sustainability

Review

Critical Review of Trends in Modular Integrated Construction Research with a Focus on Sustainability

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Abstract: Modular integrated construction (MiC) is an innovative technology that minimizes the adverse impacts of construction not only in terms of material resources, energy consumption and environmental issues but also by reducing construction times and costs. The widespread adoption of these practices could therefore contribute to the construction industry's sustainable development. Despite the increasing public attention of MiC with a number of published works in various aspects, there is still a lack of systematic assessment of its sustainability performance. We therefore reviewed the published literature addressing the sustainability of MiC over the last two decades using a desktop research method integrating a bibliometric search with quantitative and qualitative analyses. Our objective was to investigate, evaluate, and summarize the ongoing research trends for sustainability-related studies in MiC published in leading construction journals to identify promising potential directions for future research. This research is intended to serve as a useful resource for practitioners and researchers seeking to better understand the significance of this outstanding technology as we strive to develop a more sustainable construction environment.

Keywords: modular integrated construction; off-site construction; sustainability; sustainable development; research trends; future direction

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1. Introduction

Over the past few years, the concept of sustainability in construction, or sustainable construction, has become a global concern due to our growing awareness of the adverse effects which the construction industry often has on the environment. These include issues such as (1) virgin land use (e.g., forests, wetlands), which reduces biodiversity and leads to soil degradation; (2) the overexploitation of natural resources, many of which are non-renewable; (3) air and water pollution; (4) excessive water and energy consumption; (5) waste production, and (6) the noise pollution caused by construction activities [1]. In this context, modular integrated construction (MiC) is emerging as a cutting-edge and effective alternative to conventional on-site building methods. The increasing use of this technique is an economically viable way to address many of these issues.

MiC is one of the main off-site construction methods in which separate modules are manufactured under controlled conditions in factories (85–90% of the project work) and then transported to the site for installation to create a completed building [2,3]. In order to provide value-for-money in the construction process, MiC applies the theories of modularity, modularization, design for manufacture and assembly (DfMA), and lean production, benefitting from their numerous environmental, economic, and social benefits to help achieve sustainability goals [4]. Compared to conventional construction methods, in addition to the construction time and cost savings achieved, MiC offers a number of advantages that contribute to sustainability in terms of the material resources required, energy consumption, and environmental issues [5,6]. For example, a study conducted by [7] found that implementing MiC can reduce construction greenhouse gas emissions by 32 kg/m^2, approximately 3.2% below the level that would have been created if conventional methods had been used. In another study focusing on construction materials during the manufacturing phase, an evaluation of the embodied carbon emissions revealed that employing a MiC approach reduced the impact on the environment by roughly 36% compared to its conventional counterpart [8]. Jaillon and Poon [9] found a reduction of 65% (on average) in the construction waste on-site due to the implementation of MiC techniques. Despite its numerous advantages, however, this innovative technology faces many challenges that impede its performance, particularly technical, financial, and organizational barriers [10].

The growing popularity of this construction technique has attracted the attention of researchers, who have examined a number of different aspects of MiC in recent years. There is now an extensive literature on this topic, including studies on associated cost-increasing risk factor in MiC implementation [11], the reductions in greenhouse gas emissions achieved [12], and the benefits and barriers of implementing MiC [13–15]. The huge volume of work published in this field in the last few years highlights the need for a systematic analysis of the literature to identify the key research themes, the contributions made by authors in various countries, and to qualitatively analyze these contributions. Abdelmageed and Zayed [16] made a useful start on such an analysis, assessing the numerous knowledge areas related to MiC by integrating a bibliometric search, a quantitative analysis, and a qualitative analysis. Their paper, published in 2020, identified a number of themes and ongoing trends in MiC research, as well as current gaps that would benefit future research. They proposed six main categories for MiC research, namely building design, management aspects, construction operations, sustainability, information management technologies, and "other", comprising 27.1%, 23.4%, 17.8%, 10.3%, 10.3%, and 11.1%, respectively, of the publications to date.

There have also been numerous papers reviewing specific categories. While some have looked at life cycle performance [17], barriers to the adoption of MiC [10], management of MiC [18], and critical risk factors in MiC applications [19], others have focused on methodologies and techniques [20], MiC applications in high-rise projects [21], and the performance of MiC practices in specific countries, including Malaysia [22], Hongkong [9], China [23], and the United Kingdom [24]. However, none of the extant literature sought to appraise the development of studies related to sustainability in MiC implementations specifically, even though sustainability is a critical factor in the decision-making process for MiC projects [25]. Since the adoption of the United Nation's *2030 Agenda for Sustainable Development* [26], scholars and practitioners have been working to develop sustainable building methods as part of the effort to meet the *Agenda*'s Sustainable Development Goals (SDGs). Surveys of the relevant literature therefore provide snapshots of the state-of-the-art of sustainability in the construction industry at a specific point in time, increasing stakeholders' awareness of the current issues as well as giving practitioners insights into future industry developments and their implications and directing researchers towards potentially fruitful future research areas.

This study therefore aims to systematically summarize the existing literature and present the current trends in MiC research from the perspective of sustainability. We will (1) quantitatively assess the research contributions in MiC studies related to sustainability; (2) develop a bibliometric science map for sustainability-related MiC papers that will include publication statistics, the geographical distribution of papers and authors, countries and journals making significant contributions, cite relevant papers, and examine authorship patterns, and (3) provide a research framework that addresses the research gaps identified between existing MiC papers in specific areas and propose directions for future research that will support and enhance the sustainability of MiC. Our ultimate objective is to expand the knowledge of academics in the field and encourage practitioners to appreciate the sustainable contribution to be gained by implementing this innovative approach more widely for construction projects. By providing a comprehensive overview of the current research trends in MiC research related to sustainability, we hope to guide researchers' future study orientations by signposting the way forward.

2. Methodology

Systematic literature reviews are an effective scientific approach that involves synthesizing knowledge for a specific study subject utilizing a systematic and objective process [27]. It plays an important role, yielding insights into the status of research on a particular topic, identifying knowledge gaps and generating recommendations for future research [28]. Using a method recommended by previous researchers [16,29], MiC research papers related to sustainability published from 2000 to 2021 were retrieved and analyzed to identify current research trends and the main research interests related to sustainability of MiC. Despite the fact that MiC has been employed since the 1960s, MiC- related research has only gained traction in the turn of the century [16]. In addition, after being initially presented in 1994, the definitions and framework for sustainable construction implementation were more strictly established in the 1999 Agenda 21 by International Council for Research and Innovation in Building and Construction (CIB) [30]. Research on the sustainability in construction has consequently gained increasing attention since 2000. Therefore, the last two decades have been chosen as the timeframe for the analysis. The methodology adopted consisted of three steps: (1) paper selection; (2) quantitative analysis, and (3) qualitative analysis (Figure 1).

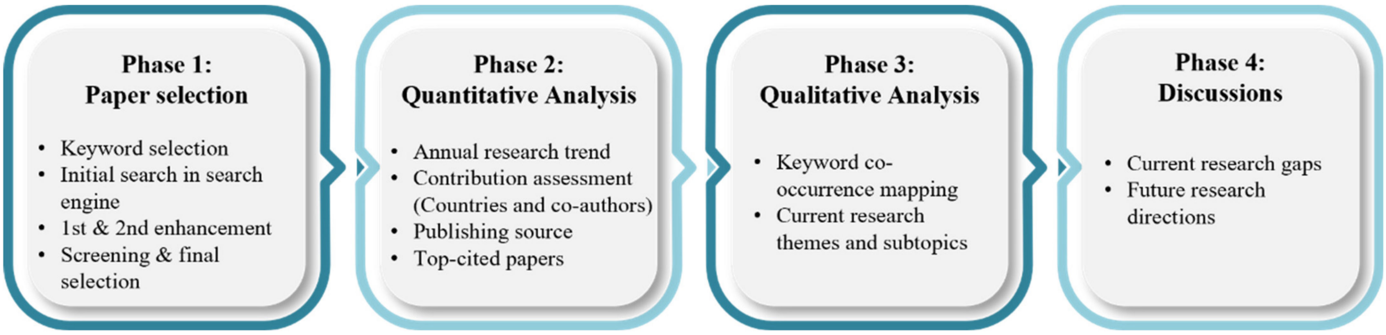

Figure 1. Research stages.

2.1. Paper Selection

To improve the coverage of the included studies in a systematic literature review, a variety of relevant databases are normally used [31]. However, here, Scopus was the sole search engine due to its wide coverage, high accuracy, and the ease with which structured queries could be constructed compared to alternative literature databases such as Google Scholar, Web of Science, and the ASCE library [32–34].

To find the required literature, a set of keywords were utilized to perform a comprehensive desktop search using the title/abstract/keywords to find relevant papers. Keywords were selected by skimming articles to find the proper terms and phrases, as well as those to avoid. The initial search keywords used to capture all MiC-related papers were as follows:

TITLE-ABS-KEY ("modular construction" OR "modular integrated construction" OR "MiC" OR "modular building" OR "prefabricated modular building" OR "prefabricated prefinished volumetric construction" OR "PPVC" OR "modular home" OR "modular building system" OR "prefabricated modular unit" OR "industrialized building system" OR "IBS" OR "offsite construction" OR "off-site construction" OR "prefabricated" OR "prefab" OR "pre-fab" OR "prefabricated construction" OR "pre-fabrication" OR "prefabrication" OR "pre-fabricated" OR "preassembly" OR "pre-assembly" OR "pre-assembled" OR "preassembled" OR "on site assembly" OR "on-site assembly").

To limit the search to MiC research, specifically sustainability, an additional section was added:

AND TITLE-ABS-KEY ("Sustainable Construction" OR "Sustainable Building" OR "Green Building" OR "Construction Sustainability" OR "Green Technology" OR "Green Technologies").

The following code was also added to specify the year of publication, the intended area, and the type and language of documents:

AND PUBYEAR > 2000 AND (LIMIT-TO (SUBJAREA, "ENGI") OR LIMIT-TO (SUBJAREA, "ENER")) AND (LIMIT-TO (DOCTYPE, "ar") OR LIMIT-TO (DOCTYPE, "cp") OR LIMIT-TO (DOCTYPE, "re")) AND (LIMIT-TO (LANGUAGE, "English")).

For the period 1 January 2000 to 30 September 2021, the search uncovered 452 Scopus records, although this included some unrelated publications despite these restrictions. Manual screening to limit the results to the intended area of study was therefore needed. The title, abstract, and in some cases, the full paper was examined to ensure that unrelated documents were removed, thus increasing confidence in the results of the analysis. Ultimately, 85 documents were found to be suitable for inclusion (Figure 2).

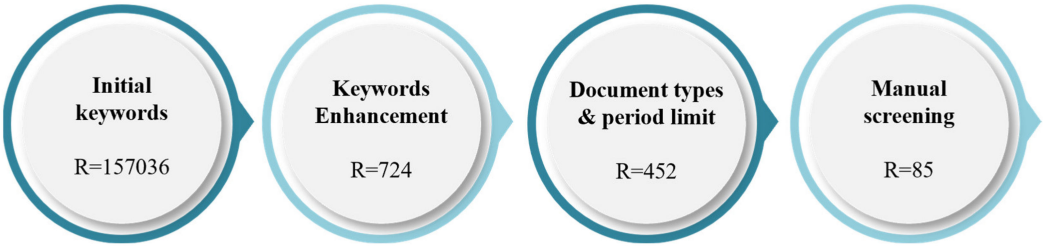

Figure 2. Results of each search step.

2.2. Quantitative Analysis

The next step was to perform the statistical evaluation of the bibliometric features in the retrieved literature. There were 85 documents extracted to serve as the input. The paper distribution based on the year of publication was analyzed to indicate the growth and trends in MiC research on sustainability. The contribution of researchers located in individual countries to each research field were examined to determine each country's industrial practice and technologies progress on that subject [35]. Statistical studies of journals, top authors, research locations, and most cited articles were all conducted.

To determine the co-authors' and countries' contributions to MiC research in the field of sustainability, the formula developed by Howard, Cole [36] was adopted. This formula has also been used by other researchers conducting similar research reviews to identify research trends in green building (GB) construction [29], management of MiC [18], and construction partnering practices [35]. The proposed equation is shown in Equation (1) below:

$$Score = \frac{1.5^{n-1}}{\sum_{i=1}^{n} 1.5^{n-i}} \quad (1)$$

where n denotes the number of authors and i denotes the order in which they appear. Using this approach, the author credits in a multi-authored work are proportionally distributed. Table 1 presents a detailed score matrix for the authors, assigned from one point of each paper. The resulting matrix was used to analyze the contributions of authors and their countries to MiC research on sustainability over the study period.

Table 1. Score matrix for a sample multi-authored paper.

	Order of Specific Co-Authors				
	1	**2**	**3**	**4**	**5**
1	1.00				
2	0.6	0.4			
3	0.47	0.32	0.21		
4	0.42	0.28	0.18	0.12	
5	0.38	0.26	0.17	0.11	0.08

This method identifies the top contributors to a particular research field, enabling researchers to trace the achievements of previous contributors and assisting them to assess their contributions to advancing research in the area of interest based on their findings. In addition, by utilizing VOSviewer, a text-mining software tool, bibliometric maps of scientific research fields were generated to make full use of the bibliographical data, keywords, and citations.

2.3. Qualitative Analysis

The aim of this analysis was to provide insights into the research pattern of MiC studies related to sustainability by reviewing relevant MiC research papers selected utilizing the method discussed above, rather than to analyze the entire population of MiC- related studies. It is therefore critical to keep in mind that the findings reported here are obtained from a very specific research paper sample space. The chosen sample is comprised of three types of documents: articles (56.5%), conference papers (35.3%), and review papers (8.2%). Conference papers are included by reason of their impact on the qualitative measure of keyword occurrence, which reflects the sample and trends in the literature, and therefore supports a deeper understanding of MiC research [37]. To achieve this, a bibliometric map of keyword co-occurrences created by VOSviewer version 1.6.17 was used for topic clustering. VOSviewer is a software application developed by Van Eck, N.J. and Waltman, L. in Netherlands to create and visualize bibliometric networks. Documents from these clusters were then examined and summarized in order to complete the categorization and feed into an in-depth discussion of the research themes identified and reveal any knowledge gaps. A research framework was then developed to highlight future research directions and assist researchers, as well as contribute to the body of knowledge.

3. Quantitative Analysis

Research publications are a major pathway that enable researchers and academic institutions to affect industrial practice [38]. The relevance of the geographical distribution of the research being reported in these publications is based on our belief that the quantity of academic publications on a specific subject in a country is likely to reflect how far industrial practice and innovations advance on the subject in that country [35]. Figure 3 shows the number of annual MiC research publications globally that are related to sustainability over the two decades from 2000 to 2021.

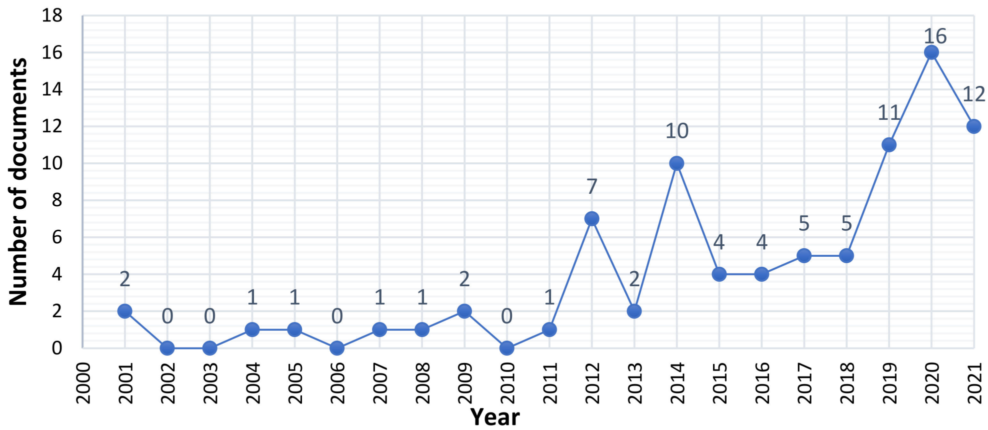

Figure 3. Annual publication trend of MiC research related to sustainability.

Although there is some fluctuation in the number of papers from year to year, there is generally a significant upward trend over the years. This pattern reflects the way that sustainability in MiC research is attracting more attention from academics. The graph shows that few studies on the sustainability of modular construction were published until 2012, when there was a sudden spike in the number of papers published. This can be explained by the fact that sustainability as a concept was just beginning to emerge during that period. Additionally, the adoption of SDGs might also be considered as a partial influence on this tendency. In fact, the Sustainable Development Goals (SDGs) originated as a result of the Rio 20+ United Nations Summit in 2012, before being formed with the Agenda 2030 and officially approved by the leaders of 193 nations in 2015 [39]. Following the endorsement of the agenda, a significant number of publications have examined, analyzed, and in some cases, criticized the SDGs in terms of their local application and usage as a framework for industries and economic sectors [40]. This may partly explain why the figures then leveled off in the four years from 2015 to 2018, albeit at a higher level, before rising sharply to reach a peak of 16 papers in 2020. This trend was accelerating; 12 papers had already been published by the end of July 2021, with more papers expected by the end of that year. This is unsurprising, given that sustainability is now a topic of concern in countries around the world due to our growing awareness of the importance of environmental issues and global climate change [29]. To summarize, the results show that interest in MiC research related to sustainability has increased considerably in the second decade compared to the first decade of the twenty-first century, indicating that the sustainability of MiC is becoming more significant to the worldwide construction industry.

3.1. Sources That Publish MiC Research Related to Sustainability

Identifying the sources that publish research related to sustainability was the first objective for the scientometric analysis. Table 2 presents a list of the 14 sources with the highest number of documents and citations. Looking at Table 2, the *Journal of Cleaner Production* has published the most research papers, with a total document count of 8 found by the Scopus search engine, followed by *Sustainability (Switzerland)* with the second highest number of papers of 7; *Energy and Buildings* was third, with 4 papers.

Table 2. Sources of publishing MiC research work related to sustainability.

Sources	Documents	Cited By
Journal of Cleaner Production	8	225
Sustainability (Switzerland)	7	21
Energy and Buildings	4	336
Proceedings of the Institution of Civil Engineers: Engineering Sustainability	3	11
IOP Conference Series: Earth and Environmental Science	3	1
Construction Management and Economics	2	208
Building and Environment	2	116
Procedia Engineering	2	50
Journal of Green Building	2	33
Research Journal of Applied Sciences, Engineering and Technology	2	9
E3S Web of Conferences	2	6
Malaysian Construction Research Journal	2	5
IOP Conference Series: Materials Science and Engineering	2	1
Proceedings—FIB-Symposium on Concrete and Environment 2001	2	-

In terms of the number of citations, papers in the *International Journal of Sustainable Construction Engineering and Technology* were the most often cited, at 336, with the *Journal of Cleaner Production* ranked second, at 225, followed by *Construction Management and Economics*, where 2 highly influential papers had been cited 208 times. This finding is a clear indicator reflecting the quality and impact of specific journals for MiC research work related to sustainability that will serve as a useful reference list to guide scholars searching for relevant papers in this field.

3.2. Countries That Are Actively Engaged in MiC Research Related to Sustainability

Research papers and reports are one of the most important ways for researchers and academic institutions to influence industrial research and development (R&D) [38]. The quantity of papers published reporting research on a given topic in a country or region should thus provide a good indication of how far that country or region's industrial practice and innovations have progressed in that field [35]. We therefore examined the research contribution of each to acquire an overview of the current status of sustainability in MiC practices in specific countries or regions.

The research contribution of each country or region was calculated by accumulating the scores for each author engaged in MiC research related to sustainability working in that country or region. Equation (1) was utilized to calculate a numerical score representing each researcher's contribution. Table 3 summarizes the results of the calculations of the origins of the papers identified, together with the total numbers of documents, citations, and researchers involved. Only countries having more than two documents are presented in Table 3 below.

Table 3. Countries of origin of researchers publishing MiC research papers related to sustainability.

Country	Documents	Citations	Score	Number of Researchers
Malaysia	15	161	13.9	48
China	15	145	12.21	34
Australia	13	424	9.37	22
Canada	8	382	8	12
Hong Kong	9	342	6.82	13
United States	7	179	6.28	16
United Kingdom	7	107	4.7	13
Italy	4	35	3.21	13
Iran	3	7	1.3	2
Czech Republic	2	3	2	7
Germany	2	1	2	5
Greece	2	0	2	9
Spain	2	1	2	4
India	2	12	1.77	5

Interestingly, these results show that researchers in both developed and developing countries are working on MiC-related research, confirming that sustainability in MiC is a global concern. Malaysia, China, and Australia consistently published the most MiC papers related to sustainability in the selected journals throughout the study period, with scores of 13.9, 12.21, 9.37 and 15, 15, 13 documents, respectively. Taken together, these countries have contributed as many papers on MiC research related to sustainability than all the other countries combined. Developing countries like Malaysia and China have shown a significant interest in promoting MiC research in the field of sustainability. Since modular development has only become a priority in recent years in these countries, they receive lower numbers of citations than other developed countries even though they are clearly the largest contributors to MiC research during the study period.

When calculating the number of citations, however, research papers from Australia were cited the most, with 424 citations, followed by Canada and Hong Kong, with 382 and 342, respectively. Remarkably, the top influential countries identified in our analysis, namely the USA, Canada, Australia, the United Kingdom, China, and Malaysia, were the same as that reported in a recent literature review of research on MiC, even though different attributes were selected for each ranking [16]. This supports the reasonableness of our research findings.

3.3. Top Cited MiC Research Papers Related to Sustainability

When an existing perspective is presented, the authors are advised to cite their sources for the assertions and opinions expressed. Citing a relevant paper provides evidence to support their argument [18]. The citation index is thus becoming a critical tool for assessing the impact of research articles [35]. According to the analysis, a 2012 paper by Aye et al. entitled "Life cycle greenhouse gas emissions and energy analysis of prefabricated reusable building modules" [41] was identified as the most cited document, with 218 citations within the study period. A 2008 paper by Jaillon and Poon [42] that focused on promoting sustainable construction aspects of prefabrication in dense urban environment, achieved the second highest number of citations, at 190, followed by a 2016 paper by Kamali and

Hewage [17] entitled "A systematic review on life cycle performance of modular buildings", with 150 citations. Literature reviews and case study analyses were the most popular research methodology of the most often cited MiC papers about sustainability; a list of these top-cited MiC papers related to sustainability and the research methodologies utilized by each article are presented in Table 4.

Table 4. Top-cited MiC research papers related to sustainability.

Source	Title	Year	Citations	Research Methodology
[41]	Life cycle greenhouse gas emissions and energy analysis of prefabricated reusable building modules	2012	218	Case study analysis
[42]	Sustainable construction aspects of using prefabrication in dense urban environment: A Hong Kong case study	2008	190	Questionnaire survey and case study analysis
[17]	Life cycle performance of modular buildings: A critical review	2016	150	Systematic document analysis
[43]	Effects of lean construction on sustainability of modular homebuilding	2012	96	Case study analysis
[44]	Measuring the impact of prefabrication on construction waste reduction: An empirical study in China	2014	84	System dynamics (causal-loop diagram and stock-flow diagram)
[45]	Development of performance criteria for sustainability evaluation of modular versus conventional construction methods	2017	83	Interview and questionnaire survey
[46]	Sustainability perceptions of off-site manufacturing stakeholders in Australia	2019	80	Qualitative content analysis
[47]	Assessment of embodied energy and global warming potential of building construction using life cycle analysis approach: Case studies of residential buildings in Iskandar Malaysia	2015	76	Life cycle assessment
[48]	Sustainability and resiliency metrics for buildings—Critical review	2016	71	Literature review
[49]	Life cycle sustainability performance assessment framework for residential modular buildings: Aggregated sustainability indices	2018	45	Analytic Hierarchy Process (AHP) and multi-criteria decision analysis (MCDA)
[50]	Critical sustainability factors in industrialised building systems	2012	36	Literature review, survey, and statistical data analysis
[51]	Sustainability criteria for Industrialised Building Systems (IBS) in Malaysia	2011	35	Literature review
[52]	Environmental impact of industrial prefabricated buildings: Carbon and Energy Footprint analysis based on an LCA approach	2014	33	Life cycle assessment, case study analysis
[53]	Using life cycle assessment methods to guide architectural decision-making for sustainable prefabricated modular buildings	2012	33	Life cycle assessment, case study analysis
[54]	Lean principles for prefabrication in green design-build (GDB) projects	2005	30	Literature review and case study analysis

4. Co-Author Contributions

Table 5 presents a list of the most active authors working on sustainability in the context of MiC. As mentioned earlier, the formula takes into account both the specific order in which the authors are listed and the number of authors. The threshold was set at two documents where a researcher was included as a co-author. Twenty authors met this requirement. M. Kamali, at the University of British Columbia in Canada, and R. Yunus at the Universiti Tun Hussein Onn Malaysia are the authors with the highest contributions to sustainability-related MiC research, with a score of 2.74, followed by K. Hewage, who co-authored five papers with Kamali as second author, achieving a score of 1.84. R. Rostami from Malaysia, J. Yang from Australia, and X. Hu from Australia also gained contribution scores of more than 1.0. This is not unexpected because Canada, Malaysia, and Australia are included among the top countries that contributed most of the relevant papers included in this analysis. Furthermore, it is worth noting that the impact of a particular author may be measured by the number of citations their research papers attract. For instance, Hewage and Kamali earned a total of 307 citations, while the two papers written by Aye were cited 219 times. This result could be useful for individuals interested in MiC research and sustainability as it could help them develop helpful collaborations for future research opportunities.

Table 5. Analysis of co-author contributions.

Author	Country	Affiliation	Documents	Citations	Score
Kamali M.	Canada	University of British Columbia	5	307	2.74
Yunus R.	Malaysia	Universiti Tun Hussein Onn Malaysia	5	90	2.74
Hewage K.	Canada	University of British Columbia	5	307	1.84
Zayed T.	Hong Kong	The Hong Kong Polytechnic University	4	31	0.83
Khoshnava S.M.	Malaysia	UTM Construction Research Center	3	11	0.88
Lamit H.	Malaysia	Centre for the Study of Built Environment in the Malay World (KALAM)	3	11	0.52
Rostami R.	Malaysia	Center for the Study of Built Environment in the Malay World (KALAM)	3	11	1.12
Yang J.	Australia	Queensland University of Technology	3	89	1.2
Abdelmageed S.	Hongkong	The Hong Kong Polytechnic University	2	9	0.7
Aye L.	Australia	The University of Melbourne	2	219	0.7
Chong H.-Y.	Australia	Curtin University	2	82	0.72
Dave M.	Australia	UNSW Australia	2	16	0.84
Hu X.	Australia	Deakin University	2	82	1.07
Hussein M.	Hong Kong	The Hong Kong Polytechnic University	2	1	0.45
Li Z.	Hong Kong	The Hong Kong Polytechnic University	2	93	0.26
Pan W.	Hong Kong	The University of Hong Kong	2	28	0.61
Prasad D.	Australia	UNSW Australia	2	16	0.28
Shen G.Q.	Hong Kong	The Hong Kong Polytechnic University	2	84	0.64
Teng Y.	Hong Kong	The University of Hong Kong	2	28	0.92
Watson B.	Australia	UNSW Australia	2	16	0.43

4.1. Keyword Repetition Analysis

Van Eck and Waltman [55] contended that keywords are the foundation of all core study subjects in the academic literature. A bibliometric analysis may disclose a subject's knowledge structure through a statistical study of the most often occurring terms in the existing literature, since author and index keywords reflect the most valuable information included in the articles [56]. It can also identify the limits of knowledge in the study domain, as well as providing correlations and trends between research areas [16]. A thorough examination of the most frequently mentioned keywords might be sufficient to identify the prominent research frontiers in a particular subject [57].

Table 6 presents the statistical details for the most active keywords in the papers published on sustainability and MiC. Here, the link determined the network's complexity among keywords and the total link strength indicated the interrelatedness of the keywords. The keyword mapping utilized VOS Viewer's keywords' co-occurrence analysis (Figure 4); the occurrence threshold, which was set to 2, identified 32 relevant keywords out of the 211 considered. "Sustainability" was the most repeated keyword, followed by "Prefabrication" and "Offsite Construction". While these keywords reflect the major usage found in the literature, less frequently repeated keywords covered more tightly focused knowledge topics. Total link strength was then considered to identify relevant subfields and research issues. For instance, keywords that identified specific subjects in MiC research, such as "Life cycle assessment (LCA)", "Bench marking", "Green construction", "Life cycle performance", and "Sustainability criteria", scored total link strengths of 14, 10, 9, 8, and 6, respectively. Broader research themes identified in the literature will be discussed in the next section.

Table 6. Analysis of keyword repetitions.

Label	Cluster	Links	Total Link Strength	Occurrences	Avg. Pub. Year	Avg. Citations	Avg. Norm. Citations
Sustainability	6	22	50	32	2016	19.8	0.8
Prefabrication	1	9	16	12	2016	46.9	1.1
Off-site construction	8	8	16	9	2018	42.6	1.4
Modular construction	2	11	21	8	2018	42.9	2.5
Industrialized building systems (IBS)	5	9	15	8	2016	17.1	0.8
Life cycle assessment (LCA)	3	11	14	6	2017	52.0	1.8
Sustainable construction	1	5	7	5	2016	39.2	0.5
Malaysia	4	6	12	4	2014	7.3	0.5
Sustainability assessment	1	7	8	4	2020	9.5	0.6
Benchmarking	2	7	10	3	2018	24.7	1.7
Green construction	4	5	9	3	2014	4.7	0.2
Construction	1	5	5	3	2018	1.3	1.1
Modular building	3	4	5	3	2016	19.0	0.7
Embodied energy	5	3	3	3	2017	75.7	1.5
Modular integrated construction	7	2	3	3	2021	3.0	1.2
Prefabricated buildings	3	2	2	3	2018	11.3	1.1
Life cycle performance	2	7	8	2	2017	97.5	2.9
Construction industry	4	6	7	2	2017	2.0	0.1
Sustainability criteria	2	5	6	2	2018	64.0	3.6
Sustainability indicators	2	4	6	2	2018	23.0	1.6
Guidelines	1	3	4	2	2020	0.5	0.0
Housing	1	2	4	2	2019	7.5	0.4
Conventional construction	2	3	4	2	2019	42.0	2.7
Industry 4.0	1	3	3	2	2021	0.5	0.7
Energy efficiency	3	3	3	2	2017	17.0	1.0
Sensitivity analysis	3	2	3	2	2018	39.5	2.2
Case studies	7	3	3	2	2021	11.5	3.6
Lean construction	8	2	3	2	2012	50.5	0.9
Modular design	2	2	2	2	2014	6.5	0.4
Energy	6	1	2	2	2016	5.5	0.9
Stakeholders	6	1	2	2	2016	58.0	3.0
Prefabricated construction	5	1	1	2	2020	5.5	0.6

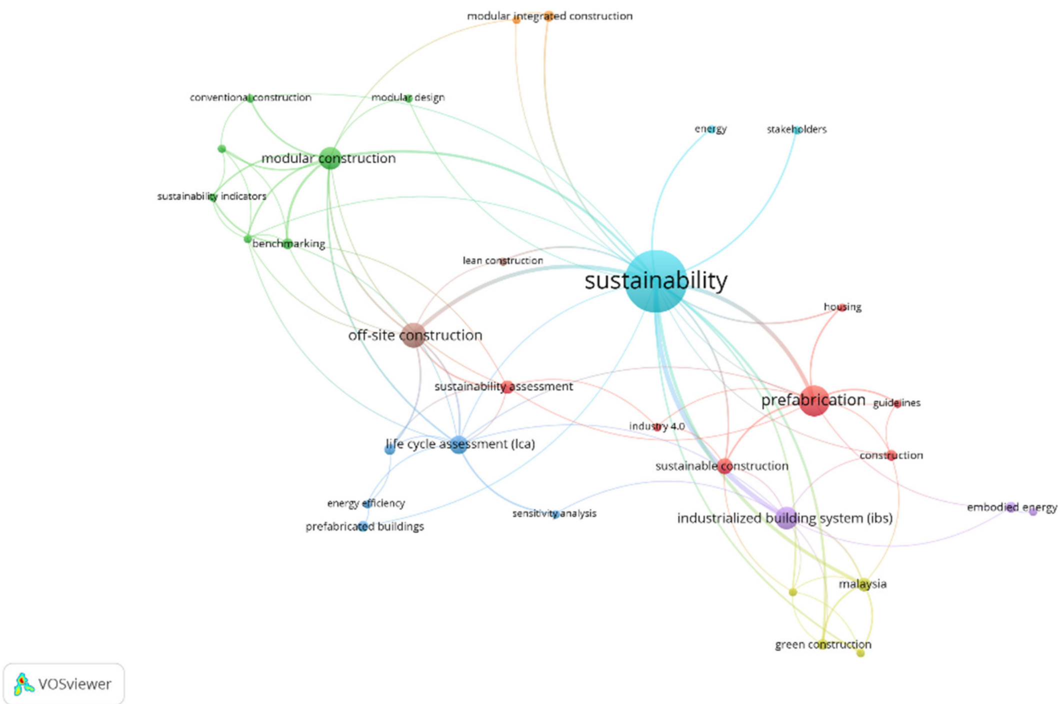

Figure 4. Bibliometric map of keyword co-occurrence, constructed using VOS viewer.

5. Qualitative Analysis

Sustainable development has long been a topic of interest for researchers in many different fields. For those working on MiC, sustainability is an important focus, accounting for 10.3% of the papers published, comparable to the numbers published on construction operations, building design, management aspects, and information management technologies [16]. This section presents the thematic analysis conducted to identify the current trends in MiC research from the perspective of sustainability.

The keyword co-occurrence map in Figure 4 contains eight clusters, which represent domains that are conceptually related. Based on this result and an additional quality analysis, the themes of interest in current MiC research related to sustainability were categorized and the results are presented in Table 7. Four main categories of research were identified, namely: (1) sustainable operation of MiC; (2) advanced technology for MiC; (3) sustainability assessment, and (4) energy performance.

Table 7. Main categories of MiC research related to sustainability.

Research Topics	Sub-Topics	Percentage of Papers (%)
Sustainable operation of MiC	Sustainable benefits and challenges of MiC, Critical factors influencing sustainable construction capability of MiC, Combination of GB and MiC, Potential contribution of MiC to sustainable construction practices	42 (49.4)
Sustainability assessment	Life Cycle Assessment comparison of MiC and conventional methods, Sustainability factors to assess MiC, Embodied carbon/carbon footprint evaluations, Environmental impact assessments, Sustainability assessment frameworks for MiC	29 (34.1)
Advanced technology for MiC	Green building technologies for MiC, Modular components with sustainable performance, Optimization of modular component, Efficiency evaluation of modular components in construction, Sustainable design strategies for MiC	8 (9.4)
Energy performance	Energy consumption assessments, Energy efficiency evaluations, Embodied energy comparisons of MiC and conventional methods	6 (7.1)

5.1. Sustainable Operation of MiC

The majority of the documents examined focused on the sustainable operation of MiC, with 42% of papers falling under this area. The literature in this theme covers a wide range of sub-topics that fundamentally center on problems related to the implementation and development of MiC projects. These studies were particularly interested in investigating the factors and perspectives that potentially encourage or impede MiC usage, such as sustainable building performance, sustainability factors that affect the ability to successfully implement MiC applications, and potential combinations of MiC and GB approaches.

A number of studies promoted the sustainable benefits of MiC when compared to traditional construction methods [13,42,58,59], while others identified the obstacles hindering MiC implementations to support green and sustainability objectives [60,61]. For instance, Nahmens and Ikuma [43] examined the effects of MiC on different dimensions of sustainability, highlighting the way this construction method had a significant positive environmental impact by reducing material waste by 64%, a considerable social impact by avoiding unnecessary critical safety hazards such as excessive force, bad posture, and struck-by incidents, and a considerable economic effect by cutting production hours by 31%. Kamali and Hewage [17] conducted a critical review on the benefits and challenges of MiC, focusing specifically on the excellent environmental performance of modular facilities over their life cycle. MiC buildings were found, on average, to deliver a better life cycle performance, especially for features such as a building's energy performance.

To demonstrate the sustainable benefits of this type of construction, several case studies conducted analyses of individual projects, including "The Stack" in Korea [4], an adaptable modular sustainable commercial building "Co2nverse" in Europe [62], and a modular LEED gold building in Long Beach, California [63]. A comprehensive list of sustainability factors impacting MiC implementation developed by Saleh and Alalouch [64] indicated that environment-related factors were commonly regarded as the most important factors, followed by implementation-related factors and social-related factors, with economic-related factors being considered the least important.

MiC practice that hindered MiC implementations included cost issues, policy issues, the lack of expertise and/or knowledge, and a general lack of understanding about green and sustainable issues, in descending order of importance [65]. Despite such obstacles, the wider adoption of MiC is still expected to be a key technology in the future as the construction industry comes under more pressure to achieve sustainability goals [59]. Various studies have explored the factors that are critical for successful MiC implementations that support green practices and sustainability. Research by Hu, Chong [46] indicated that stakeholders' perceptions regarding the sustainability of MiC encompass social, environmental, and economic sustainability dimensions, with "high quality", "customer-focused approach and customization", "cost effectiveness and affordability", and "innovation" being the most frequently mentioned. Similarly, the same concerns related to the Triple Bottom Line (TBL) involved 18 sustainable factors for MiC implementation and their interrelationships, as identified in a study by Yunus, Hamid [66]. They noted that support from the authorities' efforts was a vital preliminary step in projects seeking to adopt sustainable practices for MiC applications in Malaysia. Moreover, Dang, Niu [60] concluded that construction enterprises should focus on prefabricated construction business scope expansion, improving project delivery quality, supporting technology investment and innovation, and boosting the return on investments in technology to enhance industry's practitioners' ability to undertake sustainable MiC projects.

The potential combination of MiC and Green Building (GB) was mentioned in several papers. Tang [67] discussed the comprehensive implementation of BIM in green construction for MiC, identifying four important aspects, namely scheme optimization design, construction layout, construction management, and energy saving and control cost. A GB modular system consisting of 18 modules divided across various system elements was suggested by Bai [68] for optimizing the design process and reducing the need to repeat work, as well as facilitating and adjusting elements of a scheme in a timely manner, thanks to foreknowledge regarding the rate of economy and technology. Moreover, to emphasize the synergies to be gained by combining the principles of MiC and GB, a project for a modular LEED Gold office building was developed [63]. The study described the project's attempt to provide a "lean and green" model for design and construction that not only fulfills the modularity and LEED Gold requirements but is also feasible from a cost perspective. This is a particularly useful case study for those in the construction industry seeking to implement lean and green practices.

5.2. Sustainability Assessment

Sustainability assessments of MiC projects have received a lot of attention from researchers. Most studies have focused on assessing the greenhouse gas (GHG) emissions associated with MiC, as these are responsible for serious environmental issues such as global warming and ozone depletion. For example, a study by Ma, Sun [69] indicated a likely reduction of carbon intensity due to MiC. They employed a hierarchical fuzzy comprehensive evaluation based on Analytic Hierarchy Process (AHP) to construct a science-based, reasonable evaluation model with which to measure the overall carbon emission of MiC buildings. They developed an evaluation index system for analyzing the carbon emissions of MiC buildings for three construction phases, namely, production in plants, logistics transportation, and assembly construction. Applying their new model to a case study of a project in Zhengzhou City, Henan Province, identified a moderate level of carbon emissions, with an evaluation score of 0.45. They also proposed a number of emission-cutting strategies, including expanding the building industry's market scale, optimizing the usage of building materials, establishing special funding for MiC buildings, and enhancing MiC monitoring. Other studies have reported quantitative assessments conducted to directly compare the carbon emissions between MiC and conventional construction methods.

Generally, most of these studies found that MiC reduces carbon emissions significantly compared to their conventional counterparts, with MiC buildings reducing carbon dioxide equivalent emissions by 30% [70], 46.9% [12], 11% [52], and 42.76% [71]. For instance, in a case study conducted in a developing country by Pervez, Ali [12], MiC accounted for a total of 3449.73 kg CO_2-equivalent GHG emissions, while its conventional counterpart resulted in a total of 6501.91 kg CO_2-equivalent GHG emissions, so MiC resulted in a reduction of 3052.19 kg CO_2-equivalent GHG emissions (46.9%). This is one of several case studies that suggested that MiC is more environmentally friendly than conventional construction, which represents important information for those seeking to reduce the construction industry's global carbon footprint.

Several researchers have sought to define an ecological footprint to benchmark the sustainability of MiC buildings and components [72]. The objective here was not only to assess the associated CO_2 emissions but also to provide a comprehensive estimate of the resources and energy from the prefabricated process life cycle. Similarly, Lim, Yahya [73] estimated the amount of GHG based on materials and resources created for a MiC structure to be 0.127 tons of fossil CO_2 Eq per square meter of floor area. This can be used to calculate the carbon footprint of other MiC constructions with comparable attributes simply by multiplying the total build-up area by a factor of 0.127 tons of fossil CO_2 Eq.

Life cycle assessment (LCA) and life cycle impact assessment (LCIA) are effective tools that are now being widely utilized to assess the sustainability of building projects. In an LCIA comparative study on the MiC method for different structures, particularly those involving steel and concrete [74], the results indicate that steel construction produces higher emissions (9623.13 kg CO_2 Eq) than comparable concrete structures (8264.03 kg CO_2 Eq) in the GHG category. However, the same study found that steel MiC reduced emissions compared to concrete MiC in non-renewable energy measures by roughly 37%, in respiratory inorganics by 38%, in land occupation by 43%, and in mineral extraction by 40%. A comparative LCA analysis for material and construction stage of residential apartment complexes in Iskandar Malaysia to determine the life cycle impact assessment between MiC and conventional concrete cast in situ, [47] revealed that conventional concrete cast in situ has a higher global warming potential (GWP) than MiC, with the difference being 11.7% and 20.42% in the material and construction stage, respectively. These differences are considerable, especially for the construction stage, at least partly because MiC requires less time to build than cast-in-place structures, which has a direct impact on the total impact of GWP on the environment. However, a comparative LCA study on three single-family dwellings (one conventional and two modular) [75] revealed that neither modular nor conventional construction methods are the complete answer for environmentally friendly construction. These findings demonstrate that implementing techniques such as optimal designs, and reductions in material and labor transportation for both modular and conventional building projects, as well as an increase in the yearly production of modular manufacturing facilities, can improve the construction industry's environmental performance.

The process of picking an appropriate construction method among the various alternatives for a specific building project is still far from straightforward, since the overall environmental trade-offs offered by each of these construction methods remain unclear. Challenges remain due to issues such as implicit system boundaries; inconsistent methods, models, and units, and limited accountability [76]. Given these concerns, various systems have been developed in an effort to enhance sustainability performance assessment throughout the construction life cycle, including sustainability assessment frameworks [49,77], sustainability assessment models [78,79], and sustainability performance criteria [45,51]. Sustainability assessment of building systems themselves as components of the entire building have also been proposed [80,81]. For instance, a sustainability evaluation criterion proposed by Kamali and Hewage [45] sought to distinguish between the sustainability of modular and conventional construction methods, examining 33 sustainability performance indicators based on three TBL sustainability categories, i.e., environmental, economic, and social, that were identified and rank assessed by construction professionals. Their findings can help construction industry experts develop a thorough understanding of the most applicable TBL sustainability criteria for their project, balanced over the projected life cycle to support sustainable construction. In a later study, Kamali, Hewage [49] took this further, proposing a step-by-step framework as a methodology to estimate the overall sustainability performance indices of individual residential buildings. These sustainability performance criteria were developed and analyzed using AHP multi-criteria decision analysis and the Elimination and Choice Translating Reality (ELECTRE) method. They concluded by utilizing the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) and validating a case study to deliver a more practical benchmarking approach. Despite limitations in sample size and the limited number of case studies examined, the guidelines in this study established a useful starting point for the residential modular building benchmarking process.

Likewise, Liu and Qian [78] developed a theoretical model based on life cycle sustainability assessment (LCSA) that combined environmental life cycle assessment, life cycle cost analysis, and social life cycle assessment. Their integrated AHP-ELECTRE approach was designed to tackle issues related to comparing and ranking numerous decision-making alternatives. A comparative case study analysis of three building structural designs presented to indicate the feasibility of the proposed LCSA model concluded that a semi prefabricated design was the best alternative in terms of the sustainability level achieved followed by MiC-based design, with conventional construction coming in last. In this investigation, MiC did not achieve the highest ranking as expected due to its immature market and the consequent increase in costs and energy consumption during the construction process.

Other MiC research related to sustainability assessment focused on measuring other environmental indicators such as waste generation, waste disposal [44], and interior microclimate [82]. These studies play an important role in enhancing stakeholders' understanding of MiC's potential and its relevance to sustainability, as well as providing guidelines for incorporating sustainability issues and concepts into MiC implementations.

5.3. Advanced Technology for MiC

To enhance the sustainability of MiC construction, several advanced technologies and strategies have been investigated by various researchers. Key technologies for MiC towards GB were proposed by Li [83] with the goal of providing a point of reference for the future development of MiC technologies. These comprised: (1) establishing a model guide system, (2) logistics management technology for prefabricated components, and (3) high-precision quick-release combined formwork construction. Dave, Bilbao [84] utilized AccuRate Sustainability, Australia's national benchmark software tool, in an iterative process to create optimal designs for various orientations and climate zones in Australia. This study investigated the process of enhancing the performance of an existing design as well as generating a thermally optimized new design, demonstrating that an integrated design approach that strategically incorporates flexibility and economically rationalizes redundancy in the type, amount, and placement of shading, glazing, and insulation which can result in a resilient overall design solution. With significantly improved results for thermal performance when compared to existing designs, this study shows the potential for a more holistic approach to net zero energy and self-sufficient modular dwellings.

In terms of modular building components, Naji et al. [85] conducted a multi-objective optimization investigation of building envelopes to better understand the impacts of envelope components on energy performance and indoor environmental quality, with the aim being to create a more sustainable building by minimizing objective functions such as life cycle cost, annual thermal discomfort hours, and annual daylight unsatisfied hours. This study utilized the Transient System Simulation Tool (TRNSYS) and EnergyPlus simulation manager for the parametrics + Evolutionary Algorithms (jEPlus + EA) as the optimization tool. The resulting optimal solutions achieved a reduction of 27–31% in life cycle cost compared to the baseline and a reduction of 6–55% among the various locations tested in terms of thermal discomfort hours. Li, Lu [86] took a different approach, highlighting the environmental performance of each construction component and developing optimum options for an integrated envelope design for MiC buildings throughout both phases, design, and renovation. Two types of thermal insulation materials, namely, high insulation panels and aerogel blankets, were analyzed to investigate the potential utility of a climate-responsive building approach known as "reverse install". The building facades were also dynamically modified in response to climate change by utilizing diverse modular building envelope modules such as sunshades, preheaters, ventilation, air filtration, pest control, and other functional needs to improve the building's climatic adaptability. In a study examining the sustainable prefab housing solution for wall components [87], a simulation comparing commercially available fly ash brick and industrial waste of co-fired blended ash brick revealed that using these bio-based prefab panels could cut peak cooling demand by a factor of six, making buildings considerably more energy efficient. An implementation for mass housing ranging above 100 units was projected to yield sustainable efficiency not only environmentally but also economically. Turner, Oyekan [88] explored a framework that applied embedded IoT (Internet of Things) which enabled sensing technology within all stages of a modular building life cycle and highlighted the use of concrete as a modular sensing structure. They concluded that monitoring the material's health in situ, as well as recoding environmental parameters over time, could increase the lifespan of such structures. In an industry under pressure to cut CO_2 emissions, the possibility of turning building components into plug-and-play IoT-compliant assets opens new opportunities for whole life cycle control of concrete usage.

5.4. Energy Performance

There are many reports in the literature comparing the energy usage associated with the adoption of MiC with that of conventional building methods. Zaini, Ibrahim [89] found that the total energy consumption due to building materials in MiC and conventional projects were 26.93 CO_{2eq}/m^2 and 39.57 CO_{2eq}/m^2, respectively, with MiC enjoying a 31.94% reduction compared with conventional methods. However, Abey and Anand [90] argued that the embodied energy per unit floor area of MiC building was actually higher due to the use of prefabricated wall panels instead of brick infill, which was assumed for the conventional building. In particular, the building embodied energy of MiC buildings, utilizing prefabricated wall panels, was 5.01 GJ/m^2, while that of conventional buildings adopting brick infill walls was much lower, at 4.02 GJ/m^2. Their study also implied that using wire-cut bricks and fly ash bricks rather than wall panels would reduce the total embodied energy of the building by 15% and 40%, respectively.

As a building's total energy consumption is the sum of its embodied energy and operation energy, the cumulative energy consumed during its lifetime to assure the security and habitability of its occupants should be taken into consideration. A numerical simulation analysis with EnergyPlus suggested that new MiC building elements deliver a better energy performance than conventional building elements [91]. This is because the enhanced energy performance focuses primarily on heating loads, whereas cooling loads are not substantially reduced as a result of implementing additional building envelope measures. The results obtained showed the potential utility of MiC when it comes to reducing the energy demand for both heating and cooling periods, as well as improving indoor comfort for the inhabitants. Faludi, Lepech [53] compared the life cycle impacts for individual life cycle phases for a building as built (with 30% photovoltaic energy), a prefabricated commercial building with average energy use in California, and a net-zero-energy building (100% photovoltaic energy), based on a building lifetime of 50 years. Even without the benefits of PV panels, the energy models showed that an MiC building would consume around 60% less energy than a comparable typical building in the same climate zone and geographic location. Even for a high-efficient MiC building, these findings indicate that lowering energy impacts during the building usage phase through energy efficiency and clean energy generation should be the primary goal for a more sustainable design of a commercial MiC building. With that concern, the authors went on to consider several potential design options such as using supplementary cementitious materials to replace cement in concrete, using recycled carpet, reducing insulation, or removing the raised floor ventilation system.

As the above discussion demonstrates, in addition to the numerous advantages of MiC compared to conventional construction methods, namely the significant time and cost savings, higher manufacturing quality and precision, easier component dismantling and reuse, and reduced environmental degradation, MiC has considerable potential for achieving an advanced level of thermal and energy performance. To fully achieve this potential, modular building systems developed to address the targets set for net Zero Energy Buildings (nZEB) must pursue higher levels of quality in the built environment by adopting high-performance solutions [92]. Some attempts have already been made to appraise the mass customization for zero-energy housing because incorporating energy-efficient components made using mass manufacturing techniques customized to address the specificities of each site and its future users is key for sustainable design [93]. Mass customization has been described by Japanese manufacturers as that which enables end-users to customize their future homes in detail, including a wide range of environmental features, while effectively communicating the dwelling's eventual operational energy costs and carbon footprints through sophisticated tools, visuals, catalogues, guides, and models. By supporting end-users to make informed choices, these companies are taking the lead in the production of zero-energy and zero-carbon dwellings.

6. Discussion

Based on the findings of the qualitative analysis in the previous section, a research framework was established to present the current status of MiC research related to sustainability (Figure 5). The framework reflects the current themes and topics, and accordingly, the limitations and future directions for future research. The left side of Figure 5 depicts the categorization for the main topics including sustainable operation, sustainability assessment, advanced technology, and energy performance, which were further subdivided into several subtopics. The gaps that these researches face are then outlined as a foundation for recommending new paths. Eventually, research directions toward sustainability of MiC are proposed, which are presented in detail in this section. The proposed directions may serve as helpful references for academics in future research to add to the existing corpus of MiC knowledge regarding sustainability.

6.1. Social Sustainability

The concept of sustainable development was developed based on the interrelationships between three main TBL dimensions, i.e., environmental, economic, and social. However, our review of the literatures revealed a lack of research on social sustainability. Despite being mentioned in several studies as one of the characteristics promoting sustainability [46,77,94], the social dimension is largely ignored. Indeed, there is some imprecision in much of the language used, with non-equivalent terms being used interchangeably, for example, green buildings and high-performance buildings, and sustainable buildings being confused with ecologically responsible buildings, such as energy- efficient ones. Social sustainability has consequently garnered less attention in the context of sustainable development than it deserves. There is, thus, a strong case to be made for focusing on social sustainability as a potential research topic for studies on MiC. Despite its numerous definitions, aspects, and features explored in various literature contexts, social sustainability has been defined as meeting a variety of human needs, preserving nature, and achieving social justice, as well as supporting human dignity and political involvement [95]. Under the social dimension, future studies on MiC could usefully focus on health and well-being, safety and security, sensitivity to local cultures, employment opportunities and, especially, post occupancy evaluation. These social issues need to be thoroughly mapped in coordination with the objectives of sustainable development. Moreover, a better understanding of users' satisfaction could greatly enrich the recognition of practitioners about users' actual demand, hence affecting stakeholders' consideration of using MiC in construction practice and, consequently, contributing to advancing MiC in the future.

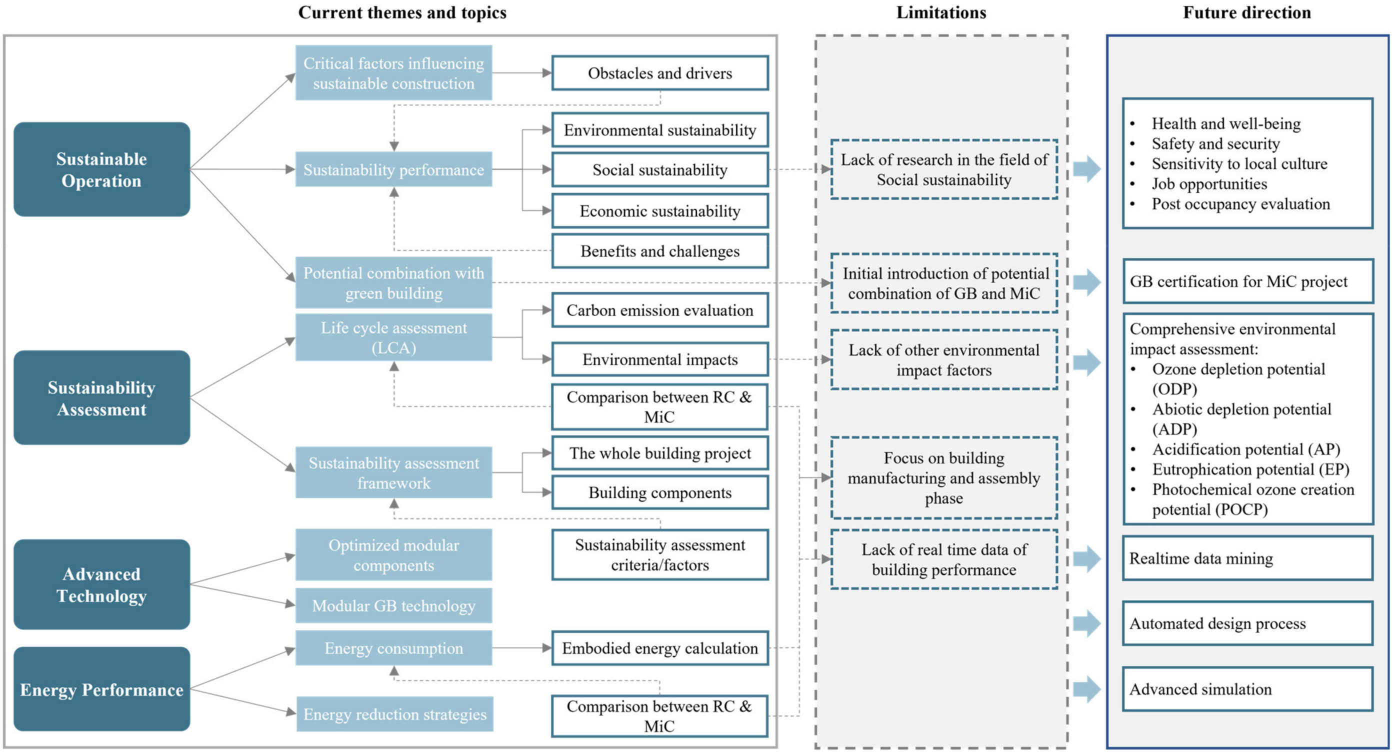

Figure 5. Research framework for MiC research related to sustainability.

6.2. Green Building Certification for MiC

As part of the effort to achieve this goal, there is a growing awareness of the need to develop new sustainability evaluation tools that include all the TBL components. Various studies have reported the development of tools to evaluate the sustainability of MiC buildings, as mentioned in the previous section. However, these generally go no further than proposing frameworks or models, or focus on assessing particular aspects, for example, carbon emissions. Due to the limited effectiveness of the existing rating systems, the question is whether or not current GB rating tools should be utilized to evaluate MiC buildings.

The most widely accepted GB rating systems, such as LEED, BREEAM, and Green Mark, could also be applied for MiC projects in various structural forms, ranging from prefabricated building components and parts through to whole building units. To show the potential for combining MiC and GB, a report by a LEED AP recommended the alignment of MiC industry with the Prerequisite and Credit requirements embedded in the LEED building rating system report [96]. The report summarized the advantages of MiC related to LEED V3 prerequisites and credit categories, i.e., (1) sustainable site, (2) water efficiency, (3) energy and atmosphere, (4) material and resources, (5) indoor environmental quality, (6) innovation and design process, and (7) regional priority. These advantages make MiC a leader when it comes to GB practices thanks to the off-site processes utilized that support efficiency, safety, flexibility, and adaptability.

However, these sustainability evaluation methods have not yet been widely used for evaluating the success of MiC projects, and the rules and standards regarding the application of GB certification to MiC implementation levels in construction projects remain unclear. An important point is that for LEED, when prefabricated modular components are employed as part of a larger building, the individual components or subassemblies do not themselves earn LEED certification. This is because they must not only fulfill the LEED criteria that apply to them but are also subject to the LEED rating system as it applies to the finished building type under consideration [97]. In addition, a LEED V4 project must be in a permanent location on existing land. Therefore, the existing rating system cannot be applied to mobile MiC projects that may be relocated to a new site. Hence, more research and studies are needed to explore the possibility of establishing a GB rating system specifically designed for MiC projects, as opposed to conventional site-built structures. Accordingly, newly built or renovated structures, as well as the reuse of existing buildings should be considered when conducting evaluations and approving GB certification.

6.3. Environmental Impact Assessment

Regarding environmental impact assessments, the prior MiC research has mainly focused on examining GHG emissions, GWP, respiratory inorganics, land occupation, and mineral extraction. However, many other indicators have also been used to assess the environmental impact of a project, especially in the construction industry, including ozone depletion potential, acidification potential, abiotic depletion potential, photochemical ozone creation potential, eutrophication potential, water, and pollution footprint, among others. Other categories that may be mentioned are human health, ecosystem production capacity, non-biological resources, influence on biodiversity, and cultural and recreational value [98]. Depending on their environmental goals and ecological features, countries choose and develop their own LCIA procedures based on the environmental impact categories that are most important in their context. These indicators could be considered for further LCIA research on MiC in the future. Additionally, sustainability assessments should continue to be conducted throughout the project life cycle, including the building operation and demolition phases, as the existing studies have mostly concentrated on the building embodied phase. Here, real-time data mining and advanced simulations will be both useful and necessary.

6.4. Real Time Data Mining, Advanced Simulation, Automated Design Process

The IoT, A.I. and cloud computing provide new prospects for smart applications in the construction industry in general, and modular construction in particular. Recent advances in technology have contributed significantly to the sustainable development of MiC in terms of enhanced construction schedule and process, valuable decision-makers, better supplies and services, higher reliability, and lower costs. Several of the technological solutions discussed in Section 5.3 have helped to optimize the sustainability performance of MiC. Integrated modular envelopes, analytical tools to generate optimized designs, and industrialized lightweight volumetric modular modeling all provide useful information. According to the findings of this study, however, there has been very limited research on the topic of real-time data mining (DM), advanced simulation, and automated design process.

DM is a powerful tool for automatically discovering hidden knowledge from enormous and complicated databases. While DM applications might already be adopted in some areas of construction, such as waste management [99], cost overrun prediction [100], and structural health warnings [101], how could it impact the field of MiC? DM could play a potentially valuable role in MiC through real-time site monitoring and building performance data collection, not only in the early project stage but right through from construction to operation. The knowledge generated could feed into construction partners, especially architects and engineers, facilitating performance data collection, filtering, analytics, interpretation, and storage for prediction, as well as optimizing building structures and designs for their future projects. This IoT-based application provides an opportunity for the creation of cutting-edge construction solutions that improve the delivery of smart construction in the future construction projects. One potential research methodology for this area might be an experimental approach using sample modular units. These modular units could also be exploited to develop collaborations between academic and business researchers by sharing the database collected. This would make it possible to test the performance of individual MiC components such as wall panels, thermal sensing systems, smart home systems, and green roofs, etc. In addition, this could be extended to examine the differences between the actual performance of a building and simulations. Advanced simulation could be especially beneficial for creating a variety of viable solutions for project modeling during the design phase. Advanced simulation covers numerous areas such as visual simulations (for tasks such as manufacturing, transportation, handling, and the assembly of modules), building physics simulations (to model the acoustic, thermal, and visual properties, as well as inhabitants' comfort and air quality), energy consumption and fire safety simulations, to name just a few.

Automated generative design systems should also receive more attention from MiC researchers as the design process is based on multiple repetitions of the same volumetric modular units or modular components. By changing standards, parameters, and/or spatial properties, this technology can provide instant insights that enable designers to explore and optimize design solutions. Therefore, research is needed to develop methods, algorithms, and tools that support automated generative design processes, enabling designers to select the best combination of building layout, components, and materials, enhance the project's lifetime value, and improve cost efficiency. All these can contribute to achieving the desired sustainability goals.

7. Conclusions

This study was conducted to provide fresh insights into the latest sustainability research trends and advances in the MiC industry through a systematic analysis of the sustainability-related MiC research documents published throughout the last two decades. In this study, 85 documents were retrieved by filtering the 161,762 results initially identified from the Scopus database and subjected to an in-depth analysis. The results revealed a significant growth in the number of MiC research publications related to sustainability in the last few years, demonstrating the mounting global concern related to construction sustainability issues. Our quantitative analysis revealed that researchers in Malaysia, China, Australia, Canada, and Hong Kong are publishing the most papers on the selected aspects of MiC. Professor M. Kamali from the University of British Columbia in Canada is the author who has contributed the most to MiC research related to sustainability, achieving the highest score and the most citations, at 2.74 and 307, respectively. The *Journal of Cleaner Production* was the top publishing source, with 8 documents, while the *International Journal of Sustainable Construction Engineering and Technology* was identified as the most-cited journal source, with 336 citations.

Regarding the qualitative analysis, the topics of interest for MiC research related to sustainability were classified into 4 categories: (1) Sustainable operation of MiC; (2) Sustainability assessment; (3) Advanced technology for MiC, and (4) Energy performance. Of these, "Sustainable operation of MiC" was the most common topic. Based on the critical review of related literature, a research framework was developed to illustrate the research themes and their subtopics. Research gaps were discussed, and potential research directions proposed to encourage deeper explorations within the MiC field related to sustainability. The directions suggested for future research include social sustainability, GB certification for MiC, environmental impact assessment, real-time data mining, advanced simulation, and an automated design process.

This paper provides a useful overview of this relatively new field and should thus help researchers and practitioners in the construction industry to gain a general understanding of the current status of MC research related to sustainability. Academics, practitioners, corporations, and governmental organizations may find it useful to refer to the researchers featured in the highlighted profiles to strengthen partnerships and develop future collaboration opportunities. The proposed research directions may also be useful references for researchers planning future research to supplement the current body of MiC knowledge related to sustainability. Finally, it is important to note that this analysis might be improved by increasing the sample size and including more document types such as government reports, thesis outputs, and literature published in languages other than English.

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References

1. Ofori, G.; Iv, C.B.; Gang, G.; Ranasinghe, M. Impact of ISO 14000 on construction enterprises in Singapore. *Constr. Manag. Econ.* **2000**, *18*, 935–947. [CrossRef]
2. Kawecki, L.R. *Environmental Performance of Modular Fabrication: Calculating the Carbon Footprint of Energy Used in the Construction of a Modular Home*; Arizona State University: Tempe, AZ, USA, 2010.
3. Smith, R.E. *Prefab Architecture: A Guide to Modular Design and Construction*; John Wiley & Sons: Hoboken, NJ, USA, 2010.
4. Ahn, Y.H.; Kim, K.-T. Sustainability in modular design and construction: A case study of 'The Stack'. *Int. J. Sustain. Build. Technol. Urban Dev.* **2014**, *5*, 250–259. [CrossRef]
5. Kamali, M.; Hewage, K. A Framework for Comparative Evaluation of the Life Cycle Sustainability of Modular and Conventional Buildings. In Proceedings of the 2015 Modular and Offsite Construction (MOC) Summit, Edmonton, AB, Canada, 19–21 May 2015; pp. 40–48. [CrossRef]
6. Shin, H.K.; Lee, J.S.; Jung, C.W.; Ahn, Y.H. Relocatable modular buildings for a short-term international event: The pyeong-chang winter olympic games. *J. Green Build.* **2020**, *15*, 3–35. [CrossRef]
7. Mao, C.; Shen, Q.; Shen, L.; Tang, L. Comparative study of greenhouse gas emissions between off-site prefabrication and conventional construction methods: Two case studies of residential projects. *Energy Build.* **2013**, *66*, 165–176. [CrossRef]
8. Jang, H.; Ahn, Y.; Roh, S. Comparison of the Embodied Carbon Emissions and Direct Construction Costs for Modular and Conventional Residential Buildings in South Korea. *Buildings* **2022**, *12*, 51. [CrossRef]
9. Jaillon, L.C.; 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]
10. Wuni, I.Y.; Shen, G.Q. Barriers to the adoption of modular integrated construction: Systematic review and meta-analysis, integrated conceptual framework, and strategies. *J. Clean. Prod.* **2019**, *249*, 119347. [CrossRef]
11. Lee, J.-S.; Kim, Y.-S. Analysis of cost-increasing risk factors in modular construction in Korea using FMEA. *KSCE J. Civ. Eng.* **2016**, *21*, 1999–2010. [CrossRef]
12. Pervez, H.; Ali, Y.; Petrillo, A. A quantitative assessment of greenhouse gas (GHG) emissions from conventional and modular construction: A case of developing country. *J. Clean. Prod.* **2021**, *294*, 126210. [CrossRef]
13. Wai, C.T.; Yi, P.W.; Olanrewaju, O.I.; Abdelmageed, S.; Hussein, M.; Tariq, S.; Zayed, T. A critical analysis of benefits and challenges of implementing modular integrated construction. *Int. J. Constr. Manag.* **2021**, 1–24. [CrossRef]
14. Blismas, N.G.; Pasquire, C.L.; Gibb, A.G. Benefit evaluation for off-site production in construction. *Constr. Manag. Econ.* **2006**, *24*, 121–130. [CrossRef]
15. Schoenborn, J. *A Case Study Approach to Identifying the Constraints and Barriers to Design Innovation for Modular Construction*; Virginia Tech.: Blacksburg, VA, USA, 2012.
16. Abdelmageed, S.; Zayed, T. A study of literature in modular integrated construction—Critical review and future directions. *J. Clean. Prod.* **2020**, *277*, 124044. [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. Li, Z.; Shen, G.Q.; Xue, X. Critical review of the research on the management of prefabricated construction. *Habitat Int.* **2014**, *43*, 240–249. [CrossRef]
19. Wuni, I.Y.; Shen, G.Q.P.; Mahmud, A.T. Critical risk factors in the application of modular integrated construction: A systematic review. *Int. J. Constr. Manag.* **2019**, *22*, 133–147. [CrossRef]
20. 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]
21. Pan, W.; Yang, Y.; Yang, L. High-Rise Modular Building: Ten-Year Journey and Future Development. In Proceedings of the Construction Research Congress 2018, New Orleans, LA, USA, 2–4 April 2018; pp. 523–532. [CrossRef]

22. Chai, T.J.; Tan, C.S.; Chow, T.K.; Ling, P.C.H.; Koh, H.B. A Review on Prefab Industrialised Building System Modular Construction in Malaysia: The Perspective of Non-structural Studies. In *International Conference on Architecture and Civil Engineering Conference*; Springer: Singapore, 2018; pp. 11–21. [CrossRef]
23. Zhou, Z. The hindrances of using modular constructions in Sichuan Province of China: A comprehensive literature review. *IOP Conf. Ser. Earth Environ. Sci.* **2021**, *676*, 012090. [CrossRef]
24. Agha, A.; Shibani, A.; Hassan, D.; Zalans, B. Modular Construction in the United Kingdom Housing Sector: Barriers and Implications. *J. Archit. Eng. Technol.* **2021**, *10*, 236.
25. Nabi, M.A.; El-Adaway, I.H. Modular Construction: Determining Decision-Making Factors and Future Research Needs. *J. Manag. Eng.* **2020**, *36*, 04020085. [CrossRef]
26. Cf, O. *Transforming Our World: The 2030 Agenda for Sustainable Development*; United Nations: New York, NY, USA, 2015.
27. Webster, J.; Watson, R.T. Analyzing the past to prepare for the future: Writing a literature review. *MIS Q.* **2002**, *26*, 13–23.
28. Greene, J.C.; VCaracelli, J.; Graham, W.F. Toward a conceptual framework for mixed-method evaluation designs. *Educ. Eval. Policy Anal.* **1989**, *11*, 255–274.
29. Darko, A.; Chan, A.P. Critical analysis of green building research trend in construction journals. *Habitat Int.* **2016**, *57*, 53–63. [CrossRef]
30. Du Plessis, C. Agenda 21 for sustainable construction in developing countries. *CSIR Rep. BOU E* **2002**, *204*, 2–5.
31. Wuni, I.Y.; Shen, G.Q. Towards a decision support for modular integrated construction: An integrative review of the primary decision-making actors. *Int. J. Constr. Manag.* **2019**, *22*, 929–948. [CrossRef]
32. Wuni, I.Y.; Shen, G.Q.; Osei-Kyei, R. Scientometric review of global research trends on green buildings in construction journals from 1992 to 2018. *Energy Build.* **2019**, *190*, 69–85. [CrossRef]
33. Aghaei Chadegani, A.; Salehi, H.; Yunus, M.M.; Farhadi, H.; Fooladi, M.; Farhadi, M.; Ale Ebrahim, N. A comparison between two main academic literature collections: Web of science and scopus databases. *Asian Soc. Sci.* **2013**, *9*, 18–26. [CrossRef]
34. Mongeon, P.; Paul-Hus, A. The journal coverage of Web of Science and Scopus: A comparative analysis. *Scientometrics* **2016**, *106*, 213–228. [CrossRef]
35. Hong, Y.; Chan, D.W.M.; Chan, A.P.C.; Yeung, J.F.Y. Critical Analysis of Partnering Research Trend in Construction Journals. *J. Manag. Eng.* **2012**, *28*, 82–95. [CrossRef]
36. Howard, G.S.; Cole, D.A.; Maxwell, S.E. Research Productivity in Psychology Based on Publication in the Journals of the American Psychological Association. *Am. Psychol.* **1987**, *42*, 975–986.
37. Lopez, D.; Froese, T. Analysis of Costs and Benefits of Panelized and Modular Prefabricated Homes. *Procedia Eng.* **2016**, *145*, 1291–1297. [CrossRef]
38. Cohen, W.M.; Nelson, R.R.; Walsh, J.P. Links and Impacts: The Influence of Public Research on Industrial R&D. *Manag. Sci.* **2002**, *48*, 1–23. [CrossRef]
39. Caiado, R.G.G.; Filho, W.L.; Quelhas, O.L.G.; Nascimento, D.L.D.M.; Ávila, L.V. A literature-based review on potentials and constraints in the implementation of the sustainable development goals. *J. Clean. Prod.* **2018**, *198*, 1276–1288. [CrossRef]
40. Goubran, S. On the Role of Construction in Achieving the SDGs. *J. Sustain. Res.* **2019**, *1*, e190020. [CrossRef]
41. 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]
42. Jaillon, L.; Poon, C.S. Sustainable construction aspects of using prefabrication in dense urban environment: A Hong Kong case study. *Constr. Manag. Econ.* **2008**, *26*, 953–966. [CrossRef]
43. Nahmens, I.; Ikuma, L.H. Effects of Lean Construction on Sustainability of Modular Homebuilding. *J. Arch. Eng.* **2012**, *18*, 155–163. [CrossRef]
44. Li, Z.; Shen, G.Q.; Alshawi, M. Measuring the impact of prefabrication on construction waste reduction: An empirical study in China. *Resour. Conserv. Recycl.* **2014**, *91*, 27–39. [CrossRef]
45. 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]
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. Wen, T.J.; Siong, H.C.; Noor, Z.Z. Assessment of embodied energy and global warming potential of building construction using life cycle analysis approach: Case studies of residential buildings in Iskandar Malaysia. *Energy Build.* **2015**, *93*, 295–302. [CrossRef]
48. Marjaba, G.; Chidiac, S. Sustainability and resiliency metrics for buildings—Critical review. *Build. Environ.* **2016**, *101*, 116–125. [CrossRef]
49. Kamali, M.; Hewage, K.; Milani, A.S. Life cycle sustainability performance assessment framework for residential modular buildings: Aggregated sustainability indices. *Build. Environ.* **2018**, *138*, 21–41. [CrossRef]
50. Yunus, R.; Yang, J. Critical sustainability factors in industrialised building systems. *Constr. Innov.* **2012**, *12*, 447–463. [CrossRef]
51. Yunus, R.; Yang, J. Sustainability Criteria for Industrialised Building Systems (IBS) in Malaysia. *Procedia Eng.* **2011**, *14*, 1590–1598. [CrossRef]
52. Bonamente, E.; Merico, M.C.; Rinaldi, S.; Pignatta, G.; Pisello, A.L.; Cotana, F.; Nicolini, A. Environmental Impact of Industrial Prefabricated Buildings: Carbon and Energy Footprint Analysis Based on an LCA Approach. *Energy Procedia* **2014**, *61*, 2841–2844. [CrossRef]

53. Faludi, J.; Lepech, M.D.; Loisos, G. Using life cycle assessment methods to guide architectural decision-making for sustainable prefabricated modular buildings. *J. Green Build.* **2012**, *7*, 151–170. [CrossRef]
54. Luo, Y.; Riley, D.R.; Horman, M.J. Lean principles for prefabrication in green design-build (GDB) projects. In *13th International Group for Lean Construction Conference: Proceedings*; International Group on Lean Construction: Lima, Peru, 2005.
55. Van Eck, N.J.; Waltman, L. Visualizing bibliometric networks. In *Measuring Scholarly Impact*; Springer: Cham, Switzerland, 2014; pp. 285–320.
56. Chen, D.; Liu, Z.; Luo, Z.; Webber, M.; Chen, J. Bibliometric and visualized analysis of emergy research. *Ecol. Eng.* **2016**, *90*, 285–293. [CrossRef]
57. Su, H.-N.; Lee, P.-C. Mapping knowledge structure by keyword co-occurrence: A first look at journal papers in Technology Foresight. *Scientometrics* **2010**, *85*, 65–79. [CrossRef]
58. Wong, P.S.; Kanellopoulos, M.P.; Edmonson, L. An empirical analysis of the effect of prefabrication on fostering sustainable construction. In *Proceedings of the 21st International Symposium on Advancement of Construction Management and Real Estate*; Springer: Singapore, 2018; pp. 185–195.
59. Bhattacharjee, S.; Pishdad-Bozorgi, P.; Ganapathy, R. Adoption of Pre-Fabrication in Construction to Achieve Sustainability Goals: An Empirical Study. In Proceedings of the Construction Research Congress 2016, San Juan, Puerto Rico, 31 May–2 June 2016. [CrossRef]
60. Dang, P.; Niu, Z.; Gao, S.; Hou, L.; Zhang, G. Critical Factors Influencing the Sustainable Construction Capability in Prefabrication of Chinese Construction Enterprises. *Sustainability* **2020**, *12*, 8996. [CrossRef]
61. Khoshnava, S.M.; Rostami, R.; Ismail, M.; Lamit, H. Obstacles and Drivers in Steering IBS towards Green and Sustainability. *Res. J. Appl. Sci. Eng. Technol.* **2014**, *8*, 1639–1647. [CrossRef]
62. Giuliani, I.; Aston, W.; Stewart, A. The Design and Development of an Adaptable Modular Sustainable Commercial Building (Co 2 nserve) for Multiple Applications. *Int. J. Vent.* **2009**, *8*, 123–133. [CrossRef]
63. Parrish, K. Lean and green construction: Lessons learned from design and construction of a modular leed® gold building. In *20th Conference of the International Group for Lean Construction*; IGLC: Lima, Peru, 2012.
64. Saleh, M.S.; Alalouch, C. Sustainable construction in oman: The potential role of the industrialized building systems. *J. Eng. Res. [TJER]* **2020**, *17*, 1–10. [CrossRef]
65. Hamid, Z.A.; Ali, M.C.; Anuar, K.; Kamar, M.; Zura, M.; Zain, M. Towards a sustainable and green construction in Malaysia. *Malays. Constr. Res. J.* **2012**, *11*, 55–64.
66. Yunus, R.; Hamid, A.R.A.; Noor, S.R.M. An integrated approach for sustainability in the application of industrialised building system (IBS). *Int. J.* **2019**, *17*, 115–121.
67. Tang, X. Research on Comprehensive Application of BIM in Green Construction of Prefabricated Buildings. *IOP Conf. Ser. Earth Environ. Sci.* **2021**, *760*, 012006. [CrossRef]
68. Bai, G.H. Research on Modular Construction and Evaluation of the Green Building Technique System. *Appl. Mech. Mater.* **2014**, *513–517*, 2583–2585. [CrossRef]
69. Ma, W.; Sun, D.; Deng, Y.; Meng, X.; Li, M. Analysis of Carbon Emissions of Prefabricated Buildings from the Views of Energy Conservation and Emission Reduction. *Nat. Environ. Pollut. Technol.* **2021**, *20*, 39–44. [CrossRef]
70. Amiri, A.; Caddock, P.; Whitehead, M. Accounting for the greenhouse gas emissions of construction: A UK case study. *Proc. Inst. Civ. Eng.-Civ. Eng.* **2013**, *166*, 82–88. [CrossRef]
71. Li, H.X.; Esfahani, M.N.; Gul, M.; Yu, H.; Mah, D.; Al-Hussein, M. Carbon Footprint of Panelized Construction: An Empirical and Comparative Study. In Proceedings of the Construction Research Congress 2014: Construction in a Global Network, Atlanta, GA, USA, 19–21 May 2014; pp. 494–503. [CrossRef]
72. Shen, Q.; Liu, Y. Predicted model of ecological footprint based on PLCA. *IOP Conf. Ser. Mater. Sci. Eng.* **2019**, *688*, 055035. [CrossRef]
73. Lim, P.Y.; Yahya, K.; Aminudin, E.; Zakaria, R.; Haron, Z.; Zin, R.M.; Redzuan, A.A.H. Carbon footprint of construction using industrialised building system. *IOP Conf. Ser. Mater. Sci. Eng.* **2017**, *271*, 012107. [CrossRef]
74. Balasbaneh, A.T.; Ramli, M.Z. A comparative life cycle assessment (LCA) of concrete and steel-prefabricated prefinished volumetric construction structures in Malaysia. *Environ. Sci. Pollut. Res.* **2020**, *27*, 43186–43201. [CrossRef] [PubMed]
75. Kamali, M.; Hewage, K.; Sadiq, R. Conventional versus modular construction methods: A comparative cradle-to-gate LCA for residential buildings. *Energy Build.* **2019**, *204*, 109479. [CrossRef]
76. Pan, W.; Li, K.; Teng, Y. Briefing: Life-cycle carbon assessment of prefabricated buildings: Challenges and solutions. *Proc. Inst. Civ. Eng.-Eng. Sustain.* **2019**, *172*, 3–8. [CrossRef]
77. Kamali, M.; Hewage, K. Sustainability performance assessment: A life cycle based framework for modular buildings. In Proceedings of the 6th International Construction Specialty Conference (CSCE/CRC 2017), Vancouver, BC, Canada, 31 May–3 June 2017.
78. Liu, S.; Qian, S. Towards sustainability-oriented decision making: Model development and its validation via a comparative case study on building construction methods. *Sustain. Dev.* **2019**, *27*, 860–872. [CrossRef]
79. Qi, K.; Qi, Y.; Ji, Y. An Engineering Consumption Differences Calculation Model for Prefabricated and Conventional Buildings in China. In *ICCREM 2019: Innovative Construction Project Management and Construction Industrialization*; American Society of Civil Engineers: Reston, VA, USA, 2019; pp. 640–647. [CrossRef]

80. Vega, R. Methodology for the sustainability assessment of facades. In *Proceedings of the Institution of Civil Engineers-Engineering Sustainability*; Thomas Telford Ltd.: London, UK, 2015.
81. Ryklová, P.; Mančík, Š.; Lupíšek, A. Environmental Benefits of Timber-Concrete Prefabricated Construction System for Apartment Buildings—A Simplified Comparative LCA Study. *IOP Conf.Ser. Earth Environ. Sci.* **2019**, *290*, 012083. [CrossRef]
82. Kubečková, D.; Kraus, M.; Šenitková, I.; Vrbová, M. The Indoor Microclimate of Prefabricated Buildings for Housing: Interaction of Environmental and Construction Measures. *Sustainability* **2020**, *12*, 10119. [CrossRef]
83. Li, S.C. Green building Technology of Prefabricated Building. In *E3S Web of Conferences*; EDP Sciences: Les Ulis, France, 2020.
84. Dave, M.; Bilbao, J.; Dickson, J.; Watson, B.; Prasad, B.D.; Sproul, P.A. Towards Sustainable Modular Housing: A Case Study of Thermal Performance Optimisation for Australia. In Proceedings of the 30th International PLEA Conference: Sustainable Habitat for Developing Societies: Choosing the way forward, Hong Kong, China, 16–18 December 2014.
85. Naji, S.; Aye, L.; Noguchi, M. Multi-objective optimisations of envelope components for a prefabricated house in six climate zones. *Appl. Energy* **2020**, *282*, 116012. [CrossRef]
86. Li, J.; Lu, S.; Wang, W.; Huang, J.; Chen, X.; Wang, J. Design and Climate-Responsiveness Performance Evaluation of an Integrated Envelope for Modular Prefabricated Buildings. *Adv. Mater. Sci. Eng.* **2018**, *2018*, 1–14. [CrossRef]
87. Chippagiri, R.; Gavali, H.R.; Ralegaonkar, R.V.; Riley, M.; Shaw, A.; Bras, A. Application of Sustainable Prefabricated Wall Technology for Energy Efficient Social Housing. *Sustainability* **2021**, *13*, 1195. [CrossRef]
88. Turner, C.; Oyekan, J.; Stergioulas, L. Distributed Manufacturing: A New Digital Framework for Sustainable Modular Construction. *Sustainability* **2021**, *13*, 1515. [CrossRef]
89. Zaini, N.; Ibrahim, S.H.; Darmansah, N.F.; Razali, A.W.; Tamjehi, S.D.; Zaini, A.A.; Hamza, H.; Syed Sahimi, S.N. Energy Consumption Assessment on Industrialised Building System (IBS). *Malays. Constr. Res. J.* **2020**, *32*, 51–57.
90. Abey, S.T.; Anand, K.B. Embodied Energy Comparison of Prefabricated and Conventional Building Construction. *J. Inst. Eng. (India) Ser. A* **2019**, *100*, 777–790. [CrossRef]
91. Tsoka, S.; Theodosiou, T.; Papadopoulou, K.; Tsikaloudaki, K. Assessing the Energy Performance of Prefabricated Buildings Considering Different Wall Configurations and the Use of PCMs in Greece. *Energies* **2020**, *13*, 5026. [CrossRef]
92. Antonini, E.; Longo, D.; Gianfrate, V. Towards nZEB: Modular pre-assembled steel systems for residential buildings. *Eco-Archit. V. Harmon. Archit. Nat.* **2014**, *142*, 349–360. [CrossRef]
93. Jimenez-Moreno, P. Mass Customisation for Zero-Energy Housing. *Sustainability* **2021**, *13*, 5616. [CrossRef]
94. Rostami, R.; Khoshnava, S.M.; Rostami, R.; Lamit, H. Green and sustainability policy, practice and management in construction sector, a case study of Malaysia. *Res. J. Appl. Sci. Eng. Technol.* **2015**, *9*, 176–188.
95. Littig, B.; Griessler, E. Social sustainability: A catchword between political pragmatism and social theory. *Int. J. Sustain. Dev.* **2005**, *8*, 65. [CrossRef]
96. Modular Building Institute. Modular Building and the USGBC's LEED Version 3.0 2009 Building Rating System. 2009. Available online: https://growthzonesitesprod.azureedge.net/wp-content/uploads/sites/2452/2021/06/Modular_09V3LEED.pdf (accessed on 18 August 2022).
97. Pham, D.H.; Kim, B.; Lee, J.; Ahn, Y. An Investigation of the Selection of LEED Version 4 Credits for Sustainable Building Projects. *Appl. Sci.* **2020**, *10*, 7081. [CrossRef]
98. Park, W.-J.; Kim, R.; Roh, S.; Ban, H. Analysis of Major Environmental Impact Categories of Road Construction Materials. *Sustainability* **2020**, *12*, 6951. [CrossRef]
99. Lu, W.; Chen, X.; Peng, Y.; Shen, L. Benchmarking construction waste management performance using big data. *Resour. Conserv. Recycl.* **2015**, *105*, 49–58. [CrossRef]
100. Williams, T.P.; Gong, J. Predicting construction cost overruns using text mining, numerical data and ensemble classifiers. *Autom. Constr.* **2014**, *43*, 23–29. [CrossRef]
101. Guo, A.; Jiang, A.; Lin, J.; Li, X. Data mining algorithms for bridge health monitoring: Kohonen clustering and LSTM prediction approaches. *J. Supercomput.* **2019**, *76*, 932–947. [CrossRef]