Construction Robotics Excellence Model: A framework to overcome existing barriers for the implementation of robotics in the construction industry

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Abstract –

The construction industry is characterized by low productivity and inefficient processes. In addition, the level of digitalization and automation in this industry is low compared to other industries. Although the added values of using robots in the industry have been known for a long time and the technology has been available for several decades. Nevertheless, the use and implementation of robotic systems is still slow.

The aim of this work is to identify the barriers to the introduction of robots in the existing literature and to supplement them with an empirical study focused on the German construction industry, and subsequently to derive meta-barriers. In addition, a holistic model for overcoming barriers is developed

Based on a literature review, the already identified barriers for implementation in the construction industry are identified, clustered and five meta-barriers are derived. The literature review is complemented by an empirical study in the German construction industry. Based on the results, the Construction Robotics Excellence Model is presented. The model serves as a generic framework for overcoming existing barriers and promoting the implementation of robotics systems in the construction industry.

The results of the article show the versatility of the existing barriers in the construction industry and the need for a framework to support the implementation and use of robotics in the construction industry.

Keywords –

Robotics, Barriers, Construction Robotics Excellence Model

1 Introduction

The construction industry is a significant industrial sector in the world due to its large economic output and high social relevance [1–3]. Nevertheless, the industry has been characterized by inefficiency and low productivity for many decades [4,5]. In addition, the industry still has a low level of digitalization and automation in direct comparison with other business sectors [6]. This is attributed to the limits reached by the construction industry [7].

In other industries, for example the automotive, manufacturing and aerospace industry, the added value of robotic systems has been known for several decades and has been successfully implemented in existing process structures [8]. In the construction industry, robotic systems have been developed since the 1960s [7,9,10]. Several fields of application [11] and added values have been identified [8,12], but the implementation of the technology is still progressing very slowly [7]. One reason for this are the specifics of the construction industry, such as the heterogeneous production environments and many unique processes in the construction projects, etc.. [6].

This article examines and identifies these barriers to the introduction of robots into the construction industry in a global and national context. As a result, a general framework, the Construction Robotics Excellence Model (ConRoX), for companies to overcome these existing barriers and introduce robots is derived.

2 Related Work

In addition to the possibilities and potential of robots in the construction industry, the barriers to the introduction and use of robot technology in this sector need to be considered. In a literature analysis, a total of nine scientific papers were identified that address existing barriers to the introduction of robots in the construction industry. The articles were analyzed, the identified barriers extracted and grouped into five higher-level clusters. These five clusters represent generic meta-barriers of the construction industry (s. Table 1). The identified generic meta-barriers include social, economic and technical aspects. The most concise meta-barrier is the I. Adoption & Implementation with a total of 15 subordinate individual barriers. This meta-barrier refers to the complexity of the construction industry, its heterogeneous environment and the low level of digitalization and productivity. The second cluster (II. Skeptical Attitude) considered from the social perspective refers to the skeptical attitude of the construction industry and its fundamental resistance to innovation and new technologies and includes 12 individual barriers. Another meta-barrier (IV. Lack of knowledge) from the social perspective considers the lack of knowledge and expertise of the personnel about the subject area of robotics and automation as well as the lack of competences to deal with the technologies. A concise economic meta-barrier (III. High Costs) is derived from the still high acquisition, usage and maintenance costs for robots. From a technical perspective, meta-barrier V. No Standardization results from the lack of uniform standards at the organizational, process and information technology levels.

Table 1 List of identified meta-barriers

Barriers	**Source**	**List of quantity**
I. Adoption & Implementation		*15*
Difficulties of implementation in complex structures	[13]	
Resources limitation of the companies	[14]	
Lack of interoperability between organizational units and the general fragmentation of the construction industry	[14]	
To integrate the automation flexibly into the overall process from the start	[15]	
Traditional procurement methods that need to be adapted	[16]	
Changes are associated with risks and uncertainties	[16]	
Conflicts of interest when the contractor is added during the design	[16]	
Incompatibility with existing construction processes	[17]	
Inconsistency in the structure of the construction industry	[17]	
The complexity of the supply chain with different players in the implementation	[8]	
Unstructured nature of construction site	[8]	
Different requirements characterize market diversity	[8]	
Variability of building types	[8]	
Limitations of adopting new technologies in the construction industry	[3]	
Adoption inefficiencies and low productivity of robots	[3]	
II. Skeptical attitude		*12*
Concerns of the workers	[18]	
Basic rejection of new technologies of workers	[13]	
The pronounced concern for safety	[14]	
Resistance to change	[14]	
The attitude of the management and team level	[19]	
The emotional stress of replacing humans with robots	[15]	
The disinterest of designers in disruptive technologies,	[16]	
Resistance to new construction designs	[16]	
Lack of worker acceptance	[17]	
Skeptical attitudes of stakeholders towards innovative technologies	[8]	
The expectation of a new technology	[3]	
Concerns about the adoption of a new technology	[3]	
III. High costs		*10*
High acquisition costs	[18]	
High costs for acquisition, maintenance, and operation of robots	[13]	
High investment and maintenance costs in the company	[15]	
Automation is associated with high costs	[16]	
Ownership and operation are associated with high costs	[16]	
Cost intensity	[17]	
High acquisition, operation, and maintenance costs	[17]	
High cost of adoption	[3]	
Declining public funding	[3]	
Insufficient economic efficiency and associated profitability of introducing a robot to achieve real cost reductions	[3]	

IV. Lack of knowledge		*9*
Adapting new process structures	[18]	
Low level of competence in the use of technology	[14]	
Access to technologies knowledge	[19]	
Limited experience in automation	[16]	
Limited practical experience of designers on site	[16]	
Lack of knowledge of designers about construction methods in automation	[16]	
Difficulty in handling	[17]	
Low technological competence of project stakeholders	[17]	
Unproven effectiveness and immaturity	[3]	
V. No standardization		*6*
Lack of standardized construction elements	[16]	
No standardized processes	[16]	
Lack of references for the design	[16]	
Rapid replacement and changes due to the high technological progress	[16]	
The new roles and responsibilities that are emerging among planners	[16]	
Difficulty in procuring robots	[17]	

The results of the previously published articles on the barriers to the use of robot systems in the construction industry include many barriers from different perspectives. These perspectives were investigated, specified and clustered into generic meta-barriers. In the next chapter, the existing conclusions from the literature analysis are extended by an empirical study focusing on the German construction industry.

3 Research Design

3.1 General Methodology

In the previous chapter the general state of the art on the already identified barriers for the use of robotics in the construction is elaborated based on a literature review.

Based on the results, the general approach is set up with two consecutive tasks, (i) the empirical quantitative study and (ii) the derivation and presentation of the framework. In a first step, an empirical study will be carried out as a quantitative survey with an inductive approach. The topic of the study focuses on the identification of challenges for the use of robotics in the German construction industry. Additionally, the organizational, process and information levels are considered from a strategic and operational perspective. The evaluation of the survey provides barriers for the implementation of robot systems in the German construction industry. The barriers are specified into the three categories - social, technical and economic. Based on the results, a general framework for the qualitative implementation and effective and efficient use of robotic systems is designed. This framework is termed the Construction Robotics Excellence (ConRoX) model. For a better understanding of the ConRoX model, the individual components are explained in more detail. This is followed by a discussion of the added value of the ConRoX model, its limitations, and its future potential for the construction industry.

At the end of the article, a critical review of the results is provided and an outlook on the resulting research is presented.

3.2 Structure of the empirical quantitative study

The structure of the empirical part is developed according to Diekmann and divided into the (a) data collection and (b) data evaluation. [20]

The primary question for the empirical study focuses on the barriers for the implementation of robotics in the German construction industry. The survey expands on the knowledge already gained from the preceding literature analysis.

The data collection method of the empirical study is conducted as an internet survey [20,21]. The survey is explicitly aimed at professionals in the construction industry. The conscious selection of the interviewed group is chosen with care and a total of three criteria that have to be fulfilled are defined as markers. The first criterion is several years of professional experience and/or an academic title of the respondent in the field of civil engineering as well as initial experience in robotics. The second criterion is the existence of the company's main business field in the German construction industry. The third and last criterion is that the respondent's field of activity must be in the construction execution phase.

For the experimental design of the Internet survey, the ex-post-facto design is chosen and conducted as a cross-sectional survey in a period of six weeks [22–24]. To obtain measurable and representative results, no limit is set on the number of participants. [20,25]. For the analysis of the collected data, an inductive approach using the statistical method of inferential statistics is provided. The method of inferential statistics for analyzing the survey data is used to derive general statements about the barriers of the robot implementation in the German construction industry from the results [24,25].

The survey is structured according to Raithel and is implemented as a written, structured and standardized online survey. In the process, individual persons are questioned in a structured manner [22]. In total, the survey contains 26 questions with a mixture of closed-ended (73%) and hybrid (23%) and one open-ended questions (4%). The questions are divided into five main categories - General information of the respondent (category 1), the status quo of robotics in the respondent's company on the topic area (category 2), barriers (category 3) and drivers (category 4) of the implementation of robotics and the approaches to overcome the barriers (category 5) [26]. The main focus in this paper is on categories 2 and 3 due to only capturing the existing experience of German enterprises with robotics and elaborate the significant barriers. The other categories are not considered in this research paper.

In category 3, respondents were given 32 different hypotheses to choose from. These hypotheses were divided into three categories - social, technical, and economic - for further specification [20,21,26] The basis of the 32 hypotheses findings from the knowledge is derived from the identified barriers from the previous literature analysis. To assess the importance of all predefined hypotheses, a unipolar ordinal scale with a total of six response options ranging from “disagree” (1) to “strongly agree” (6) is provided for the evaluation. The ranking of the most important barriers is made based on the cumulative sum (presented as a cumulative percentage) of the level of agreement S_z (S_z: sum of the positive responses of option 5 & 6). The barriers with the highest level of agreement are presented in Table 2 as survey category results.

4 Empirical Quantitative Study

4.1 Data Collection

The survey data was collected using a web survey over a period of six weeks, from August 16th, 2021 to September 27th, 2021. The respondents were limited to specialists and managers in the construction industry. The focus of the study was on the German construction sector. A total of 130 companies and associations were contacted. However, merely 65 questionnaires were completely answered. The overall response rate of the surveys is 50.0%. According to Diekmann, a response rate of over 20% are rarely achieved, tending to be around 5% [20]. For this reason, the existing response rate of 50.0% can be classified as representative.

4.2 Data Evaluation

Due to the focus in this scientific article, the following evaluation of the study will focus on category 3 (barriers to implementing robotics). In addition, Category 2 (status quo of robotics in German enterprises) is evaluated at the beginning of the evaluation. The other categories will not be considered within the scope of the research article.

4.2.1 Results: Experience with Robotics in German construction companies

This section evaluates the questions in Category 2 – the status quo of robotics in German enterprises. The result was that the majority of the respondents in total 73.7% have not yet gained knowledge about the use of robotics and automation technologies. In contrast, 26.3% of the respondents already gained experience using robots, either directly in the traditional in-situ execution (11.6%) or in industrial prefabrication (14.7%) (s. Figure 1). Next, the expected time horizon for the implementation of robotics and automation technology was asked. Only 5.30% are already planning implementation. For 23.2 %, the implementation is planned in 5 years, for 12.5 % in 10 years, for 14.3 % in 15 years and for 17.9 % not at all. construction companies

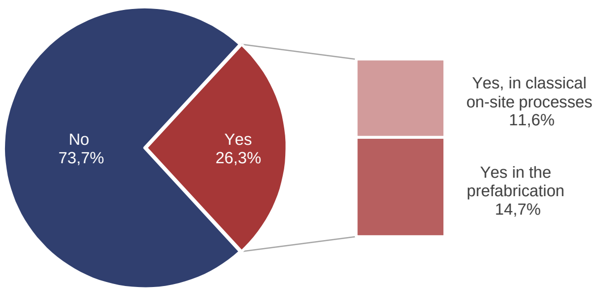

Figure 1 Use of robotic systems in German

4.2.2 Results: Barriers of robotic implementation

The ranking of the most important barriers (s. Table 2) is based on the cumulative sum (represented as cumulative percentage) of the level of agreement S_z (S_z: sum of positive responses of option 5 & 6). The barriers with a degree of agreement $S_z > 55$ % were characterized as main barriers after the evaluation. In total, 12 main barriers on a social, technical and economic level were identified from the 32 hypotheses with the corresponding level of agreement.

Seven barriers were identified in the economic area. Hence, this area presents the most barriers. The barriers relate on the one hand to monetary aspects, such as a lack of resources in the company, high acquisition costs and a lack of incentives from the state. On the other hand, they address strategic issues, such as a missing consistent implementation strategy or a lack of best practice. The high number of economic barriers illustrates the importance of the field for future construction robotics. Above all, clear overarching strategies and financial support are needed in this context. On a social level, three barriers were identified. These are all in the context of a lack of expertise and training opportunities, as well as a lack of knowledge about the potential uses of robotics. Without increased knowledge of the technology, companies do not yet see the point of implementing it, as the long-term added value is not yet obvious. On the technical level, two barriers were identified. The respondents consider the dynamic and heterogeneous construction site environment and the lack of standardization of processes to be the main obstacles.

In the comparison of the results of the literature analysis and the empirical study, it can be deduced that each identified individual barrier of the studies can also be classified in the meta-barriers. This strengthens the generality of the meta-barriers and its broad applicability.

The other 20 hypotheses from the survey consider, for example, aspects relating to the use of data in the construction industry, human-machine collaboration on the construction site, or a lack of acceptance and resistance among employees. These aspects were rated as manageable by the respondents.

Table 2 Identified barrier to construction robotics implementation.

Barriers	**Results of the Evaluation [%]**						**S_z (5+6) [%]**	**Meta-Barrier**
	1	**2**	**3**	**4**	**5**	**6**		
A. Social Level								
A.1 Lack of advanced training	1.0	8.0	6.0	10.0	40.0	36.0	76.0	IV.
A.2 Low level of employee expertise	1.0	9.0	7.0	11.0	27.0	45.0	72.0	IV
A.3 Lack of knowledge about possible applications slows down implementation	0.0	1.0	11.0	16.0	39.0	33.0	72.0	IV
B. Technical Level								
B.1 Lack of standardized processes	0.0	8.0	12.0	20.0	37.0	23.0	60.0	V.
B.2 Problems due to dynamic construction site environment	7.0	5.0	14.0	19.0	38.0	17.0	55.0	I.
C. Commercial Level								
C.1 Limited resources for SMEs	1.0	3.0	4.0	18.0	41.0	33.0	74.0	I.
C.2 High acquisition costs	0.0	1.0	13.0	20.0	27.0	39.0	66.0	III.
C.3 No consistent implementation strategy	0.0	0.0	12.0	27.0	35.0	26.0	61.0	V.
C.4 Lack of government support for the use of robotic systems	0.0	11.0	4.0	24.0	33.0	28.0	61.0	III.
C.5 Lack of skilled workers in the construction industry for the implementation	0.0	4.0	11.0	24.0	34.0	27.0	61.0	II.
C.6 Tight project timeline leaves little time to implement new technologies	7.0	4.0	4.0	24.0	29.0	32.0	61.0	I.
C.7 No existing best practice	0.0	1.0	11.0	31.0	34.0	23.0	57.0	V.

5 Construction Robotics Excellence Model

In order to compete in the increasingly dynamic and complex economy, continuous improvement of the company at the strategic and operational levels is essential [27–30]. This continuous optimization goes hand in hand with the pursuit of excellence of the company [29,31]. As a support and framework for companies to cope with complexities, adapt to constant changes as well as increase performance, a variety of excellence models have been developed in the last decades for a wide range of sectors [32,33]. There are generic, cross-industry models of excellence, such as the Malcolm Baldrige National Quality Award (Baldrige), European Foundation for Quality Management (EFQM), Deming Prize Japan or the National Quality Award and Swedish Institute for Quality (SIQ) [29,34,35]. In addition, there also exist discipline-specific excellence models, such as the Service Excellence Model [36], the Sustainable Excellence Model [37], the Data Excellence Model [38] or the Construction Excellence Model [39] and many more.

Derived from the twelve identified barriers in the literature review in conjunction with the defined meta-barriers from the literature review, the Construction Robotics Excellence Model is presented as a holistic solution approach. The Construction Robotics Excellence Model (ConRoX Model) is a generic framework to overcome the existing barriers and for the qualitative implementation of robot systems in the construction industry (see Figure 2). The ConRoX model considers all necessary levels - organization, processes and IT - of a construction company. Furthermore, the model shows which criteria are necessary as enablers for the use of the existing interface potentials between the robot systems and the business capabilities of the company.

Table 3 Derivation of the enablers

Barriers from survey	Meta-Barrier	Resulting enabler
A2, B1, C1, C5	I.; V.	Organization
	II; V.	Roles & Responsibilities
B1, B2, C6	V.; III.	Processes & Methods
A1, A2, A3, C5	II; IV.	Training & Education
C4, B1, B2	I.; V.	Legal & Regulations
Manageable barriers according to survey results, yet an important technological component for the companies for robotic implementation	I.; V.	Data
	I.; V.	Application Systems

The ConRoX model is divided into three interdependent areas - potentials, enablers and results. The first area of potentials serves to create knowledge about the robotic capabilities, to identify synergies with the company's own corporate capabilities and to identify fields of application. The step of identifying potentials results from the defined economic and social barriers of the empirical investigation. Thereby the social barrier A.3 is overcome, since basic knowledge is identified before an acquisition and/or employment of the robotics in the enterprise. At the same time, potentials are identified to support the minimum resources in the company (C.1) and the basis for an implementation strategy (C.3) and new required organizational and process structures (B1) are defined.

The second stage, “Enablers and Implementation”, lists seven relevant parameters for a successful implementation of robotic systems. These seven parameters include an implementation from different perspectives and cover all relevant company levels - organization, processes, data and application systems. Table 3 shows from which identified barriers the individual enablers were derived. The enablers support the overcoming of the barriers to the multi-beneficial use of robotics when applying the ConRoX-model.

All defined enablers result from the indexed barriers of the survey and the defined meta-barriers. Therefore, they are directly related to the barriers and consequently contribute to their direct elimination (see Table 2). In addition, the important technical component of data and application systems is included in the model. Thus, all essential aspects on the social, economic and technical level are considered in the model.

Furthermore, the ConRoX model refers to the definition of a company-wide robotics strategy as well as to the definition of concrete goals and use cases for the future use of robotics systems in the company. The parameters located in the inner circle of the model (Robotic strategy, Robotic Objectives and Robotic Use Cases) result from the barriers C.3-No consistent implementation strategy and C.7-No best practice. They provide the company with a guideline for the development of a company-wide robotics strategy and the definition of concrete objectives as well as use cases for the use of robotics in the company. Since the enabler level is a key component, the level is further integrated with a continuous improvement (CIP) approach. The third level of the model are the results of the successful use of the identified potentials (level 1), considering the enablers for implementation as well as the precise definition of strategy, goals and application fields. The results of the third level and the simultaneous successful implementation and use of robots in the company counteract the barriers C.2-High acquisition costs and C.7 n-o best practice. Through the positive results, new best practices are defined in the company, new knowledge is generated and the added value of the use of robots compared to the high acquisition costs becomes apparent. The intended result through the use of the model is the increase of the business value of the company and the achievement of excellence in the company in the economic (Business Excellence) and technical (Robotic Excellence) aspects. The foundation of the model is the company's general and permanent pursuit of excellence and continuous self-optimization.

6 Discussion

The aim of the article was to develop the Construction Robotics Excellence Model based on the previously identified barriers and defined meta-barriers for the implementation of robotics in the German construction

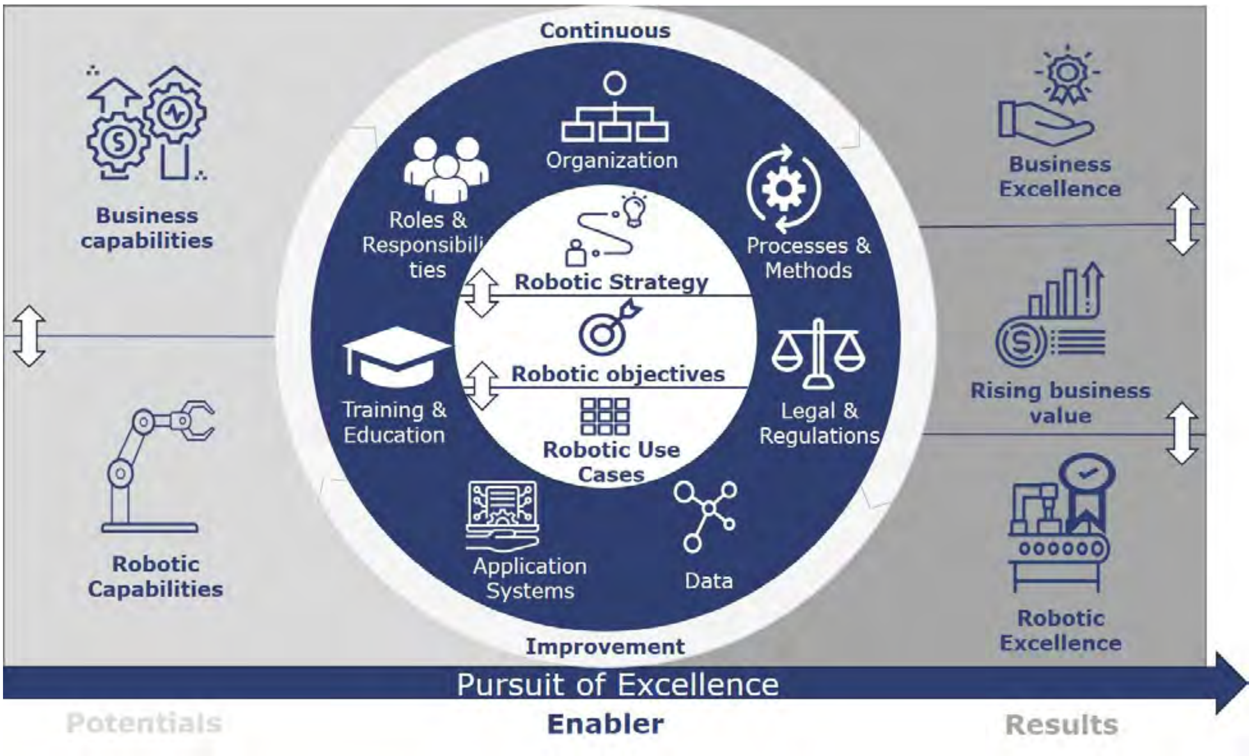

Figure 2 Construction Robotics Excellence Model (Own representation based on [38])

industry. As a result of the literature analysis, five meta-barriers were defined and enriched by the results of the survey with a total of twelve significant barriers on a social, technical and economic level. The barriers identified in the literature and the empirical study show the need for a generic framework for the implementation of robotics in the construction industry. This gap is addressed by the model. It serves as a guide for construction companies that want to implement robotics systems in their enterprise structures in the future. In addition, the model identifies seven essential enablers at the organizational, process and information levels in the company. These enablers serve a company before and during the implementation phase for the successful implementation of robotic systems and the achievement of resulting added values. The model closes a significant gap and minimizes existing obstacles and corporate reluctance to adopt robotics. In addition, the use of the ConRoX model will simplify the implementation of robotic systems and make it more efficient. In this regard, the model will also further promote interest in robotic systems in the construction industry. Likewise, the model will help to increase the level of automation in the industry as a whole, thereby increasing its productivity in the long term.

The ConRoX model is comprehensively described as a strategic framework for implementing robotics systems in the construction industry based on identified barriers in this article, but it still requires consideration of limitations. For example, the survey only considered the German construction industry and placed it in context with existing findings from other literature. In addition, 65 people participated in the survey. For further specification of the model, the next step should be to obtain further expert opinions, for example through interviews. The model is a first generic approach to support the implementation of robotic systems in the construction industry. The ConRoX was developed based on the identified barriers in conjunction with knowledge of existing models of excellence from other industries. As a result, further scientific review and further specification of the model's content is needed. In addition, the model should be tested for practicality in defined, realistic use cases in collaboration with companies.

In future research, drivers for the implementation of robotics in the construction industry in a national as well as international context should be investigated in addition to the already identified challenges. Moreover, the holistic model should be checked for validation. Furthermore, an additional specification of the contents of the generic model is required. To ensure that the theoretical model can also serve for companies in practice in the future, its practical usability should be investigated in specific use cases with partners from the industry. In addition, research should be conducted to identify key performance indicators and application areas for robotic systems in the construction industry.

7 Conclusion

This paper presents a holistic framework for the adoption of robotics in the construction industry derived from the identified barriers. At the beginning, a literature review is conducted to analyze the existing barriers to the adoption of robotics in the construction industry and the derivation of meta-barriers. This is followed by an empirical study to identify barriers that are specific to the German construction industry. As a result, a total of twelve barriers are identified. Based on the identified barriers the Construction Robotics Excellence Model is developed. The model serves as a generic framework for companies to implement robotic systems. The ConRoX model considers three different areas of robotics implementation - the potentials, the enablers and the results for qualitative implementation. Furthermore, the model presents the expected results of successful implementation at the end.

Despite the ConRoX model, further research activities in the field of construction robotics are needed in the future to explore the existing technical, economic and social problems and to further minimize the existing passive mindset of the industry. In this way, the added value of robotics technology can also find its way into the construction industry in the medium and long term, increase productivity and counteract the shortage of skilled workers

References

[1] R. Bogue, What are the prospects for robots in the construction industry?, IR 45 (2018) 1–6. https://doi.org/10.1108/IR-11-2017-0194.

[2] K. Hampson, J.A. Kraatz, A.X. Sanchez (Eds.), R&D Investment and Impact in the Global Construction Industry, Taylor and Francis, Hoboken, 2014.

[3] J.M. Davila Delgado, L. Oyedele, A. Ajayi, L. Akanbi, O. Akinade, M. Bilal, H. Owolabi, Robotics and automated systems in construction: Understanding industry-specific challenges for adoption, Journal of Building Engineering 26 (2019) 100868. https://doi.org/10.1016/j.jobe.2019.100868.

[4] Construction Industry Handbook 2012 '[Research report], 2012.

[5] T. Linner, Automated and Robotic Construction: Integrated Automated Construction Sites, Technical University Munich, Munich, 2013.

[6] McKinsey Global Institute, Reinventing Construction through a Productivity Revolution, 2017. https://www.mckinsey.com/business-functions/operations/our-insights/reinventing-construction-through-a-productivity-revolution.

[7] T. Bock, The future of construction automation: Technological disruption and the upcoming ubiquity of robotics, Automation in Construction 59 (2015) 113–121. https://doi.org/10.1016/j.autcon.2015.07.022.

[8] G. Carra, A. Argiolas, A. Bellissima, M. Niccolini, M. Ragaglia, Robotics in the Construction Industry: State of the Art and Future Opportunities, in: Proceedings of the 35th International Symposium on Automation and Robotics in Construction (ISARC), Taipei, Taiwan, International Association for Automation and Robotics in Construction (IAARC), 2018.

[9] B. Chu, D. Kim, D. Hong, Robotic automation technologies in construction: A review (2008) 85–91.

[10] K.S. Saidi, T. Bock, C. Georgoulas, Robotics in Construction,, in: Springer Handbook of Robotics, 2016, pp. 1493–1520.

[11] S.M.S. Elattar, Automation and robotics in construction: opportunities and challenges (2008) 21–26.

[12] S. Martinez, C. Balaguer, A. Jardon, J. Navarro, A. Gimenez, C. Barcena (Eds.), Robotized lean assembly in the building industry, 2008.

[13] Z. Struková, M. Líška, Application of Automation and Robotics in Construction Work Execution 2 (2012) 121–125.

[14] R.A. Stewart, S. Mohamed, M. Marosszeky, An empirical investigation into the link between information technology implementation barriers and coping strategies in the Australian construction industry, Construction Innovation 4 (2004) 155–171. https://doi.org/10.1108/14714170410815079.

[15] A. Oke, C. Aigbavboa, S. Mabena, Effects of Automation on Construction Industry Performance, in: Proceedings of the Second International Conference on Mechanics, Materials and Structural Engineering (ICMMSE 2017), Beijing, China, Atlantis Press, Paris, France, 2017.

[16] P.s. Mistri, H.A. Rathod, Remedies over Barriers of Automation and Robotics for Construction (2015) 1–4.

[17] R. Mahbub, Framework on the Barriers to the Implementation of Automation and Robotics in

the Construction industry 3 (2015) 21–36.

[18] O. Akinradewo, A. Oke, C. Aigbavboa, M. Mashangoane (Eds.), Willingness to Adopt Robotics and Construction Automation in the South African Construction Industry, 2018.

[19] D. Trujillo, E. Holt, Barriers to Automation and Robotics in Construction, EasyChair, 2020, 257-247.

[20] A. Diekmann, Empirische Sozialforschung - Grundlagen, Methoden, Anwendungen, Rowohlt Taschenbuch Verlag, Renbek bei Hamburg, 2008.

[21] R. Schnell, P.B. Hill, E. Esser, Methoden der empirischen Sozialforschung, tenth. Aufl., Oldenbourg, München, 2014.

[22] J. Raithel, Quantitative Forschung: Ein Praxiskurs, VS Verlag für Sozialwissenschaften, Wiesbaden, 2006.

[23] J. Bortz, N. Döring, Forschungsmethoden und Evaluation: Für Human- und Sozialwissenschaftler ; mit 87 Tabellen, fourth., überarb. Aufl., [Nachdr.], Springer-Medizin-Verl., Heidelberg, 2006.

[24] E. Raab-Steiner, M. Benesch, Der Fragebogen: Von der Forschungsidee zur SPSS-Auswertung, fourth., aktualisierte und überarb. Aufl., facultas.wuv; Facultas-Verl., Wien, 2015.

[25] M. Eisend, Grundlagen empirischer Forschung: Zur Methodologie in der Betriebswirtschaftslehre, Springer Gabler, Wiesbaden, 2017.

[26] H.-B. Brosius, Methoden der empirischen Kommunikationsforschung: Eine Einführung, VS Verlag für Sozialwissenschaften, Wiesbaden, 2016.

[27] B. Enquist, M. Johnson, Å. Rönnbäck, The paradigm shift to Business Excellence 2.0, International Journal of Quality and Service Sciences 7 (2015) 321–333. https://doi.org/10.1108/IJQSS-03-2015-0032.

[28] J. Nenadál, D. Vykydal, D. Waloszek, Organizational Excellence: Approaches, Models and Their Use at Czech Organizations, QIP Journal 22 (2018) 47. https://doi.org/10.12776/QIP.V22I2.1129.

[29] A. Muhammad Din, M. Asif, M.U. Awan, G. Thomas, What makes excellence models excellent: a comparison of the American, European and Japanese models, The TQM Journal 33 (2021) 1143–1162. https://doi.org/10.1108/TQM-06-2020-0124.

[30] O.K. Al Zawati, O.Y. Hammad, I. Alsyouf (Eds.), Assessing organizations against excellence models: will subject matter experts add value to the assessment outcomes? An exploratory study, 2018.

[31] P. Sampaio, P. Saraiva, A. Monteiro, A comparison and usage overview of business excellence models, The TQM Journal 24 (2012) 181–200. https://doi.org/10.1108/17542731211215125.

[32] R. Williams, B. Bertsch, A. van der Wiele, J. van Iwaarden, B. Dale, Self-Assessment Against Business Excellence Models: A Critiqueand Perspective, Total Quality Management & Business Excellence 17 (2006) 1287–1300. https://doi.org/10.1080/14783360600753737.

[33] S.-G. Toma, P. Marinescu, Business excellence models: a comparison, Proceedings of the International Conference on Business Excellence 12 (2018) 966–974. https://doi.org/10.2478/picbe-2018-0086.

[34] B. Talwar, Comparative study of framework, criteria and criterion weighting of excellence models, Measuring Business Excellence 15 (2011) 49–65. https://doi.org/10.1108/13683041111113240.

[35] J. Gómez-Gómez, M. Martínez-Costa, Á.R. Martínez-Lorente, Weighting the dimensions in models of excellence – a critical review from a business perspective, Measuring Business Excellence 20 (2016) 79–90. https://doi.org/10.1108/MBE-01-2016-0007.

[36] M. Gouthier, A. Giese, C. Bartl, Service excellence models: a critical discussion and comparison, Managing Service Quality 22 (2012) 447–464. https://doi.org/10.1108/09604521211281378.

[37] S. Amir Bolboli, M. Reiche, A model for sustainable business excellence: implementation and the roadmap, The TQM Journal 25 (2013) 331–346. https://doi.org/10.1108/17542731311314845.

[38] T. Pentek, A capability reference model for strategic data management, University St.Gallen, St. Gallen, 2020.

[39] H.A. Bassioni, T.M. Hassan, A. Price, Evaluation and analysis of criteria and sub‐criteria of a construction excellence model, Eng, Const and Arch Man 15 (2008) 21‐41. https://doi.org/10.1108/09699980810842043.