A STUDY ON SUSTAINABLE BUILDING DEVELOPMENT IN THE CONTEXT OF TRANSITION FROM CONSTRUCTION 4.0 TOWARDS 5.0

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Abstract
The aim of this study is to to analyse the theoretical framework of Industry 4.0 and Industry 5.0 and their implications for the construction industry, as well as explaining their possible effects, by using an empirical research based on the existing scientific literature.
Industry 4.0 is an under-researched area in the construction industry, even though this field has a high benefit for the parties involved. Industry 5.0, on the other hand, stands for direct cooperation between robots or intelligent machines and humans. According to the ideas of the European Commission, Industry 5.0 consists of a triad: human orientation, sustainability and resilience.
Since this paper represents an outcome of an early PHD research, the methodology chosen was examining other similar research in the literature of Industry 4.0 and Industry 5.0 in the construction industry, new established concepts (such as Building Information Modeling, Product Lifecycle Management, sustainability).

Key words: *sustainable building development*, industry 4.0, c*onstruction 4.0*, industry 5.0, *construction 5.0.*

JEL Classification: *L16; L74; O14*

I. INTRODUCTION

The main challenges are sovereignty, interoperability and sustainability (cf. Federal Ministry for Economic Affairs and Energy 2019: 28). The connection between real estate and Industry 4.0 can be viewed from several angles. Firstly: What can and must real estate do for Industry 4.0 (cf. Facility Management 2018)? However, the more interesting and less researched question is: What can Industry 4.0 do for buildings? Building technology and the coordination of operations alone can lead to more sustainable use. There is already a planning method, known as BIM (Building Information Modeling), which records the physical and functional properties of a building from the basic design to deconstruction or demolition (cf. Liebchen 2014, cited in Liebchen 2015: 105). In addition to Industry 4.0, Logistics 4.0, or Smart Logistics, is still relevant in the construction industry, which addresses the specifics of the construction industry (including the uniqueness of projects, limited possibility of prefabrication, limited space capacity for warehousing, limited freight splitting, especially in the bulk goods sector, very large object variety, strong weather dependency) (cf. Moring et al. 2018: 46). Taking this technology into account, the sustainability of the structure can already be determined in the planning phase. Industry 5.0, on the other hand, stands for direct cooperation between robots or intelligent machines and humans. According to the ideas of the European Commission, Industry 5.0 consists of a triad: human orientation, sustainability and resilience (cf. Breque et al. 2021: 14). Equivalent to resilience at this point are robustness and subsistence (cf. Weidner 2021: 41). This results in a move away from Industry 4.0 and the fundamental approaches of cost minimization and profit maximization. People and sustainability have been newly added in this area. With increasing digitization and networking in digital platforms, information security is becoming increasingly relevant.

Despite the ongoing automation and digitalization trends in all economic sectors, the production environment of the construction industry is still characterized by manual activities, paper-based processes and other interfaces. The implementation of Industry 4.0 offers numerous opportunities to eliminate these deficits and make all processes in the construction value chain more efficient. In the existing scientific literature, it is considered that the main role of the Internet of Things is to optimize the production, due to the fact that processes including machines are automized and no intervention of the human being is needed anymore, which imposes as well a reorganization of activities agrees with the clients (Fogoros et al., 2020).

However, companies operating in the construction industry tend to be reluctant to implement Industry 4.0 – despite its market maturity and high benefit expectations. Among other things, this is linked to the fact that the implications associated with the implementation of Industry 4.0 are still unknown. In addition, many economic, technological, social and legal questions remain unanswered. All these factors contribute to the fact that there is still no talk of a broad application of Industry 4.0 technologies in the construction industry (cf. Austria & Teuteberg 2017: 71).

In the context of this article, the implementation of Industry 4.0 and Industry 5.0 in the construction industry will be addressed. The aim is to show the impact of Industry 4.0 and Industry 5.0 on the construction industry.

The research question on which the work is based can be formulated as follows: What impact do Industry 4.0 and Industry 5.0 exert on the construction industry? To answer this question, the first step is to explain the theoretical foundations of Industry 4.0 and Industry 5.0. Building on this, the implications of Industry 4.0 and Industry 5.0 for the construction industry will be shown. The industry must always be considered from the point of view of sustainability, knowing that sustainability supposes the capacity of a business to last, by protecting the environment (Fogoros et al., 2020) and the currently most important building material will be used to show how sustainable the construction industry can currently be. Based on recent research, creating resilience with the aid of digital transformation supposes balancing short-term necessity with realizing long-term opportunity (Fogoros et al., 2022). Finally, the insights gained are summarized and an outlook is given in the research perspective.

II. A REVIEW OF LITERATURE ON INDUSTRY 4.0 AND INDUSTRY 5.0

Industry 4.0 can be understood as a sub-area of digitalization that aims to secure comprehensive networking and increase efficiency and effectiveness. In the foreground of Industry 4.0 is Smart Factory – a smart factory operated with such technologies as robots, databases, cyber-physical systems, etc. The main components of Industry 4.0 are Smart Products, Smart Services, Smart Enterprises, etc. (cf. Bendel 2017: 162–163). The most important characteristics of Industry 4.0 are autonomation, automation, flexibilization and individualization. Autonomation can be defined as the assumption of standardized routine tasks by machines, with humans taking over maintenance and monitoring functions. Automation refers to production processes and the production cycle. Flexibilization stands for developed response capabilities to external changes. Individualization is about adapting production to individual wishes and requirements of customers (cf. Bendel 2017: 163–165).

The main content areas of Industry 4.0 are artificial intelligence, actuator and sensor technology, modular and flexible production systems and their architectures, the sovereignty of data spaces, computing and communication technologies, the biologization of technical systems and products, etc. (cf. Research Advisory Board of the Industry 4.0 platform/acatech - German Academy of Science and Engineering 2022: 5). The main challenges discussed in the context of Industry 4.0 relate to sovereignty, interoperability and sustainability. These challenges simultaneously emerge as the cornerstones and most important goals of Industry 4.0. For Industry 4.0 to fully develop its potential, a high level of interoperability is indispensable. This involves an appropriate regulatory framework, favourable standards, the integration of Industry 4.0 as part of these standards, artificial intelligence, etc. Sovereignty stems from ensuring such factors as digital infrastructure, technological development and security. Sustainability relates to good work and education, climate protection and social participation (cf. Research Advisory Board of the Industry 4.0 platform/acatech - German Academy of Science and Engineering 2022: 5).

Industry and the associated networking of system, production facilities and also buildings entail the risk of an increase in the potential for attack and threat in cyberspace (cf. Schlinkert in Rechtsfragen der Industrie 4.0: 66).

Industry 5.0 stands for direct cooperation between robots or intelligent machines and humans. This allows production sequences and all processes to be continuously optimized and made more efficient and sustainable. The focus of Industry 5.0 is on robots that support people in working faster and better (cf. IFPM Institute 2023: n.d.). This involves the use of such technologies as Big Data, Internet of Things, etc. These technologies make all processes tangible and give them a human component. The focus of Industry 5.0 is thus on cooperation between man and machine, with artificial intelligence and robotics developing into its central technologies (cf. IFPM Institute 2023: o. p.).

Since Industry 5.0 focuses on cooperation between humans and machines to increase production efficiency and promote human productivity, it is expected that in the future the focus of Industry 5.0 will be on the further development of cognitive computer technologies and artificial intelligence. This will help to increase business efficiency and increase the demands on workers to learn how to deal constructively with artificial intelligence and robots. Accordingly, Digital Twins are seen as the central technology of Industry 5.0 (cf. Adel 2022: 13).

Digital Twins is a technology that enables the development of new systems in various areas as well as a deeper understanding of existing systems. Basically, Digital Twins represent nothing more than a virtual representation of a production unit in the cloud based on artificial intelligence (cf. Dalibor et al. 2022: o. p.). Furthermore, Digital Twins can define digital information constructs about a physical system that are linked to this system. The resulting digital representation ideally includes all information regarding the system design that can be collected in the physical world. As a result, digital twins can increase the productivity, competitiveness, and efficiency of production systems, with applications in such use cases as production planning, layout planning, maintenance, and production control (see Kritzinger et al. 2018: 1016–1018).

Industry 4.0 and Industry 5.0 can be represented graphically as follows. A precise separation cannot be made, as the change and development toward Industry 5.0 are in a fluid process:

The differences between industry 4.0 and industry 5.0

Nr. Crt.	**Industry 4.0**	**Industry 5.0**
1	Comprehensive digitization of industrial production	Direct collaboration between robots, intelligent machines and humans
2	Important components: - Smart Factory - Smart Products - Smart Services - Smart Enterprises - Cost minimization - Profit maximization	Important components: - Artificial intelligence - Cognitive computer technology - Human orientation - Sustainability - Resilience - Cooperation Human/Machine

Source: authors' own research.

III. RESEARCH OBJECTIVS AND METHODOLOGY

The aim of this study is to analyse the possibility of the implementation of Industry 4.0 and Industry 5.0 on the construction industry, as well as explaining their possible effects, by using an empirical research based on the existing scientific literature. As the digitization phenomena is very complex nowadays in several domains, so is the case of the construction industry which must adapt its flow, optimize and improve the efficiency of the production workflows and processes with the aid on new technologies.

Since this paper represents an outcome of an early PHD research, the methodology chosen was examining other similar research in the literature of Industry 4.0 and Industry 5.0 in the construction industry, new established concepts (such as Building Information Modeling, Product Lifecycle Management, sustainability) and digital transformation in general. This will help us to obtain an overall view on the construction 4.0 and Building Information Modeling as well as on the construction 5.0 and sustainability, improving the quality of future research on this topic. The primary research goal is understanding the aftermath of Industry 4.0 on buildings, while considering that Building technology and the coordination of operations alone can lead to more sustainable use. To acknowledge this, the first step is to explain the theoretical foundations of Industry 4.0 and Industry 5.0. Moreover, the implications of Industry 4.0 and Industry 5.0 for the construction industry will be shown. The industry must always be considered from the point of view of sustainability, and the currently most important building material will be used to show how sustainable the construction industry can currently be. Finally, the insights gained are summarized and an outlook is given in the research perspective.

IV. RESEARCH RESULTS ON THE CONSTRUCTION 4.0 AND BUILDING INFORMATION MODELING (BIM)

It may be assumed that the construction industry will be significantly influenced by Industry 4.0 and Industry 5.0. However, the extent of these influences has not yet been comprehensively explored and researched. This is particularly true when it comes to Industry 5.0, which has a considerable need for research even without reference to the construction industry. Industry 5.0 contributes to the technological update of various industries and offers solutions for society. Artificial intelligence and robotics enable radical workplace innovation and optimize human-machine interactions in a human-centric way. This not only increases industrial resilience, but also makes it more sustainable. All these factors are exerting a transformative influence on industry, with employees requiring a redefinition of their own roles and competencies (see Directorate-General for Research and Innovation 2021: n.d.).

Central characteristics of Industry 4.0 are simulation and modeling. These basic technologies serve to master complex interrelationships and support interdisciplinary collaboration. In the construction-specific definition, this function is assumed by the Building Information Modeling method, which is seen as a central element of Industry 4.0 in the construction industry. This involves a method for mapping digital planning models of structures, including the functional and physical properties of these structures as well as other relevant information such as time and costs. Building Information Modeling as a method covers all phases of the product life cycle - from planning to construction and maintenance to the final assembly of a structure. Under this assumption, the requirement for holistic product lifecycle management for more sustainable production design is also met. Great importance is attributed to product lifecycle management - both in the classic concept description and in the construction-specific view (cf. Austria & Teuteberg 2017: 74).

Building Information Modeling as a trend method can be used in many construction projects. However, the models created in this way are, according to the existing conditions, rather rarely used after the construction phase. There is still a lack of concepts to consistently continue the created digital building model during the utilization phase. There is a considerable need for research and practical application in this field. In addition, there is an increasing focus on sustainability in the construction industry. The production and processing of building materials has a negative impact on the climate and the environment. This is particularly true to produce concrete, as concrete is the most widely produced and used material. Extending the service life of concrete structures can thus make a major global contribution to improving sustainability in the construction industry. In this context, construction quality and quality assurance during the construction phase are increasingly gaining importance as important issues. Even if small funds are invested, this has a positive effect on the quality and service life of a structure (cf. Große 2019: 705).

Overall, it should be noted that the construction industry is a laggard when it comes to digitalization and the implementation of Industry 4.0, which is evident from concrete examples of applications in the construction industry. However, the vision of a networked and digital construction site considering various technical possibilities is already a reality today, even if it will have to be further developed in the future. Central concepts of Industry 4.0 and Industry 5.0 that find an application in the construction industry are modularization, cloud technologies, mobile computing, social media, RFID-based applications and other technologies (cf. Austria & Teuteberg 2017: 75).

V. RESEARCH RESULTS ON THE CONSTRUCTION 5.0 AND SUSTAINABLE DEVELOPMENT

Industry 5.0 is hardly imaginable without sustainability. When it comes to the topics of resource conservation and environmentally conscious construction, the planning and production of buildings is clearly of primary importance, followed by their use, so that sufficient resources are still available for future generations and environmental conditions remain tolerable. Nowadays, however, there is a lack of support with regards to the life cycle of the building beyond: Industry 5.0 is intended to provide support here. In addition to manufacturing, other major resource consumptions occur during repairs, maintenance, expectations or deconstruction of the structure. However, if an inventory list of the building is already created during the manufacture/extension of the structure and recorded in a central database, the deconstructed building material (resource) can be used in a new structure during deconstruction.

Then, this requires comprehensive recording of the building materials used and precise scheduling of the various construction projects. This approach is not feasible with the current conditions, because there is a lack of building materials that are suitable for reuse, since currently deconstruction is often not taken into account in the construction of the building and most resources are processed in existing buildings (already constructed buildings). It is also currently state of the art and practice that materials are used that have been mixed or contaminated (so-called composite materials), which leads to reuse being difficult or impossible.

The most used building material is concrete, and as a composite it is found in almost every structure. Recycling, however, is a challenge. Recycling in road construction is possible but to a small extent (cf. Röbert 1981: 7). The aim should not be to recycle building materials, but to keep the pure basic material at the same quality level, which means that the building material remains in its original form. To stay with the example of concrete, a subsequent separation into its basic materials is technically and economically no longer possible. Recycling is possible to a very limited extent since the cement content of the so-called recycled concrete is about the same as that of the new concretes (cf. Hügel 2022: 44).

Only the aggregates can be reduced, which leads to a preliminary saving of resources due to the recycling. However, the effort for this is considerably higher, no building materials must be consumed, but high amounts of energy have to be used to process the old concrete to such an extent that recycling and the following reuse is possible (cf. Hügel 2022: 44). Then, however, the consideration arises whether it is not more sustainable to use

cements of the class CEM II or III, because these are more CO2-efficient than the usually used CEM I (which must be added to the recycled concrete) (cf. Hügel 2022: 44). An important approach for reuse at the same level is the use of soluble compounds (recovery of single-variety base materials) and the avoidance of composite materials (cf. Hügel 2022: 40). These properties are not present in concrete.
Apart from the technical reuse of building materials just discussed, an inventory list of building materials and components with the materials must be created in a database that allows new construction projects to be planned and designed accordingly. This database must be made available to the various stakeholders so that a new structure can access the raw materials of the structure being rebuilt.

VI. Conclusion and Outlook

In the context of this article, the implementation of Industry 4.0 and Industry 5.0 in the construction industry was addressed. The aim was to explain the effects of Industry 4.0 and Industry 5.0 on the construction industry. The research question that was pursued was formulated as follows: What impact do Industry 4.0 and Industry 5.0 exert on the construction industry? This research question is answered below.

Industry 4.0 and Industry 5.0 are having a serious impact on the construction industry, as they are helping to optimize and make more efficient the production workflows and processes in the construction industry. In addition, the interfaces in human-machine cooperation in the construction industry can be automated and optimized so that the quality of this cooperation is brought to a new level. At the same time, it should be considered that apart from the established concepts (such as Building Information Modeling, Product Lifecycle Management, sustainability, etc.), further impacts of Industry 4.0 and Industry 5.0 on the construction industry have not yet been fully explored. There is a significant need for research in this regard.

Against this backdrop, it would be essential from a research perspective to investigate the impact of Industry 4.0 and Industry 5.0 on the construction industry in detail - and to do so both in theory and in the practice of technological implementation. This is particularly true of Industry 5.0, whose influences on the construction industry have been little addressed. But the effects of Industry 4.0 also require further investigation. First and foremost, theoretical research in the form of literature reviews is conceivable, as well as empirical studies that can be designed as surveys or interviews. In this context, it is important to draw on the expertise of professionals who are familiar with Industry 4.0 and Industry 5.0.

From the point of view of sustainability, it would be desirable to initially dispense with composite materials, especially concrete. The high amount of concrete used and its resource requirements as well as the negative CO2 impact speak in favour of this. However, the state of the art does not offer any significant substitute. Concrete is currently indispensable in tunnel and bridge construction as well as in civil engineering and building construction. Therefore, the recycling of concrete remains necessary to conserve the remaining resources. The optimization of recycling alone cannot be achieved without Industry 4.0 / 5.0.

VII. References

1. Adel, A. (2022) Future of industry 5.0 in society: human-centric solutions, challenges and prospective research areas, *Journal of Cloud Computing*, 11(40), pp. 1-15.
2. Bendel, O. (2017) Die Industrie 4.0 aus Sicht der Ethik, in S. Reinheimer (Hrsg.), *Industrie 4.0*, Springer Vieweg, Wiesbaden, S. 161-172.
3. Breque, Maija, Lars De Nul und Athanasios Petridis (2021): Industry 5.0 – Towards a sustainable, human-centric and resilient European industry, Brüssel: European Commission, S. 14.
4. Bundesministerium für Wirtschaft und Energie (BMWi) (2019) Schlaglichter der Wirtschaftspolitik, Monatsbericht Oktober 2019, Berlin, S. 28.
5. Dalibor, M., Jansen, N., Rumpe, B., Schmalzing, D. et al. (2022) A Cross-Domain Systematic Mapping Study on Software Engineering for Digital Twins, *The Journal of Systems & Software*, 193, 111361.
6. Directorate-General for Research and Innovation (2021) *Industry 5.0: Towards more sustainable, resilient and human-centric industry*, https://research-and-innovation.ec.europa.eu/news/all-research-and-innovation-news/industry-50-towards-more-sustainable-resilient-and-human-centric-industry-2021-01-07_en, Zugriff am 16.02.2023.
7. Facility Management (2018): Industrie 4.0 und Immobilien als Herausforderung der Zukunft, [online] https://www.facility-management.de/artikel/fm_Industrie_4.0_und_Immobilien_als_Herausforderung_der_Zukunft_3200288.html [19.06.2022]
8. Fogoros, T.E., Bitan, G.E., Olaru, S.M. (2020) : From traditional to digital: a study on business models in the context of digitalization. Proceedings of The 3rd International Conference on Economics and Social Sciences, Bucharest, Romania.
9. Fogoros, T.E., Olaru, M. , Ilie, C.,Gavril, R.M. (2022): A study on factors influencing business resilience in the context of digital transformation. Ecoforum Journal, Volume 11, 2(28), http://www.ecoforumjournal.ro/index.php/eco/article/view/1367/812.
10. Fogoros, T.E., Maier, D., Iordache, A., Bitan, G.E. (2020): A study on factors influencing sustainable entrepreneurship in European Union countries. Proceedings of the 6th BASIQ International Conference on New Trends in Sustainable Business and Consumption,pp. 950-957.
11. Forschungsbeirat der Plattform Industrie 4.0/acatech – Deutsche Akademie der Technikwissenschaften (2022) *Themenfelder Industrie 4.0 – Forschungs- und Entwicklungsbedarfe zur erfolgreichen Umsetzung von Industrie 4.0*, 2. Auflage, München.
12. Große, C. U. (2019) Bauwerksmanagement 4.0? *Beton- und Stahlbetonbau*, 114(10), S. 705-706.
13. Hügel, R. (2022) Herausforderungen und Chancen der Bauwirtschaft unserer Beitrag zur Nachhaltigkeit, in 18. Symposium Baustoffe und Bauwerkserhaltung Karlsruher Institut für Technologie (KIT), KIT Scientific Publishing, Karlsruhe, S. 35-47.

14. IFPM Institute (2023) *Industrie 5.0,* https://ifpm.institute/industrie-5-0/, Zugriff am 16.02.2023.
15. Kritzinger, W., Karner, M., Traar, G., Henjes, J., Sihn, W. (2018) Digital Twin in manufacturing: A categorical literature review and classification, *IFAC PapersOnline*, 51-11, 1016-1022.
16. Liebchen, Jens H.: Building Information Modeling (BIM) – Ein neues Tätigkeitsfeld für Dienstleister im Bauwesen (2015), in: Viering, Markus, Nina Rodde und Christian Zanner (Hrsg.), Immobilien- und Bauwirtschaft aktuell – Ent-wicklungen und Tendenzen – Festschrift für Professor Bernd Kochendörfer, Wiesbaden: Springer Vieweg, S. 106.
17. Moring, Andreas, Lukas Maiwald und Timo Kewitz (2018): Bits und Bricks: Digitalisierung von Geschäftsmodellen in der Immobilienbranche, Wiesbaden: Springer Fachmedien.
18. Oesterreich, T.D., Teuteberg, F. (2017) Industrie 4.0 in der Wertschöpfungskette Bau – Ferne Vision oder greifbare Realität?, in S. Reinheimer (Hrsg.), Industrie 4.0, Springer Vieweg, Wiesbaden, S. 71-89.
19. Röbert, S. (1981) Lebensdauer und Wiederverwendung von Baustoffen, Akademie Verlag, Berlin, S. 7.
20. Schlinkert, Hans-Jürgen (2018) in G. Hornung (Hrsg.), Rechtsfragen der Industrie 4.0, Nomos Verlag, Kassel, S. 66.
21. Weidner, Silke: Stadtplanerische Aspekte der resilienten Stadt (2021), in: Just, Tobias und Franziska Plößl (Hrsg.), Die Europäische Stadt nach Corona – Strategien für resiliente Städte und Immobilien, Wiesbaden: Springer Fachmedien, S. 41