

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Abstract. Innovation initiatives are crucial for any industry because their future growth depends on it. Innovative technologies that can have a great impact on the construction industry, such as building information modelling, automation and robotics, augmented reality, virtual reality, simulation, internet of things were reviewed in this article. In spite of that, innovation implementation in the construction sector has generally lagged behind other industry sectors affecting the productivity as well. The governments are aiming to improve this through increasing the level of investments into manufacturing and innovative research in this area. This article reviews the process of adopting innovative technologies and the reasons why there are obstacles to their implementation. It is expected that integration between machines and humans will enhance human capabilities, allowing them to concentrate on more creative and value added, socially important activities in the future. There is also need of changing thinking in order to transfer the results of these technological studies into production in the construction industry.

1. Introduction
Innovation in general can be understood as an actual use of any idea, technology or material that is perceived to be new to the respective adopting unit [1]. Innovation activities include all financial, development and commercial activities carried out by the company, which should lead to result in an innovation for the firm [2]. Successful management of innovations requires attentive studying of innovative activity. At start, there is a need to make a difference between innovations and insignificant modifications in technological processes or products like esthetic changes in colors or forms. Such changes do not have apparent impact on properties, parameters and product cost. Depending on the external parameters, innovations were classified as product innovations and process innovations [3]. The definition of product innovation is a new or improved service or good that is significantly different from the previous units and that has been introduced on the market. A process innovation is a new or improved process that is significantly different from the firm’s previous processes and that has been brought into use by the firm [2].

Innovation processes play an important role in meeting the growing needs of industry and keeping a competitive advantage for enterprises. Huge amount of studies in construction sector shows that new technologies have a positive effect on overall productivity, efficiency and safety. For example, innovations in biotechnology and materials are allowing the development of new intelligent materials and processes and can reduce the impact of natural resources scarcity [4]. Despite the obvious advantages, the process of adoption new and innovative technologies is very slow and insecure because of the complexity, conservative nature of construction companies and high implementation risk. Suppliers make great efforts to overcome this and spread their technologies [1].
The construction industry is one of the main factors contributing to the growth of the economy and employment in each country, but it still has the lowest research and development intensity with less than 1% of net sales (according to the EU R&D table for 2015) [5]. In this regard, the following research questions were formulated:

1. Which technologies in the construction industry are associated with innovative technologies within the framework of the Industry 4.0 concept?
2. Which innovative technologies are widely used in the construction industry in recent years?
3. Which innovative technologies are still not very used?
4. What are the obstructions to the adoption and implementation of new innovative technologies?

The main purpose of this article is to make a comprehensive review of the existing literature, provide a structured and accomplishment vision of the topic of the article, by answering the above research questions.

2. Research methodology
First of all, an initial scan and review of existing literature and practices was made. Major innovative construction technologies commonly discussed in the literature were identified. To write this article with high-quality and up-to-date information, the following two sources were mainly used: Journal search from Web of Science and SCOPUS. High attention was payed to the impact factor of each journals and to the publication date. So by setting journal selection criteria were chosen the most recent articles from 2016 to 2019 years. Besides, were decided to include practical publications, even when most of them are not peer-reviewed and, therefore, can be considered as opinion-based and biased [5]. Withal, some of the none-scientific web pages', like open Google search, libraries and databases were reviewed too, for complete and more accomplish point of view in this problematic. At the same time, we included publications from all areas in order to get a comprehensive overview of the state of the art, but mainly from Civil engineering, Industrial and Manufacturing engineering. For searching engine, the following words combinations and keywords were used: “Construction industry” plus “Innovation in constructions”, “Building information modeling”, “Internet of Things”, “Automation”, “Product-Lifecycle-Management (PLM)”, “Smart City”, “Smart Building”, “Robotics”, “Simulation tools”. The total volume of documents for analysis reaches 6,540 units. At the second stage of relevance assessment, we evaluated the content of articles by reading the title and analyzing the abstract. After evaluation and selection, 526 articles remained. In addition, precautions have been taken to eliminate of irrelevance and duplication. It is expected that with these data, current problems of constant importance and emerging issues will be identified with major transformative potential in the construction industry.

3. The concept of Industry 4.0 in the construction industry
Industry 4.0 is a popular term to describe the trend for the growing use of information data and automation technologies in the manufacturing environment [5]. But mainly, Industry 4.0 is a strategy that characterizes the fourth industrial revolution after the appearing of mechanization, electrification, and computerization [7]. Industry 4.0 is mentioned under other synonyms in the literature like Smart Production, Smart Manufacturing or Industrial Internet [5].

Twenty years ago, the architectural designs were represented in two dimensions on paper, or, in 3 dimensions, by means of models. Customer experience was limited to these dimensions until recently, when new ways of interaction and communication of space and architectural objects appeared using commercial modeling programs in 2D and 3D. The greater development of Building information modeling confirms a tendency towards the visual transformation of the architectural object and the transformation construction process into information [6]. BIM can be described as a platform that contains all the information about the process and the product throughout the entire life-cycle of the constructed object [8]. It does not represent a design methodology but a high-performance tool, particularly attractive to construction companies. The great interest of this methodology lies in some facilities to modify the architectural object together with its costs and its estimated energy demand.
The difficulty of visualizing the design object to the consumer facilitated the experience in 3 dimensions and demanded the immersion of the subject in the space prior to its actual materialization. Virtual reality (VR) brought the object closer to the render stage and facilitated 3D animations, however, the subject could not experience space. This spatial limit is overcome by what is known as "immersive reality" or "virtual immersion". This technology has continued to advance today to provide the latest in construction, Augmented Reality. This is the way to see a two-dimensional element in 3D and to share the information (in 4D, 5D and 6D) that it contains, just by having a smartphone [6].

Already in 1910, the French artist Villemard made a postcard that depicts his vision of a construction site in 2000. International Association of Automation and Robotics in Construction, continuing to organize annual symposia on this issue (since 1984) unknowingly shared Villemard's early vision that robotics will become commonplace at construction sites by the year 2000 in countries with developed economics [9]. But Villemard’s vision has not materialized yet. It is expected that integration between people and machines will expand human capabilities, but will not replace them at all. This will allow people to focus on more creative, valuable and socially essential activities [10].

The ongoing 4th Industrial Revolution relates to the development and application of new innovative technologies such as advanced robotics, artificial intelligence, additive manufacturing, simulation, augmented reality, industrial Internet, cybersecurity, cloud computing, big data and analytics, smart and multifunctional materials, enabling the integration of physical and virtual worlds [11]. There are some benefits the construction industry can obtain through Industry 4.0:

- reduced labor costs through the use of automatic workflows and robotics;
- use of embedded sensors like RFID (Radio frequency identification) can reduce material costs through the automatic tracking of materials and equipment;
- time savings by using prefabrication and additive manufacturing;
- BIM-based platforms, cloud platforms or social media applications can significantly improve collaboration among companies and help to keep projects within budget and shorten project delivery time;
- improving work safety on-site by using wearable technologies like, Smart Helmets, Smart Glasses or Smart Work Clothes [7].

We decided to group the identified technologies, synonyms, concepts and terms into 3 main clusters and 17 concepts to build a concept list by reviewing existing literature. If an article is associated with two or more concepts, it has been grouped into all of them. The Table 1 presents the comparison of the statistical results of the scientific and technical resources about the concept of Industry 4.0 in years 2010-2015 identified by Oesterreich and Teuteberg [5] with the results in years 2016-2019 obtained by authors.
Table 1. The summary of statistical results on the concept of Industry 4.0 – comparison of the research results from 2010-2015 [5] and authors' research.

| Cluster                        | Key technologies and concepts in the context of Industry 4.0 | Num. of relevant scientific publications | Num. of relevant technical publications |
|-------------------------------|-------------------------------------------------------------|------------------------------------------|----------------------------------------|
|                               |                                                             | 2010-2015 / 2016-2019                   | 2010-2015 / 2016-2019                 |
| Smart Factory                 | Cyber-Physical systems (CPS)                               | 2 / 8                                    | 0 / 4                                  |
|                               | Radio-Frequency identification (RFID)                      | 11 / 47                                 | 6 / 25                                 |
|                               | Internet of Things (IoT)/ Services (IoS)                   | 0 / 6                                    | 27 / 35                                |
|                               | Automation                                                 | 21 / 71                                 | 3 / 28                                 |
|                               | Modularisation/Prefabrication                             | 7 / 18                                  | 4 / 15                                 |
|                               | Additive Manufacturing                                     | 0 / 14                                  | 8 / 10                                 |
|                               | Product-Lifecycle-Management (PLM)                         | 2 / 7                                   | 3 / 7                                  |
|                               | Robotics                                                   | 6 / 29                                  | 13 / 20                                |
|                               | Human-Computer Interaction (HCI)                           | 2 / 26                                  | 1 / 5                                  |
| Simulation and modelling      | Simulation tools/Simulation models                         | 55 / 68                                 | 1 / 13                                 |
|                               | Building information Modelling (BIM)                       | 30 / 146                                | 11 / 42                                |
|                               | Augmented/Virtual/Mixed reality                           | 18 / 40                                 | 13 / 9                                 |
| Digitisation and virtualisation| Cloud Computing                                            | 6 / 8                                   | 5 / 11                                 |
|                               | Big Data                                                  | 0 / 13                                  | 9 / 6                                  |
|                               | Mobile Computing                                           | 2 / 8                                   | 1 / 7                                  |
|                               | Social media                                              | 3 / 4                                   | 6 / 7                                  |
|                               | Digitisation                                              | 4 / 13                                  | 8 / 11                                 |
| Total                         |                                                             | 169 / 526                               | 119 / 255                              |

Many publications have been found about Industry 4.0 in the construction industry, and their number is growing every year. In the other hand, authors admitted that existing studies focused on the possibility of adopting Industry 4.0 in the construction industry rather than on the developing theoretical plan for realizing the adoption [12].

Despite the given advantages of many technologies, their widespread adoption by construction companies has not yet taken place. The technologies mentioned are currently on different levels of maturity. For example, Cloud Computing, Mobile Computing, BIM or Modularization have reached market maturity therefore they are currently available. On the other hand, Additive Manufacturing, Augmented, Virtual and Mixed Reality technologies are still at the formative stage and don’t ready for mainstream use [15]. Dallasegaa et al. say that according to the technical literature, modern technologies as GIS, RFID, E-Business, 3D printing and BIM are currently finding their way into practice in customer supply chain and facility management [7].

The development of new and unique technologies or materials is a complex and durable process. It may take decades for one new technology to reach industry level and years to completely replace old technologies and methods in the industry [10]. Furthermore, the new technologies and the growing level of automation and digitalization of design and manufacturing processes will require more technically qualified employees. In particular, it is expected that employees will need skills in computing, digital techniques, analytical thinking, manufacturing methodologies and machine ergonomics. The authors argue that technology connects and leads from a technological-instance to transcendental effects. This means that "invention stimulates invention." It has its own impulse, and even when undesirable side effects become obvious (for example, car pollution becomes a problem), it is almost impossible to stop the wave of innovation [13]. Since construction has its tendency to transit from manual control systems and equipment to automate and machine-dominated operations, it is recognized as an important area for
future research. Additionally, many governments support corporations in implementing new technologies. Acceleration the pace of technologies diffusion is possible by facilitating their implementation, that’s why it is crucial to know how, why and where construction companies could adopt new technologies [1].

4. Obstructions to the adoption and implementation of innovative technologies

Technological advancement of the new technology has the potential to improve quality, design, sustainability and productivity dramatically. However, reviewed literature shows that there are many barriers, which can impede the effective adoption of these technologies. Ramilo and Embi classified these challenges into six categories, such as technological, organizational, financial, psychological, governmental, and process barriers [15].

![Figure 2. Obstructions to the implementation of innovative technologies](image)

There is some correlation between size of the organization and new technology implementation process. Small organizations are highly affected by financial, psychological and organizational barriers that result in technological problems with large consequences on the company. Medium-sized architectural organizations have the same barriers as well, but are less affected by psychological barriers. Large organizations have significant projects with good investments that can support digital innovation, so they are less affected by barriers compared to small and medium-sized firms. Thus, financial barriers are the most important among the all six barriers presented [15]. Currently, the various stages of the construction process can be described as opaque, slow, uncertain. According to Ermolli and De Toro the main problems are:

- the lack of a structured activities to update professional data for managing the entire process;
- the inadequacy of the current organizational models of the process, since they no longer correspond to new tools and new organization and management methodologies aimed at increasing synergies between main contractor and client;
- the low use of IT tools for the management and collection of the huge amount of data generated during construction process;
- the complexity of integration and exchange of information between numerous process participants;
- the widespread use of remuneration criteria based on the lowest price form, which takes economic aspect as a priority, ignoring the quality aspect [14].

There are two main gaps in the European manufacturing domain, that need to be addressed with funding mechanisms and specific instruments. The first lies between fundamental research and applied research while the second lies between applied research and market development [10].

5. Conclusion

The main purpose of this article was to investigate the current state of Industry 4.0 related to innovative technologies in the construction industry, and to identify obstacles to the adoption and implementation of these technologies in construction by providing an overview of existing literature. It can be concluded from the preceding analysis that the specific definition of the Industry 4.0 in the concept of construction industry include plenty of interdisciplinary technologies which enable the automation, digitisation and integration of the construction processes at all stages of the construction value chain. Withal the process of adoption new advanced and innovative technologies is very slow and insecure because of the
complexity, conservative nature of construction companies and high implementation risk. In spite of it suppliers are making determined efforts to overcome this and spread their technologies. Moreover, it was found that the size of the organization has a significant relationship with the obstructions to digital innovation. This conclusion means that smaller organizations face more barriers to digital innovation whereas larger organizations face fewer barriers.

6. References
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