Key Barriers to Industry 4.0 in Construction Industry

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Abstract

The construction industry makes significant contributions to the national GDP. The rapid increase in urban population resulted in increased demand for quality and productivity. Industry 4.0 offers an opportunity for the construction industry to grow sustainably. The term Industry 4.0 includes a range of technologies used to develop a digital value chain and enable automated manufacturing. The primary objective of this paper is to determine the status of industry 4.0 and its implementation in the construction industry. Using content analysis methods, this study analyzed 108 peer-reviewed articles published from January 2016 to December 2021, to reveal the most important key barriers to a successful implementation of Industry 4.0 technologies in the construction sector. The results shed light on some real challenges that can affect industry 4.0 applications and suggest directions for further research.

Keywords: Industry 4.0, Construction 4.0, Qualitative Analysis, Factor Analysis.

1 Introduction

Industry 4.0 concept started in Germany in 2011 as a vision for advanced manufacturing. As reported by Zhou et al (2015), to solve the European debt crisis and as a recovery plan, the German Government presented a strategy for Industry 4.0, to consolidate and promote global German manufacturing power. The main aim of Industry 4.0 is to increase the digitization of production. Industry 4.0 is the fourth industrial revolution, which is led by intelligent manufacturing. The fourth revolution went beyond the industry, and it reaches the construction sector, it is tagged as "construction 4.0". Therefore, Construction 4.0 represents all technological changes related to the implementation of new work methods which are related to processes, materials, and markets. In other words, according to Sawhney et al (2020), construction 4.0 is the adoption of the industry 4.0 framework and technologies for the construction sector. These technologies include 3d printing, automation, 3d scanning, virtual reality, drones, reverse engineering, sensors, artificial intelligence, robots, data mining, and more.

The following section represents a literature review of the implementation of industry 4.0 in the construction industry. The third section illustrates the research methodology then the data and results are discussed in the fourth section. Final conclusions, research limitations, and future research are highlighted in the fifth section.

2 Literature Review

As stated by Brettel et al (2017), industry 4.0 is a new industrial stage in which there is an integration between manufacturing operations systems, information, communication technologies,

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the internet of things, and cyber-physical systems. In other words, industry 4.0 seeks to describe the intelligent factory, with all processes interconnected by the Internet of Things. This integration of industry 4.0 has a lot of benefits to the employees and business. Nowadays, employees have more power than ever in their relationships with employers. Industry 4.0 supports employee growth by creating a management culture that encourages communication and training. As reported by Kagermann et al (2015), industry 4.0 allows employees to advance their skills. Employees will be able to be trained and embrace the process of continuous learning. The enforcement of industry 4.0 has a lot of benefits for the company and business. It can reduce product costs, increase productivity, lower operating costs, and improve product quality. According to Telukdarie et al (2018), virtual planning systems, simulation models, forecasting, analysis, and synthesis, all virtually help production and reduce manufacturing costs. As stated by Vaidya et al (2018); industry 4.0 allows manufacturers to visualize and analyze real-time data, which leads to production optimization and reinforcing economic competitiveness. In addition to that, Rüßmann et al (2015), reported that industry 4.0 helps employers to adopt new business models, production processes, and other innovations. This will lead to a new level of mass customization production with lower cost and higher quality. It allows for a faster response to customer needs. Moreover, it reduces production costs and improves the speed, productivity, flexibility, and quality of the product and the production process.

The prospects of the global construction industry are promising. The main driving forces of the market are the growth of the construction activities like urbanization, the housing market, and infrastructure. According to Gurney et al (2020), the construction industry will be an engine of global economic growth in 2030, with output expected to be 35% higher than in the ten years to 2020, according to a new global forecast. The fund spent on the construction industry accounted for 13% of global GDP in 2020 and it is expected to reach over 13.5% in 2030. A cumulative total of US$135 trillion in construction output is forecasted in the decade to 2030.

With the growth of the construction industry and the technological advancements in construction technology, the construction 4.0 market has experienced significant progress over the past decade. As stated by García et al (2019), by adopting construction 4.0, the construction industry will no longer be fragmented but will become a highly integrated industry, with an integrated construction process, organization, and projects. As reported by Forcael et al (2020), construction 4.0 derives from the foundation of industry 4.0 but focuses on and relates to the construction sector.

3 Research Methodology

The primary aim of this research was to identify the key barriers to implementing industry 4.0 in the construction industry. NVivo (NVivo qualitative data analysis software; QSR International Pty Ltd. Version 12, 2021) is a software program used for qualitative and mixed-methods research. In this research, NVivo software was used to analyze the textual contents of 108 articles in the English language in peer-reviewed journals published between January 2016 and December 2021. These 108 articles are related to the implementation of industry 4.0 in the construction industry. Computer text analysis was chosen for its ability to analyze the textual content of a large number of articles. The analysis provided the number of occurrences of each barrier within the selected sample of 108 publications. The research methodology is depicted in Figure 1, and a detailed description of the steps taken is represented in the following sections.

3.1. Initial dimensions

Based on the literature review of the implementation of industry 4.0 in the construction industry, a list of six dimensions was assembled. The list includes barriers (economic, environmental, organizational, security, social, and technological) found in the literature that can affect the implementation of industry 4.0 in the construction industry. These six dimensions and their source are listed in Table 1.

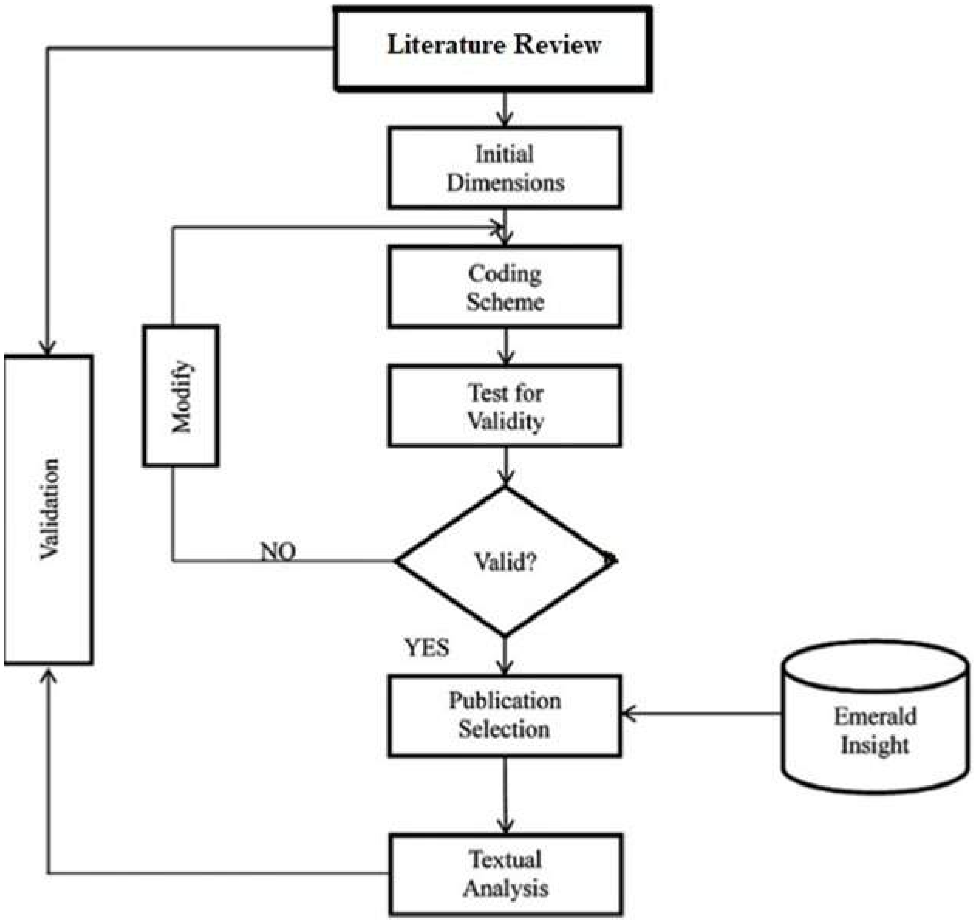

Figure 1. Research Methodology

Table 1 Dimensions & Sources

	Dimension	**Source**
1	Economic	Michaloski et al (2010), Erdogan et al (2010)
2	Environmental	Son et al (2010), Abubakar et al (2014)
3	Organizational	Zakari et al (2014), Erdogan et al (2010), Popov et al (2010), Wong et al (2014)
4	Security	Zakari et al (2014), Abubakar et al (2014), Wong et al (2014), Mahamadu et al (2013), Volk et al (2014)
5	Social	Michaloski et al (2010), Abubakar et al (2014)
6	Technological	Zakari et al (2014), Abubakar et al (2014), Erdogan et al (2010), Wong et al (2014)

3.2. Coding scheme

A list of possible codes representing each dimension was proposed. The list of codes was validated by a panel of faculty members working in Industry 4.0 at Wichita State University. Through the validation process, faculty members recommended the inclusion of each code or not. They also could recommend additional codes based on their field experience. To avoid bias, each dimension was given seven codes. The list of final codes used to perform the textual analysis is shown in Table 2.

Table 2: List of Final Codes

Dimension	Code
Economic	Investment, Cost, Profit, Gains, ROI, Benefits, Loss
Environment	Energy Consumption, Sustainability, Climate Change, Global warming, Recycling, Fuel, Atmosphere
Organizational	Development, Skill, Transformation, Training, Support, Planning, Suppliers
Security	Legal, Data, Information, Safety, Risks, Policy, Contractual
Social	Knowledge, Resistance, Innovation, Adoption, Behavior, Culture, Company Size
Technological	Implementation, Automation, Computing, Software, Digitization, Connectivity, Programming

3.3. Publication selection

An initial search of publications with titles containing the word 'Industry 4.0' was performed. A second search was performed for publications with tiles containing 'Construction 4.0'. The search included all articles listed in the Wichita State University library database (https://libraries.wichita.edu/home) in the English language. To ensure reporting accuracy, the Preferred Reporting Items for Systematic Review and Meta-Analyses (PRISMA) guidelines were followed. As shown in Figure 2, the initial search resulted in 2,587 results related to industry 4.0 this number was reduced to 1,556 by limiting the search to peer-reviewed articles only. The remaining number of publications was further reduced from 1,556 to 61 by limiting the search to publications related to the construction industry. These 61 publications were considered for further research. The second search of construction 4.0 resulted in 1,095 publications related to construction 4.0. This number was reduced to reach 47 articles, by limiting the search to peer-reviewed articles only. As a result, 108 publications were considered units for textual analysis. These 108 publications were divided into 61 publications related to industry 4.0, and 47 publications related to construction 4.0.

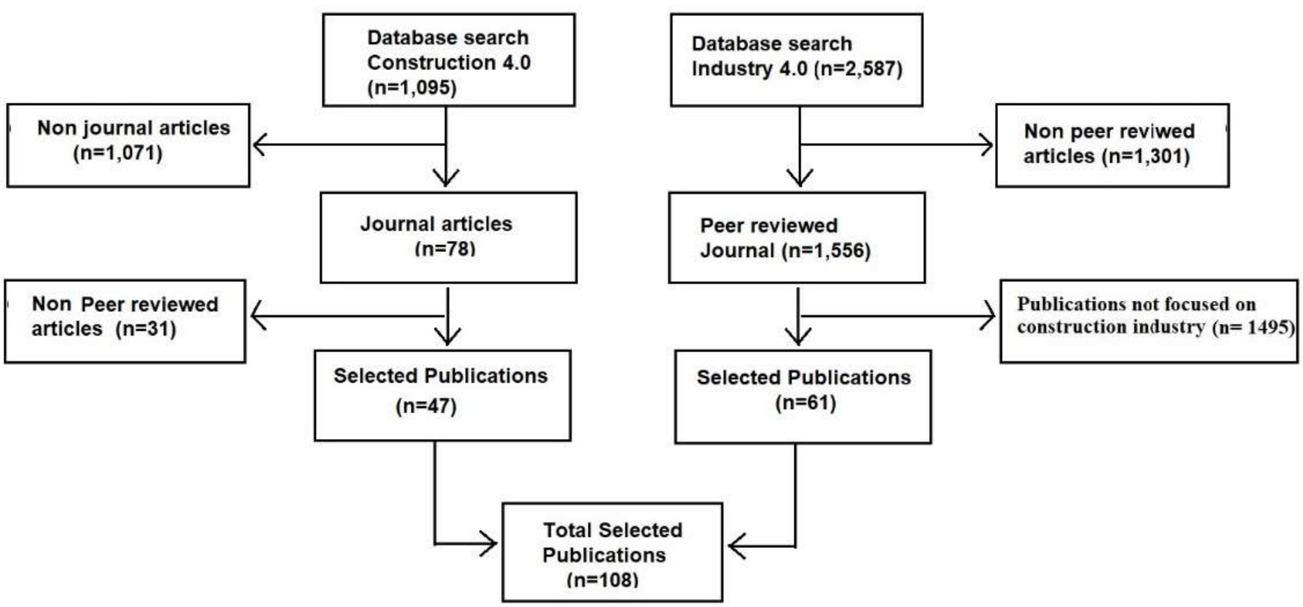

Figure 2: PRISMA Flowchart for Publication Selection

4 Data Analysis

In 1950, Joseph M. Juran rephrased the theories of Italian economist Vilfredo Pareto (1848-1923) as the Pareto principle, often referred to as the 80-20 rule 20% of the sources cause 80 % of the problem. As noted by Sanders (1987), this tool helps in the prioritization of the reasons which contribute to 80% of the problem. The rule postulates that in any series of variables (problems or errors), a small number will account for most of the effect. A Pareto analysis of the results was performed to recognize the vital dimensions contributing to the majority of the count. In other words, the analysis provided the number of occurrences of each dimension and its code within the selected sample of 108 publications. The Pareto chart in Figure 3 indicates that security, social, technological, and organizational represent almost 85% of the total count. It can be noted that these four dimensions represent the most common dimensions used within the sample of publications to identify barriers to implementing industry 4.0 in the construction industry. Also, it does not appear that environmental and economic barriers received enough interest in published research.

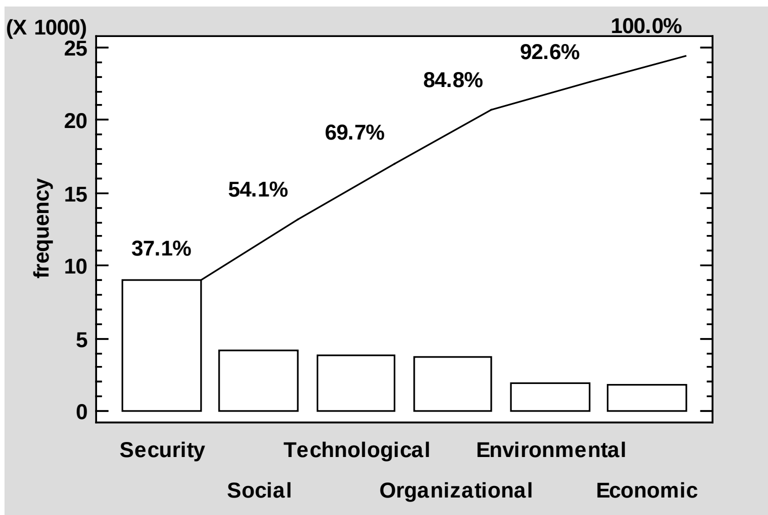

Figure 3. Pareto Chart for Frequency

A contingency table was constructed using the publications as rows and the dimensions as columns, this resulted in a 108 X 6 matrix. Then Statgraphics software (Statpoint Technologies Inc., Centurion version 18,2022) was used to test the analysis. Bartlett's test of Sphericity was used to test the hypothesis that the correlation matrix amongst the variables is an identity matrix, indicating that they share no common variance. Since the test resulted in a Chi-Square = 146.138 and a P-value equal to 0.0001 and less than 0.05, so it can be concluded that the hypothesis is rejected.

As reported by Cureton (2013), factor analysis consists of a group of procedures for analyzing the relations among a set of random variables observed, counted, or measured within the group. Factor analysis deals with the relations among the random variables, it provides a score for each variable. As stated by DeCoster (1998), factor analysis is a collection of methods used to examine how underlying constructs influence the responses to several measured variables.

In addition, the factorability test was used to indicate whether or not it is likely to be worthwhile attempting to extract factors from a set of variables. The Kaiser-Meyer-Olsen KMO measure indicates how much common variance is present. As noted by Saphores et al (2009), for factorization to be worthwhile, KMO should normally be at least 0.6. Since KMO = 0.72, it can be concluded that factorization is likely to provide interesting information about the underlying factors. The purpose of the factor analysis is to obtain a small number of factors that account for most of the variability.

Table 3 illustrates the results of the factor analysis. It shows the Eigenvalue, percentage of variance, and cumulative percentage of each of the total counts. The screen plot suggested that the six dimensions can be presented using two factors, with an eigenvalue greater than 1.0. These two components together account for 62% of the variability in the total count.

Table 3. Results of Factor Analysis

Component Number	Eigenvalue	Percent of Variance	Cumulative Percentage
1	2.62072	43.679	43.679
2	1.12036	18.673	62.351
3	0.856545	14.276	76.627
4	0.581205	9.687	86.314
5	0.429725	7.162	93.476
6	0.391442	6.524	100.000

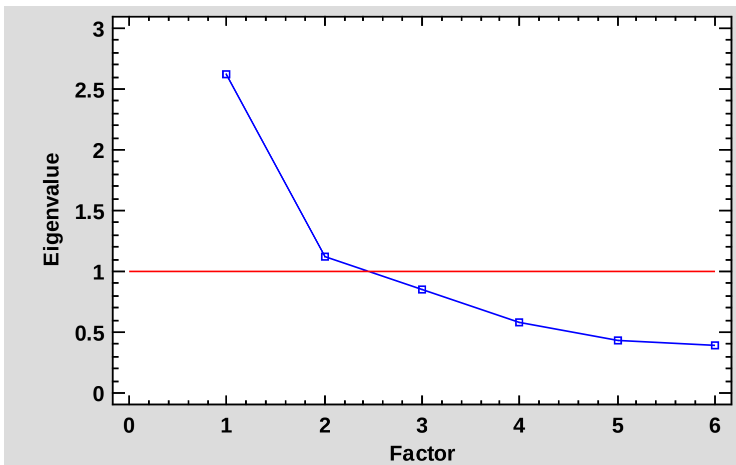

Figure 4. Screen Plot

It is important to mention that the six dimensions considered in this research are not claimed to be comprehensive. A different number of articles or different citations may lead to new dimensions. The results of the factorial analysis are presented in Table 4. These results indicate that the six dimensions can be reduced to two key factors meta dimensions: administrative barriers and security barriers.

Table 4. Factor Score Coefficients

	Factor 1	***Factor 2***
	Administrative	***Security***
Security	0.396645	0.837803
Social	0.79211	-0.2625
Technological	0.721264	0.360523
Organizational	0.684001	-0.349827
Environmental	0.555005	0.119618
Economic	0.734742	-0.287885

Administrative barriers included social, economic, technological, organizational, and environmental dimensions. Social barriers appear to have the highest weight within the first factor (79%). Security barriers contributed 83% to the second factor. These results suggest that security standards are needed to protect corporate data assets and support the implementation of construction 4.0. In addition, social barriers can be attributed to the nature of the construction industry and its business model.

5 Conclusions

Over the last few years, industry 4.0 has been introduced as a popular term for the integration between manufacturing operations systems, information, communication technologies, the internet of things, and cyber-physical systems. The adoption of industry 4.0 in the construction industry will enable the digitization, automation, and integration of the construction processes.

The primary aim of this research was to explore the key barrier to industry 4.0 in the construction industry. The results of this research indicated that published research articles have focused on security, social, technological, and organizational dimensions as the main barriers to implementation. Furthermore, within the sample of publications, it can be concluded that security was the most frequently cited barrier, and economics (consider finances?) was the least frequently cited barrier to implementation. In addition, the results of the factor analysis suggested two main factors, administrative and security, that appear to dominate the key barriers to implementing industry 4.0 in the construction industry.

Finally, it is important to shed the light on some important limitations of this research. The six dimensions considered in this research are not claimed to be comprehensive. Furthermore, time is an important factor in determining the stability of the identified barriers. The results presented in this paper should be viewed as a static representation of barriers addressed in published research (January 2016, December 2021). Research efforts over future periods would prove the longitudinal validity of the proposed dimensions. In addition, in this research 108 peer-reviewed publications were used for the textual analysis, and no attempts were made to stratify the publications based on region or number of citations. Stratifications of publication according to these factors may help identify additional factors.

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7 Appendix

The list of references for the 108 peer-reviewed articles used in the content analysis is available on: https://bit.ly/industry4key