Construction 4.0 Organisational Level Challenges and Solutions

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Contributor: Orsolya Heidenwolf

The construction industry (CI) is ancient and has evolved along with humanity, yet it has become increasingly inefficient due to fragmentation, the use of traditional solutions and the lack of innovative technologies and methodologies which are no longer sustainable. The Fourth Industrial Revolution has started to transform this industry, and Construction 4.0 (C4) can advocate this change to become a more efficient cyber-physical ecosystem. However, technology alone will not solve all challenges. While research on C4 focuses mainly on technology, management also plays a key role

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1. Introduction

The Fourth Industrial Revolution has reached the construction industry (CI) [1] and construction organisations [2]. CI has a long history, almost as long as that of humans. The digital transformation hit this highly fragmented [3] ancient industry [4] and demands changes through the CI supply chain [5] and value chain [6]. The new technologies, methodologies [7] and digital solutions [8] bring significant challenges and solutions for every stakeholder. While building information modelling (BIM) is the catalyst of this revolution, it is not the final solution. While organisations, projects [9], management [1] and governments face several challenges, new stakeholders [10] have realised the opportunity in the CI. The CI can delay the change but cannot prevent it.

Construction 4.0 (C4) is an increasingly frequently mentioned and widespread term in social media; however, there is limited research on the exact definition. C4 is mentioned as applying Industry 4.0 (I4) principles/technologies in the CI [4][7][11][12]. The peculiarity of C4 compared to I4 is that it has significantly more uniqueness in it. C4 is a change of approach based on significantly closer collaboration across the entire supply and value chain, supported by industrial processes, methodologies [7][12][13][14][15][16][17] and innovative tools [4][7][12][13][14][15] through a digital platform(s). Digitization can also significantly reduce lead times, costs, environmental impact and carbon emission, but its completion still has significant demand and supply constraints. Nevertheless, previous studies have concluded that the introduction of Construction 4.0 technologies is a major challenge in this generally slow industry, with only 6% of construction companies in 2019 taking advantage of it [18].

The COVID-19 pandemic has pointed out that the workforce in CI is in a particularly vulnerable position, and the effective application of technology [19] and the creation of a virtual work environment [20] providing possible solutions to the current situation. The overall industry transformation will result in significant efficiencies in addition to the current pandemic, which I4 has already demonstrated in many cases. The purpose of this article is to understand the challenges and solutions of C4. There are such studies in Industry 4.0, but in C4, these have not been explored. Therefore, it is important to understand these factors and what the dominant experts in the CI think about this to achieve a more sustainable industry.

2. Industry 4.0 (I4) Principles

The technological development brought about by the Fourth Industrial Revolution has had a major impact on both society and the economy, thus significantly impacting corporate competitiveness and social welfare. This phenomenon was first outlined in 2011 [21] and it refers to the integration of information and communication technologies in an industrial environment [22]. In the I4 era (1) digitisation, optimisation and personalisation of production; (2) automation and adaptation; (3) human–machine collaboration; (4) value-added services and warehousing; and (5) automatic data exchange and communication were defined as the five key elements [23]. Zezulka et al. [17] added three more elements to I4: (6) digitisation and network integration, (7) new market models and (8) digitisation of products and services. Integration of technologies can be implemented from different perspectives, such as horizontal (network between organisations), vertical (interrelating technologies within organisations) and end-to-end (interrelating technologies through entire processes) [24][25]. Consequently, digitalisation affects the entire value chain from business models to management systems [26]. In addition, I4 is also expected to lead to more sustainable production, with reduced material consumption and reduced waste [27][28][29], which is especially important for the CI. The main driving factors and barriers of I4 have been identified as human resources, organisation, management, market condition and competition, financial resources and profitability, productivity and efficiency, customer satisfaction and technological and process integration [29][30]. Expectations for Industry 4.0 include increased productivity, better use of resources and better product quality. In addition to the usual benefits, it also allows flexibility in production, i.e., series production can be economical, even when the size of the series is a single piece [4].

3. The Concept of C4

I4 can radically improve the CI. The Boston Consulting Group hypothesized in 2016 that the CI will be “soon” characterized by connected systems of sensors, intelligent machines, and new software applications—all integrated on a central platform of building information modelling [31]. Unlike other industries, i.e., manufacturing, construction has been slow to adopt these new technologies [32]. Moreover, many authors conclude that construction is still rather low-tech, using heavily craft-based methods, hence the implementation of C4 is falling behind expectations and faces great challenges [18][33].

One possible explanation for the slow implementation is that the application of robotics and automation is limited in the CI, because the complexity of the tasks to be performed is much higher than in other industries and the need for dynamic change and adaptation is common in on-site construction projects [7][33]. The CI is often characterised by high diversity of agents who are reluctant to change [11]. Moreover, other factors such as extreme fragmentation and lack of collaboration also limit the implementation of innovative construction technologies [11].

Nevertheless, in this era, the new phenomenon called C4 has appeared and is widely referred in the media, used on social media. The amount of research in C4 is growing exponentially; however, there is still limited research available on the topic. Based on a Scopus keyword search, 9 articles were published between 2015 and 2019, 15 in 2020 and 8 in 2021. In the keyword search, we considered articles whose keywords included “construction 4.0” and then limited the search to “industry 4.0”, “construction industry”, and the “industrial revolution”. In presenting the present theoretical background, we have thoroughly examined the articles explored in the Scopus database and their references.

Consequently, the aim of the article is to foster the implementation of I4 in the construction sector by highlighting barriers and their potential solutions. Although the digitalisation of the CI may bring further solutions, the present research focuses specifically on the phenomena of construction 4.0 and its challenges and solutions.

Despite the limited research on the topic of C4, it is mentioned as the application of I4 principles/technologies in the CI [4][7][11][12]:

1. C4 as the application of I4 in the CI;

2. Application of industrial processes and new methods;

3. Construction-specific innovative tools: devices, information technology, materials;

4. Industry-wide collaboration between construction professionals, start-ups and digital firms.

Industrialised processes and new methodologies can bring new effective ways to the built environment [34] and C4 is definitively reshaping the CI, making it more attractive [1][11][35]. Additive manufacturing (3D printing), modularisation [14] and off-site construction [7] are new elements of the C4 era compared to I4. BIM methodology is the essence of the C4 environment [7][12][13][14][15][16]. A new method called digital twin construction is emerging by improving BIM combined with lean construction thinking, artificial intelligence, AI and data-based construction management [16]. In addition, a new process, a product life-cycle management that manages the product from design to retirement, was added as a new element of C4 [14].

Construction-specific innovative tools: devices, information technology and materials are additional elements of C4. Robotics [4][7][12][13][14][15] and RFID [7][12][14] are mentioned as additional elements of the evolving industry, however, augmented reality, virtual reality [7][12][13][14][15] and IoT [12][14][15] were also mentioned as the key devices of C4 despite those also being I4 devices.

Other information technologies are mentioned by previous studies, the following in empirical studies, three of which are worth mentioning. First, mobile computing was mentioned as a new element in construction [14], while artificial intelligence and machine learning [4][7][13][15][16] and big data analysis [7][14][15] both appear in industrial and construction environments. In addition, new materials concerning industrialisation are part of this evolution [15].

New stakeholders in the C4 environment have not been studied. However, Danel et al. [36] introduced C4 as a collaboration based on I4 principles between construction professionals, start-ups and digital firms, which calls for scholarly attention. Former researchers, however, concluded that I4 imposes a new socio-technological challenge that economic actors cannot solve on their own or through traditional inter-organizational cooperation and learning [37]. Technological disruptions demand a paradigm shift in solving problems and the consequent learning [38][39][40][41]. Nevertheless, it is important to highlight that previous studies have focused mainly on the manufacturing industry in order to gain insights about organisational challenges (i.e., the works of Cimini et al. [42] and Veile et al. [43] and Müller et al. [44]).

4. Organisational Level Challenges behind C4

Cimini et al. [42] argued that understanding and modelling the role of humans is crucial to develop efficient manufacturing systems of the future. In line with their argument, the successful implementation of C4 calls for moving beyond technology in the investigation of barriers to change [38]. Such a barrier is the limited availability of skilled labour, especially in developing countries [45]. While the CI has already struggled with the lack of human resources and labour [15], the effect of the COVID-19 pandemic has brought further mental health and burnout challenges to the industry [46]. New skills are the major challenges to the implementation of C4 [1][7][10][47][48]. Social and mindset change is crucial to prepare workers for the future human and robot collaboration [1][4] that brings new roles and tasks for daily work [7][49]. Furthermore, implementing more and more robots in the industry brings ethical questions and can increase the unemployment rate [15].

Organisations face new challenges with new workflows [1][7] and organisational change [1][50] that technology demands but old business models [10] and hierarchical organisations [51] hindering the transformation. The low innovation culture [4] and the low speed of technology implementation [1] can be accelerated through well-defined digital partnering agreement [2]. SMEs have a small value in applying I4 principles [50].

Management face knowledge and decision problems. The growing number of innovations demand extra technological knowledge [4] and external support [47]. In the absence of data on technology investment, decision making becomes increasingly difficult [52]. On the other hand, the management decision is made even more difficult by the employees [12] who do not value technological innovation.

The high initial **cost** is hindering technological adaptation [1][49][53][54][55][56][57]; meanwhile, technologies that provide expensive training [50] in most cases have a lack of cost–benefit study [49].

Table 1 summarises the main challenges for C4 identified in the literature. The table shows that in the C4 environment, Maskuriy et al. [1] and Muñoz-La Rivera et al. [7] identified most of the challenges. Five articles identified that new skills for the workforce is a challenge. Furthermore, three articles highlighted the need for change in organisational and work processes. The initial high costs were also mentioned in three studies.

Table 1. Challenges behind Construction 4.0 (C4) are identified from in the literature.

Challenge	Sources
New skills for human labour	[1][7][10][47][48]
Organisational and workflow changes	[1][7][50]
Management knowledge in technologies	[12]
The high initial cost of new technologies	[1][49][53]

5. Organisational Level Solutions behind C4

There is a great deal of debate today about the job-creating or destructive effects of I4 [54]. There is no doubt that the I4 paradigm influences and shapes the professional skills and competencies required in the future [55][56], therefore, its effective implementation requires special attention to the organizational structure [42]. C4 is reshaping the CI, making it more attractive [1][11][35]. The recent pandemic proved the value of human resource efforts, especially in terms of well-being and occupational health in the sector [46]. Technology demands new skills but creates new roles [10] to support knowledge transfer to robots [11]. Social network analysis can help increase workers' skills and transfer knowledge inside the organisation [51].

Contrary to Newman et al. [50], Lekan et al. [13] discuss SMEs as the beneficiaries of the technologies. Furthermore, digital partnering is a new solution for businesses to successfully implement new technologies [2] and group construction in a new collaborative resource-sharing way [10] Organisations can solve the innovation challenges by involving research and development [1][10][49] by applying cross-functional networks inside especially hierarchical organisations [51] and by implementing the innovations to every level of the organisational strategy [57]. Furthermore, sustainable change can drive further the C4. Although C4 is not mentioned, Henderson et al. [58] found that collaborative organisations in megaprojects can drive this sustainable change by applying learning logic. The method supports strategic and action steps to focus on inclusion and experimentation.

Managers can apply new methodologies. Situational leadership can solve innovation challenges [59]. Scenario planning is a new tool for managers and researchers [10].

Technologies can increase competitiveness in the global market by allowing local companies to step out internationally [2] or increase the local competitive advantages by a new business model such as digital partnering

[52].

From a financial point of view, Alaloul et al. [35] suggested activity-based *costing* to use as a tool to "(1) identify the inspection activities; (2) compute the cost driver rate; and (3) to enable the performance of the scenario analysis by manipulating the volume of cost drivers under different scenarios". Sacks et al. [16] emphasised that technologies can reduce the cost of workers and materials. Furthermore, the platform business model can solve complex management problems and solve supply chain, material and equipment issues, leading to cost saving [6].

Table 2 summarises the solutions behind C4 identified from the literature. Most articles highlighted the importance of involving research and development and making the industry more attractive. The main studies on this phenomenon were carried out by Lavikka et al. [10] and Garcia de Soto et al. [11].

Table 2. Solutions behind C4 identified from the literature.

Solution	Sources
Make CI more attractive	[1][11][35]
New roles and skills	[10][11]
Social network analysis	[51]
Digital partnering and group construction	[2][10]
Involve research and development and innovation	[7][14][15]
Situational leadership	[59]
Early technology involvement	[11][33]
Sustainable solutions	[10][35]
Increase competitiveness	[2][52].

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