



Identifying The Influencing Factors Of Design Standardization In The Industrialization Of Architecture: Review And Future Directions

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Abstract

The industrialization of construction will be the main path of development and the future of the construction industry. How to achieve the industrialization of construction is one of the important issues of this industry. As the core of building industrialization, design standardization is a major technique to improve performance. The purpose of this research is to investigate the most advanced design standardization method for the industrialization of architecture. Through a bibliometric-qualitative review process, this research investigates the factors influencing design standardization in industrialization of architecture. Bibliometric analysis is used to create science maps based on academic publications from Scopus (183 publications on design standardization, 1,444 publications on industrialization of construction, and 101 publications on design standardization for industrialization of construction) for qualitative review of 43 research publications (including articles, reviews, conference papers), and especially concentrating on design standardization rules that will help industrialization of architecture. After conducting a thorough quantitative analysis and in-depth discussion of design standardization for industrialization of architecture, various factors were identified and potential future directions for further exploration were provided: modularization, Industry 4.0 and supply chain management, sustainability and lean construction, off site construction and prefabrication, information technologies, BIM, Robotics and 3D printers, automation in the production process, internet of things, intelligent automated data collection technology, mobile user interface device, WLAN, lidar/reality capture, construction simulation technologies, materials logistics management, and virtual design and construction (VDC). This research has added to our understanding of design standardization for industrialization of architecture that will help to improve AEC practice in the future.

Keyword: *Industrialization Of Architecture, Design Standardization, In-Depth Discussion, Standardized Products, Advanced Construction*

1. Introduction

The construction industry has made a few progress in the production process over the past years compared to other manufacturing industries that have standardized and managed production processes.[1]

This few improvement in the construction industry and the production process in construction has caused damages such as increased cost and time, low quality and low profitability in construction; however, by applying changes to the process and progress in the construction process, it is possible to compensate for the damages [2].

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The necessity of design standardization has not been realized in the construction and design process, and this issue expresses what principles are important for the implementation of design standardization and achieving a standardized design in architecture, including 1) the most recent studies and factors within design standardization for industrialization of architecture 2) how to achieve the perfect correlation between design standardization and industrialization of architecture and 3) what are the study requirements of design standardization for industrialization of architecture. In order to fill the gap and answer the questions, this research is looking for the relationship between these factors for use in industry and university through a quantitative-qualitative method in the field of standardization of design and industrialization of architecture.

2. Literature Review

This part discusses expanding literature on design standardization and industrialization of architecture to clarify the need of the mixed review on design standardization for industrialization of architecture offered in this research.

2.1. Design Standardization - Related Review

Production industries have been using design standardization tools and principles since the past years, which describe it in different ways. Some of these interpretations in the construction industry and production design are as follows :

1. "Standardization of design is the use of manufacturing processes and methods that are regular and repeatable and have the possibility of predicting and a background of successful operation and precedent" [3];
2. "Designing the elements and components of a system in a systematic way that leads to increased repetition, high performance, reduced errors and increased productivity following the production process of that system" [4];
3. "The definition of design standardization of system includes the activities that are carried out for projects with larger scales using design standardization and that similar outputs and setting the project plan strategically and the process of project orientation on a larger scale are similar to previous projects and be the same"[5]. Design standardization includes

extensive use of elements, components, parts and processes in which there is a lot of repetition, and regular and systematic, predictable and successful practice process [3, 6].

2.2. Industrialization of Architecture - Related Review

The industrialization of the construction and architecture industry is such a systematic process that can be repeated and predicted with high and standardized performance of building systems. It is possible to control and review multiples and use the experience of designing, manufacturing and assembling the building system to improve performance [7].

In understanding the concept of industrialization of construction, it deals with the process that provides the standardization of building systems, the systematic review and control of the production and construction process, which provides the possibility of repetition and continuous improvement [8,9]. The purpose of the industrialization of manufacturing is the manufacturing process with innovative techniques that are used from the basis of design to execution by advanced industry and intelligent automation.

2.3. Design Standardization for Industrialized Construction

Design standardization in the industrialization of architecture and the construction process is a clear concept that includes the use of elements and processes with predictable and repeatable performance systematically" [6]. The background of industrialization is the standardization of design and production, where the modules are produced, transported and installed under control in the factory [10]. The use of innovative standards leads to improved knowledge performance [11]. Standardization of design in industrialization of construction causes efficiency and productivity [6]. The benefits of industrialization process integration and design standardization can be improved quality and performance and increased control and safety with the prediction that saves money, time, higher profit and less error [6].

3. Research Methodology

The integration of standardization of design and industrialization of construction is one of the main goals of research and identification of effective components in this field in order to

advance future research. Mixed-review method is used to achieve the main goal of the research. In the mixed method, bibliometric analysis and systematic analysis have been used, which leads to the subjective interpretation, and the research process is logical and scientific [12].

3.1. Mixed-review method

A mixed method is a great way to conduct research that combines quantitative and qualitative methodologies together [13]. For this purpose, the mixed review method has been used to strengthen and minimize the weaknesses in quantitative and qualitative methods [14]. In this paper, we make use of both qualitative and quantitative methods to gain a comprehensive understanding of the topic at hand, and by doing so, we are able to make up for any shortcomings that come with using either method alone. In the review process, the mixed-review method is a useful way to combine both quantitative and qualitative review methods [15]. By utilizing the quantitative review method, we can reduce the potential for bias in manual qualitative reviews and gain a deeper understanding of the results [16, 15]. The current research uses the bibliometric review as the quantitative method and systematic review as the qualitative method. The details of each method and their

advantages are expounded. In this research bibliometric mapping is used to explore the knowledge domain and research trends related to standardization of design and industrialization of architecture based on the available literature [17,18,19]. In this research, the mixed method used has 3 steps based on the Scopus database (see Fig. 1). Stage 1: In order to determine the fields of knowledge and the effective components of standardization of design and industrialization of architecture, bibliometric analysis is used. Stage 2: Integration of design standardization and industrialization of architecture by means of bibliometric analysis .This stage corresponds to the previous stage and identifies the field and research emphasis related to the two issues of standardization of design and industrialization of construction. Stage 3: The use of systematic analysis in relation to the components of design standardization for industrialization of architecture. Studies available in the Scopus database in the field of standardization and industrialization of architecture are collected and categorized. The categorization structure is determined through a consensus discussion based on quantitative analysis of research themes (i.e., Stage 1 and Stage 2) and the qualitative method.

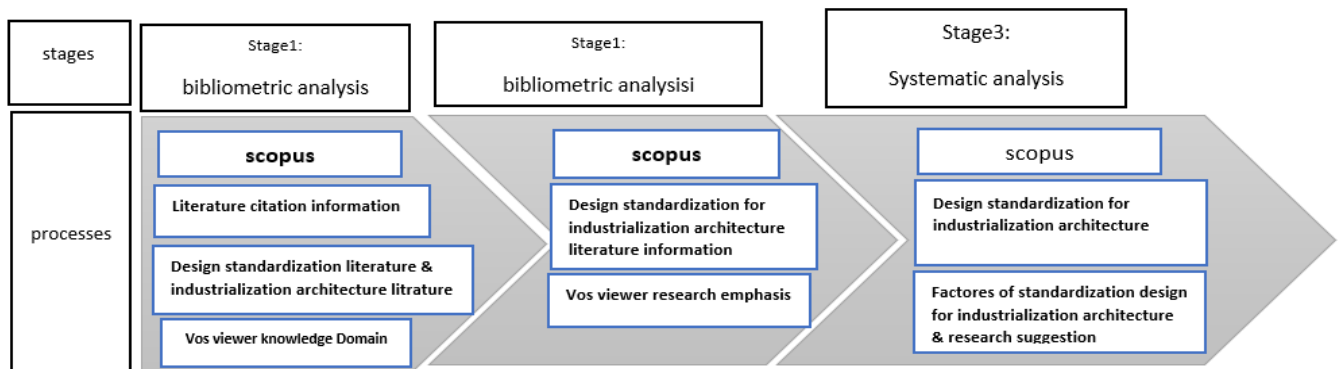


Figure 1. An Overview of Research Methodology

3.2. Bibliometric Analysis (Stages 1 and 2)

The bibliometric analysis has been done to determine the research process in the field of design standardization and industrialization of architecture. According to the research method and Figure 1, bibliometric analysis is done in the first and second steps for the issues of design standardization and industrialization of architecture.

3.2.1. Data Collection

Gathering existing research is essential for this project, as it will determine the sources used to reach a conclusion. The current study decided to use Scopus as the literature database. We retrieved literature related to "design standardization" in this database by using the keywords "design standardization" and "standardization," combined with either "construction," "building," "architecture," or "manufacture." In order to get a thorough

collection of research on industrialization of architecture, we chose the following keywords: "industrialization" or "industrialized" and "construction", "building" or "architecture". To retrieve all publications related to the selected keywords, we have set the keyword search field in Scopus to search through titles, abstracts, and keywords sections. Considering the developmental history of design standardization, a 15-year search period from January 2009 to August 2023 is an appropriate

choice. In order to narrow down our results to the appropriate engineering scope, we conducted several screenings. For instance, papers related to medicine or agriculture weren't included in this step. A further refining process was conducted by checking the source title in order to exclude papers from irrelevant journals or conference proceedings. After screening, the remaining articles were included in the bibliometric analysis. Table 1 presents search strategies and keywords.

Table 1. Literature Search Strategies and Their Results

Topic	Search keywords	Time period	Number of results
Design standardization	All(("design standardization") AND ("standardization") AND ("construction" OR "building" OR "architecture" OR "manufacture"))	2009-2023	183
Industrialization of architecture	All ("industrialization" or "industrialized") AND ("construction" OR "building" OR "architecture")	2009-2023	1,444
Design standardization & industrialization of construction	All (("design standardization") AND ("construction" OR "building" OR "architecture" OR "manufacture") AND ("industrialization" OR "industrialized" OR "construction" OR "building" OR "architecture"))	2009-2023	101
Design standardization & industrialization of construction	Manual screening based on the 101 studies in stage 2	2009-2023	43

3.3. Systematic Analysis (Stage 3)

After we carefully studied the bibliography in the first two steps, we were able to conduct a qualitative analysis of selected papers, as seen in Figure 1. The research team took the time to manually complete the task, which resulted in summarizing and discussing the research themes of each paper amongst themselves. Qualitative analysis provides a comprehensive look at the design standards for industrial architecture and helps to uncover the factors influencing their design for future buildings and industrial structures. In this stage, the way we acquire data is similar to the method we used in

Stage 2. To find existing literature on standardization of design for industrialization of architecture, we are combining the first and second queries in Table 1. Although some of the articles generated after the analysis may be duplicates or off-topic, they need to be removed in order to have a successful systematic analysis. To ensure accuracy, we conduct screenings before beginning our systematic analysis of the literature in focus. Afterwards, we review and categorize the identified academic articles one-by-one based on their research focus in relation to the industrialization of architecture process

4. Results and Findings

4.1. Bibliometric Analysis

4.1.1. Design Standardization and Industrialization of Architecture

In order to specify the field of knowledge for the standardization of design and **4.1.1.1. Co-occurrence Analysis of Author’s Keywords in Design Standardization**

The studies were conducted on 183 articles that were retrieved from the Scopus database for quantitative analysis, and 40 related words were selected from 2175 with a minimum repetition of 5 words. The co-occurred keywords are

industrialization of architecture, the quantitative analysis and bibliometrics (VOSviewer) and co-occurrence of key words are used, and the drawn network is to show the results of bibliometric analysis for the desired subjects.

separated and marked by several clusters with different colors in Figure 2. Detailed quantitative analysis report is shown in Figure 2, Table 2. A quantitative review of 183 articles shows that modularization, in addition to standardization, is the most repeated in the relevant articles.

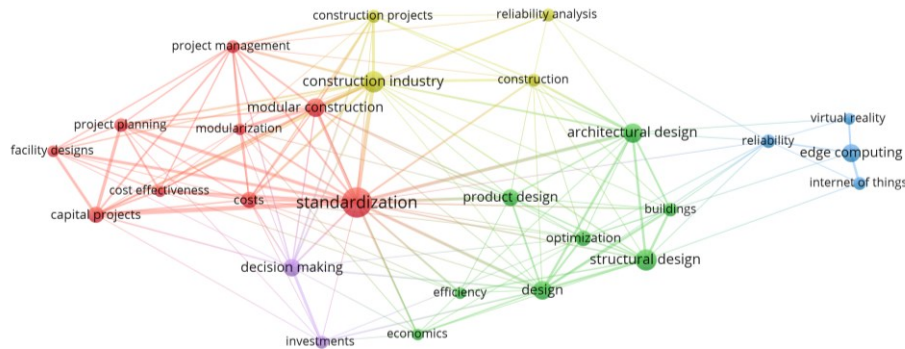


Figure 2. Author’s Keywords Co-occurrence Analysis of Design Standardization

Table 2.Top Keywords in Design Standardization

keyword	Occurrence	Average year published	Total link	keyword	Occurrence	Average year published	Total link
Standardization	40	2017	97	Cost Effectiveness	9	2020	24
Construction industry	18	2020	65	Optimization	5	2019	23
Structural design	18	2015	50	Modularization	6	2017	22
Modular construction	14	2019	46	Construction	5	2022	21
Design	14	2014	44	Facility design	7	2021	21
Architectural design	15	2018	42	Reliability	11	2014	21
Capital project	10	2022	38	Product design	6	2015	20
Decision making	12	2020	38	Investment	6	2017	16
Edge computing	13	2018	37	Internet of things	6	2020	13
Project management	6	2019	34	Reliability	5	2029	13
Costs	10	2020	33	analysis	5	2021	12
Buildings	7	2015	30	Economics	5	2018	12
Construction projects	6	2021	29	Efficiency	6	2019	12
Project planning	7	2019	29	Virtual reality			

According to the key words and clusters specified in Figure 2 and the detailed analysis reported in Table 2, a few issues of expression and summary are raised:

1) Modular construction and modularization (red cluster, middle-left)

Modularization has been proposed during the past decades and has been used to improve

performance and construction in the production process, during which modules and components are transferred from the factory to the site, which has been analyzed in detail and deeply in a number of recent studies [20, 21, 22, 23]. The benefits of this technique include saving money and time, more profitability and more quality, and optimal performance in the direction of safety in the work environment and environmental damage. [23].

2) Optimization and product design (green cluster, lower-right)

Design standardization saves time and money and improves performance in the manufacturing process, as well [24, 25, 26, 27, 28]. In addition to saving money and time, standardization of design improves performance and raises the quality of products [3, 29]. In order to improve performance in the manufacturing industry, standardization is widely used by professionals who are in the production process (successful projects)[20].

3) Technologies in the design standardization (blue cluster, middle right)

Advanced technologies are used in all manufacturing industries except the construction industry [31]. The construction

industry does not use technology and innovations like other industries. [30,31]. Due to the lack of advanced technologies related to the construction industry, there has been no positive change in the design, construction and project management process in recent decades [31], which causes larger projects to suffer from longer time (20%) and higher cost than the budget (80%) [30].

4.1.1.2. Co-occurrence Analysis of Author's Keywords in Architecture Industrialization

A new trend has been applied regarding the industrialization of construction according to the previous step. 50 words were selected from 3248 words with a minimum repetition of 10 keywords. Detailed quantitative analysis related to bibliometric analysis is shown in Table 3. According to Table 3, in the literature review of industrialization of construction, sustainability has been widely discussed, and industrialization based on automation has been proposed after 2016, which according to Table 3 is one of the main topics in the field of industrialization, and some other key words such as off-site construction, sustainability, industry 4.0, standardization, modular design, etc., are among the topics discussed in the articles.

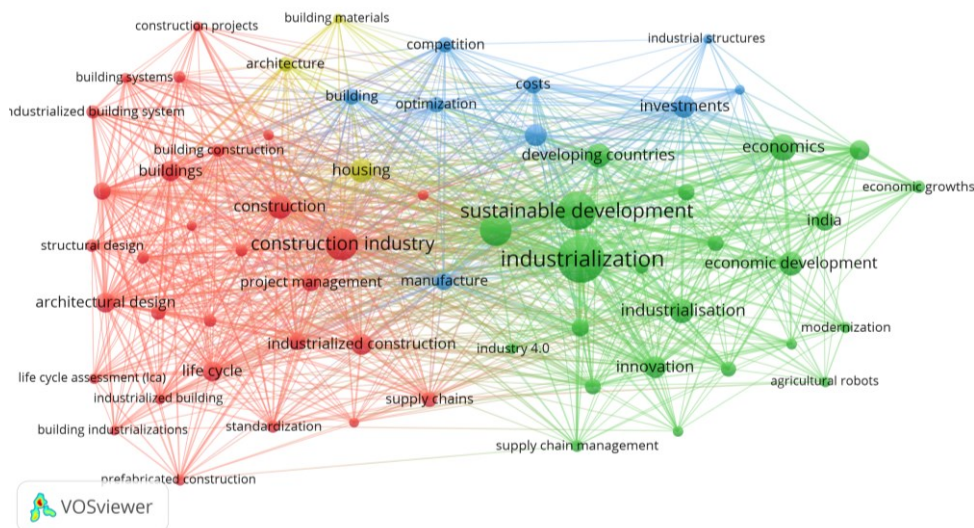


Figure 3. Author's Keyword Co-occurrence Analysis of Industrialization of Architecture

Table 3.Top Keywords in Industrialization of Architecture

keyword	Occurrence	Average year published	Total link	keyword	Occurrence	Average year published	Total link
Industrialization	256	2017	1669	Manufacturing	29	2020	212
Sustainability	112	2018	565	Productivity	21	2018	206
Economics	80	2018	635	Prefabrication	27	2017	153
Investment	57	2017	495	Industrialized building	31	2017	142
Population statistic	50	2019	342	System(ibs)	25	2017	121
Life cycle	47	2019	335	Modular construction	17	2016	121
Innovation	46	2017	334	Standardization	19	2015	105
Industrialized	55	2017	322	Product design	17	2014	101
Countries	46	2016	288	Technology	18	2016	99
Energy use	37	2018	282	Building information modeling	21	2018	98
Costs	35	2018	231	Modernization	24	2020	95
Optimization	32	2017	224	Industry 4.0	18	2019	83
Developing word	29	2017	218	Automation	17	2020	91
Project management	25	2018					

According to the research clusters in Figure 3 and quantitative analysis figures from Table 3, the discussed topics are as follows:

(1). Industry 4.0 and supply chain management (green cluster, lower-middle; green cluster)

The main cause of the industrial 4.0 revolution is the rapid growth of information and communication technologies and their use in the supply chain, after which the construction 4.0 has been proposed due to the use of these technologies [32]. Technological advances that have caused changes in the demands and transformation in business, this expansion in the transformation and change in the business process generally use the operational and management frameworks in order to solve the evolving challenges [33].

(2) Costs and supply chain (blue cluster, top middle, red cluster; lower middle)

The construction industry generates a lot of waste in the construction process [34] and it will have negative effects on the environment [35]. In order to solve these problems, the traditional manufacturing process of production and supply chain management was introduced to the construction industry [34]. The purpose of construction supply chain (csc) management

is to save money and time in the production process [36].

4.1.2. design standardization for industrialization construction

According to Figures 3 and 4, one of the main characteristics of industrialization is standardization, which has been estimated in 101 results in the Scopus database and has received less attention than standardization (183) and construction industrialization (1444) (see Table 2).

4.1.2.1. Co-occurrence Analysis of Author's Keywords

Based on the number of selected articles on standardization of design for industrialization of construction, 101 articles were quantitatively analyzed using the software VOSviewer and considering the co-occurrence of key words. The minimum keywords occurrence was set to 10, and 43 words out of 706 keywords were selected, which can be seen in Figure 4 and drawing with VOS viewer software. The bigger circle and font in the map mean the number of times and repetition of that word [37]. Detailed information from the bibliometric quantitative analysis is included in Table 4.

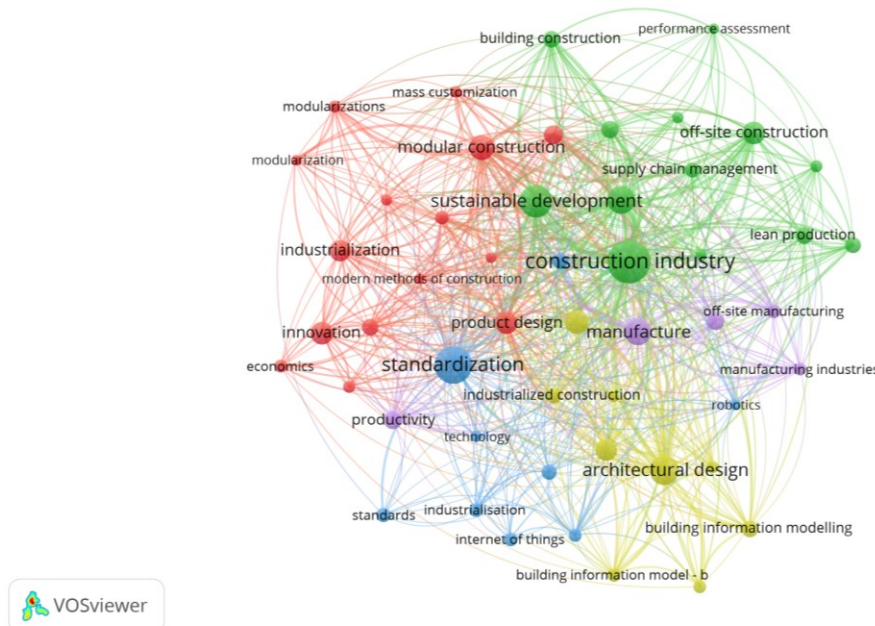


Figure 4. Author’s Keyword Co-occurrence of Industrialization of Architecture

Table 4. Top Keywords in Design Standardization for Industrialization of Architecture

Keyword	Occurrence	Average Year Published	t.l	Keyword	occurrence	Average Year Published	t.l
Sustainable development	95	2018	42	Supply chain management	21	2015	27
Standardization	131	2014	46	Lean construction	11	2017	22
Project management	71	2015	46	Modern method of	16	2015	15
Manufacture	65	2016	46	Construction	13	2015	20
Life cycle	45	2019	33	Automation	14	2016	15
Prefabrication	51	2019	23	Mass customization	21	2018	17
Modular construction	56	2018	41	Technological	12	2017	20
Off-site construction	48	2019	34	development	15	2019	14
Production design	45	2016	40	Industry4.0	13	2021	17
Supply chain	32	2017	23	Optimization	17	2027	19
Costs	25	2017	28	Economics	10	2022	17
Innovation	46	2016	26	3d printers	10	2015	15
Building information modeling	25	2019	24	Internet of thing	15	2017	14
Industrialized buildings	18	2020	34	Robotics	13	2016	17
Off-site manufacturing	15	2019		Machine design			

According to the research clusters in Figure 4 and quantitative analysis figures from Table 4, the discussed topics are as follows:

(1) Sustainability (green cluster, top-middle)

The development of the industrialization of construction includes standardization of design, factory production process, assembly, information management and installation on the site. Improving performance and quality is in the direction of safety and environmental protection. Developing the industrialization of construction aims at the development of

sustainable and lean construction, which transforms extensive construction into intensive construction and aims at the development of the construction industry in the future [38].

(2) Modular construction and modularization (red cluster, top left)

Modularization in the production process has been widely discussed in the construction industry. The Construction Industry Institute (CII) has conducted extensive studies in the

field of modularization in PPMOF (prefabrication, preassembly, modularization, and offsite fabrication) [20]. CII support described that modularization has many uses in order to improve buildability by architects, owners and prefab contractors [39].

(3) Off site construction and prefabrication (green cluster, top right)

The leading technology of the construction industry is off-site construction [40,41]. Prefabrication and production of parts and modules in a controlled environment is one of the off-site construction activities [42,43]. In order to improve competitiveness in capital projects and solve industry challenges, offsite construction has many benefits [44,29]. Off-site construction techniques are important in recent studies [45].

(4) Information technology and BIM (building information model) (red cluster, right lower)

BIM (building information model) is considered as an important and widely used information technology in design standardization and modularization, which is important in improving design and construction quality [46]. BIM (building information modeling) technology is used to integrate design and improve the design quality of the production process in design companies, and the information modeling of components and input materials is done in a way that all design disciplines cooperate and reduce conflicts in the direction of standardization and integration of the design of prefabricated components and modules [47].

(5) Robotics and internet of things

(blue cluster, right lower and blue cluster, left lower)

Digitization and the application of new technologies in the construction industry, which include the use of BIM, virtual design and construction (VDC) and robotics, are effective in the production and construction process. In the direction of variation in the construction industry, there must be a strategic approach to the use of technology and innovative activities, and the United Nations stated in 2021 that extensive changes in the field of construction industry will occur and with the use of technology and innovation, the

long term vision is predictable [48,49]. According to the reviews conducted in the research literature, in most of the publications related to the standardization of design for industrialization of construction, the issue is new and after 2016 the two issues (standardization of design and industrialization of construction) were compared and each was reviewed separately. Sustainable development, modular construction, building information modeling, information technology, and modern method view are the most important keywords shown in Figure 4, indicating that modularization is one of the main issues in the standardization of the production process and industrialization of construction, and that the standardization of design is the basis for the use of emerging technologies such as BIM, robotics and 3D printers, which can be in the direction of development of the construction industry.

4.3. Systematic Analysis

The integration of design standardization and industrialization of construction is considered in a deeper study by the systematic analysis of the selected articles in the 2nd stage. Out of the 101 selected articles after the refinements, 43 articles were selected for qualitative and systematic review, which were classified into 3 groups after the refinement of the articles:

(1) Standardization of design codes for prefabricated components (2) standardization is based on modularization (3) information technology in the process of production and construction.

4.3.1. Design Phase: Design Codes and Standards for Prefabricated Components

In expressing the concept of standardization of design, Qu Zhenliang defined the design of buildings with different uses according to building standards, design codes and integrated building modules and specific technical regulations. The main parameters of the specific dimensions of the buildings and the components used in them are in accordance with technical and economic comparisons, arranged in order to create a series system that creates controlled conditions in the specialized and centralized production process, from design to manufacturing, by the latest technologies of the day for large quantities of goods, which allows the ability to change and

replace components and lateral accessories in the widest possible range[50].

4.3.2. Design Phase: Standardization Strategy for Modular Industrial Plants

Improving quality, saving money and time, increasing productivity, improving performance, working environment safety and reducing environmental effects are the advantages of this technique [23]. In order to improve industrialization of construction, it is necessary to use the design standardization and modularization technique, correctly [20,22]. The advantages of modularization, standardization of design and prefabrication, preassembly, and off-site fabrication (PPMOF) techniques have made it possible to use these techniques in the industrialization of construction using modern technologies and modern construction methods and building information modeling (BIM), which improves performance, quality and sustainability [51].

4.3.3. Design Phase: Information Technology in the Process of Building

It is possible to develop the modularization technique in design using innovative technologies such as building information modeling (BIM), automation in the production process, and information technology. [45,52]. Considering that all components and parts of the project cannot use the standardization of design technique for frequent repetition, in order to use optimal modularization without restrictions, it is necessary to integrate standardization with modularization [53]. Choi et al. (2019a) conducted a research in the field of identifying advanced technologies related to design standardization, according to which the technologies that can be used for design standardization are: (1) modularization (2) lidar/reality capture (3) intelligent automated data collection technology (4) mobile user interface device (5) WLAN (6) construction simulation technologies, and (7) materials logistics management [54].

Robotics and 3D printers, internet of things, intelligent automated data collection technology, mobile user interface device, WLAN, construction simulation technologies, materials logistics management, and virtual design and construction (VDC). The current research aims at improving the knowledge of

5. Conclusion

This research has investigated the current status of studies related to the field of standardization of design for the industrialization of architecture. The current study employed the mixed review research method (bibliometric analysis and qualitative review) for the development of scientific maps of standardization of design and architectural industrialization and identifying the factors and knowledge gap. For this study, we used VOSviewer to conduct a quantitative review of literature on standardization of design for industrialization of architecture that was sourced from Scopus. The research focused on the current academic articles and found that they cover the entire life cycle of industrialization of architecture projects. In terms of standardization of design research, there have already been studies focused on standardization of design by modular construction and modularization, standardization design for optimization, product design and technologies in the design standardization. As for industrialization of architecture research, Industry 4.0 and supply chain management and costs and supply chain for industrialization architecture are pointed to. Through a collaborative discussion, the primary research topics were identified from bibliometric analysis, which were synthesized and created a categorization structure. Then, a categorization structure was used to look at the identified factors in-depth and develop a standardization of design for industrialization of architecture. Investigations on the standardization of design have revealed some important findings related to improving the performance and quality of construction; as a result, some factors related to standardization of design for industrialization of architecture were identified that are modularization, Industry 4.0 and supply chain management, sustainability and lean construction, off site construction and prefabrication, automation in the production process, information technologies, BIM,

performance in the industrialization of architecture by evaluating standardization of design for industrialization of architecture and recognizing the factors and needs of future research and referring to the steps necessary to achieve success in the standardization of design for the industrialization of architecture.

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