buildings

Article

Industrialized Construction and Sustainability: A Comprehensive Literature Review

Guillermo Sotorrío Ortega [1,2], Alfonso Cobo Escamilla [1] and José Antonio Tenorio Ríos [2,*]

[1] Escuela Técnica Superior de Edificación, Universidad Politécnica de Madrid, 28040 Madrid, Spain; sotorrio@ietcc.csic.es (G.S.O.); alfonso.cobo@upm.es (A.C.E.)
[2] Eduardo Torroja Institute for Construction Science, Spanish National Research Council (CSIC), 28033 Madrid, Spain
* Correspondence: tenorio@ietcc.csic.es

Abstract: The industrialized model of construction is gaining more and more prominence in the specialized literature and in discussion forums wherein the different economic, social, and environmental advantages it offers compared with the traditional model are shown. The greater control over all processes results in savings in materials, less waste, less traveling to the construction site, and optimized energy consumption. Furthermore, this construction model often involves a higher quality finish and complex construction details of better quality. All these aspects make industrialized construction an interesting model from the perspective of sustainability. This study aims to investigate the relationship between industrialized construction and sustainability, and the benefits associated with it. A systematic review of the literature was performed based on research published between 2000 and 2022. The methodology followed consisted of searching for different combinations of keywords. Then, a quantitative and qualitative analysis was conducted to see the total number of publications and study aspects, such as their temporal and geographical evolution, and the subject areas they dealt with. After this analysis, our discussion and conclusions revealed some of the gaps existing in the research studies conducted in order to propose possible lines of research for the future.

Keywords: construction; building; industrialized; modular; prefabrication; sustainability; environment

check for updates

Citation: Sotorrío Ortega, G.; Cobo Escamilla, A.; Tenorio Ríos, J.A. Industrialized Construction and Sustainability: A Comprehensive Literature Review. *Buildings* **2023**, *13*, 2861. https://doi.org/10.3390/buildings13112861

Academic Editors: Antonio Caggiano and Pramen P. Shrestha

Received: 25 September 2023
Revised: 1 November 2023
Accepted: 11 November 2023
Published: 15 November 2023

1. Introduction

What is known as the traditional model of construction involves carrying out all the necessary tasks for constructing a building on site. These tasks are generally undertaken by workers with varying degrees of experience who perform the tasks following the status quo, that is, with little innovation, thereby limiting progress with regard to the materials used and construction techniques. Dependence on the human factor is an inherent part of the traditional construction model, leaving open a large number of variables that can have a negative effect on the construction quality, accuracy of stakeouts, planning expenses, generation and classification of waste, consumption of materials, and compliance with the periods of execution. In the traditional model, other factors such as the large number of displacements of workers to the site, the greater number of occupational accidents [1], the unexpected problems that arise on site due to the lack of a correct definition, or the subsequent repairs result in variances in costs and environmental forecasts.

There are multiple definitions of industrialized construction and different ways of referring to it, the most common being an organizational model that uses a series of innovations, most of them in the field of factory construction technology, that make it possible to construct buildings more quickly, economically, and efficiently [2]. The construction process is divided into two phases: the production of elements off-site in a production plant, and their assembly on the building site itself. According to the percentage of the activity carried out off-site, we are faced with a building with a greater or lesser degree of industrialization.

The industrialization of the construction process, as in any sector, should be directed at increasing the productivity of the resources available, improving the quality of the end product, business efficiency, customer satisfaction, and control of execution times, and generating less waste [3–5]. This can be achieved thanks to having greater control over processes in which construction details are defined beforehand, which helps to ensure greater accuracy and improved compliance with deadlines, also making quotes easier to adjust. This model also offers enhanced quality control compared with traditional methods since the materials are manufactured in a controlled environment and away from adverse climate conditions.

Most end users cannot notice any differences in the use or appearance between an industrialized building and one built using traditional methods, highlighting the fact that there is no perceived inferior quality of the standardized process. A further reason for the advances in industrialization could be the market and the current economic and social situation [6] driven by the industrialized model, motivated because the sector is being financed by venture capital funds and other large investment companies that aim to include modifications that make processes more efficient, such as the principles of the fourth industrial revolution to digitalize and industrialize the construction industry. In addition to the new technology, these companies also offer new business models that deviate from the classic tendering systems [7]. The industrialized model enables construction companies to execute buildings more efficiently, and what is equally or more important, with greater control. All this control results in the optimization of both the execution and delivery times and the resources available, reducing the risk of unforeseen expenses and budget deviations.

The study of the industrialization of the building sector, and the pros and cons of its implementation, has drawn the attention of scientists and professionals more and more, leading to an increase in recent years in the number of research studies. In 2015, Lessing [8] analyzed the phenomenon from a holistic perspective, observing the characteristics of industrialized homes, establishing categories, and identifying business models for the expansion of the sector.

This study aims to investigate the relationship between industrialized construction and sustainability, and the benefits associated with it. To achieve this aim, a systematic review was conducted of the existing scientific literature taking into consideration papers published between 2000 and 2022.

In its most current definition, sustainable construction can be considered as the building model that takes into account the environmental impacts related to the entire construction process, from the design and planning phase to construction, building usage, and even demolition and waste management [9].

If a search is conducted of reviews of the literature exclusively about industrialized construction, it is possible to find several examples [10]. For example, Jin et al. [11] carried out an interesting review of the general literature, comparing conventional and industrialized construction. Another example is that of Qi et al. [12], whose review identified the main lines of research and the gaps in the research regarding the application of emerging technology in industrialized construction.

When the search is limited to systematic reviews of the literature on industrialized construction and its influence on sustainability, one can be found by Li et al. [13], whose study in 2022 was about the growing popularity of industrialized construction. The authors conducted an exhaustive review of the literature and used scientometric analysis to gain a better understanding of the current state of knowledge, identifying subjects of research and proposing lines for the future. In turn, Kedir et al. [14] conducted a systematic review of the literature on the efficiency of the use of resources in the industrialized construction of homes. Jussila et al. [15], in their systematic review of the literature on the development of the market for constructing wooden flats, highlighted the increase in the profitability of industrialized prefabrication and the benefits of sustainability.

Among the critical reviews of the literature that studied the relationship between industrialized construction and sustainability, two research studies stand out. Ruoyu et al. [16] performed a review that reported that most existing studies use the life cycle analysis method. In turn, Kamali and Hewage [17] conducted an extensive critical review of the literature on the benefits and challenges provided by the modular construction method compared with its conventional counterpart.

The present article complements the existing literature that relates to industrialized construction and sustainability, providing a general perspective through a systematic review of all the research articles published. The reviews found may lack some published studies since they have not taken into consideration all the possible terms that industrialized construction is known by in different geographical environments. In this sense, the present study aims to pool the existing knowledge by including synonyms and other possible names for this construction technique. Furthermore, regarding the subject matter, the reviews found focus their analysis on the advantages provided by this kind of construction or comparisons with traditional methods. This review has attempted to evaluate what the research papers were about, and rather than directing the analysis in one way or another, we tried to identify which subject is the focus of most papers and where there may be gaps in the knowledge.

The work is structured as follows: first, the research methodology is presented, explaining how the search was conducted and which keywords were used. The second part is the quantitative and qualitative analysis of the publications. Finally, after summarizing the results obtained, they are discussed, and certain conclusions are drawn.

2. Materials and Methods

With the aim of analyzing the role of industrialized construction in the transition of a sector towards a more sustainable model by obtaining information from numerous publications, the methodology followed was based on the consultation of previous studies from reviews of the literature from other fields [18,19].

The approach adopted has made it possible to provide scientists and professionals in the sector with reliable results and conclusions. Given the nature of the topic, the most relevant publications and authors from recent years were examined. Specifically, the focus was on identifying emerging trends, gaps, and areas of interest in the literature, rather than conducting a comprehensive systematic review. Although the PRISMA (Preferred Reporting Items for Systematic reviews and Meta-Analyses) methodology, while recommended, was not mandatory for our study, we adhered to its principles to the extent necessary to meet our objectives. This strategic approach allowed us to effectively contextualize the topic, explore key contributions, and gain a deeper understanding of the evolution of the field. Through this methodological framework, we aimed to provide a nuanced and insightful analysis of the current state of research.

The research methodology was developed in four main phases, along with a preliminary phase. These five phases are illustrated in Figure 1. The phases were organized into the identification of the publications based on search criteria, screening to ensure the accuracy of the information, and inclusion to ensure consistent and comparable results. Finally, the results were analyzed quantitatively and qualitatively.

Before the first phase in which publications were selected (PHASE 1), there was an initial phase involving the selection of the keywords to use in the search (PHASE 0). This was based on the different ways of referring to industrialized construction in scientific articles, on the basis of earlier reviews [14], and a search on a normative and commercial level for other possible names.

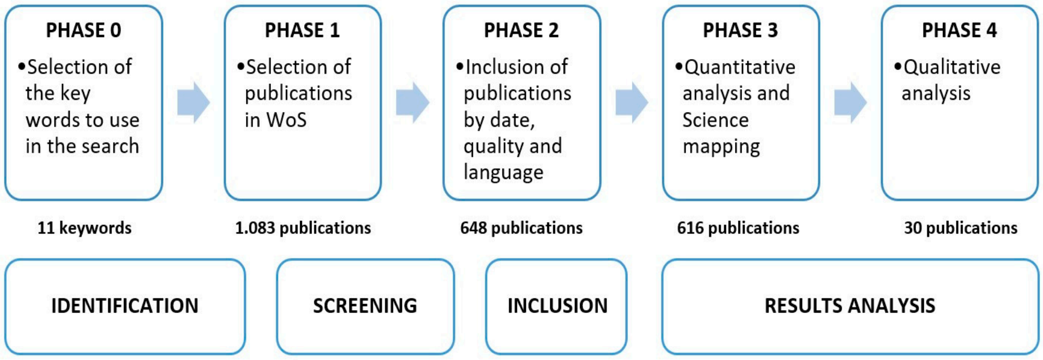

Figure 1. PRISMA flow diagram.

The keywords chosen to denominate industrialized construction were:

"Industrialized construction", "Industrialized building system", "Off-site construction", "Offsite construction", "Prefabrication", "Prefabricated construction", "Prefabricated building", "Modular construction", and "Modular integrated construction".

The choice of keywords that relate these terms to industrialized construction and sustainability was made on the basis of previous publications that reviewed sustainable construction [20] and the environment [21]. This resulted in the terms: "environment" and "sustainability".

The inclusion criterion was that these words had to appear in the title of the article, its abstract, or in the indexation of the publication (keywords). Limiting the search to the title was considered unrepresentative, so it was necessary to analyze the keywords and the abstract so that the link with the desired area was strong enough.

The search for publications was carried out using the Web of Science (WoS) database, a service provided by the data analysis company Clarivate Analytics, based in London. Access was thanks to the Spanish Foundation for Science and Technology (FECYT), under the Ministry of Science and Innovation of Spain.

The decision was made to use the Web of Science in this work because it is considered one of the most widely used and influential literature databases worldwide. Birkle et al. [22] stated in their work that WoS is the oldest, most used, and most authoritative publication and research citation database in the world.

Table 1 shows the results of the first attempt with the keywords mentioned above.

Table 1. Results of the search of the WoS using the initial keywords.

Topic (Title, Abstract or Index)			Results
Industrialized construction	And	Environment	21
Industrialized building system			6
Off-site construction or offsite construction			83
Prefabrication			193
Prefabricated construction			100
Prefabricated building			57
Modular construction			141
Modular integrated construction			6
Industrialized construction	And	Sustainability	9
Industrialized building system			11
Off-site construction or offsite construction			82
Prefabrication			179
Prefabricated construction			70
Prefabricated building			25
Modular construction			61
Modular integrated construction			18

It is worth highlighting the importance of terms such as "prefabrication", "prefabricated construction", or "modular construction" which account for the largest number of results. This can be attributed to the fact that they are the most widely accepted in the sector, although this depends on the country. Also of note is that terms referring to prefabrication have been used the longest. Others, such as the term "precast", have been excluded as they are limited to building and civil engineering elements made out of concrete with structural functions. The terms included below consider the incorporation of these prefabricated structural elements into their industrialized systems, not solely as prefabricated structural components, but as part of a construction system.

In search of the combination of keywords that would provide the most representative result, without neglecting any of the terms, the search was finally conducted as follows:

"Industrialized construction" OR "Industrialized building system" OR "Off-site construction" OR "offsite construction" OR "Prefabrication" OR "Prefabricated construction" OR "Prefabricated building" OR "Modular construction" OR "Modular integrated construction" And "environment" OR "sustainability". The aforementioned search of the WoS produced an initial result for the second phase.

The second phase (PHASE 2) consisted of including or excluding publications according to the criteria of the publication date, quality, and language. Regarding the date, the study was limited to articles published between 2000 and 2022, thereby reducing the number of publications to 959. The second inclusion criterion was language, namely that the articles were written in English. The total then decreased to 896 publications. Next, quality criteria were applied, according to which the following were excluded: book chapters, conference proceedings, extended summaries, presentations, and conferences. In other words, only articles from indexed journals were included. After applying these criteria, the number of publications was reduced to 648 from different fields of research.

Finally, an initial analysis of these fields of research revealed that, as a result of including the term "modular construction", which is also used in biology, there were several articles from subject areas such as: "Biochemistry Molecular Biology", "Genetics Heredity", "Health Care Sciences Services", and "Mathematical Computational Biology. So as not to include these results, these areas of research were eliminated, producing a final result of 616 studies to work with.

The next step, PHASE 3, was the quantitative analysis and the process of analyzing the scientific production known as "science mapping" [23], which was applied to gain a more detailed knowledge of the data of the publications and to identify the main journals in terms of the number of publications and the main contributions of the authors in terms of publications and citations.

Using the tools [24,25] on the Web of Science itself, it was possible to analyze the publications from the point of view of publication dates, country (or countries) of origin of the research team, contributions of the different authors, or the field of the scientific journals in which the articles were published. It also allowed for relationships between them to be established and for research trends to be determined [26].

The tool used for the science mapping was VOSviewer, which enabled the creation of node maps, establishing relationships between the different publications [27–29].

The final phase (PHASE 4) was an analysis of the qualitative content. This involved analyzing the content of the 30 most cited articles according to the WoS, these having been selected from among the 616 articles in PHASE 2. To analyze the relationship between industrialized construction and sustainability in these publications, different subject areas were established, assigning the articles to one of these according to their content. This enabled possible knowledge gaps to be identified; that is, fields into which less research has been conducted.

3. Results

3.1. Quantitative Analysis Results

The quantitative analysis was conducted with the result of the searches in the WoS with the criteria described above, wherein 616 articles were included. Figure 2 shows the distribution of the articles by year of publication; it is possible to observe in the figure the growing interest in scientific publications in the transition of construction towards an industrialized model and its relationship with sustainability. It can be seen that there were few publications in the first few years, more in the last decade, and many more in the last three or four years.

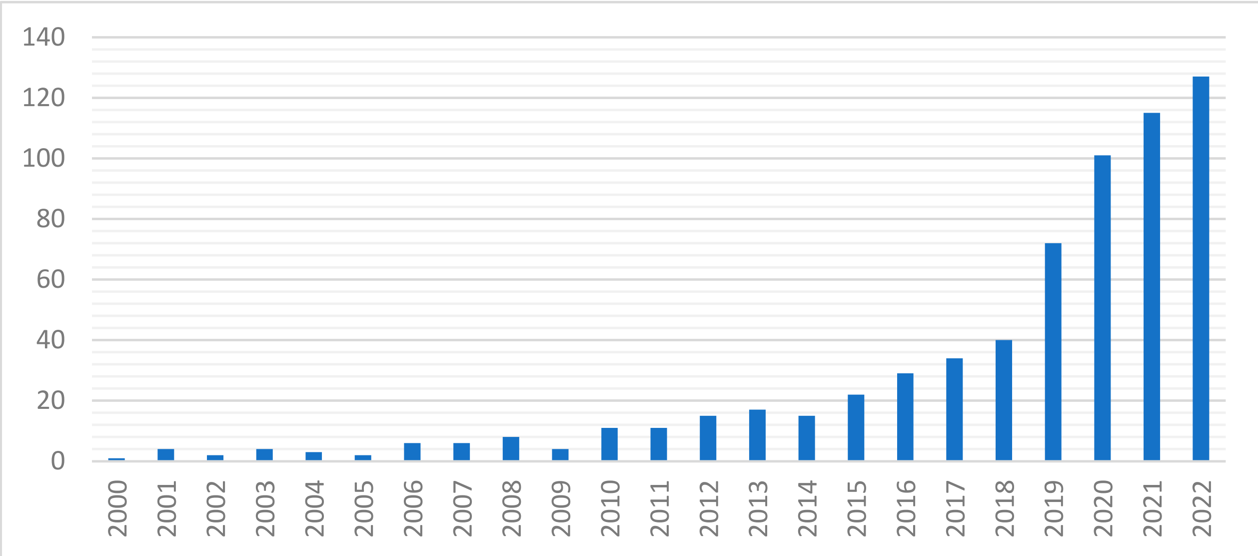

Figure 2. Number of publications per year (2000–2022).

If we also compare the number of scientific articles exclusively about the industrialized model, without taking into account its effect on sustainability, we will also see a growth in its evolution, which can be observed in other reviews, such as the one by Jin et al. [11].

The quantitative analysis of the results obtained from the perspective of the country of publication revealed interesting results, mainly when connecting this scientific production with the gross domestic product (GDP) of each country. In Figure 3, the countries are listed in order of their GDP for 2021, according to data from the International Monetary Fund (IMF) [30].

The fact that China is in the first position, with over half of the publications, is not striking when taking into account its high GDP and scientific production in almost every field. However, the high level of scientific production in this field is of note in countries such as the United Kingdom and Australia, or to a lesser extent, Canada and Malaysia. This is evidence of the keen scientific interest in this field, given the high scientific production compared with other countries with a higher GDP such as Germany or France. This could be the result of the greater acceptance and implementation in the construction sector of the industrialized model, resulting in scientists addressing their research in recent years towards the environmental advantages of this model. Finally, regarding the country of origin of the publications, what is surprising among all the other data is the scientific production of the USA, which, having the highest GDP and with huge scientific production in other fields, is only in fourth place in scientific production related to industrialized construction and sustainability.

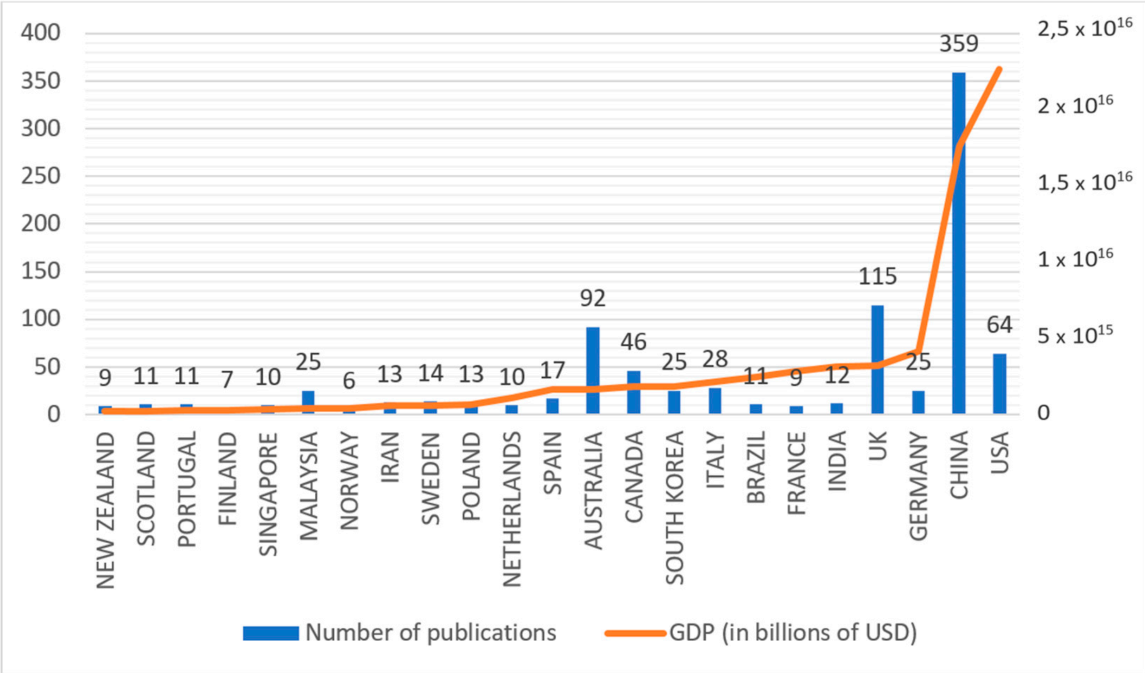

Figure 3. Number of publications from each country, in order of GDP for 2021.

In the next step, all of the literature was analyzed according to the number of contributions of each author according to data from the WoS. Table 2 shows the 25 authors with the most publications in this field and Figure 4 indicates the relationships between them.

Table 2. List of the 25 authors with the most contributions.

No.	Author	Number of Publications
1	Li, Z	15
2	Li, X	11
3	Wang, Y	11
4	Al-hussein, M	10
5	Pan, W	10
6	Wu, Z	10
7	Wu, Zz	10
8	Li, L	9
9	Li, Zf	9
10	Wang, J	9
11	Liu, Y	8
12	Wang, X	8
13	Zhang, S	8
14	Lu, Ws	7
15	Mao, C	7
16	Wei, Pan	7
17	Yuan, M	7
18	Yuan, Mq	7
19	Zayed, T	7
20	Hong, J	6
21	Hong, Jk	6
22	Li, Xd	6
23	Liu, G	6
24	Mendis, P	6
25	Orlowski, K	6

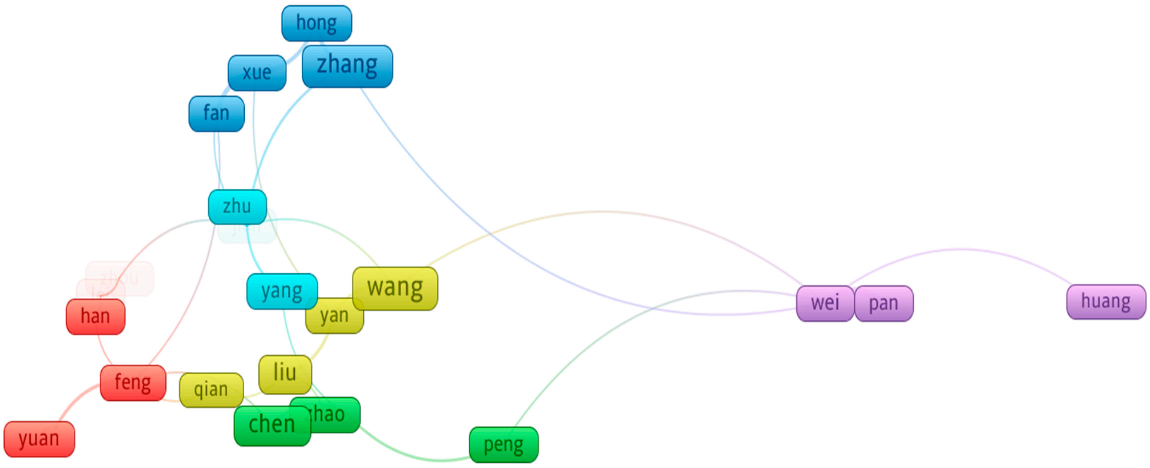

Figure 4. Co-author relationships of the publications (graph generated by the VOSviewer tool).

Of note is the large volume of publications from Chinese authors and their co-author relationships.

Table 3 summarizes the first 20 research areas of the journals the publications are from, according to the number of articles. One of the columns highlights the percentage of publications related to a specific area versus the 616 publications included in the study, always according to the data used from the WoS.

Table 3. Research areas of the journals the publications are from.

No.	Journal Research Areas	Number of Publications	% of 616
1	Engineering	474	76.95%
2	Construction Building Technology	376	61.04%
3	Business Economics	282	45.78%
4	Environmental Sciences Ecology	246	39.94%
5	Computer Science	168	27.27%
6	Science Technology Other Topics	146	23.70%
7	Energy Fuels	136	22.08%
8	Mathematics	84	13.64%
9	Materials Science	81	13.15%
10	Geography	63	10.23%
11	Instruments Instrumentation	57	9.25%
12	Automation Control Systems	39	6.33%
13	Architecture	31	5.03%
14	Physics	26	4.22%
15	Social Issues	25	4.06%
16	Robotics	23	3.73%
17	Chemistry	19	3.08%
18	Urban Studies	17	2.76%
19	Forestry	16	2.60%
20	Public Administration	12	1.95%

The results are a surprise with regard to the position of Engineering ahead of Construction Building Technology, with 76% of the articles being found in journals having the former as a research area and 61% in journals with the latter. It is also noteworthy that the percentage is slightly higher—45% compared with 39%—in the case of Business Economics versus Ecology. Finally, it is of interest that Architecture is the area of interest of the journals in only 5% of the articles.

Below, a clustering analysis of research areas was conducted, aiming to provide a deep and comprehensive insight into the current scientific landscape. The degree centrality measure, based on the number of publications and their relevance in the academic network, was utilized to assess the significance of each thematic area. This technique precisely identified the most influential and central areas in relation to publication volume and their interconnections with other research domains.

It is essential to emphasize that, although this technique provided valuable insights into the academic network's structure, the final classification of the top five thematic areas in the qualitative study was determined in accordance with the specific objectives outlined earlier in the article. This analysis, combined with the subsequent qualitative approach, allowed for a comprehensive and precise depiction of trends and developments in the analyzed research areas.

Figure 5 illustrates the clustering analysis of research areas that was carried out, with each node representing a thematic area and the connections between these nodes revealing the relationships between the areas. Significantly, it is noted that "Construction Building Technology" emerges as the central node, indicating its significant influence on the network. This prominence in the network suggests it is above the rest as a key thematic area that has a high influence on the other areas.

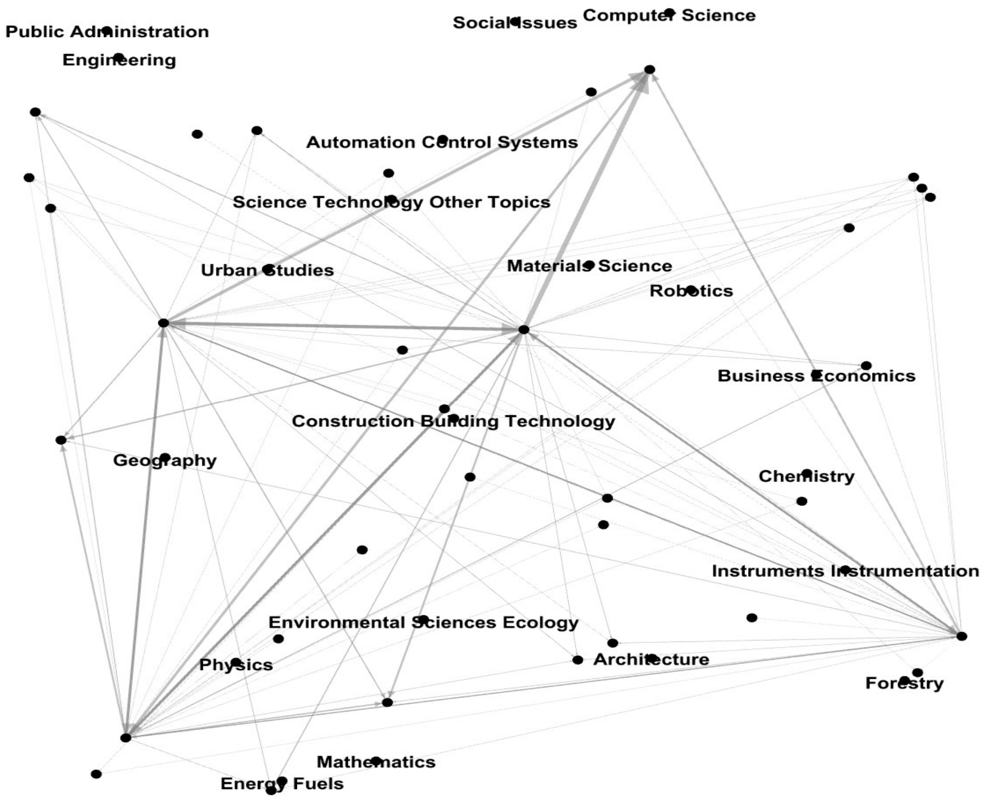

Figure 5. Clustering analysis of research areas (graph generated by Gephi).

In addition, areas such as "Materials Science", "Urban Studies", "Environmental Sciences Ecology", and "Architecture" are also highlighted, showing their relevance and close links to the central node. These subject areas intertwine with numerous other disciplines, revealing their cross-cutting impact and importance in the context of scientific study. The arrangement and strength of these connections provide a profound view of the structure of knowledge in our domain, identifying areas that serve as pillars and points of convergence for diverse research. This centrality analysis not only defines the knowledge structure in our article but also opens the door to new interdisciplinary explorations and enriches the overall understanding of our field of study.

In the final step of the quantitative study, a list was prepared of the 30 most cited articles (see Table 4) according to the data from the WoS database. It is of note that the two articles with the most citations are by authors that are not among those with the most publications with the search parameters used in this study, namely, Pavlovic [31] and

Aye [32]. What is more, they are from countries that are not among the most productive, Pavlovic being from Serbia and Aye from Australia. However, this could be due to the fact that, while meeting the search criteria, the article by Pavlovic is about metallic connectors for prefabricated elements. Nevertheless, the subject matter of each article was analyzed below in the qualitative study.

To find the most productive authors in terms of their number of articles, it is necessary to go to the fourth position, where we find Chen [33] with his article about the selection of construction methods in concrete buildings according to sustainability criteria.

Table 4. List of the 30 most-cited articles.

No.	Author		Total Citations	Citations in 2021	Citations in 2022
1	Pavlovic et al.	[31]	307	60	62
2	Aye et al.	[32]	263	45	40
3	Kamali and Hewage	[17]	258	57	69
4	Chen et al.	[33]	255	31	27
5	Cao et al.	[34]	184	41	38
6	Aarseth et al.	[35]	179	42	29
7	Jaillon and Poon	[36]	163	32	32
8	Akanbi et al.	[37]	150	43	46
9	Tam	[38]	147	13	10
10	Hwang et al.	[39]	143	29	34
11	Hong et al.	[40]	141	20	32
12	Lu and Yuan	[41]	139	17	9
13	Kamali and Hewage	[42]	134	25	38
14	Li et al.	[43]	133	32	37
15	Zhang et al.	[44]	127	22	30
16	Mao et al.	[45]	122	23	26
17	Hu et al.	[46]	112	71	17
18	Ghisellini et al.	[47]	111	33	32
19	McKenna et al.	[48]	111	15	26
20	Jiang et al.	[49]	109	25	26
21	Lu and Yuan	[50]	109	17	21
22	Wang et al.	[51]	105	23	14
23	Babic et al.	[52]	105	13	8
24	Telesca et al.	[53]	97	13	13
25	Ajayi et al.	[54]	88	18	15
26	Loss et al.	[55]	87	18	22
27	Pons and Wadel	[56]	87	12	12
28	Pan et al.	[57]	83	10	15
29	O'Connor et al.	[58]	81	13	13
30	Innella et al.	[59]	79	21	32

The quantitative study revealed how the relevance of both industrialized and sustainable construction and their relationship to each other has been increasing over the last few years. During first few the years contemplated in this study, there were hardly any studies published that met the search criteria used. Then, more studies were found that were published in the last decade, with numbers increasing significantly over the last few years.

Another conclusion to be drawn is that the country with the greatest scientific production on the subject is China, and authors from this country have published the most articles. However, among those with the most citations, there are also authors that are not the most productive in terms of the number of articles meeting the search criteria used in this study. This could indicate two things: either their research does not focus on the subjects included in the search criteria in the WoS, or their article met the inclusion requirements, but was not really a good fit with the subject under study. These aspects are analyzed below in the qualitative study.

3.2. Qualitative Analysis Results

Below, in the qualitative analysis of the 30 most-cited publications, an in-depth study was conducted of different aspects such as the subject area. Five subject areas were then established:

1. Sustainability and life cycle analysis. Sustainability in industrialized construction and the evaluation of its impact on the environment by means of the life cycle analysis (LCA) tool.
2. Circular economy and waste reduction. The transition of the construction sector through industrialization towards a circular model in which on-site and manufacturing waste is decreased, promoting the recycling and reuse of materials.
3. Development of industrialized construction. Development and implementation of industrialized construction and studying its challenges, barriers, and opportunities.
4. Integration of technology in construction. Industrialized construction is partly based on the use of new technology to optimize building processes.
5. Industrialized construction systems. The study of new installation and assembly systems makes it possible to optimize the benefits of assembly in terms of the quality, deadlines, and cost of the processes.

Table 5 shows the 30 most-cited articles, classified by the following subject areas.

First, it is of note that most of the articles—ten in total—refer to the general sustainability of industrialized construction and, in particular, to evaluating the environmental impacts of sustainability by means of the ACV methodology. Next, there are eight articles classified in the area of circular economy and the reduction in waste achieved by the industrialization of construction processes.

Regarding life cycle analysis as a methodological tool for measuring the environmental impact of industrialized construction, several studies stand out. The study by Aye et al. [32] aimed to show that prefabricated construction provides better results in terms of environmental impact than conventional building methods with concrete. The aims of the study were achieved by means of a comparative study in a residential building. This study is among those with the most citations and, given that it was published in 2011, it stands out for being innovative at that time. The study by Cao et al. from 2015 [34] followed the same line.

Of note too is the research by Chen et al. [33] that conducted a survey of clients/developers, engineers, contractors, and manufacturers of prefabricated concrete to capture their perceptions about the importance of different sustainable performance criteria to compare several construction methods.

The reviews by Kamali and Hewage [42] and Aarseth et al. [35] are also among the most cited in this subject area. The former [31] presents an extensive critical review of the literature on the benefits and challenges provided by the modular construction method compared with its conventional counterpart. The latter [33] is a systematic review of the literature about strategies used in the organization of projects to achieve sustainability aims in general, not specifically in industrialized construction.

Regarding the articles from the subject area of "Circular economy and waste reduction", one that stands out due to the number of citations is that by Akanbi et al. [37] which evaluated the whole-life salvage performance of the structural components of buildings. They reported that buildings with a steel structure, demountable connections, and prefabricated assemblies produce recoverable materials that are mostly reusable. These are key aspects of industrialized construction.

Table 5. Classification of the 30 most-cited articles by subject area.

Author		Title of Article
		1. Sustainability and. Life Cycle Analysis
Aye et al.	[32]	Life cycle greenhouse gas emissions and energy analysis of prefabricated reusable building modules
Chen et al.	[35]	Sustainable performance criteria for construction method selection in concrete buildings
Kamali and Hewage	[17]	Life cycle performance of modular buildings: A critical review
Cao et al.	[34]	A comparative study of environmental performance between prefabricated and traditional residential buildings in China
Aarseth et al.	[35]	Project sustainability strategies: A systematic literature review
Jaillon and Poon	[36]	Life cycle design and prefabrication in buildings: A review and case studies in Hong Kong
Hong et al.	[40]	Life-cycle energy analysis of prefabricated building components: an input-output-based hybrid model
Kamali and Hewage	[42]	Development of performance criteria for sustainability evaluation of modular versus conventional construction methods
Hu et al.	[46]	Sustainability perceptions of off-site manufacturing stakeholders in Australia
Pons and Wadel	[56]	Environmental impacts of prefabricated school buildings in Catalonia
		2. Circular Economy and Waste Reduction
Akanbi et al.	[37]	Salvaging building materials in a circular economy: A BIM-based whole-life performance estimator
Lu and Yuan	[41]	Exploring critical success factors for waste management in construction projects of China
Tam	[38]	On the effectiveness in implementing a waste-management-plan method in construction
Ghisellini et al.	[47]	Evaluating the transition towards cleaner production in the construction and demolition sector of China: A review
Lu and Yuan	[50]	Investigating waste reduction potential in the upstream processes of offshore prefabrication construction
Wang et al.	[51]	Identifying best design strategies for construction waste minimization
Telesca et al.	[53]	Flue gas desulfurization gypsum and coal fly ash as basic components of prefabricated building materials
Ajayi et al.	[54]	Reducing waste to landfill: A need for cultural change in the UK construction industry
		3. Development of Industrialized Construction
Hwang et al.	[39]	Key constraints and mitigation strategies for prefabricated prefinished volumetric construction
Zhang et al.	[44]	Exploring the challenges to industrialized residential building in China
Mao et al.	[45]	Cost analysis for sustainable off-site construction based on a multiple-case study in China
Jiang et al.	[49]	A SWOT analysis for promoting off-site construction under the backdrop of China's new urbanisation
Pan et al.	[57]	Establishing and Weighting Decision Criteria for Building System Selection in Housing Construction
O'Connor et al.	[58]	Critical Success Factors and Enablers for Optimum and Maximum Industrial Modularization
Innella et al.	[59]	Lean Methodologies and Techniques for Modular Construction: Chronological and Critical Review
		4. Integration of Technology in Construction
Li et al.	[43]	Integrating RFID and BIM technologies for mitigating risks and improving schedule performance of prefabricated house construction
Babic et al.	[52]	Integrating resource production and construction using BIM
		5. Industrialized Construction Systems
Pavlovic et al.	[31]	Bolted shear connectors vs. headed studs behaviour in push-out tests
McKenna et al.	[48]	Key challenges and prospects for large wind turbines
Loss et al.	[55]	Connections for steel-timber hybrid prefabricated buildings. Part I: Experimental tests

4. Conclusions

The first conclusions to be obtained are those from the initial searches for publications performed in the Web of Science (WoS) database. These confirm that the most widely accepted term in the construction sector when referring to off-site work is "prefabrication". This term, in combination with others such as "modular construction", produced the findings for the study conducted.

With the initial search, the WoS produced a result of 959 publications. After applying the inclusion criteria of date of publication, quality, and language, the final number of articles was 648. The quality criterion was then considered to limit the study to articles from indexed journals, excluding book chapters, conference proceedings, extended summaries, presentations, and conferences. The initial 648 articles were reduced to 616 definitive ones to work with after analyzing the research areas and rejecting 32 publications that belonged to the area of biology.

The search performed showed that the earliest publication into the effect of the industrialization of dwellings on sustainability was from 1986. However, it was only in the last decade that research truly began in this field, with 60% of the studies being published in the last three or four years. However, this study was limited to articles published between 2000 and 2022 in order to determine the progress made during this century.

From all the data analyzed in the quantitative study, besides the evolution over the years, the conclusion could be drawn that, although China is the country with the greatest scientific production in absolute terms, the most productive countries in relation to their GDP are the United Kingdom and Australia, this being attributed to this model of construction being more widely established.

On a geographical level, it is possible to highlight two main publication hubs. The first comprises Asian countries such as China, South Korea, and Malaysia. The second is in Europe, featuring the scientific production of the UK and Italy. Outside of these locations, it is worth mentioning Australia and Canada, which present notable levels of production.

Regarding the quantitative analysis of the authors, among those with the most citations are authors who are not the most productive in terms of the number of articles published. This could be attributable to the fact that their lines of research do not focus on the search criteria followed in the Web of Science, but their work conducted in this field has been very well received.

For the qualitative study of the 30 most-cited publications, five subject areas were established, with the articles then divided into these categories. It is of note that most of the articles refer to the sustainability of industrialized construction and to evaluating its environmental impacts by means of life cycle analysis.

There are also some of the most cited studies comparing industrialized construction with conventional methods, showing that industrialized construction is more environmentally friendly [34,42].

In this study, a comprehensive bibliographic analysis was conducted; however, it is necessary to acknowledge the limitations of the methodology employed. Firstly, it is important to mention that the availability and accessibility of bibliographic sources may have been subject to certain restrictions. These limitations should not have been significant given that the data relied upon was sourced from the Web of Science. It is essential to note that the quality and accuracy of the gathered information were contingent upon the precision and completeness of the citations in the original sources.

Another limitation worthy of consideration was the geographical restriction of the consulted sources. Although efforts were made to encompass a wide range of scientific literature, certain geographic regions might not have been proportionally represented in our review. This geographic disparity could lead to a biased perspective on the investigated relationships, as specific dynamics in certain areas might not have been entirely captured in our analysis.

A final detail to consider when interpreting the collected data is that they are subject to the inherent limitations of any bibliographic review. Subjectivity in source selection and evaluation, as well as in information synthesis, may have introduced certain biases into our conclusions. Despite efforts to maintain objectivity and impartiality in our analysis, these limitations must be taken into account when interpreting the results of this study.

The conclusion can be drawn that the search carried out did not yield a representative number of research studies in which the initial indicators were established in the design phase. These indicators would make it possible to compare the different construction options and evaluate the level of industrialization or highlight the other criteria necessary to establish a methodology for making decisions about which construction system to adopt according to sustainability criteria.

All the authors reported a direct relationship between environmental sustainability and industrialization, but they simply addressed the advantages of industrialization in the field of environmental sustainability, disregarding social and economic sustainability. These factors are no less important when it comes to maintaining the economic development of the sector, thereby achieving enhanced social well-being.

Our approach differs from previous publications in that they mainly focused on the advantages of industrialized construction compared to traditional methods or overlooked certain studies due to terminological limitations. In our review, we addressed this knowledge gap by encompassing a wide range of synonyms and possible names for industrialized construction in different geographical contexts. This meticulous inclusion allowed us to offer a comprehensive overview of the relationship between industrialized construction and sustainability, covering not only the obvious benefits of this construction technique but also identifying areas where further research is needed.

By comparing our work with previous studies, we identified emerging trends and patterns in the existing research. We observed that many studies focused on environmental and economic improvements, but we also identified a critical area of research related to the social and cultural implications of industrialized construction which has been relatively undervalued in the existing literature. This finding suggests a promising direction for future research.

Author Contributions: Conceptualization, G.S.O. and J.A.T.R.; methodology, G.S.O. and J.A.T.R.; software, G.S.O.; validation, G.S.O., A.C.E. and J.A.T.R.; formal analysis, A.C.E. and J.A.T.R.; investigation, G.S.O.; resources, A.C.E. and J.A.T.R.; data curation, G.S.O.; writing—original draft preparation, G.S.O.; writing—review and editing, G.S.O.; visualization, G.S.O. and J.A.T.R.; supervision, A.C.E. and J.A.T.R.; project administration, J.A.T.R.; funding acquisition, J.A.T.R. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: The data generated are available in the article.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Ahn, S.; Crouch, L.; Kim, T.W.; Rameezdeen, R. Comparison of Worker Safety Risks between Onsite and Offsite Construction Methods: A Site Management Perspective. *J. Constr. Eng. Manag.* **2020**, *146*, 05020010. [CrossRef]
2. Offsite Fabrication: Prefabrication, Preassembly and Modularisation, Whittles Publishing—Publication Index | NBS. Available online: https://www.thenbs.com/PublicationIndex/documents/details?Pub=WHITTLES&DocID=304112 (accessed on 9 June 2023).
3. Yepes, V.; Pellicer, E.; Ortega, A.J. Designing a Benchmark Indicator for Managerial Competences in Construction at the Graduate Level. *J. Prof. Issues Eng. Educ. Pract.* **2012**, *138*, 48–54. [CrossRef]
4. Pellicer, E.; Yepes, V.; Correa, C.L.; Alarcón, L.F. Model for Systematic Innovation in Construction Companies. *J. Constr. Eng. Manag.* **2014**, *140*, B4014001. [CrossRef]
5. Han, Y.; Yan, X.; Piroozfar, P. An overall review of research on prefabricated construction supply chain management. *Eng. Constr. Archit. Manag.* **2022**. [CrossRef]
6. MacAskill, S.; Mostafa, S.; Stewart, R.A.; Sahin, O.; Suprun, E. Offsite construction supply chain strategies for matching affordable rental housing demand: A system dynamics approach. *Sustain. Cities Soc.* **2021**, *73*, 103093. [CrossRef]

7. Hall, D.M.; Lessing, J.; Whyte, J. New Business Models for Industrialized Construction. In *Industry 4.0 for the Built Environment: Methodologies, Technologies and Skills*; Bolpagni, M., Gavina, R., Ribeiro, D., Eds.; Springer International Publishing: Berlin/Heidelberg, Germany, 2022; pp. 297–314. [CrossRef]
8. Lessing, J. Industrialised House-Building—Conceptual Orientation and Strategic Perspectives. Ph.D. Thesis, Lund University, Lund, Sweden, 2015.
9. Thomas, R.V.; Nair, D.G.; Enserink, B. Conceptual framework for sustainable construction. *Archit. Struct. Constr.* **2023**, *3*, 129–141. [CrossRef]
10. Wuni, I.Y.; Shen, G.; Robert, O.-K. Sustainability of off-site construction: A bibliometric review and visualized analysis of trending topics and themes. *J. Green Build.* **2020**, *15*, 131–153. [CrossRef]
11. Jin, R.; Gao, S.; Cheshmehzangi, A.; Aboagye-Nimo, E. A holistic review of off-site construction literature published between 2008 and 2018. *J. Clean. Prod.* **2018**, *202*, 1202–1219. [CrossRef]
12. Qi, B.; Razkenari, M.; Costin, A.; Kibert, C.; Fu, M. A systematic review of emerging technologies in industrialized construction. *J. Build. Eng.* **2021**, *39*, 102265. [CrossRef]
13. Li, L.; Luan, H.; Yin, X.; Dou, Y.; Yuan, M.; Li, Z. Understanding Sustainability in Off-Site Construction Management: State of the Art and Future Directions. *J. Constr. Eng. Manag.* **2022**, *148*, 03122008. [CrossRef]
14. Kedir, F.; Hall, D.M. Resource efficiency in industrialized housing construction—A systematic review of current performance and future opportunities. *J. Clean. Prod.* **2021**, *286*, 125443. [CrossRef]
15. Jussila, J.; Nagy, E.; Lahtinen, K.; Hurmekoski, E.; Hayrinen, L.; Mark-Herbert, C.; Roos, A.; Toivonen, R.; Toppinen, A. Wooden multi-storey construction market development—Systematic literature review within a global scope with insights on the Nordic region. *Silva Fenn.* **2022**, *56*, 10609. [CrossRef]
16. Jin, R.; Hong, J.; Zuo, J. Environmental performance of off-site constructed facilities: A critical review. *Energy Build.* **2020**, *207*, 109567. [CrossRef]
17. Kamali, M.; Hewage, K. Life cycle performance of modular buildings: A critical review. *Renew. Sustain. Energy Rev.* **2016**, *62*, 1171–1183. [CrossRef]
18. Mohamed Shaffril, H.A.; Samsuddin, S.F.; Abu Samah, A. The ABC of systematic literature review: The basic methodological guidance for beginners. *Qual. Quant.* **2021**, *55*, 1319–1346. [CrossRef]
19. Mengist, W.; Soromessa, T.; Legese, G. Method for conducting systematic literature review and meta-analysis for environmental science research. *MethodsX* **2020**, *7*, 100777. [CrossRef]
20. Det Udomsap, A.; Hallinger, P. A bibliometric review of research on sustainable construction, 1994–2018. *J. Clean. Prod.* **2020**, *254*, 120073. [CrossRef]
21. Çimen, Ö. Construction and built environment in circular economy: A comprehensive literature review. *J. Clean. Prod.* **2021**, *305*, 127180. [CrossRef]
22. Birkle, C.; Pendlebury, D.A.; Schnell, J.; Adams, J. Web of Science as a data source for research on scientific and scholarly activity. *Quant. Sci. Stud.* **2020**, *1*, 363–376. [CrossRef]
23. Chen, C. Science Mapping: A Systematic Review of the Literature. *J. Data Inf. Sci.* **2017**, *2*, 1–40. [CrossRef]
24. Moral-Munoz, J.A.; López-Herrera, A.G.; Herrera-Viedma, E.; Cobo, M.J. Science Mapping Analysis Software Tools: A Review. In *Springer Handbook of Science and Technology Indicators*; Glänzel, W., Moed, H.F., Schmoch, U., Thelwall, M., Eds.; Springer International Publishing: Berlin/Heidelberg, Germany, 2019; pp. 159–185. [CrossRef]
25. Pradhan, P. *Science Mapping and Visualization Tools Used in Bibliometric Scientometric Studies: An Overview*; INFLIBNET Centre: Gandhinagar, India, 2017.
26. Chen, C.; Song, M. Visualizing a field of research: A methodology of systematic scientometric reviews. *PLoS ONE* **2019**, *14*, e0223994. [CrossRef] [PubMed]
27. van Eck, N.; Waltman, L. Software survey: VOSviewer, a computer program for bibliometric mapping. *Scientometrics* **2009**, *84*, 523–538. [CrossRef] [PubMed]
28. Xie, L.; Chen, Z.; Wang, H.; Zheng, C.; Jiang, J. Bibliometric and Visualized Analysis of Scientific Publications on Atlantoaxial Spine Surgery Based on Web of Science and VOSviewer. *World Neurosurg.* **2020**, *137*, 435–442.e4. [CrossRef]
29. van Eck, N.J.; Waltman, L. VOSviewer Manual. Manual for VOSviewer Version, 2011, vol. 1, no 0. Available online: https://www.vosviewer.com/documentation/Manual_VOSviewer_1.5.2.pdf (accessed on 8 May 2023).
30. World Economic Outlook Database, April 2021. IMF. Available online: https://www.imf.org/en/Publications/WEO/weo-database/2021/April (accessed on 20 April 2023).
31. Pavlović, M.; Marković, Z.; Veljković, M.; Buđevac, D. Bolted shear connectors vs. Headed studs behaviour in push-out tests. *J. Constr. Steel Res.* **2013**, *88*, 134–149. [CrossRef]
32. Aye, L.; Ngo, T.; Crawford, R.H.; Gammampila, R.; Mendis, P. Life cycle greenhouse gas emissions and energy analysis of prefabricated reusable building modules. *Energy Build.* **2012**, *47*, 159–168. [CrossRef]
33. Chen, Y.; Okudan, G.E.; Riley, D.R. Sustainable performance criteria for construction method selection in concrete buildings. *Autom. Constr.* **2010**, *19*, 235–244. [CrossRef]
34. Cao, X.; Li, X.; Zhu, Y.; Zhang, Z. A comparative study of environmental performance between prefabricated and traditional residential buildings in China. *J. Clean. Prod.* **2015**, *109*, 131–143. [CrossRef]

35. Aarseth, W.; Ahola, T.; Aaltonen, K.; Økland, A.; Andersen, B. Project sustainability strategies: A systematic literature review. *Int. J. Proj. Manag.* **2017**, *35*, 1071–1083. [CrossRef]
36. Jaillon, L.; Poon, C.S. Life cycle design and prefabrication in buildings: A review and case studies in Hong Kong. *Autom. Constr.* **2014**, *39*, 195–202. [CrossRef]
37. Akanbi, L.A.; Oyedele, L.O.; Akinade, O.O.; Ajayi, A.O.; Davila Delgado, M.; Bilal, M.; Bello, S.A. Salvaging building materials in a circular economy: A BIM-based whole-life performance estimator. *Resour. Conserv. Recycl.* **2018**, *129*, 175–186. [CrossRef]
38. Tam, V.W.Y. On the effectiveness in implementing a waste-management-plan method in construction. *Waste Manag.* **2008**, *28*, 1072–1080. [CrossRef] [PubMed]
39. Hwang, B.-G.; Shan, M.; Looi, K.-Y. Key constraints and mitigation strategies for prefabricated prefinished volumetric construction. *J. Clean. Prod.* **2018**, *183*, 183–193. [CrossRef]
40. Hong, J.; Shen, G.Q.; Mao, C.; Li, Z.; Li, K. Life-cycle energy analysis of prefabricated building components: An input–output-based hybrid model. *J. Clean. Prod.* **2016**, *112*, 2198–2207. [CrossRef]
41. Lu, W.; Yuan, H. Exploring critical success factors for waste management in construction projects of China. *Resour. Conserv. Recycl.* **2010**, *55*, 201–208. [CrossRef]
42. Kamali, M.; Hewage, K. Development of performance criteria for sustainability evaluation of modular versus conventional construction methods. *J. Clean. Prod.* **2017**, *142*, 3592–3606. [CrossRef]
43. Li, C.Z.; Zhong, R.Y.; Xue, F.; Xu, G.; Chen, K.; Huang, G.G.; Shen, G.Q. Integrating RFID and BIM technologies for mitigating risks and improving schedule performance of prefabricated house construction. *J. Clean. Prod.* **2017**, *165*, 1048–1062. [CrossRef]
44. Zhang, X.; Skitmore, M.; Peng, Y. Exploring the challenges to industrialized residential building in China. *Habitat Int.* **2014**, *41*, 176–184. [CrossRef]
45. Mao, C.; Xie, F.; Hou, L.; Wu, P.; Wang, J.; Wang, X. Cost analysis for sustainable off-site construction based on a multiple-case study in China. *Habitat Int.* **2016**, *57*, 215–222. [CrossRef]
46. Hu, X.; Chong, H.-Y.; Wang, X. Sustainability perceptions of off-site manufacturing stakeholders in Australia. *J. Clean. Prod.* **2019**, *227*, 346–354. [CrossRef]
47. Ghisellini, P.; Ji, X.; Liu, G.; Ulgiati, S. Evaluating the transition towards cleaner production in the construction and demolition sector of China: A review. *J. Clean. Prod.* **2018**, *195*, 418–434. [CrossRef]
48. McKenna, R.; Ostman vd Leye, P.; Fichtner, W. Key challenges and prospects for large wind turbines. *Renew. Sustain. Energy Rev.* **2016**, *53*, 1212–1221. [CrossRef]
49. Jiang, R.; Mao, C.; Hou, L.; Wu, C.; Tan, J. A SWOT analysis for promoting off-site construction under the backdrop of China's new urbanisation. *J. Clean. Prod.* **2018**, *173*, 225–234. [CrossRef]
50. Lu, W.; Yuan, H. Investigating waste reduction potential in the upstream processes of offshore prefabrication construction. *Renew. Sustain. Energy Rev.* **2013**, *28*, 804–811. [CrossRef]
51. Wang, J.; Li, Z.; Tam, V.W.Y. Identifying best design strategies for construction waste minimization. *J. Clean. Prod.* **2015**, *92*, 237–247. [CrossRef]
52. Babič, N.Č.; Podbreznik, P.; Rebolj, D. Integrating resource production and construction using BIM. *Autom. Constr.* **2010**, *19*, 539–543. [CrossRef]
53. Telesca, A.; Marroccoli, M.; Calabrese, D.; Valenti, G.L.; Montagnaro, F. Flue gas desulfurization gypsum and coal fly ash as basic components of prefabricated building materials. *Waste Manag.* **2013**, *33*, 628–633. [CrossRef] [PubMed]
54. Ajayi, S.O.; Oyedele, L.O.; Akinade, O.O.; Bilal, M.; Owolabi, H.A.; Alaka, H.A.; Kadiri, K.O. Reducing waste to landfill: A need for cultural change in the UK construction industry. *J. Build. Eng.* **2016**, *5*, 185–193. [CrossRef]
55. Loss, C.; Piazza, M.; Zandonini, R. Connections for steel–timber hybrid prefabricated buildings. *Part I Exp. Tests. Constr. Build. Mater.* **2016**, *122*, 781–795. [CrossRef]
56. Pons, O.; Wadel, G. Environmental impacts of prefabricated school buildings in Catalonia. *Habitat Int.* **2011**, *35*, 553–563. [CrossRef]
57. Pan, W.; Gibb, A.G.F.; Dainty, A.R.J. Strategies for Integrating the Use of Off-Site Production Technologies in House Building. *J. Constr. Eng. Manag.* **2012**, *138*, 1331–1340. [CrossRef]
58. O'Connor, J.T.; O'Brien, W.J.; Choi, J.O. Critical Success Factors and Enablers for Optimum and Maximum Industrial Modularization. *J. Constr. Eng. Manag.* **2014**, *140*, 04014012. [CrossRef]
59. Innella, F.; Arashpour, M.; Bai, Y. Lean Methodologies and Techniques for Modular Construction: Chronological and Critical Review. *J. Constr. Eng. Manag.* **2019**, *145*, 04019076. [CrossRef]