Identification of the most serious barriers slowing down the process of the construction sector transformation towards the Construction 4.0 platform.

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Abstract

The extent to which the construction sector is lagging behind other sectors of the economy in terms of productivity, innovation uptake or competitiveness is at a critical level. There are now tools and ways to mitigate this negative trend. One of them is the Construction 4.0 technology and process platform derived from the concepts of the Fourth Industrial Revolution. Despite its existence for several years, it has certain barriers to its faster introduction into standard construction practice. The aim of this paper was to present an overview, based on a focused bibliographic search and own findings, of the efforts associated with the introduction of Construction 4.0. Among the most frequently cited and also as the most serious possible obstacles are financial difficulties associated with the cost of technology purchase and concerns about return on investment, personnel risks associated with the lack of professional staff to use the new technologies, personnel-ethical risks associated with the increase in unemployment, and process risks within supply chains. The findings will inform follow-up research studies to find solutions to accelerate the uptake of this innovation platform based on automation and digitalization in the construction sector.

Keywords

Construction 4.0, Transformation, Barriers, Innovation, Sustainability.

1. Introduction

Compared to previous industrial revolutions, it is the fourth one that is expected to become active almost worldwide thanks to globalization trends. The changes brought about by this revolution are being felt in almost all industries, but with varying degrees of intensity. The modification of Industry 4.0 into a Construction 4.0 (C4) concept or platform is expected to be a great help to the overall development of this traditional, and very slowly emerging industry (Adepoju & Aigbavboa, 2020; Zabidin et al., 2020). As the study by Yousif et al. (2022) puts it, the construction industry will not keep pace with other industries in productivity for an estimated 20 years.

The potential of digital transformation and wider use of automation in the sector can not only bring higher productivity, promote positive changes in the workforce profile, reduce costs, promote greater competitiveness and ensure more efficient use of resources to improve the environmental reputation of the industry (Wang & Guo, 2022; Kozlovska et al., 2021). Despite the claimed benefits, the exploration of new technologies and processes related to C4 is still in its infancy (Schönbeck et al., 2020). There are a number of review studies that describe the benefits of C4 or its individual components. However, very few address the barriers that prevent them from being more intensively integrated into construction processes. The aim of this study is to provide relevant information and insights into what are the current and expected barriers that, despite efforts to accelerate the C4 initiative, mean that we are still practically at the beginning.

1.1 The roles of Construction 4.0

Despite its gradual introduction from 2019 onwards, Construction 4.0 can be seen as a development trend or a developing area of research in the construction industry. Its idea is based on the convergence of trends and technologies embedded in the fourth industrial revolution. The aim is to transform the environment where they are applied. Theoretically, C4 encompasses several cutting-edge technologies and addresses a number of theoretical concepts that aim towards automation, integration, collaboration, innovation, optimization, decentralization and sustainability. Its primary goal is to innovate the physical environment, increase productivity, expand collaboration and optimize sustainability trends at the corporate and social level (Wang & Guo, 2022)

From an engineering perspective, C4 is the application of Industry 4.0 concepts in the sector, that is the application of digital technologies and processes adapted to the construction environment (Franco et al., 2020). It can be imagined as a new dimension or platform for the different processes associated with the design, planning, execution and management of construction projects and works. Among the specific tasks of C4, it is possible to include, for example, bridging innovation with established practices but implementing a process of convergence between clients and contractors.

Construction 4.0 technology	Categorization by Oesterreich & Teuteberg (2016)			Categorization by Sawhney et al.(2020)		
	Simulation and modelling	Smart Factory	Digitalization and virtualization	Design/digital layer		Construction/Physical Layer – Construction Site
				Digital Tools	Data	
Building Information Modelling/Management (BIM)	x				x	
Simulation	x					
AR/VR/MR	x			x		
Cyber-Physical Systems		x				
Radio-Frequency Identification		x				
Internet of Things		x				x
Automation		x				x
Prefabricated		x				
3D printing		x				x
Product-Lifecycle Management		x				
Robotics		x				x
Cloud solutions			x	x	x	
Mobile Computing			x			
Big Data			x			
Social Media			x			
Digitisation			x			
Laser Scanning				x		
Blockchain				x		
Drones				x		
Cybersecurity				x		
Big Data/Machine Learning/ Neural Networks			x	x		
Artificial Intelligence				x		
Sensor						x
Offsite Construction						x

Fig. 1. Overview of technologies taken for Construction 4.0

Figure 1 shows that in 2016, the possibilities of using Industry 4.0 for the needs of the construction industry were only gradually generated. By 2020, this list has expanded to include tools, based on technological development or client demand. It is to be expected that there will be no final list of C4 technologies. The above overview, e.g. does not include the approach that the Smart Contract, which is already currently taken as a permanent part of C4.

The key element of C4 and its best identifiable component is BIM. This successor of CAD systems is used by the participants of a construction investment project during the life cycle for the purpose of virtual modelling and information sharing (Tezel & Aziz, 2017). A combination of laser scanning, drones and video mapping is planned to be used for the needs of progress tracking on site. In order to increase process efficiency, productivity and safety, RFID is planned to be deployed which can track the location and movement of machines, materials and workers (Pärn & Edwards, 2017; Santos et al., 2017; Perrier et al., 2020). The use of GIS is planned to be used in combination with several technologies such as BIM or different sensors. The goal is information fusion (Perrier et al., 2020). Modelling systems include AR/VR/MR to enable digitization of the environment (Dallasega et al., 2018), machine learning will be used in real time data analysis (Whyte & Hartmann, 2017), robotics can be used for complicated technological tasks such as steel beam erection (Perrier et al., 2020). Manufacturing automation can contribute to increased work safety and reduced construction waste due to rationalisation of resource consumption. At the same time, its effect is expected in reducing human errors and greenhouse gas emissions, increasing productivity (ECSO, 2021; Begić, et al., 2022; Mêda et al. 2021) and in ensuring sustainable management of infrastructure (Karmakar & Delhi, 2021).

It is undeniable that C4's individual solutions and approaches will enable it to contribute to the transformation of the whole sector, taking into account better knowledge utilisation and increased efficiency. This is not only in the context of contributing to the 3 pillars of sustainability, but also towards eliminating the threats related to increasing costs or the continuous extension of the duration of work processes beyond the plan. At the same time, it is expected to contribute to improving the quality of construction work, improving the managerial control of construction and operational processes (Jemal et al., 2023), increasing new market opportunities, reorganizing business and delivery models, fostering an innovative environment and contributing to the reorganization of the relevant market (Nagy et al., 2021). C4 according to Garcia de Soto et al (2022) creates opportunities for value addition in terms of efficiency, security, growth and convenience, but at the same time supports new risks, vulnerabilities and threats associated with increasingly autonomous cyber-physical systems.

2. Methodology

The research method was a bibliographic review combined with bibliometric analysis. The study applies the PRISMA protocol approaches in its work with documents. According to Page et al. (2020), it includes a three-phase flow chart: phase 1: Identification, phase 2: Screening and phase 3: Included. The PRISMA technique is a set of considerations in conducting evidence-based systematic reviews and appears to be the most appropriate approach for the needs of our study. In addition, it is also used for research in the field of civil engineering, such as Alfadil et al. (2022) or Andersen et al. (2022).

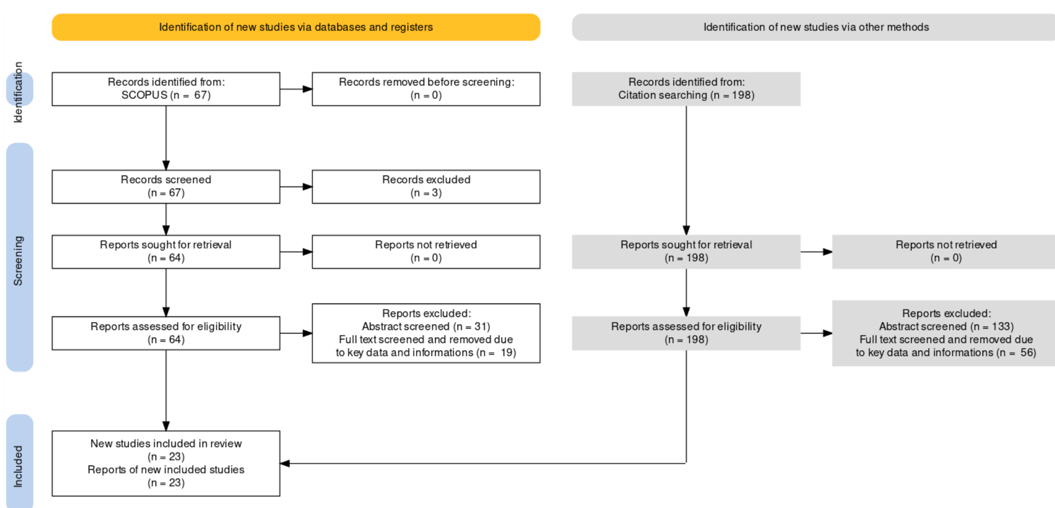

Fig. 2. PRISMA flow diagram

Initial searches were conducted in the SCOPUS database, which is more suitable for examining technically oriented studies. The algorithm was as follows *KEY (construction 4.0) AND (LIMIT-TO (PUBYEAR , 2022) OR LIMIT-TO (PUBYEAR , 2021) OR LIMIT-TO (PUBYEAR , 2020)) AND (LIMIT-TO (EXACTKEYWORD , "Construction 4.0")) AND (LIMIT-TO (LANGUAGE , "English")) AND (LIMIT-TO (SRCTYPE , "j"))* . A total of 67 publications were used for further investigation. The second search resulted in publications that cited these results but did not contain the keyword Construction 4.0. The algorithm was as follows Refined to: LIMIT-TO (LANGUAGE , *"English"*) AND (LIMIT-TO (SRCTYPE , *"j"*)) AND (EXCLUDE (EXACTKEYWORD , *"Construction 4.0"*)) AND (LIMIT-TO (SUBJAREA , *"ENGI"*)) . After further steps related to elimination based on abstract, publication availability, and overall suitability of the article for further analysis, 23 publications remained for our own research. At this point, it should be noted that the low number of remaining studies can be attributed to the orientation of the articles. These, in most cases, focus exclusively on the description of C4 technologies, without going even slightly into the problems associated with their application to real building practice. Thus, such papers are not suitable for the needs of our investigation.

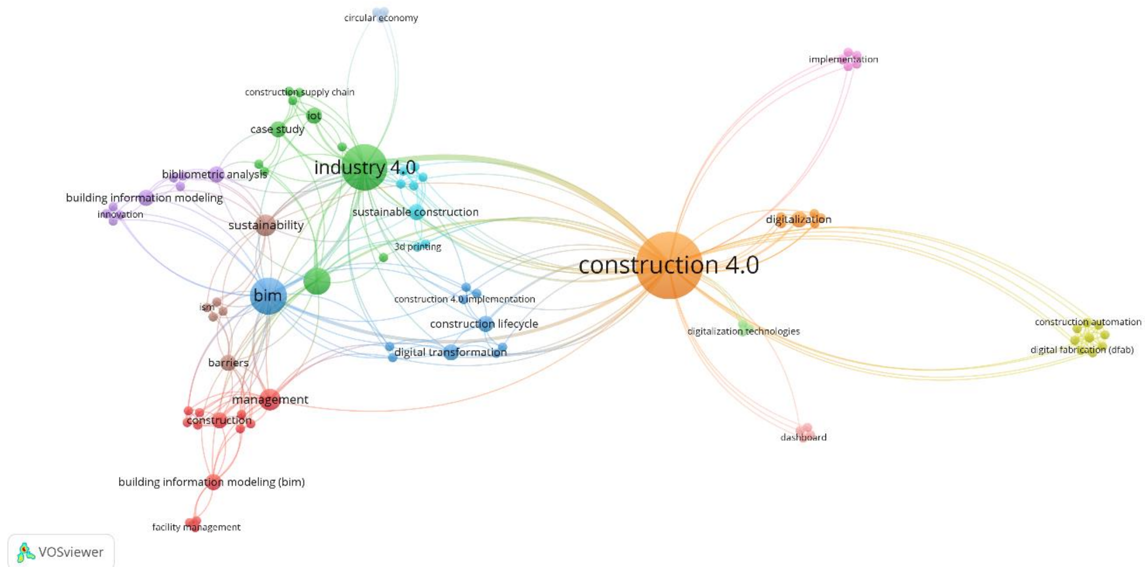

Fig. 3. VOSviewer keywords visualization

The publications that were worked with were also analyzed with VOSviewer software to generate and visualize the power of keywords (Fig.3). The size of the nodes indicates the frequency of occurrence. The curves between nodes represent their common occurrence in the same publication. The shorter the distance between two nodes, the greater the number of co-occurrences of two keywords.

3. Results

The results from the collective contributions clearly named a set of obstacles that stand in the way of a faster integration of C4 philosophy into application practice. The selection of the barriers was not easy, as these are not always individual definitions of the problems. Often the barriers are combined with each other, derived from the primary ones or are only complementary to the main barrier. Personnel concerns emerged as the clearest. They consist of two sub-categories. The first, according to Karmakar & Delhi (2021); Newman et al. (2020) & Wang & Guo (2022), is the social dimension associated with the loss of low-skilled workers through replacement by automation and digitalisation tools, and hence increasing unemployment rates in the sector. Especially in developing countries, this could pose a significant problem. As Yousif et al. (2022), Muñoz-La Rivera e al. (2021) and Al-Saeed et al. (2020) also state, it will certainly be a challenge for competent persons to strike a balance between limiting the rate of use of manpower and introducing technological innovation. In the context of the risks associated with a surplus of low-skilled workers, it is important to note that these concerns are justified if the right tools are not used. With the advent of C4, workers with varying degrees of digital skills will be needed. Also, a study by García de Soto et al. (2022) states that technological innovations in the construction industry, applied to improve productivity or safety, should not lead to an increase in unemployment and the transfer of workers to other sectors. The second part of the staffing barriers is the concern for skilled professional staff required for the deployment and use of C4 technology (Ibrahim et al., 2021; Onosen & Musonda, 2022; Jemal et al., 2023). The absence of these skills is a key issue (Adepoju & Aigbavboa, 2020; Jemal et al. 2022; Onosen & Musonda, 2022). The way to eliminate these barriers is to implement a system of retraining courses for already adapted workers or to bring new workers into the industry who already possess the skill. Despite the clear problems based on personnel, it is necessary to mention some specificities bringing some very valuable benefits. The increase in the complexity of the processes and the extent of dynamic changes associated with C4 in the different phases of the construction lifecycle is likely to increase the representation of women, cause an influx of IT professionals and allow for a higher representation of teleworking. All of this may increase the attractiveness of the sector as a whole. At the same time, it is anticipated that the combination of new C4-based processes and the modification of workers' skills will allow for a contribution to greater coordination and cooperation.

This would go some way to reducing the high degree of process fragmentation that the construction sector certainly has (Nagy et al., 2021; Karmakar & Delhi, 2021). Among the barriers cited many times is the financial aspect. This does not exclusively represent the cost of acquiring C4 technologies, but issues related to the cost of operating, servicing and repairing the equipment as well as the increased cost of expert servicing of C4 technologies also arise (Ibrahim et al., 2021; Onosen & Musonda, 2022; Jemal et al., 2023). As Larmakar & Delhi (2021) state, there are currently no reliable cost-benefit analyses that clearly present the benefits of individual technological and process innovations. This increases the level of risks present in e.g. pricing, especially in the case of construction contracts where the winner is determined based on the lowest price (Adepoju & Aigbavboa, 2020; Newman et al., 2021). The fact that business managers are responsible for efficient management and are only too reluctant to risk the possibility of investment mistakes associated with the purchase of technologies that are not essential to manufacturing operations also plays a role (Wang & Guo, 2022). It would certainly be worth considering going down the route of various innovation support schemes that could contribute to the transformation of construction technologies in firms.

Other barriers identified include those based on the specificities of the construction sector. The latter is also considered to be still highly bureaucratic according to Ariono et al. (2022), traditionalist according to Begić et al. (2022) and Adepoju & Aigbavboa (2020) and too volatile in terms of the presence of different types of risks. Wang & Guo (2022) point out the lack of strategies to implement C4 into common practice and Oke et al. (2022) state in their findings that despite the presentation of the concept of C4 based on digitalization and automation, specific mechanisms are named in a very general way, it is impossible to arrive at workable solutions and it is difficult to understand their real meaning. This barrier, according to Karmakar & Delhi (2021), is directly related to the lack of visionary vision of experts to spread awareness of the benefits offered and to motivate participants in the investment process to apply new technologies. The minimal professional and public demonstration of the capabilities of each technology at each stage of the construction life cycle, or the absence of the use of marketing tools, also plays a role (Hyarat et al., 2022). Related to this, as several studies by Oke et al. (2022), Ariono et al. (2022), Cao et al. (2022), and Onosen & Musonda (2022) indicate, is the need to conduct training, workshops, promote C4-oriented educational activities in high schools, and make universities centers for the development of advanced C4 platform technologies. The above is partly related to the poor communication of the expected roles of C4 towards the sustainability of the whole sector (Onososen & Musonda, 2022). As Franco et al. (2022) state, positive trends and research themes are present in C4. Nevertheless, the awareness of the importance of C4 to ensure the sustainability of the whole construction sector is insufficient. In their study, the author states that individual C4 technologies are not well connected to sustainability initiatives, with change efforts being individualistic in nature and a preference for mainly unilateral technical solutions rather than adopting holistic integrated management. In particular, the state and local governments, which are known to be one of the largest builders, should have a strategic role to support acceleration (Nagy et al., 2021). They can not only bring incentives for the use of C4 but also create pressure for wider deployment of C4 technologies in their own public projects (Hamza Momade et al., 2022; Newman et al., 2021).

Several barriers emerge in terms of planning and implementation of construction projects. A study by El Jazzar et al. (2021) states that there is a fundamental problem of only a very slow transition from a project-oriented mindset to a process-oriented approach. It also highlights the need to better identify at which stage of the construction lifecycle specific technologies can or should be deployed. Newman et al. (2021) and Menegon & da Silva Filho (2022) suggest that earlier phases such as projection, budgeting and scheduling are more suitable for digitalisation and can bring about the beginning of a change from dismissive attitudes. However, a high level of automation and digitisation in the design phase of construction according to (Begić et al., 2022) does not necessarily provide a benefit to the overall success of the project if the construction phase has extremely low or unapplied automation and digitisation. As stated by Hamza et al. (2022) the easiest way to implement the technologies used for construction and operation is in the planning phase, which could achieve cost savings in the initiation phase. From a construction project management perspective, the nature of the supply chain must also be mentioned as a barrier to the introduction of C4. This is mainly due to the high degree of individualism of interrelationships, not only between specific companies but also between projects. Following the construction process, some specific issues legitimately arise because of the possible application of C4 components in construction. As an example, various IoT elements that are permanently embedded in the structure of a building can be mentioned. These can be various monitoring systems for infrastructure buildings, where it is necessary to deal with their protection, management but also, for example, to provide data transmission to the evaluation environment. This implies the need to take a proactive approach to quality management, risk management and safety management during the operation and maintenance phase Perrier et al. (2022), Wang & Guo (2022) and Jemal et al. (2023), also in the context of guarantees related to the financial side.

Related to the above problems are corporate barriers. Pressures to modernise the whole sector are forcing businesses to innovate. The fundamental problem is that some processes were established long before the advent of digitalization and their transformation is both financially and time consuming, with no guarantee of return on investment (El Jazzar al., 2021). The size of enterprises is also an obstacle. In a market where small businesses and sole traders predominate, a high pace of change in the form of automation and digitalization cannot be expected. Despite the fact that larger enterprises would like to implement C4 trends, their production is often built precisely on the use of external capacities of smaller entities providing, for example, highly specialised services (Newman et al., 2021). At the same time, it is often the case that large enterprises often have outdated or inflexible business thinking and organisational structure. With the deployment of C4 in practice, the increase in costs associated with the operation, maintenance and repair of the technologies used must also be anticipated. At the same time, due to their complexity, it is necessary to have in-house staff or external service providers who can provide qualified service in the time available. As stated by Newman et al. (2021), the adoption of innovations can up to fundamentally change the previously used practices in workplaces. This can lead to a disruption of work culture, changes in work organisation as well as a deterioration in productivity. Despite the fact that some workers are open to new ideas, there are also those who are reluctant due to a lack of skills or motivation to learn new processes.

Legislative and methodological barriers also play a negative role. As Ariono et al. (2022) and Cao et al. (2022) point out, the absence of implementation procedures is a major problem in the adoption of technologies falling under C4 trends. An example is BIM. Despite their gradual diffusion, there is still a lack of universally accepted standards for their application, methods for the uniform generation of outputs and formats for data sharing between the different participants in the investment process. Enterprise risks that are slowing the uptake of C4 include issues related to the protection of sensitive data generated by the technologies and processes. Lack of attention to security issues can introduce threats to cyber security in enterprises. This issue is particularly serious from the perspective of protecting trade secrets in the context of data misuse during data sharing in the supply chain (Onososen & Musonda 2022) or from the perspective of legal protection of the inputs used (Hyarat et al., 2022). The reticence of companies is also supported by the poor possibilities, especially for the smallest companies, to use modern and secure ways for storing the generated data, which moreover must be quickly accessible (Osunsanmi et al., 2020; Jemal et al., 2023).

A barrier to wider adoption of C4 approaches is certainly the weak demand from customers (Onososen & Musonda, 2022). It is generally acknowledged that in the construction sector, the investor's primary goal is to satisfy their needs as quickly and cheaply as possible. However, they are already spending large amounts of money to meet any demands towards environmental or energy rules. The use of C4 technologies, whether in the construction phase or during operation, requires additional costs that have to be covered by someone. Hence the factor of low innovation culture in the construction industry causing slow transformation processes (Nagy et al., 2021).

4. Conclusions

Innovation in construction is a necessity. The last decade in the sector has been slow to build on previous modernisation rates and the extent of the lag cannot be ignored. It is necessary to realise that the construction sector is directly related to the economic and social development of society and is one of the sectors of the economy that have been assigned their roles in connection with ensuring sustainability. The advanced solutions presented by the Construction 4.0 platform, formed from Industry 4.0 approaches, may just be the ones to kick-start the long-demanded changes and bring about the necessary revolution. Research and expert studies published between 2020 and 2022, i.e. clearly demonstrate the usefulness of technological tools applicable in real practice. Despite this, we have a serious problem. This is the fact that we are still in the plane of presenting concepts, declaring the positive benefits of an increased share of digitisation and automation. There is a lack of fundamental knowledge associated with the real deployment of individual technologies in the form of demonstrative results. Also not available are detailed analyses assessing the financial side of putting C4 into practice, analysis of weaknesses, methodologies for managing identified risks. All this slows down the speed of commercialisation into wider construction practice. The identified barriers to acceleration in the deployment of individual C4 systems include primarily financial, staffing and process risks. This can be expanded to include shortcomings in the form of weak government support, the absence of a unified approach to introducing C4 into wider construction practice and very weak marketing. The solution could be to conduct additional studies that would provide answers to assess the process and financial efficiency of applying C4 technologies, for each phase of their life cycle. This would also improve the various financial analyses assessing the cost-effectiveness of introducing innovations. A summary of the strengths and weaknesses of specific technologies would also need to be drawn up, complemented by guidance and methodological documents related to their deployment, operation and maintenance. It goes without saying that C4 technologies bring their own characteristics of use and, with it, specific benefits and risks.

Building on the above, it is also important to be aware that the application of C4 may in some cases contradict some of the concepts associated with sustainability in the sector. Despite the assumption that C4 technologies should be conducive to these initiatives, in a secondary assessment some technologies may be shown to slow or negate the transition to greener or more energy efficient construction. They may also complicate the production process to such an extent that it becomes financially unviable. The integration of C4 components into sustainability processes should be one of the main research directions. Otherwise, there is a risk of disorientation of stakeholders. The future of the construction industry lies in the application of C4 technologies. However, it is mainly the role of the state, as both the creator of implementation policies and the largest investor, to ensure acceleration and reduce the gap between the speed of development of the different sectors of its own economy.

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