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Review

Thematic Trends in Industry 4.0 Revolution Potential towards Sustainability in the Construction Industry

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Abstract: The construction industry is currently facing challenges because of the massive waste generated by its production processes. The climate agreement also requires the industry to meet the increasing demand for sustainable building materials to achieve the energy transition. As a result, the construction industry is looking for alternative ways to meet these sustainability challenges. The implementation of the fourth industrial revolution (IR4.0) can be an opportunity for the construction industry to become more sustainable. Therefore, this paper aims to (i) ensure a detailed assessment of the existing challenges and (ii) identify the potential implementation of IR4.0 technologies in the construction industry. A set of criteria was established for searching and screening papers from three major databases (Scopus, WoS, and Mendeley), and 58 eligible articles were included in the current study. Using ATLAS.ti 22 software, a thematic analysis was conducted, and the final six themes were determined based on problems and challenges, technology and tools, information technology, consulting and business, construction management, and education. In addition, this paper identified potential prospective study paths. It is expected that the results will be useful for the future direction of the industry in addressing the challenges of IR4.0.

Keywords: construction industry; industry 4.0 revolution; thematic approaches; sustainability challenges

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1. Introduction

The construction industry is one of the largest users of global resources and polluters [1]. It, therefore, has a major responsibility to promote sustainability. The building sector consumes a large quantity of capital, which has a detrimental influence on both the environment and socio-economic aspects [2]. As a result, it is critical to mitigate these detrimental effects and guarantee sustainable development (SD). Historically, the industry has depended significantly on artisanal procedures, which have been linked to low performance and quality [3]. The sluggish rate of invention and creativity in the sector is a result of the adverse economic, social, and environmental effects of the sector, including low margins of profit, expense overruns, and considerable project delays, as well as high accident rates and unfavorable job conditions. According to research, integrating IR4.0 (also identified as Construction 4.0 (C4.0) in the construction sector) with SD can assist in addressing these difficulties [4].

The world is now advancing toward IR4.0, which focuses on industrial digital transformation, including the development of automation, intelligent systems, digitalization, artificial intelligence (AI), Big Data analytics, and Internet-of-Things (IoT). Germany originally announced IR4.0 at the Hannover Messe as a concept of a technology-driven manufacturing process combined with information and communication technologies to increase its national competitiveness in manufacturing [5]. Several research initiatives were covered in a study on the integration of Industry 4.0 to increase sustainability performance [6]. Prior research revealed that IR4.0 might assist construction organizations in increasing productivity [7]. As mentioned by the World Economic Forum [8], full digitalization in nonresidential

building will result in yearly cost savings from 13 to 21% in the construction phase and from 10 to 17% in the operations phase globally during a decade. SD may assist to meet the demands of both current and future generations by conserving water, energy, and natural resources via recycling, innovative waste management, and environmental preservation.

Implementing the concept and technology of IR4.0 can be a potential solution for sustainability in the construction industry. However, implementing such ideas requires a robust and intelligent system to handle a great deal of data and variables [9]. For the construction industry, there is still a big gap in fully adapting to IR4.0, mainly due to the lack in proper guidance and reference cases for stakeholders at this stage. The focus of this paper is to review the industry to assess the potential implementation of IR4.0 technologies in the construction industry. The suggested assessment procedure considers all types of IR4.0 technologies and advances that are now easily accessible because it is still comparatively new to the construction sector. The main objective is to identify possible solutions for improving existing processes in the construction industry using IR4.0 technologies. As far as the authors are aware, no research has yet been conducted that relates IR4.0 technologies and capabilities to the construction industry. To ensure a systematic and comprehensive review, a thematic approach is taken. In short, a detailed review of the current construction industry is conducted in this work thematic approach by (i) identifying the construction industry patterns and statistics in IR4.0 related to articles, geographical spread, and topics developed in the literature from 2017 to 2022, and (ii) evaluating the topics that can be generated in the construction industry in IR4.0 literature.

2. Methods

In this study, the non-systematic review method was used. It, unlike systematic reviews, is used to see what the literature says about a certain issue, rather than to assess the value of past study results. In this way, researchers can save time in reading or summarizing content. The term thematic review (TR) introduced by Zairul [10–12] is used since the method of this study uses a thematic analysis procedure in a literature review. Braun and Clarke [13] define thematic analysis as a method of identifying patterns and developing themes through extensive reading on the topic. The next step is to identify the pattern and form a category to understand the trend of IR4.0 adoption in the industry. The study's purpose is to analyze and interpret the data to identify future trends in the construction industry in the context of IR4.0. The selection of literature was based on several selection criteria: (1) publication from 2017–2022, (2) from SCOPUS, WoS, and Mendeley database, and (3) with the keyword IR4.0 OR 4IR (Table 1).

Table 1. Databases' search terms.

SCOPUS	(TITLE-ABS-KEY ("Construction industry") AND TITLE-ABS-KEY ("4IR" OR "IR4.0" OR "industrial Revolution 4.0")) AND PUBYEAR > 2017 AND (LIMIT-TO (PUBSTAGE, "final")) AND (LIMIT-TO (OA, "all")) AND (LIMIT-TO (DOCTYPE, "ar"))	9 results
WoS	"Industrial Revolution 4.0" OR "4IR" AND "construction" (All Fields) and Articles (Document Types) Year 2017 TO 2022	7 results
Mendeley	[fourth industrial revolution OR 4IR AND construction] Year 2017 TO 2022	135 results

The process of writing a thematic review paper (TR) can be separated into two parts: (1) quantitative and (2) qualitative. The rigor of this step ensures the trustworthiness of this document by applying the following steps (Table 2):

Table 2. Thematic Review Steps [14].

No.	Steps	Description
1	Formulating the research questions	Defining the research question serves as a road map for the succeeding steps. Pertinent parts of the question must be well-specified because they affect search tactics. The nature of the research questions is broad to provide a breadth of coverage.
2	Articles screening	This stage includes identifying relevant research and determining where to search, which phrases to use, which sources and periods to search, and which language. Comprehensiveness and breadth are critical in the search. Electronic databases, reference lists, hand-searching of major publications, and organizations and conferences are all sources. The breadth of the search is important, but so is the search's practicality. The appropriate keywords will decide the author's desired outcomes.
3	Article filtering	Inclusion and exclusion criteria are used in study selection. These criteria are based on the research question and aim of the study as well as fresh knowledge gained by reading the papers.
4	Cleaning and finalizing selected articles	The metadata of the articles will be double-checked at this stage to ensure that only the relevant articles are picked for the analysis process.
5	Data extraction and synthesis	At this point, a thematic analysis process was used to develop themes based on extensive reading on the subject. To establish consistency, the themes were chosen through an iterative procedure of contrasting and comparing features in the evaluated studies. The information will be input into the ATLAS.ti program, which will extract information for thematic evaluation. To report on the numerical element, the quantitative data were generated using standard bibliometric data. Similar coding techniques were employed by TR in the qualitative investigation for the ensuing topic analysis. It was thought that doing this would fragment and reduce the facts and, in certain cases, alter the dialectic link between reading and writing.

This article searched and selected data based on the inclusion and exclusion criteria specified above, as shown in Figure 1. The data collection has been conducted iteratively to ensure the results will be similar at least from the time of writing the article. Mendeley was selected because of the interdisciplinary nature of research and the availability of many sources, and Scopus was chosen because it offers the greatest collection of peer-reviewed papers. The WoS was filtered using article kinds, proceedings papers, and "type of documents", NOT reviews. The "Title, Keywords, and Abstract" datasets also included the analytic criteria. As search phrases, the following terms were used: IR4.0 OR 4IR AND the construction sector. Next, the articles were uploaded into Mendeley for data crunching.

Data crunching include deleting duplicate articles, changing author names, and assuring metadata accuracy. From Mendeley, all 58 articles were exported to ATLAS.ti 22 to answer RQ 1 (What are the construction industry patterns and statistics in IR4.0 in connection to articles, geographical dissemination, and themes developed in the literature from 2017 to 2022?), and RQ 2 (What are the themes that can be generated in the construction industry in IR4.0 literature from 2017 to 2022?). The article title, year, author, author's nation, periodical, the keyword utilized, and topic area were all established from the list of documents. This study's findings are classified into two categories: quantitative and qualitative. The quantitative portion will represent information acquired from numerical perspectives, such as graphs, tables, and statistics, whilst the qualitative section will develop themes generated from the chosen articles. The review highlighted arguments, issues, interventions, and numerous additional discoveries on the topic, providing a window into the future path of this research.

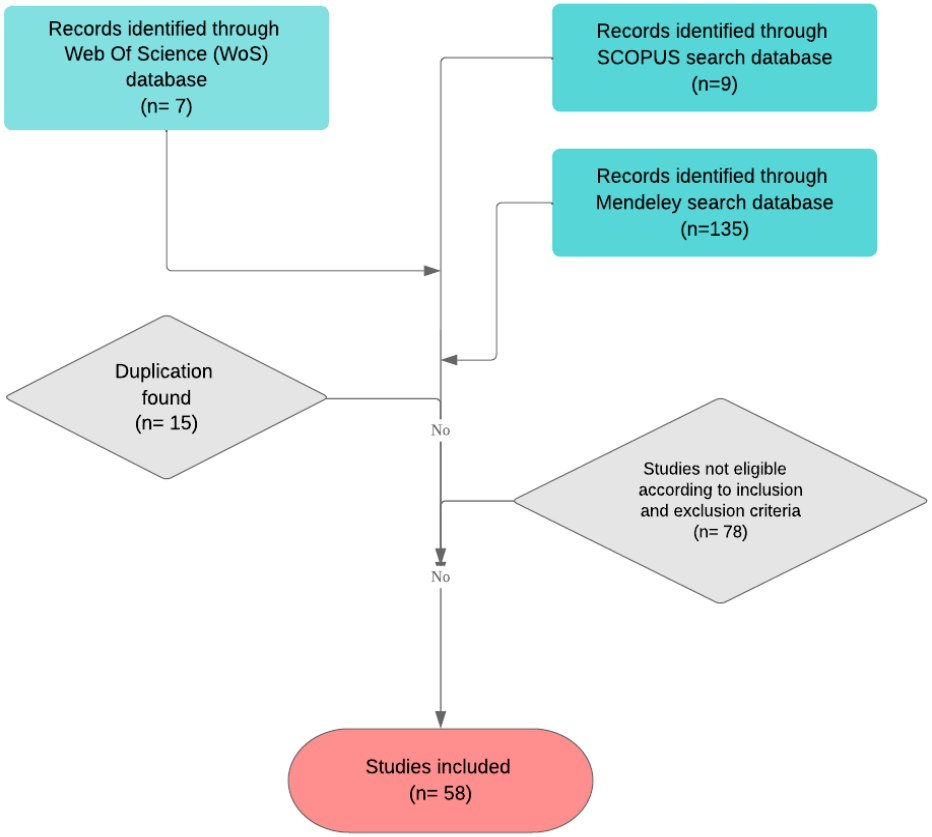

Figure 1. Inclusion and Exclusion Criteria in the thematic review.

3. Results and Discussion

This thematic analysis presented a five-year overview of IR4.0 in the construction sector. The articles chosen revealed the active collaboration between BIM and IR4.0 technologies, such as the use of BIM to support design decisions for mass customization production, structural health monitoring (SHM) using open BIM, allowing real-time schedule monitoring, smart steel bridge construction enabled by BIM and IoT, and a digital platform that uses augmented reality (AR) to provide workers with relevant information in real-time [15]. Conceptually, the included articles discuss the advantages and issues related to IR4.0 in the construction industry.

In addition, this study also has important practical implications. The findings of this literature review provide information on the possible uses of digital technologies in IR4.0 and the best areas for use in the construction sector. Very often, the IR4.0 issue remains on an abstract level, making it very challenging for practitioners to comprehend precisely how to take advantage of this new revolution in practice. This study can help project managers, site managers, and quantity surveyors better understand and evaluate their choices for strategy and possible outcomes. Our review and findings have contributed to the extant literature by offering insights into several aspects of the implementation of IR4.0. Thus, the important results of the thematic review are summarized in this section. The quantitative part at the beginning of this section will support the qualitative reporting for thematic evaluation. The first RQ will be addressed in the quantitative section, while the second will be addressed in the qualitative section.

3.1. Quantitative Findings

The year of publication, industrial background, research location, and theme subject were used to analyze the study trends, which mirror the patterns of the construction sector in the IR4.0 era to some extent (answering RQ1). The number of relevant articles published

climbed dramatically from 2017 to 2022, especially in 2020, as shown in Figure 2, but fell in 2022 due in part to the review being undertaken in early 2022.

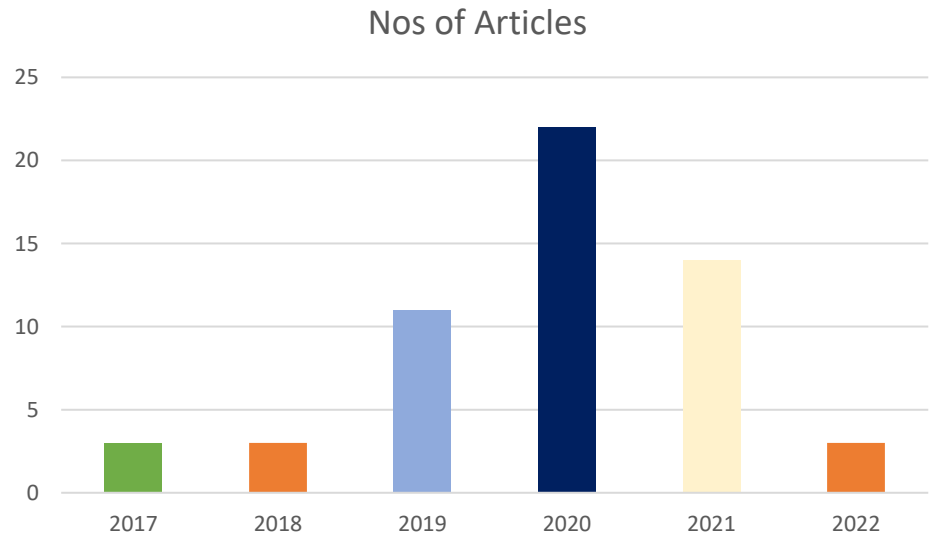

Figure 2. A breakdown of articles by year of publication.

Authors were more interested in the study site than the affiliation of the authors because that is where the researchers focused their efforts. Only when the target site was not specified was the affiliation of the first author used in its stead. Figure 3 depicts the studied country or region distribution. In terms of the number of papers, the topic of IR4.0 in the construction industry is highly popular in Asia, particularly in Malaysia.

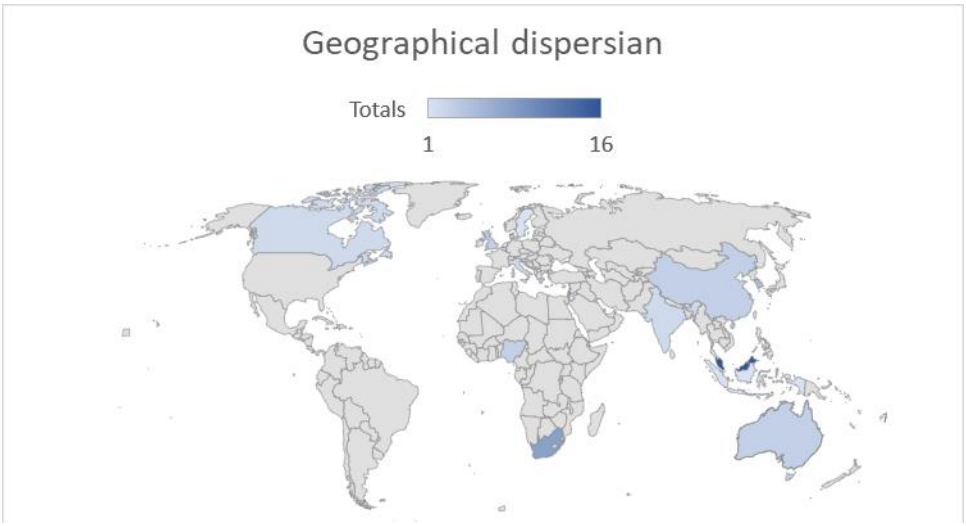

Figure 3. Geographical dispersion on the article published.

Malaysia has the highest frequency of papers on the map above (Figure 3), with 16 publications. Most of the discussion is on BIM integration in the construction industry [16], project cost difficulties in BIM [17], and the influence of inflation on labor pay [18]. At the same time, Gamil [19] offers a viewpoint on IoT in the construction industry and its potential challenges, which assists construction legislators in avoiding challenges and providing education-based campaigns to educate construction practitioners on the concept and importance of using IoT in the construction sector. The Malaysian discussion, on the other hand, centers on industrial actors' suitability for BIM technology. The findings support a previous bibliometric research on IR4.0 for the construction industry [20]. By offering an additional layer of data that may interact and cooperate in real-time throughout the project

life cycle, the results support BIM as an excellent stage for the creation of powerful and creative applications for the construction sector. Oesterreich and Teuteberg [21] acknowledged that BIM is one of the most significant construction technologies and is essential to the digitization of the built environment.

In the survey dataset, South Africa was discovered to be very much debating on integrating RFID with mobile technologies in the second rank. These findings contradict the formerly stated perspective that many academics have explored obstacles in RFID technology acceptance or variables influencing RFID adoption, although the majority of the research has been undertaken in industrialised nations [22]. The desire of construction professionals to utilize RFID and mobile technology on building sites was identified in this article [23]. Another study intends to offer the findings of a risk assessment of construction digitalization to sensitize and prepare construction organizations for unforeseen challenges that may develop during their digital transition [24]. Many studies in South Africa revolve around leadership [20], as well as university and industry collaborations [25].

The Republic of Korea was ranked third in terms of article numbers and had much emphasis on technology innovation in IR4.0, which included the invention of an ideal route procedure for construction equipment by Lee and Lim [26], as well as the growth of a 3D concrete extrusion nozzle for free-form concrete panels [27]. The study focused on a fundamental investigation of 3D printing methods for FCP manufacture and additional concrete extrusion tests that are required to examine nozzle performance accurately. The study of nozzle performance was outlined, and complementing the technologies used to apply 3D printing technology to FCP production was discussed, outlining concerns. Another notable study is on the automatic generation of heuristic-based truck movement patterns for construction equipment control [28]. Following the nations in terms of the number of publications are China (3), the United Kingdom (3), Australia (3), Nigeria (3), India (2), Canada (2), Italy (2), Sweden (1), Indonesia (1), and Slovakia (1).

Next, the paper identified themes of concern to academics using a wide definition of IR4.0. Six themes, namely T1 (issues and challenges), T2 (technology and tools), T3 (information technology), T4 (consultancy and business), T5 (construction management), and T6 (education) specifically identified from the articles examined following the study's focus topic or endogenous factors (Table 3). It should be noted that issues and challenges refer to industry challenges, while technology and tools discuss technological innovation; some of the articles discuss information technology in terms of software and hardware usage, others discuss construction management, and several articles discuss education related to IR4.0.

Table 3. Author vs. Themes.

No.	Sources	Theme 1: Issues and Challenges	Theme 2: Technology and Tools	Theme 3: Information Technology	Theme 4: Consultancy and Business	Theme 5: Construction Management	Theme 6: Education
1	Alaloul [2]	■					
2	Alaloul [18]	■					
3	Ang [17]						
4	Chai [16]			■			
5	Chen [29]					■	
6	Gamil [19]	■					
7	Herman [30]				■	■	
8	Hussain [31]			■			
9	Zabidin [32]			■	■		
10	Igwe [33]	■	■				
11	Ismail [34]		■				
12	Kavuri [35]			■		■	
13	Lau [36]	■					
14	Mahmud [37]			■			
15	Riazi [38]				■		
16	You and Feng [39]			■			
17	Lee [40]					■	
18	Belle [41]			■			

Table 3. *Cont.*

No.	Sources	Theme 1: Issues and Challenges	Theme 2: Technology and Tools	Theme 3: Information Technology	Theme 4: Consultancy and Business	Theme 5: Construction Management	Theme 6: Education
19	Balzani [42]					■	
20	Kim and Choi [43]			■	■		
21	Ningsih [44]						■
22	Couper [45]				■		
23	Osunsanmi [23]			■			
24	Iuorio [46]		■				
25	Mamter [47]			■			
26	Hisham [48]				■		
27	Zangeneh and McCabe [49]					■	
28	Aghimien [50]		■				
29	Moon [51]		■				
30	Švajlenka and Kozlovská [52]		■				
31	Gupta [53]				■	■	
32	Lekan [54]		■				
33	Aghimien [55]			■	■		
34	Lee and Lim [26]		■				
35	Alade and Windapo [56]				■		
36	Papadopoulou [57]						■
37	Huijben [58]		■				
38	Aghimien [50]				■		
39	Rymarczyk [59]	■	■				
40	Aghimien [24]			■			
41	Vestin [60]				■		
42	Alade [61]					■	
43	Dounas [62]			■			
44	Pal and Jain [63]		■				
45	Gambo and Musonda [64]					■	
46	Ji-Yeong [65]		■				
47	Ebekozien and Aigbavboa [66]		■				
48	Hamma-adama and Ahmad [67]					■	
49	Volpe [68]		■				
50	Lee [69]				■		
51	Al Balkhy [70]					■	
52	Kim [28]					■	
53	Ding and Kohli [71]		■			■	
54	Bhattacharya and Momaya [72]			■	■		
55	Aliu and Aigbav [25]				■		
56	Kasim [73]		■				
57	Malomane [74]						
58	Lee and Park [75]		■				
59	Yousif [76]					■	

In Table 4, the results show that the Engineering, Construction, and Architectural Management journal had the most published papers on this topic, with four publications, followed by Sustainability (Switzerland) with three, and the other journals with two and one article, respectively.

Table 4. Periodical vs. year of publications.

	2017	2018	2019	2020	2021	2022	Totals
2020 IEEE 8th R10 Humanitarian Technology Conference (R10-HTC)	-	-	-	1	-	-	1
Advanced Engineering Informatics	-	-	-	1	-	-	1
Ain Shams Engineering Journal	-	-	-	1	1	-	2
Alam Cipta	-	-	1	-	-	-	1
Annals of Emerging Technologies in Computing	-	1	-	-	-	-	1
Applied Sciences (Switzerland)	-	-	-	-	2	-	2
ARCOM 2020—Association of Researchers in Construction Management, 36th Annual Conference 2020—Proceedings	-	-	-	1	-	-	1
Buildings	-	-	-	-	1	-	1
Construction Innovation	-	-	-	2	-	-	2
Data in Brief	-	-	1	-	-	-	1
EG-ICE 2020 Workshop on Intelligent Computing in Engineering, Proceedings	-	-	-	1	-	-	1
Engineering, Construction, and Architectural	-	-	-	3	1	-	4
Entrepreneurial Business and Economics Review	-	-	-	1	-	-	1
Higher Education Pedagogies	-	-	-	1	-	-	1
IEEE Access	-	-	-	1	-	-	1
International Journal of Architectural Computing	-	-	-	1	-	-	1
International Journal of Construction Management	-	-	-	1	-	-	1
International Journal of Engineering and Technology (UAE)	-	1	-	-	-	-	1

Table 4. *Cont.*

	2017	2018	2019	2020	2021	2022	Totals
International Journal of Environmental Research and Public Health	-	-	-	-	-	1	1
International Journal of Housing Markets and Analysis	-	-	1	-	-	-	1
International Journal of Innovative Technology and Exploring Engineering	-	-	-	-	1	-	1
International Journal of Recent Technology and Engineering	-	-	1	-	-	-	1
International Journal of Scientific and Technology Research	-	-	1	-	-	-	1
International Journal of Supply Chain Management	-	-	-	1	-	-	1
International Journal of Sustainable Construction Engineering and Technology	-	-	-	-	1	-	1
International Journal of Sustainable Development and Planning	-	-	-	-	-	1	1
International Journal of Technology	-	-	1	-	-	-	1
IOP Conference Series: Earth and Environmental Science	-	-	-	1	-	-	1
IOP Conference Series: Materials Science and Engineering	-	-	-	1	-	-	1
Journal of Advanced Research in Dynamical and Control Systems	-	-	1	-	-	-	1
Journal of Construction Engineering and Management	1	-	-	-	-	-	1
Journal of Construction in Developing Countries	-	-	-	-	2	-	2
Journal of Construction Materials	-	-	-	-	1	-	1
Journal of Engineering, Design, and Technology	-	-	-	1	-	-	1
Journal of Leadership Studies	-	-	-	-	1	-	1
Malaysian Construction Research Journal	-	-	1	-	-	-	1
Modular and Offsite Construction (MOC) Summit Proceedings	-	-	1	-	-	-	1
Proceedings of the 2017 National Conference on Digital Technologies in Architectural Education and DADA 2017 International Conference on Digital Architecture	1	-	-	-	-	-	1
Processes	-	-	-	1	-	-	1
Supply Chain Forum	-	-	-	1	-	-	1
Sustainability	-	-	-	-	-	1	1
Sustainability (Switzerland)	-	1	1	-	1	-	3
Sustainable Cities and Society	-	-	-	-	1	-	1
Tehnički glasnik	-	-	-	1	-	-	1
Turkish Journal of Computer and Mathematics Education (TURCOMAT)	-	-	-	-	1	-	1
Turkish Online Journal of Educational Technology	1	-	-	-	-	-	1
WIT Transactions on the Built Environment	-	-	1	-	-	-	1
Totals	3	3	11	22	14	3	56

To sum up, this section responds to RQ1. The construction industry research trends for IR4.0 are reflected in the construction industry trends in general. The examined articles explored a variety of IR4.0 themes, the most popular of which was concerns and challenges, since it is the discussion on the construction industry's readiness for IR4.0 (Malaysia). Although IoT and technological tools have been suggested, there have been very few studies, mostly from the Republic of Korea, that have attempted to study consulting and construction management (Figure 4).

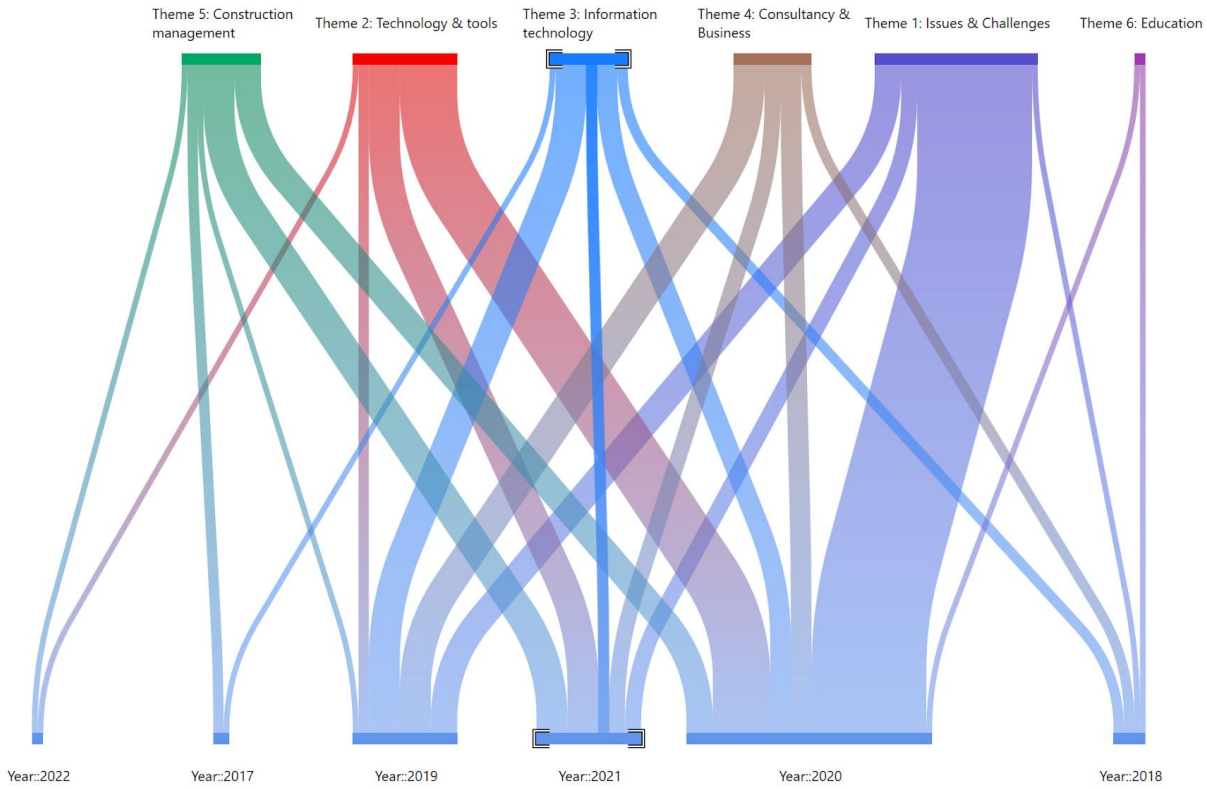

Figure 4. Themes of the study and publication years.

3.2. Qualitative Reporting

This TR paper reviewed publications and coded the patterns in the construction industry in IR4.0. However, it did not address the future direction of construction in IR4.0. In multiple rounds, the initial codes were recorded, combined, and categorized. Codes that were seldom used and could not be categorized into any topic were removed since this study was concerned with aspects that had been extensively discussed and investigated by researchers. Results from quantitative investigations that were not statistically significant were also removed. Furthermore, generic sociodemographic characteristics were not considered because they may not be universally applicable to all circumstances. Finally, six major themes emerged: (1) issues and difficulties, (2) technology and tools, (3) information technology, (4) consultancy and business, (5) construction management, and (6) education. Each theme is investigated in further detail below, and results outside of the themes or the evaluated articles will be referenced as needed for descriptive reasons (Figure 5).

The first round of coding produced 15 initial codes, and the first stage was to become acquainted with the data. The first stage was to complete a thorough review of all gathered articles and find a likely code to develop the possible theme. Big data issues, interoperability issues, costing, management, and project issues were among the phrases that prompted the creation of the initial subject. The next phase was to generate, review, and define the final theme. Finally, six major themes were identified, which will be discussed in depth in the following section.

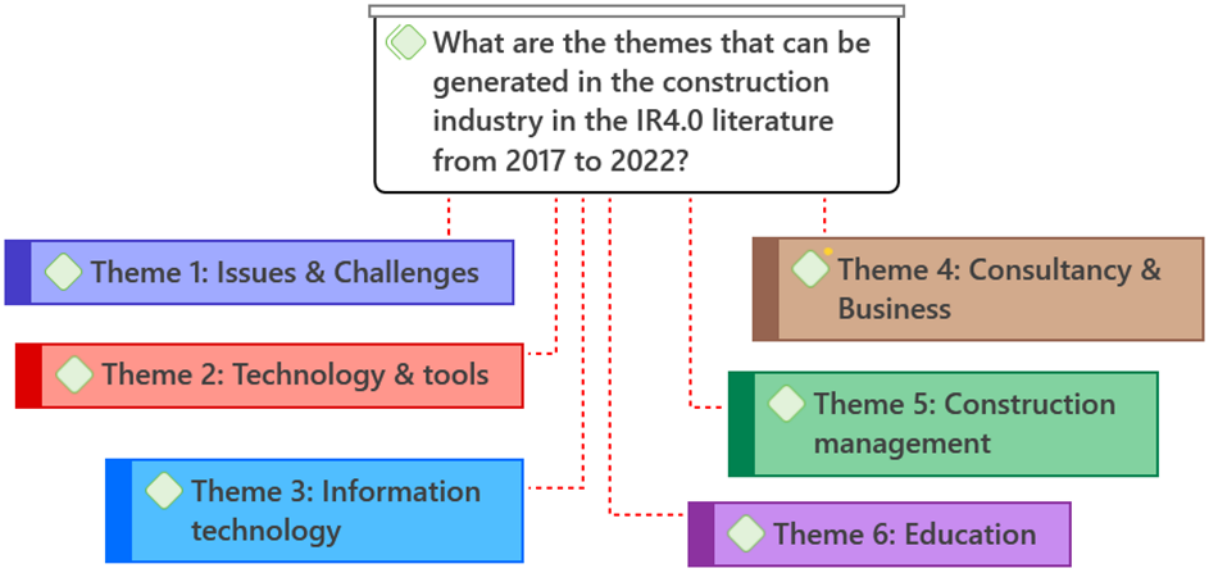

Figure 5. Overall network to answer Research Question 2.

3.2.1. Theme 1: Issues and Challenges

Several articles addressed the difficulties and challenges confronting the building sector as it prepares for IR4.0. In their paper, Lau [36] discussed the challenges of deploying Building Information Modeling (BIM) for SME contractors. Similarly, because the construction support industry is primarily comprised of SMEs, their ability to invest in technology with unknown benefits is limited [2]. Construction firms would have to rely on governing bodies and authorities to support these initiatives through funding programs and collaborative partnerships. Another study looking into the use of additive components in the building by local contractors backs this up [34].

Alaloul [2] identified various issues in IR4.0, including political, economic, social, technological, environmental, legal, and security concerns. Furthermore, the expense of implementing the technology is heavily debated among authors, which is exacerbated by the uncertainty of a return on investment. Implementation would become more difficult as more unaccounted expenses, such as those for training and equipment maintenance, would be added. In truth, Malaysia's BIM adoption rate is relatively low, with cost being the most significant barrier to BIM adoption. The government can play a role in providing incentives for key stakeholders to continue making progress in the future.

Several authors discuss the following topics: lack of safety and security, lack of documented standards, lack of benefit awareness, the improper introduction of IoT and lack of robustness in connectivity [19], implementing suitable motivational practices in the organization that will be effective in causing a positive impact on the employees [30], high implementation costs with an unclear return on investment, lack of skilled staff, and concern for the environment [36]. Notwithstanding, IR4.0 is likely to have substantial repercussions, both positive and negative, but these are the problems that key players must face to overcome future challenges in the coming days (Figure 6).

3.2.2. Theme 2: Technology Tools

Several publications have discussed technological tools in the context of digitizing construction (Figure 7). Although technology has always been part of the construction industry, the industry has suffered from a lack and slow pace of innovation [33]. Nevertheless, the introduction of IR4.0 creates a space where all automated machines are connected through technological improvements to function and transmit information without the help of humans, which increases efficiency [2]. The problem can be solved by integrating another computer technology, augmented reality (AR), into the current BIM system and connecting

the BIM model with the actual situation [16]. Currently, the capabilities of information and communication technologies (ICT) and their actual impact on the efficiency of project planning, control, and execution are gradually being recognized [33].

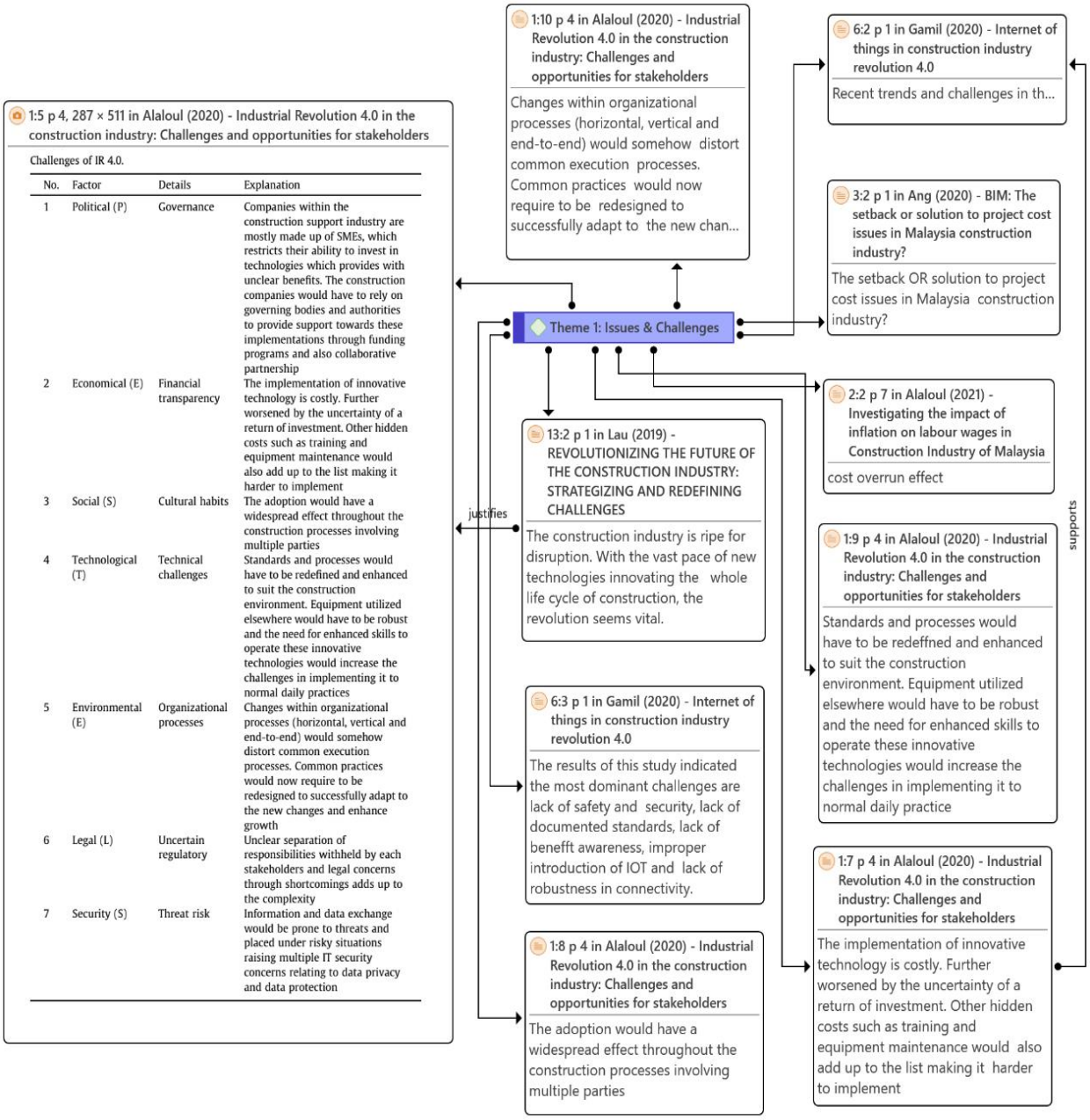

Figure 6. Theme 1 (Issues and Challenges). Note: The first number is the reference number from Table 3, the second number after the colon is the quotation, and p is the page [2,17–19,36,52].

The technologies highlighted for IR4.0, such as AR, VR, and Metaverse, tend to change the way construction cost management is approached, given their increasing use for project delivery. Therefore, the potential of these technologies for improved project and cost performance should be fully realized to maximize client spending [33]. As an alternative to traditional formative and subtractive manufacturing, additive manufacturing (AM) is an advanced manufacturing method that refers to the process of assembling materials to produce products from three-dimensional (3D) model data, often layer by layer [34]. In addition, the use of ideas like RFID, monitoring systems, BIM, and 3D printing to supply chains for the building industry has been demonstrated in the practical literature.

Construction supply chains make more use of ideas like RFID; BIM and 3D printing applications, however, still have room for growth.

Advances in manufacturing in the construction industry have led to offsite construction being a revolutionary innovation in the construction industry [46]. However, as evidenced by the findings on the inherent benefits of this technology, the implementation of innovative housing projects promises solutions to some of the problems that arise from the application of this technology.

3.2.3. Theme 3: Information Technology

One of the most prominent technologies driving information handling in IR4.0 is building data modeling (BIM). However, due to the limited contact between the real world and the virtual world, the contribution of this technology to fieldwork is quite limited [16]. Thanks to advances in computer technology, megastructures can now be built, which limits the potential growth of the industry in terms of information processing. Currently, architects' and engineers' drawings serve as the basis for building a structure. Although adopting BIM is no longer an option but rather a need for businesses to thrive in IR4.0, it does provide enormous chances for them to boost productivity and efficiency [31].

With the advent of IR4.0, technology is advancing rapidly, presenting challenges to the construction industry such as more complex and futuristic designs, a variety of building materials, green buildings, smart homes, and other issues that require the conversion of traditional construction practices to digital and contemporary technology by all stakeholders. However, the inability to find skilled BIM talent is preventing the industry from realizing the full potential of BIM [77]. As the construction sector will become more complex and difficult in the future, the industry should emphasize the use of these Internet-of-Things applications [36]. The development of other industries will leave the construction sector behind if no application facilitates the related tasks (Figure 8).

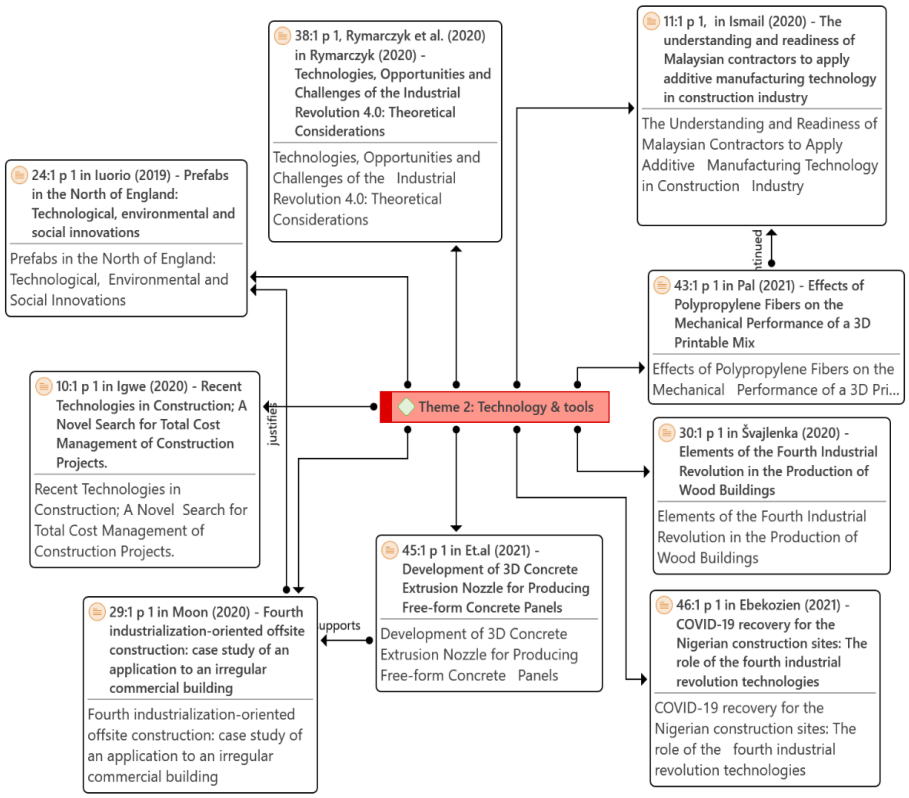

Figure 7. Theme 2 (Technology Tools). Note: The first number is the reference number from Table 3, the second number after the colon is the quotation, and p is the page [33,34,46,51,52,59,63,65,66].

The author focuses on the IoT, a disruptive technology that links physical items to the digital world through the use of devices such as sensors, actuators, RFID, cameras, and laser scanners [39]. According to the established communication protocol, ubiquitous connectivity between objects is achieved before the physical process is captured, identified, and controlled. The data collected on a construction site in real-time are fed into the models of BIM via the Internet of Things to track the construction process [39]. The real-time construction model serves as the digital twin of the building being constructed in the cyber-physical system framework proposed in this paper. However, investment in technological innovation is a long-term process that will improve the level and performance of key stakeholders, resulting in higher financial performance.

3.2.4. Theme 4: Consultancy and Business

There are several discussions on consulting and business, especially the dynamic skills and institutional theories through empowering BIM-qualified talents in Malaysia [77]. BIM tools are used by architects, engineers, and the construction sector (AEC) to increase and improve project progress by changing the way projects are designed, evaluated, built, and managed throughout the project life cycle. One article stated that the implementation of IR4.0 within the construction industry would drive the industry's performance to match that of their industry counterparts, such as the manufacturing and automotive industries. This would increase the construction industry's competitiveness in the global market [16].

Construction companies need to stay ahead of the curve and digitize their business strategy. Digitization strategy can be associated with an actionable strategy framework as outlined by Bhattacharya and Momaya [72]; Hisham [48] agrees and emphasizes the importance of companies identifying and developing appropriate plans for planning their goals, shaping their growth, and structuring their procurement techniques. In the context of Malaysia, the Malaysian government is working to liberalize the services sector through the ASEAN Framework Agreement on Services (AFAS), the General Agreement on Trade in Services (GATS), and the Trans-Pacific Partnership Agreement (TPPA) to benefit from growing global trade. This plan's long-term aim is to change the construction industry by "accelerating the growth of the Malaysian construction industry and preparing it to meet the future demands of the economy," which necessitates collaboration among the sector's many actors.

Despite the problems faced by the government in implementing IR4.0 in the construction industry, IR4.0 offers many valuable benefits to the industry, especially in terms of productivity, quality, competitiveness, etc. It also creates new career opportunities that meet a variety of needs. Therefore, switching to IR4.0 is beneficial for the industry to remain competitive [34]. In addition, a company's business performance can be affected by national and industry conditions, and unique environmental elements, government regulations, special events, and accidents can all impact business performance. They can also be affected by the interconnections that occur due to IT convergence developments when they are implemented within the organization in the future [43]. In addition, the government must support the industry to compete with major global players and remain competitive at the international level (Figure 9).

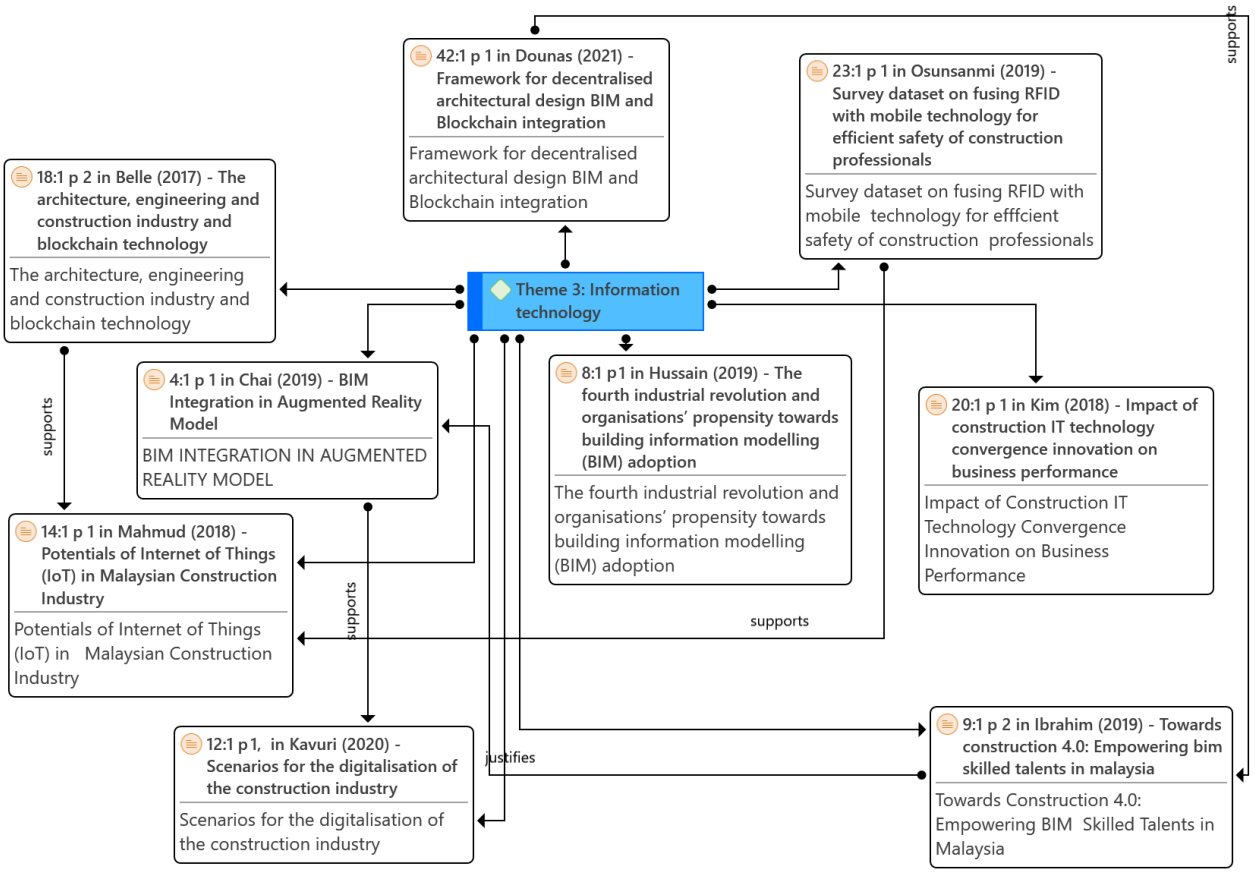

Figure 8. Theme 3 (Information Technology). Note: The first number is the reference number from Table 3, the second number after the colon is the quotation, and p is the page [16,23,28,31,35,37,41,62,77].

3.2.5. Theme 5: Construction Management

Construction management has become an important topic in the context of IR4.0. However, it also poses some threats and challenges. Due to the slow adoption of innovations at the organizational and technological levels as well as the lack of collaboration brought on by a wide range of project sizes on the construction site, as is frequently the case in Italy, the construction industry has always been characterized by a lack of sharing of best practices among all the actors and stakeholders involved. Because of this, substantial waste is still seen along the whole building value chain [42]. The results indicate that there is still a high uncertainty and fuzzy understanding among management in the construction industry concerning the way to implement the IR4.0 philosophy. They wish to learn what the basic requirements for a better transformation are. In today's building environment, companies must maintain continuously innovating construction projects or modernizing the construction processes at the top of their agenda.

Some research focusing on human resource management suggests that safety professionals should consider implementing coping skills training programs to improve individual resilience among their employees and reduce conflict-related safety outcomes [29]. An in-depth examination of motivational techniques could improve mechanisms for improving performance in the sector and provide insights into the types of people the industry currently attracts and employs. Human resource management has emerged as a critical component in ensuring the implementation of skilled workers during IR4.0. According to Herman [30], all new Quantity Surveyors should assess the driving forces of the green environment to achieve a high level of motivation. Malaysia is in the midst of the IR4.0, and the construction industry is adapting by advancing various technologies to replace traditional construction methods.

From a contractor's perspective, studies have also been published on some of the most important issues in construction. If the benefits of digital technology are to be realized, it is critical to think about and plan for the future, including unforeseen events. Using the scenario axis technique, four realistic future scenarios were created for industrial change favored by digital technology [35]. Because construction companies are slow to adopt technological innovations, overall productivity in the construction sector has remained virtually unchanged in recent years. This slow pace of technological innovation in construction is telling; it has the potential to hold back global efficiency gains [40]. As a result, construction companies must invest in developing the key resources they need to make their IR processes more successful.

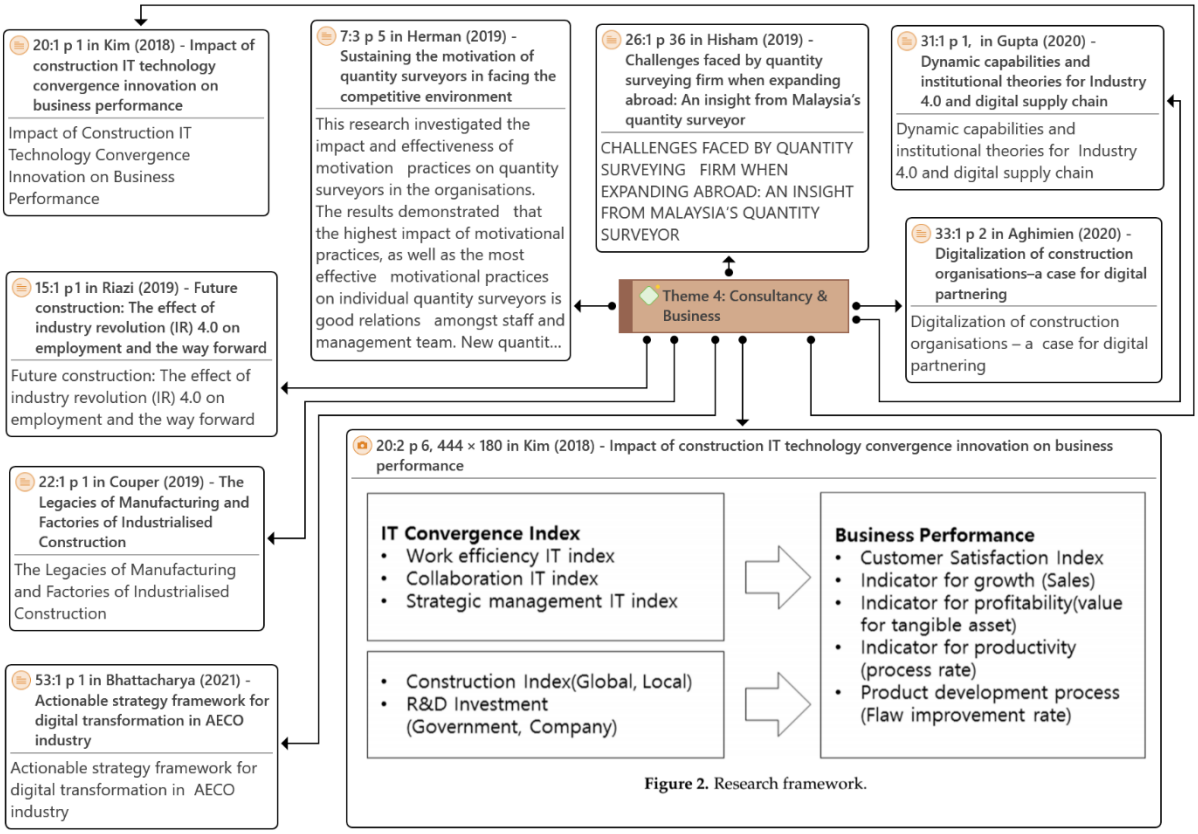

Figure 9. Theme 4 (Consultancy and Business). Note: The first number is the reference number from Table 3, the second number after the colon is the quotation, and p is the page [30,38,43,45,48,50,53,72].

Moreover, the introduction of new technologies such as automation of production processes, the IoT, or advanced materials is not enough to ensure that new opportunities to improve the productivity and competitiveness of the construction sector define IR4.0 [42]. Most industries are affected by IR4.0, including construction and those involved in the implementation of large-scale projects. However, despite these significant paradigm shifts, the track record of predicting project outcomes and estimating resources has not improved significantly. Consistent data definitions and extensible knowledge representations across the project lifecycle are two factors that complicate megaproject modeling for analytics [49]. However, leadership also plays a role in the management process. This is confirmed by research conducted by Alade [61] in South Africa, who found that the role of coach and the functions of visionary and executor, which include integrating IR4.0 technology into business operations, are still at a low level. To practically expand their knowledge, benefit from the IR4.0 era, and improve their business performance, construction professionals should be more strategic and goal-oriented. The ability of executives to understand the IR4.0 landscape is supported by a collaborative approach and extensive interaction with

experts and scientists (Figure 10). With a clear distribution of managerial framework for IR4.0 integration, the construction industry can also reap the benefits of IR4.0 from a management standpoint and is projected to create and deploy more technologies to improve the construction process. Construction businesses' process, as the heart of the project with a collaborative and autonomous synchronization system, gives a new means to anticipate, manage, and monitor the quality and performance of the project across the whole project life cycle.

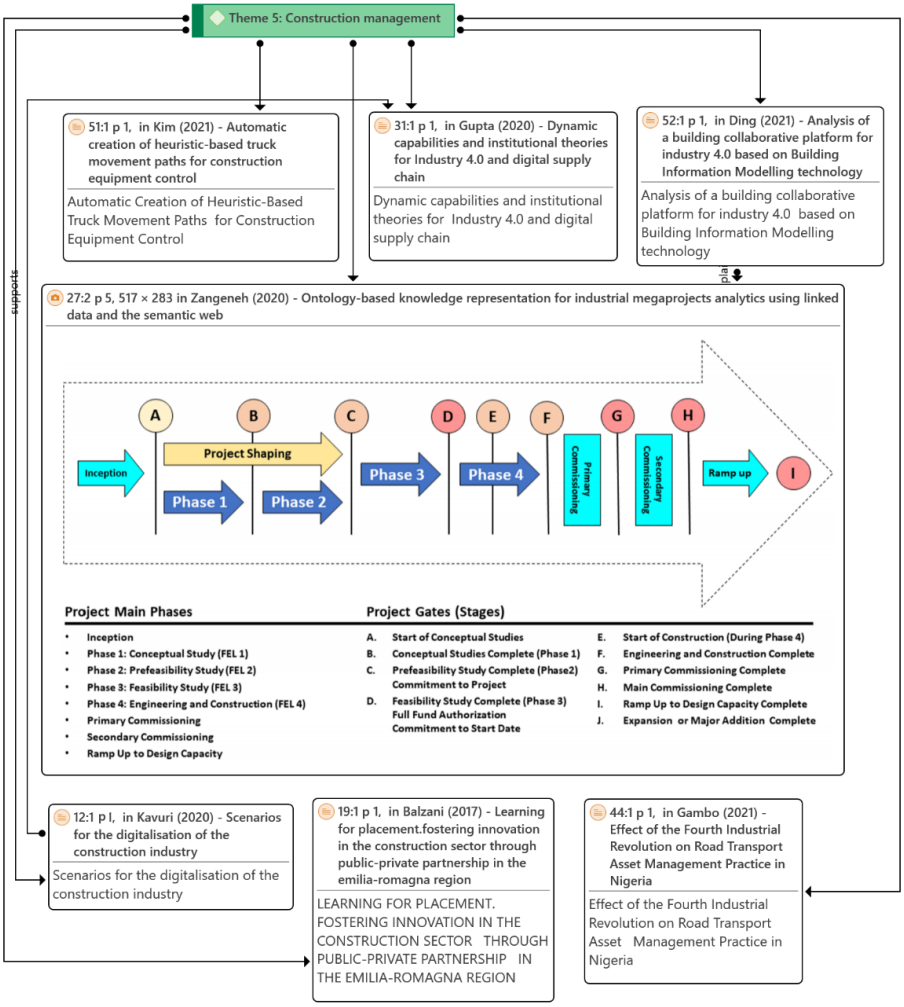

Figure 10. Theme 5 (Construction Management). Note: The first number is the reference number from Table 3, the second number after the colon is the quotation, and p is the page [28,35,42,49,53,64,71].

3.2.6. Theme 6: Education

Construction in the IR4.0 era influences the growth of construction in the IR4.0 era, although it does not contribute significantly to the literature on IR4.0. The discussion revolves around graduate employability [57] and the application of Edmodo as e-learning for construction learning [44]. A discussion of graduate employment depends on a wider range of transferable soft skills, attributes, and behaviors, collectively referred to as "graduate attributes," rather than just subject-specific expertise. Several research papers address pedagogical strategies for incorporating graduate qualities into the curriculum [57]. The learning environment is one of the many innovations currently being developed in science and technology. In addition to printed books, there are learning resources that can be downloaded (a journal or an e-book) and found through search engines. On the other hand, in addition to learning materials, there are now schools, courses, and universities that use tools to facilitate learning without requiring students and teachers to be present in person. The term "e-learning" refers to a commonly used learning tool. Thanks to changes in their previous

learning, students have new career perspectives on the latest trends. A comprehensive data analysis examines which e-learning tactics work and identifies those that are ineffective for achieving e-learning goals in IR4.0. Nevertheless, the paper argues that future graduates must be equipped with adaptable and flexible leadership skills to cope with the rapid change that IR4.0 brings. Two pillars of the proposed framework, as suggested by Papadopoulou [55] (Figure 11), that enable students to develop these characteristics are the use of the real world as opposed to simulated safe environments and its international dimension. These design principles can be adopted in the application of fieldwork throughout construction education to support transformative learning in IR4.0 (Figure 11).

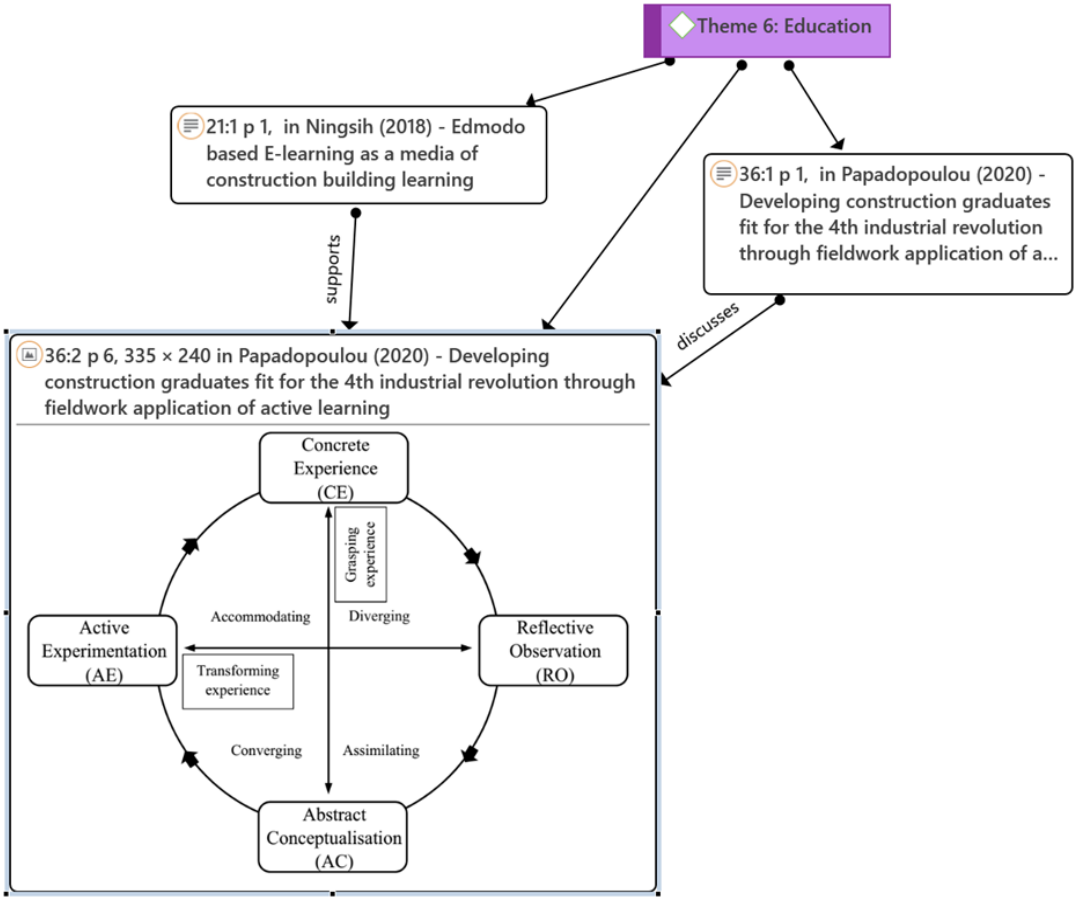

Figure 11. Theme 6 (Education). Note: The first number is the reference number from Table 3, the second number after the colon is the quotation, and p is the page [44,57].

4. Conclusions

The goal of this study was to systematize the existing body of scientific knowledge concerning the effects of IR4.0 on the construction sector. In particular, this study aims to provide an overview of the main applications of enabling technologies of IR4.0 supporting the building construction process. The authors discovered that despite an increase in contributions to the scientific literature, there is still a lack of a comprehensive overview of how IR4.0-enabling technologies might be used to support design–construction processes. The authors conducted a thematic analysis to fill this gap and discovered six themes, including challenges and difficulties, tools and technology, information technology, business and consulting, construction management, and education. For each of the themes, the impact on and main applications in the various steps of construction processes was assessed.

The findings of this study demonstrate that certain themes have received more attention in the scientific literature when taking into account both technology and processes. Specifically, the significance of the study presented is the emphasis on the ability of applied

technology to replace labor and the attempt to quantify this value by assessing efficiency. The findings of this study revealed several gaps in the literature on IR4.0 and helped identify some suggested directions for future research.

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