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Current State of Using Prefabricated Construction in Australia

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Abstract: The Australian prefabricated construction market has been developing rapidly in recent years. New prefabrication-related technologies, materials, systems and services are also emerging in the current Australian market. Although some studies have been undertaken to explore the benefits and challenges of implementing prefabrication in Australia over the past 15 years, they do not reflect the recent changes in the industry. Therefore, this study aims to fill this gap and identify the major changes in the current Australian prefabricated construction industry from industrial perceptions. Through literature reviews and industry interviews, factors reflecting major changes in the current Australian prefabricated construction, including prefabrication industry development, emerging benefits and challenges, were identified and discussed in this study. The challenges identified from interviews were classified into eight aspects related to feasibility, design, manufacturing, transportation, on-site construction, standardisation, skills and knowledge, finance and market. Furthermore, 21 recommendations and related key responsible parties were identified to tackle these challenges. The findings will provide useful references for various stakeholders to have a better understanding of the current prefabrication industry development in the Australian context and re-think how to adapt to future changes for the uptake of prefabricated construction in Australia.

Keywords: prefabrication; off-site construction; Australian construction industry; interview; benefits and challenges

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1. Introduction

Globally, the prefabricated construction market is expected to grow at a compound annual growth rate of 7.1% from 2020 to 2026 and will reach USD 174 billion by 2026 [1]. The rise in the popularity of prefabrication is due largely to its ability to reduce overall construction times [2]. It is also acknowledged as being high-quality [3] and eco-friendly [4,5], to list only a few advantages. In addition, prefabrication is recognised as having potential to overcome the housing shortage as a result of population growth and trends in household formation [6], and to address the shortage of skilled labourers in the coming years [7]. Prefabrication also makes it easier to adhere to social distancing and COVID-19 safe working guidance [8].

Over the last few years, the potential benefits and future uptake of prefabricated construction have been recognised by the Australian construction industry and clients, which has resulted in a significant expansion in interest and in its use [9–11]. Australian prefabricated construction has extended beyond single housing developments to schools, hospitals, train stations, sports buildings, healthcare facilities and community centres and the commercial building market [10]. In terms of the market size, prefabrication represents 5% of Australia's current AUD 150 billion construction industry nowadays, and it is expected to grow from the current 5% to 15% in 2025 [12]. A compound annual growth rate (CAGR) of around 7.5% is expected in the Australian prefabrication market from 2016 to 2026. As the main body in Australia's off-site construction industry and the hub for building prefabrication technology and design, prefabAUS predicts that 10% of Australian homes will be prefabricated by 2030 [9]. Furthermore, new prefabrication-related technologies, materials, systems and related services have emerged in the Australian prefabrication industry in recent years. Prefabrication comes in many shapes and sizes, from small components, to two-dimensional panels, three-dimensional volumes, a hybrid of different systems or a complete building, and can be made up of different materials, from timber, to concrete, metal, plastic or a combination [13]. More companies are entering into the prefabrication market and some are becoming leaders in prefabrication, such as the Hickory Group and Prebuilt.

Relevant previous Australian studies have been performed to examine prefabricated construction in the Australian context by seeking insights from industry professionals [14–18]. The key challenges to implement prefabricated construction identified by these studies include the industry and market culture, perceived higher project costs, lack of adequate skills and knowledge, the immense changes to existing construction processes and non-traditional designs. However, these studies were conducted at least 4 years ago. The number of interviewees for most of these previous studies is very limited, and the occupation types of interviewees are inadequate. In terms of the results, the new changes in the Australian prefabrication industry are not reflected in the existing studies. Some challenges identified by these previous studies, such as higher perceived costs, the immense changes to existing construction processes and non-traditional designs, have been largely solved or improved by the current Australian prefabrication industry. Besides the above, new benefits, such as creating opportunities for auto manufacturing employees, traditional contract types and the availability of lifting equipment, are perceived in the current prefabrication industry, but are barely mentioned in previous relevant studies.

Therefore, there is a strong need for up-to-date research to comprehensively investigate the industrial perspectives, especially those of the leaders, on the implementation of prefabrication in the Australian context. This will help both industry and academia to develop an updated understanding of current industry development and be prepared for future changes. To fill these gaps and achieve these goals, this study conducted in-depth interviews with experienced Australian industry professionals.

The rest of this paper is structured as follows. The literature review section reviews the previous research on prefabrication with a focus on the benefits and challenges. The methodology section introduces the research methods used in this study. The data analysis section includes cluster analysis and factor analysis. Current industry developments and major changes, and the industry's perspective on the benefits and challenges of prefabrication, are discussed. Furthermore, recommendations to address these challenges are proposed and key responsible parties are also identified in the discussion section.

2. Methodology

The research method applied in this study combines both a literature review and industrial interviews. This study firstly conducted a literature review on prefabricated construction in both Australia and other countries. Literature reviews help us to understand the current development of prefabrication in Australia and the world. Based on the literature review, the benefits and challenges of adopting prefabrication, and research gaps in the existing literature, are also identified. To review the existing work on prefabrication, especially the benefits and challenges, the Scopus database was used in this study to identify mainstream journals with a certain number of publications on prefabricated construction. In addition, previous prefabrication review studies [19,20] offered valuable guidance to identify top journals and search strategies in this domain. As a result, Construction Management and Economics, Automation in Construction, the Journal of Management in Engineering, Engineering Structures, Energy and Buildings, the Journal of Construction Engineering and Management, Structures, the International Journal of Construction Management, the Journal of Cleaner Production, Engineering, Construction and Architectural Management and the Journal of Building Engineering and Construction Innovation were selected as major journals or source titles to search the related literature. Then, with the identified keywords related to prefabrication and its benefits and challenges, a search strategy was developed in Scopus as TITLE-ABS-KEY ((prefabrication OR "prefabricated construction" OR "precast concrete" OR "off-site construction" OR "modular construction") AND (benefit* OR driver* OR motivation* OR challenge* OR constraint* OR limitation* OR risk* OR issue* OR impact*)). The search results were further refined by year (2002–2021), language (English), the above-mentioned source titles and document type (Article and Review). A total of 405 document results were initially found. The initial results were then screened one by one by the author to eliminate those not in the construction engineering and management field or not focusing on prefabricated construction management. Finally, a total of 130 published journal papers on the benefits and challenges of prefabrication were selected as the final search results for further analysis.

As there have been new developments and changes in the prefabrication industry in recent years, there is a need to further collect the industry's perspectives on the current development of prefabrication in Australia. Therefore, the literature review results formed the basis for the semi-structured interview design. Then, semi-structured interviews were conducted to obtain an in-depth understanding of the Australian industry's perceptions of prefabricated construction. The interview questions were structured in 3 main parts, including the basic information of interviewees and companies and their views on the current prefabrication industry development, the benefits and challenges of implementing prefabricated construction and recommendations to tackle these challenges. Since supply chain management is critical to improve the performance of prefabricated construction at an organisational level [21], therefore, this research planned to interview industry professionals from four types of companies in the supply chain of prefabricated buildings, which were consultants, manufacturers, suppliers and builders. The potential participants were required to have at least 5 years of industry experience in prefabricated construction in Australia and work at mid-level or senior-level management positions. Based on the selection criteria, the potential participants were identified by online searching, LinkedIn and personal networks.

Subsequently, an email invitation was sent to the potential participants, with the Participant Information and Consent Form attached, to invite them for an interview. After the potential participants accepted the invitation by signing the consent form and returning it to the researchers, the research team scheduled a time and location with them to conduct the interview. In total, 65 invitations were sent out and 21 industry professionals accepted the invitation. The interviews were conducted from October 2019 to April 2020; more than half of interviews were conducted by face to face, and some interviews were conducted by phone or online. The interviews were recorded by note taking and audio recording. Each interview ran for at least forty minutes and most interviews ran for one hour or above. Besides these, 4 visit opportunities to factories and 4 visit opportunities to construction sites were provided by interviewees during interviews.

A total of 21 valid interview responses were collected from 16 leading Australian prefabrication companies and Australian professional associations, which are shown in Table 1. These 21 interviewees included 4 prefabAUS Board of Directors members (out of 9), 2 chief engineers, 4 directors of prefabrication companies, 4 project or operational managers, 4 site engineers and 7 senior consultants. The prefabAUS Board of Directors deals with the governance and overall direction of prefabAUS. The categories of these 16 companies included consultants, manufacturers, suppliers and builders. These 16 companies play leading roles in the current Australian prefabrication industry, with business coverage in Australia and overseas. Seven of the 21 companies are prefabAUS company members. Besides this, some of these prefabrication companies' supply chains involve multiple stakeholders in Australia and other countries. Therefore, to a large extent, these 16 companies can be considered as representatives of the prefabrication industry in Australia. The interview content in this study can largely reflect current industry practitioners' views on prefabricated construction.

Table 1. Information sheet of interviewees.

Interviewees	Company	Company Categories	Business Coverage	Occupation(s)	Industry Experience on Prefabricated Construction
1	1	Consultant	70+ countries	prefabAUS board member	15 years or more
2	2	Consultant	AU, United Arab Emirates and England	Senior consultant	10 to 15 years
3	3	Consultant	40+ countries	Senior consultant	10 to 15 years
4	4	Consultant	All states in AU	Senior consultant	10 to 15 years
5	5	Consultant	All states in AU	prefabAUS board member	15 years or more
6	6	Supplier	AU and NZ	Senior consultant	5 to 10 years
7	7	Manufacturer	All states in AU	Operation manager	15 years or more
8	8	Manufacturer	All states in AU	Operation manager	15 years or more
9	9	Manufacturer	All states in AU	Operation manager	10 to 15 years
10	10	Consultant, manufacturer and builder	All states in AU	Chief engineer	15 years or more
11	10	Consultant, manufacturer and builder	All states in AU	Project manager	10 to 15 years
12	10	Consultant, manufacturer and builder	All states in AU	Site engineer	5 to 10 years
13	10	Consultant, manufacturer and builder	All states in AU	Site engineer	5 to 10 years
14	11	Consultant, manufacturer and builder	All states in AU	Senior consultant	10 to 15 years
15	12	Consultant, manufacturer and builder	VIC and NSW	Director	10 to 15 years
16	13	Consultant, manufacturer and builder	All states in AU	prefabAUS board member	10 to 15 years
17	14	Consultant, manufacturer, and builder	AU and NZ	Senior consultant, prefabAUS board member	10 to 15 years
18	14	Consultant, manufacturer and builder	AU and NZ	Site engineer	5 to 10 years
19	15	Consultant manufacturer and builder	All states in AU	Senior consultant	10 to 15 years
20	16	Consultant, manufacturer and builder	AU and NZ	Chief engineer	15 years or more
21	16	Consultant, manufacturer and builder	AU and NZ	Site engineer	5 to 10 years

Note: AU—Australia, NZ—New Zealand, VIC—Victoria, NSW—New South Wales.

3. Results

3.1. Literature Review Results

3.1.1. Benefits of Prefabrication

Prefabrication has been considered as an efficient and sustainable solution for future construction [22]. Based on the review of the existing literature, 15 major benefits were identified, as shown in Table 2. These benefits of implementing prefabrication can be then summarised into six major aspects based on the existing literature and the research team's interpretation, including schedule, environment, quality, cost, local issues and construction safety.

Table 2. Summary of previous research on the benefits of prefabrication.

Benefits	References	No. of References	Research Methods	Aspects
B1—Time saving	[3,14–19,23–36]	21	CS, LR, I, S	Schedule
B2—Better quality	[3,14–19,23,27–29,31,34,37–41]	18	LR, I, S	Quality
B3—Energy saving	[5,14,15,30,31,42–51]	15	LR, CS, MS	Environment
B4—Improved construction safety	[14,15,17–19,27,31,38,43,52–54]	12	I, LR, CS, S	Construction safety
B5—General cost benefits	[3,16–19,25,26,31,35,55]	10	CS, LR, S	Cost
B6—Reduce on-site work and labour	[3,14,16,17,19,24,27,28,30,43]	10	LR, CS, S	Cost
B7—Reduce on-site construction waste	[17–19,27,30,31,38,43,56]	9	I, CS, LR, S	Environment
B8—Addressing skills shortage	[14,16,17,23,29]	5	S, I, CS	Local issues
B9—Lower production cost due to remote manufacture	[57–60]	4	I, LR, S, CS	Cost
B10—Less disruption to neighbours	[19,23,28]	3	CS, LR	Environment
B11—Relief housing demand	[16,30,61]	3	LR	Local issues
B12—Waste recyclability	[54,62]	2	LR	Environment
B13—Material saving	[27,52]	2	S, LR	Environment
B14—Lightweight of prefabricated materials	[16,26]	2	I	Local issues
B15—Increase project certainty	[6]	1	CS	Cost

Note: B—benefits, CS—case study, LR—literature review, I—interview, S—survey, MS—model simulation.

The schedule benefit is one of the most critical and common drivers for industry to adopt prefabrication [29,32]. Prefabrication has significant schedule advantages over traditional construction methods [34], as it allows on-site and off-site construction work to run simultaneously [33] and reduces weather delays [35]. Fabricators work in a more controlled environment with improved supervision of labour, easier access to tools and fewer material deliveries [32], which speeds up the construction program.

The benefits related to the environment include less emissions, energy savings, reducing on-site construction waste, reducing the use of materials, improving waste recyclability and reducing disruption to neighbourhoods. Compared with the traditional construction method, prefabrication has significant environmental benefits throughout a project's lifecycle, including the reduction of greenhouse gas emissions [43], reduction of on-site construction waste [18] and reduction of material usage [27]. These reductions can enhance public health and can combat climate change, which is the fundamental goal suggested by the International Energy Agency (IEA) [63,64]. The in-factory manufacturing environment creates a lower rate of defects and re-work, and reduces waste generated during material handling, movement and storage on the construction site and material recycling processes [52]. Prefabrication also brings opportunities for more recyclable resources, such as mass timber [42]. Building components are manufactured and pre-assembled in the factory so that less noisy work is completed on site [28], which reduces the disruption to the community.

The quality benefit is another driver for industry to adopt prefabrication [29]. Prefabrication allows building pieces to be manufactured in a more controlled environment, which is under cover and away from the weather, by using an automatic process [17]. Better quality of products can be achieved due to the quality control methods adhered to within the manufacturing industry [34]. Furthermore, the computer-aided design and testing applied within prefabrication further reduces defects and re-work [39].

The cost benefits of prefabrication are justified mainly due to several general reasons. Firstly, prefabrication reduces on-site labour [17], which saves on-site labour costs. Secondly, cost savings can be achieved through the reduction of material use [55] and time-related costs. Time-related cost reductions include, but are not limited to, labour cost savings for site management, site sheds and crane, hoist and scaffolding hiring [35]. Thirdly, cost savings can be achieved as a result of the improved cost certainty [6] and reduced maintenance costs in prefabrication [55]. In some special cases, the production cost can be reduced due to remote or overseas manufacture [57].

The benefits for local issues include relieving housing demand pressure, addressing skills shortages and reducing foundation costs. The key drivers for selecting prefabrication in Australia include high labour costs and skilled labour shortages [17], especially in remote areas. Prefabrication can bring skilled trades in one location under a controlled work environment. Another issue is the increasing demand for affordable housing due to the rapid population growth in Australia's major metropolitan cities. For example, the Western Australian government has outlined short-term goals of making an additional 30,000 affordable homes available in Perth [16]. Prefabrication has great potential to solve the above-mentioned issues in a sustainable way. Furthermore, prefabrication has its advantages in some special conditions. For example, reactive soil conditions in some remote areas in Western Australia lead to high foundation costs. This issue has been regularly overcome with the lightweight modular foundation systems [16].

Prefabrication can also improve off-site construction safety and reduce on-site safety hazards. Firstly, prefabrication shifts the on-site construction environment with high safety hazards to a lower-hazard environment [17] by improving safeguards, using safer and automated equipment [54] and reducing air quality hazards through engineered ventilation [53]. Secondly, prefabrication offers a large reduction in overall on-site working time so that on-site safety hazards can be reduced [17].

3.1.2. Challenges of Prefabrication

Despite the aforementioned benefits, prefabrication also brings challenges that need to be overcome. These include cost inefficiency [65], lack of standardisation [66] and lack of a skilled workforce [24]. By reviewing the literature, 26 major challenges were identified, as shown in Table 3. These challenges can be summarised into seven aspects based on the existing literature, such as the life cycle of prefabrication projects and the research team's interpretation [14,67]. These aspects include finances and the market, skills and knowledge, standardisation, design, manufacturing, transportation and logistics and on-site construction.

Table 3. Summary of previous research on the challenges of prefabrication.

Challenges	References	No. of References	Research Methods	Aspects
C1—Cost inefficiency	[6,14–16,18,23,24,27,29,31,65,68–72]	16	S, I, CS, LR	Finance and market
C2—Lack of skilled workforce	[14,15,19,24,28,31,52,67,68,70,71,73–77]	16	CS, LR, S	Skills and knowledge
C3—Non-traditional design/DFMA/design information sharing	[18,22,23,29,65,69,70,78–80]	10	CS, LR, I, MS, S	Design
C4—Lack of standardisation	[22,31,42,52,66,68,70,71,76,77]	10	CS, LR, S	Standardisation
C5—Increased transportation and logistics considerations/restrictions	[18,24,52,67,69–71,81–83]	10	LR, S, CS	Transportation and logistics
C6—Misconceptions	[14–16,31,42,68,70]	7	LR, S	Skills and knowledge
C7—Ineffective information sharing and traceability during transportation	[58,60,69,72,84–86]	7	LR	Transportation and logistics
C8—Intermodule connection design	[69,71,87–89]	5	LR	Design
C9—Inflexible for design change	[27,65,68,70,90]	5	S, I, LR	Design
C10—Production planning	[91–95]	5	LR	Manufacturing
C11—Long design time	[24,27,38,65]	4	S, I, CS	Design
C12—Architecture aesthetics	[3,52,66]	3	CS, LR	Design
C13—Market demand	[24,31,70]	3	S, CS	Finance and market
C14—Site access	[65,68,70]	3	S, I	On-site construction
C15—Lifting safety	[80,96,97]	3	MS, LR, SA	On-site construction
C16—Protection during transportation	[52,70]	2	CS, LR	Transportation and logistics
C17—Installation safety	[97,98]	2	SA, S, I	On-site construction
C18—Compliance and inspection	[80,96]	2	LR, MS	On-site construction
C19—Lack of adoption for automated production system	[96,99]	2	LR	Manufacturing
C20—Bankability	[100,101]	2	CS, S	Finance and market
C21—Moisture control	[102,103]	2	LR	Transportation and logistics
C22—Product verification	[80]	1	MS	On-site construction
C23—Fire, thermal and acoustics testing	[96]	1	LR	Design
C24—Job reduction	[43]	1	CS	Finance and market
C25—Payment process	[6]	1	CS	Finance and market
C26—Surface protection	[102]	1	LR	Transportation and logistics

Note: C—challenges, CS—case study, LR—literature review, I—interview, S—survey, MS—model simulation, SA—statistical analysis.

The challenges related to finances and the market include cost inefficiency, market demand and job reductions, bankability and payment processes. For cost inefficiency, it is unlikely that the total cost of a single project will directly benefit from implementing the off-site technique alone due to several reasons [6]. Firstly, the wider supply chain or mass production is difficult to achieve in a single project. Secondly, the manufacturing cost cannot be reduced significantly because of the higher degree of customisation required. Thirdly, the higher initial costs related to design and tendering in prefabrication were also identified as major financial constraints [29]. In Australia, prefabrication has been mainly applied in residential projects, hotels, railway stations and educational buildings, and the current market size for prefabricated construction in Australia is still considerably small. As a result, the production cost of prefabricated components is relatively high, which results in high overall costs of prefabrication [24].

The challenges related to skills and knowledge include the lack of a skilled workforce and misconceptions. As the production, transportation and installation of prefabricated components are more complicated than traditional construction methods [68], prefabrication requires skilled construction workers, which present a shortage in the Australian construction workforce. Furthermore, there is a lack of adequate training on prefabrication [31], which further exacerbates this problem. Regarding misconceptions, many industry members and clients are still suspicious of the performance and quality of prefabrication [31], which hinders the wider adoption of prefabrication.

Lack of standardisation is another challenge. The current prefabrication design practice is largely based on the traditional building design standard, even though the structural loads might be very different in modular construction. Moreover, the on-site construction process, including assembly and quality assessment, is quite different from the traditional method [31]. Because of the lack of design guidelines for prefabricated buildings, prefabrication may fail to meet the expectations of the asset owners, who are likely to develop the perception that the prefabricated components do not meet the minimum standard requirements and do not have long-term performance [66]. Therefore, legal standards and codes of prefabrication need to be developed with regard to the whole process of prefabrication [70].

The challenges related to design include non-traditional design, intermodule connection design, long design times, architecture aesthetics, fire resistance of modules and inflexibility for design changes. Different from traditional design, design for manufacturing and assembly (DfMA) is required in prefabricated construction [79], which increases the difficulties and workloads for designers and lengthens the design period. Regarding intermodule connection design, the conventional intermodule connections mainly use direct plates and connect them with bolts, which can be problematic for the inner connecting regions [89]. Regarding building aesthetics, the standardisation of prefabricated components may lead to the similarity of buildings' appearances, and monotonous and repetitive design [65]. Steel modular construction may also have fire resistance issues depending on the construction system [96]. Furthermore, lack of design flexibility is also a limitation when using prefabrication [27] because late design modifications often incur significant extra costs.

The challenges related to manufacturing include production planning and a lack of adoption of automated production systems. For the production planning in prefabrication, many studies have proposed systems, models and algorithms, mainly for solving the flow-shop scheduling problems in factories, such as the distributed permutation flow-shop scheduling problem (DPFSP) [95] and no-wait flow-shop scheduling problem (DNFSP) [92]. Automated production systems, such as automatic wall systems and automatic floor systems, have the potential to provide numerous advantages to the construction industry. However, the level of adoption is still very low because of the high initial capital investment, low budget, current work culture and other reasons [99].

The challenges related to transportation include increased transportation and logistics restrictions, ineffective information sharing and traceability, product verification, protection during transportation, surface protection and moisture control. Increased transportation and logistics restrictions include the module's dimensional constraints, traffic control requirements when transporting heavy and bulky products in high-density populated areas and maximum limits of distance for transportation [75]. Ineffective information sharing and traceability due to the adoption of traditional methods of communication cause difficulties in logistic management [58]. To achieve real-time information sharing and traceability in prefabricated construction, many studies have proposed an Internet of Things (IoT)-enabled platform [58,85]. During transportation, vibrations of vehicles may cause damage to prefabricated components, and the intensity of damage increases with the roughness of the road surface [78]. Therefore, necessary protection during transportation should be considered at the early stage of a project.

The challenges related to on-site construction include site access, lifting safety, installation safety and quality inspections required. In Australia, there were, in total, 150 worker fatalities reported in the construction industry from 2015 to 2019 [104]. The major safety concern in prefabrication is the installation safety, because most accidents occur due to oversized and overweight component lifting [6]. Limited site access [70], inefficient product verification due to ambiguous labels [80] and slow quality inspection procedures due to the increased number of connections [96] are also identified to affect the schedule performance of prefabricated construction.

Based on the literature review on the benefits and challenges of implementing prefabricated construction, the most commonly applied research methods in these previous studies were case studies, literature reviews, interviews and surveys. Case studies were applied to measure the benefits and challenges of using prefabrication quantitatively [6,43]. Literature reviews were generally applied to identify research gaps on this topic, to identify the benefits and challenges of prefabrication qualitatively and to identify solutions for tackling these challenges [69,102]. Interviews were generally applied to collect in-depth information regarding prefabrication [16,27]. Survey questionnaires were generally applied to rank the challenges of prefabrication [27,68]. This research aims to identify the major changes in the current Australian prefabricated construction industry, including prefabrication industry developments, benefits and challenges of implementing prefabricated construction and recommendations for tackling them. To achieve these objectives, interviews were selected as the other research approach in this study. This is because interviews are especially useful when detailed or lengthy information is planned to be collected, or follow-up questions may be asked based on interviewees' responses. Moreover, interview questions are usually open-ended, which helps to collect in-depth information.

3.2. Interview Results and Analysis

The collected interview data were processed and analysed by using NVivo Pro 12. NVivo Pro 12 can organise, store and analyse data from more sources, and can analyse data with coding functions and advanced management functions. Therefore, NVivo Pro 12 was selected as the data analysis software in this study to obtain the industry insights [105]. The collected raw interview data in handwritten form were transferred into a Word document and imported into NVivo Pro 12 for content analysis, so that the useful information could be extracted from interview data. By using the coding function in NVivo, 50 interview factors were extracted from the interview data by the authors, as shown in Table 4. These interview factors can be grouped into three categories, including current industry development (10 factors), benefits (17 factors) and challenges (23 factors).

Furthermore, cluster analysis in NVivo was used to assess and group sources or nodes that share similar words. The sources or nodes clustered together in the cluster analysis diagram have higher similarity based on the occurrence and frequency of similar words. Sources or nodes with lower similarity are far apart. The size of each node indicates the number of words included in the text of the node. By selecting all interview content related to 23 challenges and selecting those clustered by word similarity and Pearson correlation coefficient, the key clusters were then generated through the cluster analysis function in NVivo Pro 12. The content in the interview files was grouped into eight clusters and presented in different colours, as shown in Figure 1. The words representing each cluster are identified as "design", "construction", "lifting", "challenges", "systems", "material", "quality" and "knowledge", respectively. These words are considered as a reference for the classification of the 23 challenges in Section 4.2.

Table 4. Interview factors analysis.

Categories	Factors
Current industry development	D1—Digital design and design optimisation process
	D2—Innovative connection design D3—Innovative material (cross-laminated timber) D4—Modular handbook D5—Innovative building system D6—Innovative design philosophy D7—Innovative facade system D8—Innovative prefabricated bathrooms D9—Supply chain management D10—Design for noise and vibration
Benefits	B1—Time saving B7—Reduce on-site construction waste B2—Better quality B4—Improved construction safety
	B3—Energy saving B5—General cost benefits B6—Reduce on-site work and labour B10—Less disruption to neighbours B12—Waste recyclability B14—Light weight of prefabricated materials B16—Create opportunities for auto manufacturing employees
	B8—Addressing skills shortage B11—Relieve housing demand B13—Material saving B9—Lower production costs due to remote manufacture B17—Fewer truck deliveries and reduced street congestion B15—Increase project certainty
Challenges	C2—Lack of skilled workforce C4—Lack of standardisation C6—Misconceptions C15—Lifting safety
	C1—Cost inefficiency C5—Increased transportation and logistics considerations/restrictions C9—Inflexible for design change C14—Site access C16—Protection during transportation C19—Lack of adoption for automatic production systems C23—Fire, thermal and acoustics testing C20—Bankability C25—Payment process C27—Availability of lifting equipment C28—Contract type C29—Capabilities inconsistency between companies C30—Lifting delay
	C13—Market demand C18—Compliance and inspection C21—Moisture control C26—Surface protection C31—Knowledge on cost analysis C32—Finish inconsistency of products

Note: D—current industry development, B—benefits, C—challenges.

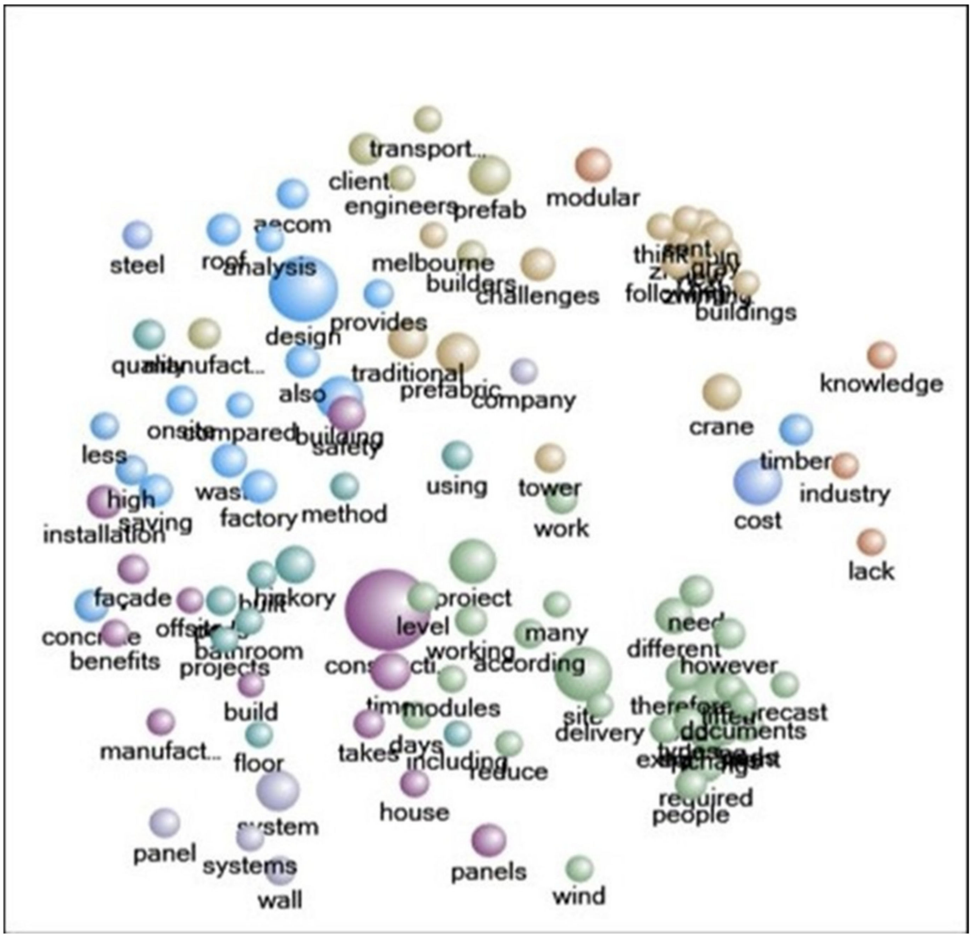

Figure 1. NVivo cluster analysis 3D diagram.

4. Discussion

4.1. Current Industry Development and Major Changes

By analysing the interview content, ten development factors are identified, as in Table 4, that reflect the current industry development for prefabricated construction. This section aims to briefly introduce how prefabricated construction has been developed in Australia in recent years by discussing these development factors. These development factors can be categorised into the following four aspects: prefabrication design, prefabrication types, prefabrication management and prefabrication guidelines.

In terms of design, many leading prefabrication companies have developed their own design process, design philosophy, connection system and acoustic consulting service to ensure building aesthetics, fabrication, constructability and serviceability of prefabricated projects. For the in-house digital design process and design optimisation process, architects and façade engineers are involved at the early design stage, which is key to ensure building aesthetics. During design, building information modelling (BIM) is used for design detail development and design coordination with builders and manufacturers, to ensure constructability and design for fabrication. The Peppers Kings Square Hotel [106] in Perth, Australia is a typical example. In this project, the Hickory patented façade system was built precisely to streamline panel sizes to window locations without compromising the aesthetics of building. Furthermore, the design philosophy can be used to generalise the building design by considering the manufacturing capability of most plants, constructability of most builders, transportation capability, logistics and other factors, to ensure that the provided design can be put in to practice with minimal risks. The Melbourne Quarter Tower Project [107], a 34-story building, is a good example to elaborate this design philosophy. The very curvy roof design, the height of this building and the complex working environment brought construction safety issues and other challenges to traditional construction methods. The consulting company redesigned the roof and provided the builder with three alternative prefabricated design options, based on their constructability and manufacturing capability. Compared with the traditional design, the implemented prefabrication design was not only safer but also more economical due to material usage reduction (around 60% steel tonnage reduction as per comment from one interviewee).

For prefabrication types, some leading prefabrication companies are applying volumetric systems in building projects. They might be structural elements, architectural elements or service elements. One typical example of a volumetric system is bathroom pods. Some leading companies are also applying hybrid prefabrication systems, which are three-dimensional systems combined with other units or systems [108]. A typical example of a hybrid system is the Hickory Building Systems (HBS), as shown in Figure 2, which is a patented building technology. Both systems are increasingly demonstrating their ability to reach multi-level [109]. Furthermore, mass timber construction is typically used in applications as a substitute for concrete and steel, and some Australian companies have used mass timber for public buildings and residential housing construction [110].

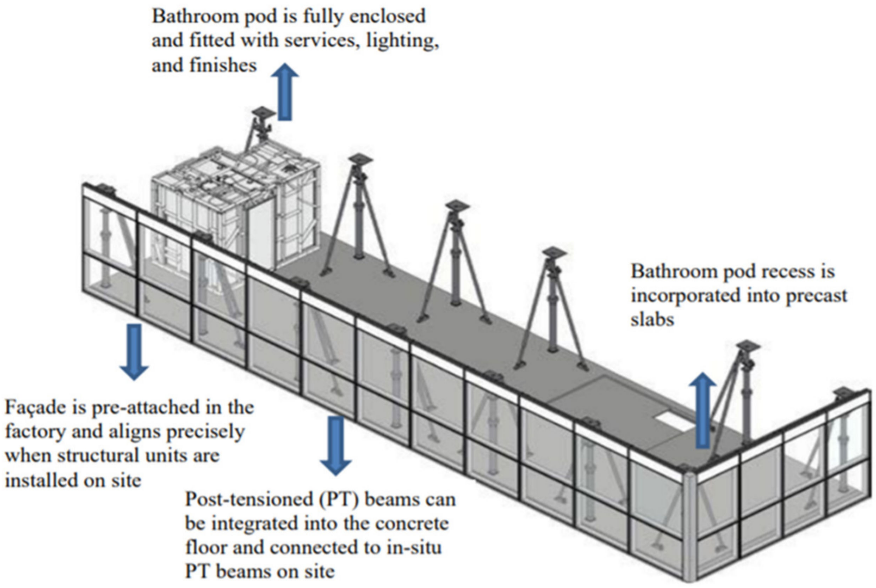

Figure 2. Hickory Building Systems (Source: [66]).

Regarding prefabrication management, supply chain integration management has been applied and proven to be key to the success of prefabricated construction where multiple parties are involved. Supply chain management covers material flow, informative flow and capital flow, and requires more negotiation skills, industry experience and knowledge of manufacturing, transportation and assembly [72]. Therefore, successful supply chain management in prefabricated construction requires all stakeholders to be familiar with the capabilities of one another and requires effective communication between them. New information and communications technology (ICT) can help to improve supply chain management through real-time communication, tracking and monitoring [4,86].

Regarding prefabrication guidelines, a modular handbook was developed by Monash University in 2017 to provide guidance to the industry on the design and construction of modular structures, by serving as a platform for the sharing of experience and knowledge advances [111]. This handbook aims to promote best practices and boost confidence among all stakeholders, from designers through to financiers. However, this modular handbook is not intended to have any legal status and focuses on the design of modular structures. Therefore, more detailed standards are required regarding manufacturing, lifting, on-site installation and building inspection.

With more industry practice, more new technologies, materials and design developments in the Australian prefabrication industry in recent years, the industry's perspective on prefabrication is also changing. For example, the immense changes to existing construction processes is not considered a major barrier to prefabrication. Industry practitioners have been adapting to the new prefabricated construction processes in recent years. According to the interviews, at the beginning, labourers can become familiar with the prefabricated construction within only a few months, and the entire process proceeds faster. Furthermore, the "non-traditional design" is not considered a challenge by the industry because many leading prefabrication companies have been changing their design philosophies, such as DfMA, collaboration at the design stage and design innovation. Recent design innovations in prefabrication projects have boosted the industry's confidence in prefabrication projects. Another change is that cost efficiency can be achieved in more and more prefabrication projects, even though cost inefficiency is still considered a challenge by some researchers and industry practitioners. The reason for the contradictory views is that the overall cost efficiency of prefabricated projects changes from case to case and depends on many project-specific factors. In general, the many benefits associated with prefabricated construction, such as shorter schedules, increased coordination, reduced on-site labour, the use of lightweight prefabricated materials and less material waste and re-work, will improve cost efficiency. However, at the current stage, cost inefficiency still occurs on some prefabrication projects due to small economies of scale, low repeatability and capability inconsistencies between companies.

4.2. Industry's Perspectives on the Benefits and Challenges of Prefabrication

Most benefits mentioned by academia are also endorsed by the industry, as shown in Table 5. These common benefits are strongly influencing the construction industry in Australia. Therefore, policymakers, developers and potential investors should fully realise and understand how these factors can benefit projects. Practitioners and researchers can collaborate to quantify these benefits and to investigate how to utilise these benefits to promote prefabricated construction.

Table 5. Benefits and challenges shared by academia and industry interviews.

Common Benefits	Common Challenges
B1—Time saving B2—Better quality B3—Energy saving B4—Improved construction safety B5—General cost benefits B6—Reduce on-site work and labour B7—Reduce on-site construction waste B8—Addressing skills shortage B9—Lower production due to remote manufacture B10—Less disruptive to neighbours B11—Relief housing demand B12—Waste recyclability B13—Material saving B14—Light weight of prefabricated materials B15—Increase project certainty	C1—Cost inefficiency C2—Lack of skilled workforce C4—Lack of standardisation C5—Increased transportation and logistics considerations/restrictions C6—Misconceptions C9—Inflexible for design change C13—Market demand C14—Site access C15—Lifting safety C16—Protection during transportation C18—Compliance and inspection C19—Lack of adoption for automated production system C20—Bankability C21—Moisture control C23—Fire, thermal and acoustics testing C25—Payment process C26—Surface protection

Note: B—benefits, C—challenges.

With the exception of the common benefits, there are two new benefits proposed by the industry but not mentioned in the previous literature. These are B16—create opportunities for auto manufacturing employees and B17—fewer truck deliveries and reduced street congestion. Prefabrication can create many job opportunities for workers, which is a strong focus of the government following the closure of several automotive manufacturing companies in the last two decades in Australia. Prefab manufacturers need a significant number of workers with automation knowledge and skills to meet the demand of prefabricated construction. Automotive manufacturing workers have advanced transferable skills in automation, which can be applied directly into the prefabrication industry. Relevant transition has been achieved in Australia. For example, the Hickory Group, one of Australia's leading construction companies, is taking on former automotive workers to build its capabilities into the future prefabricated modular construction, following the shutdown of automotive manufacturers such as Toyota and Holden in Australia [112].

Prefabrication can ease street congestion, because prefabricated components are made in factories instead of being cast in situ. This can reduce concrete truck deliveries significantly and reduce deliveries for formwork and other building components such as steel rebars. This can also save massive on-site space for material storage. Besides the above, modules integrating structural, architectural and service elements can save even more deliveries because these modules are delivered to the construction site as only one modular product, instead of multiple building elements. Furthermore, these integrated modules are delivered to sites mostly at night, to avoid major traffic disruptions.

For the challenges of using prefabrication, more than half of the challenges mentioned by academia are also endorsed by the industry, as shown in Table 5. With the exception of the common challenges, there are new challenges proposed by the industry but not mentioned in the previous literature. These include C27—availability of lifting equipment, C28—contract type, C29—capability inconsistencies between companies, C30—lifting delay, C31—knowledge on cost analysis and C32—finish inconsistency of products. These challenges were identified in the industry interviews, reflecting recent changes in the Australian prefabrication industry.

The new challenges C27—availability of lifting equipment and C30—lifting delay are related to on-site lifting. Prefabrication makes loads oversized and overweight. Therefore, more lifting and rigging equipment is required to be available and serviceable to achieve the lifting of these prefabricated loads, which is different from traditional construction methods. These may include, but are not limited to, spreader frames, lifting beams, lifting inserts, chains, slings, lifting anchors, lifting clutches and lifting plates. This increases the workload and difficulty for site workers to manage the resources. Another new and critical issue is the lifting delay, which may be caused by a few factors. The lifting of prefabricated items has higher requirements regarding weather conditions, which sometimes means that the lifting work needs to be postponed until the weather condition is satisfactory. Another reason is the poor quality of prefabricated items. When the prefabricated items are transported to the construction site, the builder may find that some prefabricated items have defects, such as cracking. In this case, another prefabricated item should be ordered from the factory, which can cause lifting delays. Moreover, the transportation of prefabricated items may fail to follow the delivery schedule, which can also cause a lifting delay.

In terms of the knowledge of cost analysis, there is insufficient knowledge in terms of comparing the prefabrication cost with traditional construction costs. This lack of information brings uncertainties to the investors for adopting prefabrication in building projects, since cost estimations and cost comparisons are their major considerations. Furthermore, the finish inconsistency of products occurs, especially for lightweight, recycled and low-carbon concrete. Cracking may happen on the surfaces of some precast concrete panels, which results in remanufacturing. This affects the final delivery of products and may cause project delays and additional costs. In addition, according to the interviews, traditional design–bid–build contract types do not align with or are not suitable for the prefabrication model, and the capabilities between prefabrication companies are highly inconsistent in the current prefabrication industry.

Based on the existing literature, such as [14,67], the cluster analysis results, interview results and the life cycle of prefabrication projects, the major challenges identified can be grouped into eight aspects, as shown in Table 6. The life cycle of prefabrication projects considered in this study includes the procurement stage, design stage, manufacturing stage, transportation and logistics stage and on-site construction stage. The industry's perspectives on the challenges of using prefabrication are also summarised in Table 6, and relevant recommendations to overcome those challenges are also proposed. Table 6 provides a valuable reference for all parties in the Australian prefabrication supply chain, to update their knowledge or understanding of the challenges in using prefabrication and their corresponding recommendations.

Table 6. Eight aspects of Australian prefabrication challenges and recommendations.

Aspects	Challenges	Industry's Perspective	Recommendations
Procurement	C25—Payment process * C28—Contract type	• Advanced cost preparation prior to on-site activities due to off-site manufacturing of building elements in prefabrication. • The most traditional and common building contract type in Australia, design–bid–build does not support early involvement of stakeholders, such as prefabrication companies.	• More detailed payment terms in contract • New construction procurement methods
Design	C9—Inflexible for design change C23—Fire, thermal and acoustics testing	• Once manufacturing starts, any design changes will result in extra costs and time. • As only limited testing results on the fire, thermal and acoustics performance of new prefabricated materials are open-source, companies generally need to perform the testing themselves and apply for approvals from the building council.	• Early collaborations in the design process • Providing more testing results in related standards
Manufacturing	* C32—Finish inconsistency of products C19—Lack of adoption for automated production system	• Finish inconsistency happens in prefabricated products, especially for lightweight, recycled and low-carbon concrete. • Most automatic production system orders are for timber (including cross-laminated timber) and very limited requests are placed on production line systems using light-gauge steel and concrete.	• Improving the knowledge and usage of quality control tools • Promoting automated production systems
Transportation and logistics	C5—Increased transportation and logistics restrictions C16—Protection during transportation	• Increased transportation and logistics restrictions include the module's dimensional constraints and traffic control requirements in transporting heavy and bulky products in high-density populated areas. • Prefabricated components may be damaged during transportation by using trucks, ships and trains, due to shock loading.	• Early collaborations in the design process • Application of ICT • Adoption of just-in-time philosophy • Transportation and logistics management planning

Table 6. *Cont.*

Aspects	Challenges	Industry's Perspective	Recommendations
On-site construction	C15—Lifting safety C18—Compliance and inspection * C27—Availability of lifting equipment * C30—Lifting delay C14—Site access C21—Moisture control C26—Surface protection	• The current standard deals with the wind effects in a simple manner, without considering load properties, wind direction, travel path, surface area of crane and surrounding environment. These factors are controlled by site workers, mainly based on their experience, which leads to a lack of consistency. • The compliance and inspection process of prefabricated construction challenges the means of inspecting projects. • Lifting delay may be due to prefabricated items' higher requirements for weather conditions, poor quality of prefabricated items and the failure of the transportation of prefabricated items to follow the delivery schedule. • More lifting and rigging equipment needs to be available and serviceable to achieve the lifting of prefabricated loads. • Prefabrication brings challenges for site access, moisture control and surface protection of prefabricated products.	• Adequate planning of lifting operation and proper lifting design • Appropriate degree of standardisation in procurement, manufacturing, on-site installation and inspection • Building inspectors specialising in prefabricated construction • Adoption of just-in-time philosophy • Early collaborations in the design process
Standardisation	C4—Lack of standardisation	• The development of codes and regulations cannot keep pace with the speed of technology development for modular construction.	• Appropriate degree of standardisation in procurement, manufacturing, on-site installation and inspection • Providing more testing results in related standards
Skills and knowledge	C2—Lack of skilled workforce C6—Misconceptions	• There is a lack of adequate skill sets in staff regarding technical knowledge, compliance, interpreting drawings in projects and people management. Designers have limited knowledge on manufacturing capability, constructability and transportation ability. • Many architects believe that prefab will affect the building aesthetics, and many clients or investors do not favour prefab.	• Courses or training programs on prefabrication • Industry workshops and conferences • On-the-job training for industry practitioners • Exhibitions, offline and online events and media reports on job training for industry practitioners
Finance and market	C1—Cost inefficiency C13—Market demand C20—Bankability * C29—Capability inconsistencies between companies * C31—Knowledge on cost analysis	• The market demand for prefabricated construction in Australia is still considerably small, which makes it difficult for small to medium prefab companies to manage the growth of the company effectively (low economies of scale). • Prefabricated construction loan is still not generalised in Australia. • The capabilities between prefab companies vary significantly, which can lead to financial risks for clients. • There is insufficient knowledge in terms of comparing the prefabrication cost with traditional construction cost.	• Financial support from government • More client-focused market research • International trade tours and trade shows for potential export markets • Engaging financial institutions' interest in prefabrication • New funding and financing models

Note: C—challenges, *—new factors.

4.3. Recommendations and Key Responsible Parties

4.3.1. Recommendations

To tackle the above-mentioned challenges, relevant recommendations for each challenge category are summarised based on the analysis of previous studies, industry interview results and local context. A total of 21 recommendations are identified, as shown in Table 6. Regarding design, one challenge is inflexibility for design changes, and the recommendation for this challenge is to involve clients, building professionals and manufacturers at the early design stage. This solution can not only reduce later design changes but also ensure building aesthetics and design for fabrication. For fire, thermal and acoustics testing, only limited testing results on the performance of prefabricated materials are open-source. Therefore, these testing results on the performance of prefabricated materials should be made available in related standards so that design engineers can use them in prefabricated building design.

Regarding procurement and contracts, the specific payment process for prefabricated projects is not standardised or certain. Title transfer details and ownership are not clear during the prefabricated construction process. To manage these payment risks, contractors need to clearly provide more details on the payment terms in prefabricated construction contracts. These details should include milestone payments, adequate payment mechanisms and the courts' decision [113]. The traditional contract type does not support the early involvement of multiple parties in prefabrication projects. To tackle this shortcoming, new construction procurement methods such as strategic partnering have been suggested [114,115] for use in prefabrication projects to achieve adequate planning.

Regarding manufacturing, the customer requests for the automatic production lines of light-gauge steel and concrete are very limited. Therefore, attending more industry events, such as prefabAUS networking events and trade shows, is recommended to promote these automated production systems. To improve the finish consistency of prefabricated products, many studies suggest to improve the knowledge and usage of basic quality control tools [116,117]. These tools include check sheets, flow charts and histograms. Besides these, graphical user interfaces for concrete production are also found to be useful to improve the production quality of precast concrete [118].

Prefabricated construction faces more transportation and logistics challenges due to oversized prefabricated components. Therefore, transportation and logistics problems should be discussed at the early design stage, with the involvement of multiple stakeholders. New technologies will provide possible solutions for transportation problems. The application of ICT, such as cloud technologies, Internet of Things (IoT), BIM and virtual reality (VR) and augmented reality (AR), has been proven to be effective to improve information exchange, reduce uncertainties during logistics and therefore improve the schedule performance of prefabricated construction [4,58,74,85,119–121]. However, there are also challenges affecting the adoption of ICT in the Australian prefabricated construction field, such as the availability of appropriate training or pedagogical approaches to transfer and share the obtained knowledge and information techniques [120]. Besides this, the just-in-time (JIT) philosophy is recommended by many studies [122,123] to reduce the wasted time of truck drivers queuing on-site and to reduce environmental emissions due to shorter transportation times. Prefabricated components may be damaged during transportation. To tackle this, a clear transportation and logistics management plan should be formulated. The manufacturer should provide the transporter with detailed information on the shape and size of the prefabricated loads in advance, in order that the most appropriate method for stabilising and securing the load can be selected. Moreover, the driver should inspect the traffic management plan and relevant areas of the construction site under the direction of the site supervisor before transportation, to verify there are no risks [124].

For on-site construction, the installation inspection process is slow due to the increased number of connections in prefabrication. Therefore, building inspectors should be trained to become familiar with the various prefabrication systems and connections, which can speed up the building consent assessment process [125]. For site access, the just-in-time philosophy and early design collaboration are recommended to tackle this challenge so that prefabricated components can be delivered at the correct time, in the correct quantities and to the correct location [65]. Moreover, just-in-time (JIT) delivery is found to be effective to reduce lifting delays [122,123]. Adequate planning of lifting operations is critical to tackle the following challenges: C15—lifting safety and C25—availability of lifting equipment. During lifting design, lifting engineers need to make sure that the lifting point and lifting inserts can take the weight and the ground conditions are sufficient. Additionally, lifting engineers need to inspect the on-site lifting operation to ensure that all lifting personnel can understand and follow the designed lifting procedure. Builders need proper planning to ensure that all required lift gear is available and serviceable before lifting.

Many studies [42,66,68] have argued that the lack of standardisation brings significant challenges to the implementation of prefabrication. The Handbook for the Design of Modular Structures was developed as a result of a collaborative project by Monash University with industrial and university partners and with support from the Victorian Government. This handbook only provides general information for the design of modular structures. Therefore, developing an appropriate degree of standardisation in prefabrication processes is suggested. These processes include procurement, manufacturing and on-site installation and inspection. To achieve this, prefabricated construction associations can play a leading role in the standardisation of prefabrication, with collaboration between stakeholders. Besides this, more testing results on the fire, thermal and acoustics performance of prefabricated materials should be provided in related standards.

For skills and knowledge, there is a lack of a competent and experienced workforce in the current Australian prefabrication market. Therefore, both industry and academia [65,69,126] have recommended that universities and professional associations should provide prefabrication-related courses or training programs to upskill the future workforce and help former automotive manufacturing workers to transfer their skills. On-the-job training is also strongly recommended to upskill builders, designers, building surveyors and quantity surveyors [125]. Furthermore, industry workshops and conferences are useful to promote prefabrication knowledge sharing within the industry [65]. Exhibitions, offline and online events and media reports regarding prefabricated construction, such as success stories of prefabrication projects, can help to increase public awareness and change clients' negative perceptions of prefabrication.

For finances and the market, more client-focused market research is needed to assess the demand for prefab and to better understand the challenges and value drivers of using prefab, as mentioned by Prefab NZ [125]. International trade tours and trade shows to potential export markets are also recommended [125]. Cost inefficiency is still a problem at the current stage. Therefore, there is still a need for the government's financial and policy support of prefabrication companies. With respect to the bankability for prefabricated construction, financial institutions are often reluctant to provide financing for prefabricated projects because there is nothing on-site and there are still many uncertainties before completion. To increase their interest and willingness to provide loans, builders need to be registered and have a good, long track record and detailed construction plan. If upfront payment is requested before the building has arrived on-site, the builders can support it with some form of security, such as a performance bond. Besides this, communication with bankers at the early stage to enhance their knowledge of the prefabrication process and the applied prefabrication system is effective to reduce misconceptions. From a mid-term to long-term perspective, there is a need for new funding and financing models to fit the characteristics of prefabrication projects, which will serve to boost the uptake of prefabricated construction [127].

4.3.2. Key Responsible Parties

Stakeholder engagement is found to have a strong correlation with the challenges related to prefabricated construction and is critical to drive the adoption of prefabricated construction [128]. Based on the literature review and the above discussion, the key responsible parties for each recommendation were identified, as shown in Table 7. There are, in total, six key responsible parties, including government, industry associations, financial organisations, construction industry practitioners, education and training institutes and research and development institutes.

Table 7. Key responsible parties.

Recommendations	Key Responsible Parties					
	Gov	IA	FO	CIP	EDI	RDI
Early collaborations in the design process				X		
Providing more testing results in related standards		X				X
More detailed payment terms in contracts				X		
New construction procurement methods				X		
Improving the knowledge and usage of quality control tools				X	X	
Promoting automated production systems				X		
The adoption of just-in-time philosophy				X		
The application of ICT				X		
Transportation and logistics management planning				X		
Adequate planning of lifting operations and lifting design				X		
Appropriate degree of standardisation in procurement, manufacturing, on-site installation and inspection		X				
Building inspectors specialising in prefabricated construction					X	
Courses or training programs on prefabrication					X	
Industry workshops and conferences	X	X		X	X	X
On-the-job training for industry practitioners					X	
Exhibitions, offline and online events and media reports		X		X		
Financial support from government	X					
More client-focused market research				X		X
International trade tours and trade shows to potential export markets	X			X		
Engaging financial institutions' interest in prefabrication			X	X		
New funding and financing models			X	X	X	

Note: Gov—government, IA—industry associations, FO—financial organisations, CIP—construction industry practitioners, EDI—education and training institutes, RDI—research and development institutes.

Engagement of the key responsible parties is important for the successful uptake of prefabricated construction in Australia. Government plays a leading role to promote prefabrication through policies, regulations and financial support. Prefabricated public housing could be a good start for its uptake. Industry associations can contribute to the development of relevant prefab standards by collaborating with industry members and academic researchers. To be more involved in prefabricated construction projects, financial organisations need to have a better understanding of the prefabrication industry through education and the outsourcing of expertise. To streamline the prefabrication process, construction industry practitioners such as designers, manufacturers, contractors and suppliers need to be involved at the early stages of prefab projects and collaborate to find optimum solutions to technical and management problems. Furthermore, education and training institutes should provide more prefab-related courses and training. Research and development institutes should lead the innovations and solve the existing problems in the prefabrication industry by collaborating with various parties.

5. Conclusions

With the increasing interest in prefabrication in recent years, the building sector in Australia has been making a significant shift to prefabricated construction, due largely to its ability to improve sustainability and productivity in construction. Moreover, prefabrication-related new technologies, materials, systems and services are changing the current Australian prefabrication market. Although previous studies have investigated the benefits and challenges of implementing prefabrication in Australia, they do not reflect recent changes in the industry. Based on a literature review and interview results, this study examined the current Australian prefabrication industry and the benefits and challenges of implementing prefabrication from industrial perspectives. The challenges identified from the industry interviews are further classified into eight aspects. To tackle these challenges, 21 recommended actions and six key responsible parties are proposed based on previous studies and the industry interview content.

This study provides a valuable reference for all parties in the prefabrication supply chain to update their knowledge of current industry developments in the Australian context. With the expected uptake of prefabrication, the findings will be useful for local industry and governments to develop roadmaps and policies in promoting prefabrication, and for practitioners such as manufacturers, contractors and consultants to reshape their competitive advantages and future strategies in the prefabrication market. The findings are also helpful references for prefabAUS to develop the future agenda for Australia's prefabricated building industry. In addition, this study will contribute to enriching global researchers and professionals' knowledge of current prefabrication development and future challenges in Australia, particularly those in the construction management domain, and inspiring them to rethink the future research directions and development of prefabricated construction due to the changing circumstances and emerging new technologies. With the recommendations identified in this study, future research could explore the implementation of these recommendations to tackle the new challenges, with particular attention to the adoption of digital technologies in prefabricated construction.

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References

1. Selbyville, D. Modular & Prefabricated Construction Market to Hit $174.37 Bn by 2026: Global Market Insights, Inc. Available online: https://www.gminsights.com/industry-analysis/modular-and-prefabricated-construction-market?utm_source=globenewswire.com&utm_medium=referral&utm_campaign=Paid_Globnewswire (accessed on 11 December 2020).
2. Oz Sahin, D.M.S.M. Value-based modelling: An Australian case of offsite manufactured buildings. *Int. J. Constr. Manag.* **2018**, *18*, 34–52. [CrossRef]
3. Lopez, D.; Froese, T.M. Analysis of Costs and Benefits of Panelized and Modular Prefabricated Homes. *Procedia Eng.* **2016**, *145*, 1291–1297. [CrossRef]
4. Li, C.Z.; Zhong, R.Y.; Xue, F.; Xu, G.; Chen, K.; Huang, G.G.; Shen, G.Q. Integrating RFID and BIM technologies for mitigating risks and improving schedule performance of prefabricated house construction. *J. Clean. Prod.* **2017**, *165*, 1048–1062. [CrossRef]
5. Ji, Y.; Li, K.; Liu, G.; Shrestha, A.; Jing, J. Comparing greenhouse gas emissions of precast in-situ and conventional construction methods. *J. Clean. Prod.* **2018**, *173*, 124–134. [CrossRef]
6. Sutrisna, M.; Cooper-Cooke, B.; Goulding, J.; Ezcan, V. Investigating the Cost of Offsite Construction Housing in Western Australia. *Int. J. Hous. Mark. Anal.* **2019**, *12*, 5–24. [CrossRef]
7. Workfast, Construction Industry: Shortage In Skilled Workers. Workfast 20/03/2017, 2017. Available online: https://workfast.com.au/blog/construction-industry-shortages-skilled-workers/ (accessed on 17 August 2021).
8. Murray, T. The Benefits of Prefabrication in a COVID-19 World. Available online: https://modbs.co.uk/news/fullstory.php/aid/19519/The_benefits_of_prefabrication_in_a_COVID-19_world.html (accessed on 17 August 2021).

9. Mordor Intelligence. *Australia Prefabricated Buildings Industry—Growth, Trends, COVID-19 Impact, And Forecasts (2021–2026)*; Mordor Intelligence: Hyderabad, India, 2019.
10. Victoria State Government. *Prefabricated Construction in Victoria*; Department of Jobs, Regions and Precincts: Victoria, Australia, 2019.
11. Dodge Data and Analytics. *Prefabrication and Modular Construction 2020*; Dodge Data and Analytics: Hamilton, NJ, USA, 2020.
12. Harrison, G. The Future Is Prefabricated. Available online: https://pursuit.unimelb.edu.au/articles/the-future-is-prefabricated (accessed on 17 August 2021).
13. PrefabNZ What Is Prefab? Available online: http://www.prefabnz.com/About (accessed on 20 January 2020).
14. Blismas, N.; Wakefield, R. Drivers, constraints and the future of offsite manufacture in Australia. *Constr. Innov.* **2009**, *9*, 72–83. [CrossRef]
15. Boyd, N.; Khalfan, M.M.; Maqsood, T. Off-site construction of apartment buildings. *J. Archit. Eng.* **2013**, *19*, 51–57. [CrossRef]
16. Sutrisna, M.; Lofthouse, B.; Goulding, J. Exploring the Potential of Offsite Construction to Alleviate Constraints to House building in Western Australia. In Proceedings of the International Research Conference: Shaping Tomorrow's Built Environment, the University of Salford in Conjunction with CIB, Salford, UK, 11–12 September 2017; pp. 896–907.
17. Wong, P.S.; Zwar, C.; Gharaie, E. Examining the drivers and states of organizational change for greater use of prefabrication in construction projects. *J. Constr. Eng. Manag.* **2017**, *143*, 04017020. [CrossRef]
18. Steinhardt, D.A.; Manley, K. Exploring the beliefs of Australian prefabricated house builders. *Constr. Econ. Build.* **2016**, *16*, 27–41. [CrossRef]
19. 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]
20. Wasim, M.; Vaz Serra, P.; Ngo, T.D. Design for manufacturing and assembly for sustainable, quick and cost-effective prefabricated construction—A review. *Int. J. Constr. Manag.* **2020**, 1–9. [CrossRef]
21. Masood, R.; Lim, J.B.P.; González, V.A.; Roy, K.; Khan, K.I.A. A Systematic Review on Supply Chain Management in Prefabricated House-Building Research. *Buildings* **2022**, *12*, 40. [CrossRef]
22. Blismas, N. *Off-Site Manufacture in Australia: Current State and Future Directions*; CRC for Construction Innovation: Brisbane, Australia, 2007.
23. Killian, P.; Arif, M.; Wood, G.; Kaushik, A. Offsite Construction in the UK Housing Sector: Barriers and Challenges. In Proceedings of the Modular and Offsite Construction (MOC) Summit Proceedings, Edmonton, AB, Canada, 29 September–1 October 2016.
24. Mao, C.; Xie, F.; Hou, L.; Wu, P.; Wang, J.; Wang, X. Cost analysis for sustainable off-site construction based on a multiple-case study in China. *Habitat Int.* **2016**, *57*, 215–222. [CrossRef]
25. Shahzad, W.; Mbachu, J.; Domingo, N. Marginal productivity gained through prefabrication: Case studies of building projects in Auckland. *Buildings* **2015**, *5*, 196–208. [CrossRef]
26. Kremer, P.; Ritchie, L. Understanding Costs and Identifying Value in Mass Timber Construction: Calculating the 'Total Cost of Project' (TCP). *Mass Timber Constr. J.* **2018**, *1*, 14–18.
27. Jaillon, L.; Poon, C.S. Design issues of using prefabrication in Hong Kong building construction. *Constr. Manag. Econ.* **2010**, *28*, 1025–1042. [CrossRef]
28. Blismas, N.; Pasquire, C.; Gibb, A. Benefit evaluation for off-site production in construction. *Constr. Manag. Econ.* **2006**, *24*, 121–130. [CrossRef]
29. Pan, W.; Gibb, A.G.F.; Dainty, A.R.J. Perspectives of UK housebuilders on the use of offsite modern methods of construction. *Constr. Manag. Econ.* **2007**, *25*, 183–194. [CrossRef]
30. El-Abidi, K.M.A.; Ghazali, F.E.M. Motivations and Limitations of Prefabricated Building: An Overview. *Appl. Mech. Mater.* **2015**, *802*, 668–675. [CrossRef]
31. Rahman, M.M. Barriers of implementing modern methods of construction. *J. Manag. Eng.* **2014**, *30*, 69–77. [CrossRef]
32. Mao, C.; Shen, L.; Luo, L.; Li, Z. Identification of Risk Factors Influencing the Implementation of Industrialized Building System in China. In Proceedings of the 19th International Symposium on Advancement of Construction Management and Real Estate, Chongqing, China, 7–9 November 2014; Springer: Berlin/Heidelberg, Germany, 2015; pp. 219–230.
33. Li, C.Z.; Hong, J.; Xue, F.; Shen, G.Q.; Xu, X.; Mok, M.K. Schedule risks in prefabrication housing production in Hong Kong: A social network analysis. *J. Clean. Prod.* **2016**, *134*, 482–494. [CrossRef]
34. Jaillon, L.; Poon, C.S. Life cycle design and prefabrication in buildings: A review and case studies in Hong Kong. *Autom. Constr.* **2014**, *39*, 195–202. [CrossRef]
35. Dunn, A. *Final Report for Commercial Building Costing Cases Studies: Traditional Design Versus Timber Project*; Forest and Wood Products Australia: Melbourne, Australia, 2015.
36. Razkenari, M.; Fenner, A.; Shojaei, A.; Hakim, H.; Kibert, C. Perceptions of offsite construction in the United States: An investigation of current practices. *J. Build. Eng.* **2020**, *29*, 101138. [CrossRef]
37. Arif, M.; Egbu, C. Making a case for offsite construction in China. *Eng. Constr. Archit. Manag.* **2010**, *17*, 536–548. [CrossRef]
38. Chen, Y.; Okudan, G.E.; Riley, D.R. Sustainable performance criteria for construction method selection in concrete buildings. *Autom. Constr.* **2010**, *19*, 235–244. [CrossRef]

39. Pan, W.; Gibb, A.G.F.; Dainty, A.R.J. Strategies for Integrating the Use of Off-Site Production Technologies in House Building. *J. Constr. Eng. Manag.* **2012**, *138*, 1331–1340. [CrossRef]
40. Tsz Wai, C.; Wai Yi, P.; Ibrahim Olanrewaju, O.; 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]
41. Linner, T.; Bock, T.J.C.I. Evolution of large-scale industrialisation and service innovation in Japanese prefabrication industry. *Constr. Innov.* **2012**, *12*, 156–178. [CrossRef]
42. Evison, D.C.; Kremer, P.D.; Guiver, J. Mass timber construction in Australia and New Zealand—Status, and economic and environmental influences on adoption. *Wood Fiber Sci.* **2018**, *50*, 128–138. [CrossRef]
43. Benson, M.; Rankin, J. Measuring the Sustainable Benefits of Modular and Offsite Construction Delivery Techniques Against Conventional On-Site Construction. In Proceedings of the Modular Offsite Construction Summit, Edmonton, AB, Canada, 29 September–1 October 2016. [CrossRef]
44. 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]
45. Sandanayake, M.; Luo, W.; Zhang, G. Direct and indirect impact assessment in off-site construction—A case study in China. *Sustain. Cities Soc.* **2019**, *48*, 101520. [CrossRef]
46. Sandanayake, M.; Li, C.Q.; Zhang, G.; Setunge, S. Environmental emissions in building construction–two case studies of conventional and pre-fabricated construction methods in Australia. In Proceedings of the SCMT4: Fourth International Conference on Sustainable Construction Materials and Technologies, Las Vegas, NV, USA, 7–11 August 2016; CreateSpace: Scotts Valley, CA, USA, 2016; pp. 1637–1644.
47. Lehmann, S. Sustainable Construction for Urban Infill Development Using Engineered Massive Wood Panel Systems. *Sustainability* **2012**, *4*, 2707–2742. [CrossRef]
48. 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]
49. Hong, J.; Shen, G.Q.; Mao, C.; Li, Z.; Li, K. Life-cycle energy analysis of prefabricated building components: An input–output-based hybrid model. *J. Clean. Prod.* **2016**, *112*, 2198–2207. [CrossRef]
50. Luo, T.; Xue, X.; Wang, Y.; Xue, W.; Tan, Y. A systematic overview of prefabricated construction policies in China. *J. Clean. Prod.* **2020**, *280*, 124371. [CrossRef]
51. Li, C.Z.; Chen, Z.; Xue, F.; Kong, X.T.; Xiao, B.; Lai, X.; Zhao, Y. A blockchain-and IoT-based smart product-service system for the sustainability of prefabricated housing construction. *J. Clean. Prod.* **2021**, *286*, 125391. [CrossRef]
52. Chang, Y.; Li, X.; Masanet, E.; Zhang, L.; Huang, Z.; Ries, R. Unlocking the green opportunity for prefabricated buildings and construction in China. *Resour. Conserv. Recycl.* **2018**, *139*, 259–261. [CrossRef]
53. Toole, T.M.; Gambatese, J. The future of designing for construction safety. In Proceedings of the 18th Annual Construction Safety Conference, Rosemont, IL, USA, 12–14 February 2008.
54. Pons, O.; Wadel, G. Environmental impacts of prefabricated school buildings in Catalonia. *Habitat Int.* **2011**, *35*, 553–563. [CrossRef]
55. Rahimian, F.P.; Goulding, J.; Akintoye, A.; Kolo, S. Review of Motivations, Success Factors, and Barriers to the Adoption of Offsite Manufacturing in Nigeria. *Procedia Eng.* **2017**, *196*, 512–519. [CrossRef]
56. 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]
57. Lu, W.; Chen, K.; Xue, F.; Pan, W. Searching for an optimal level of prefabrication in construction: An analytical framework. *J. Clean. Prod.* **2018**, *201*, 236–245. [CrossRef]
58. Zhong, R.Y.; Peng, Y.; Xue, F.; Fang, J.; Zou, W.; Luo, H.; Ng, S.T.; Lu, W.; Shen, G.Q.; Huang, G.Q. Prefabricated construction enabled by the Internet-of-Things. *Autom. Constr.* **2017**, *76*, 59–70. [CrossRef]
59. Li, C.Z.; Hong, J.; Xue, F.; Shen, G.Q.; Xu, X.; Luo, L. SWOT analysis and Internet of Things-enabled platform for prefabrication housing production in Hong Kong. *Habitat Int.* **2016**, *57*, 74–87. [CrossRef]
60. Luo, L.; Qiping Shen, G.; Xu, G.; Liu, Y.; Wang, Y. Stakeholder-associated supply chain risks and their interactions in a prefabricated building project in Hong Kong. *J. Manag. Eng.* **2019**, *35*, 05018015. [CrossRef]
61. El-Abidi, K.M.A.; Ofori, G.; Zakaria, S.A.S.; Aziz, A.R.A. Using Prefabricated Building to Address Housing Needs in Libya: A Study based on Local Expert Perspectives. *Arab. J. Sci. Eng.* **2019**, *44*, 8289–8304. [CrossRef]
62. Lehmann, S. Low carbon construction systems using prefabricated engineered solid wood panels for urban infill to significantly reduce greenhouse gas emissions. *Sustain. Cities Soc.* **2013**, *6*, 57–67. [CrossRef]
63. Pittau, F.; Malighetti, L.E.; Iannaccone, G.; Masera, G. Prefabrication as Large-scale Efficient Strategy for the Energy Retrofit of the Housing Stock: An Italian Case Study. *Procedia Eng.* **2017**, *180*, 1160–1169. [CrossRef]
64. Moradibistouni, M.; Gjerde, M. Potential for prefabrication to enhance the New Zealand construction industry. *Proc. Back Future Next* **2017**, *50*, 427–435.
65. Zhang, W.; Lee, M.W.; Jaillon, L.; Poon, C.-S. The hindrance to using prefabrication in Hong Kong's building industry. *J. Clean. Prod.* **2018**, *204*, 70–81. [CrossRef]

66. Li, H.X.; Luther, M.; Mills, A. Prefabrication in the Australian Context. In Proceedings of the 2017 Modular and Offsite Construction Summit & the 2nd International Symposium on Industrialized Construction Technology, Shanghai, China, 10–12 November 2017.
67. Abdul Nabi, M.; El-adaway, I.H. Understanding the Key Risks Affecting Cost and Schedule Performance of Modular Construction Projects. *J. Manag. Eng.* **2021**, *37*, 04021023. [CrossRef]
68. Zhang, X.; Skitmore, M.; Peng, Y. Exploring the challenges to industrialized residential building in China. *Habitat Int.* **2014**, *41*, 176–184. [CrossRef]
69. Hwang, B.-G.; Shan, M.; Looi, K.-Y. Key constraints and mitigation strategies for prefabricated prefinished volumetric construction. *J. Clean. Prod.* **2018**, *183*, 183–193. [CrossRef]
70. Mao, C.; Shen, Q.; Pan, W.; Ye, K. Major barriers to off-site construction: The developer's perspective in China. *J. Manag. Eng.* **2015**, *31*, 04014043. [CrossRef]
71. Ferdous, W.; Bai, Y.; Ngo, T.D.; Manalo, A.; Mendis, P. New advancements, challenges and opportunities of multi-storey modular buildings—A state-of-the-art review. *Eng. Struct.* **2019**, *183*, 883–893. [CrossRef]
72. Luo, L.; Jin, X.; Shen, G.Q.; Wang, Y.; Liang, X.; Li, X.; Li, C.Z. Supply chain management for prefabricated building projects in Hong Kong. *J. Manag. Eng.* **2020**, *36*, 05020001. [CrossRef]
73. Vernikos, V.K.; Goodier, C.I.; Broyd, T.W.; Robery, P.C.; Gibb, A.G. Procurement; Law, Building information modelling and its effect on off-site construction in UK civil engineering. *Manag. Procure. Law* **2014**, *167*, 152–159.
74. Mostafa, S.; Kim, K.P.; Tam, V.W.; Rahnamayiezekavat, P. Exploring the status, benefits, barriers and opportunities of using BIM for advancing prefabrication practice. *Int. J. Constr. Manag.* **2020**, *20*, 146–156. [CrossRef]
75. Schoenborn, J. *A Case Study Approach to Identifying the Constraints and Barriers to Design Innovation for Modular Construction*; Virginia Tech: Blacksburg, VA, USA, 2012.
76. Abdul Nabi, M.; El-adaway, I.H.J. Modular construction: Determining decision-making factors and future research needs. *J. Manag. Eng.* **2020**, *36*, 04020085. [CrossRef]
77. Li, Z.; Zhang, S.; Meng, Q.; Hu, X. Barriers to the development of prefabricated buildings in China: A news coverage analysis. *Eng. Constr. Archit. Manag.* **2020**, *28*, 2884–2903. [CrossRef]
78. Collins, J. Incorporating BIM into Architectural Precast Concrete Fabrication. In Proceedings of the International Symposium on Automation and Robotics in Construction, Auburn, AL, USA, 18–21 July 2016; p. 1.
79. Yuan, Z.; Sun, C.; Wang, Y. Design for Manufacture and Assembly-oriented parametric design of prefabricated buildings. *Autom. Constr.* **2018**, *88*, 13–22. [CrossRef]
80. Li, C.Z.; Xu, X.; Shen, G.Q.; Fan, C.; Li, X.; Hong, J. A model for simulating schedule risks in prefabrication housing production: A case study of six-day cycle assembly activities in Hong Kong. *J. Clean. Prod.* **2018**, *185*, 366–381. [CrossRef]
81. Kamali, M.; Hewage, K. Life cycle performance of modular buildings: A critical review. *Renew. Sustain. Energy Rev.* **2016**, *62*, 1171–1183. [CrossRef]
82. Lee, Y.; Kim, J.I.; Khanzode, A.; Fischer, M. Empirical study of identifying logistical problems in prefabricated interior wall panel construction. *J. Manag. Eng.* **2021**, *37*, 05021002. [CrossRef]
83. Yang, Y.; Pan, M.; Pan, W.; Zhang, Z. Sources of Uncertainties in Offsite Logistics of Modular Construction for High-Rise Building Projects. *J. Manag. Eng.* **2021**, *37*, 04021011. [CrossRef]
84. Xu, G.; Li, M.; Luo, L.; Chen, C.-H.; Huang, G.Q. Cloud-based fleet management for prefabrication transportation. *Enterp. Inf. Syst.* **2019**, *13*, 87–106. [CrossRef]
85. Li, C.Z.; Xue, F.; Li, X.; Hong, J.; Shen, G.Q. An Internet of Things-enabled BIM platform for on-site assembly services in prefabricated construction. *Autom. Constr.* **2018**, *89*, 146–161. [CrossRef]
86. Xu, G.; Li, M.; Chen, C.-H.; Wei, Y. Cloud asset-enabled integrated IoT platform for lean prefabricated construction. *Autom. Constr.* **2018**, *93*, 123–134. [CrossRef]
87. Sharafi, P.; Mortazavi, M.; Samali, B.; Ronagh, H. Interlocking system for enhancing the integrity of multi-storey modular buildings. *Autom. Constr.* **2018**, *85*, 263–272. [CrossRef]
88. Gunawardena, T.; Ngo, T.; Mendis, P.; Alfano, J. Innovative flexible structural system using prefabricated modules. *J. Archit. Eng.* **2016**, *22*, 05016003. [CrossRef]
89. Chen, Z.; Liu, J.; Yu, Y. Experimental study on interior connections in modular steel buildings. *Eng. Struct.* **2017**, *147*, 625–638. [CrossRef]
90. Kasperzyk, C.; Kim, M.-K.; Brilakis, I. Automated re-prefabrication system for buildings using robotics. *Autom. Constr.* **2017**, *83*, 184–195. [CrossRef]
91. Wang, K.; Huang, Y.; Qin, H. A fuzzy logic-based hybrid estimation of distribution algorithm for distributed permutation flowshop scheduling problems under machine breakdown. *J. Oper. Res. Soc.* **2016**, *67*, 68–82. [CrossRef]
92. Lin, S.-W.; Ying, K.-C. Minimizing makespan for solving the distributed no-wait flowshop scheduling problem. *Comput. Ind. Eng.* **2016**, *99*, 202–209. [CrossRef]
93. Deng, J.; Wang, L.J.S. A competitive memetic algorithm for multi-objective distributed permutation flow shop scheduling problem. *Swarm Evol. Comput.* **2017**, *32*, 121–131. [CrossRef]

94. Ho, C.T.T. *Application of Optimization to the Production Planning of Construction Prefabrication Supply Chains*; University of Washington: Seattle, WA, USA, 2019.
95. Fernandez-Viagas, V.; Framinan, J.M. A bounded-search iterated greedy algorithm for the distributed permutation flowshop scheduling problem. *Int. J. Prod. Res.* **2015**, *53*, 1111–1123. [CrossRef]
96. Liew, J.; Chua, Y.; Dai, Z. *Steel Concrete Composite Systems for Modular Construction of High-Rise Buildings*; Elsevier: Amsterdam, The Netherlands, 2019; pp. 135–149.
97. Fard, M.M.; Terouhid, S.A.; Kibert, C.J.; Hakim, H. Safety concerns related to modular/prefabricated building construction. *Int. J. Inj. Control Saf. Promot.* **2017**, *24*, 10–23. [CrossRef]
98. Li, H.; Lu, M.; Chan, G.; Skitmore, M. Proactive training system for safe and efficient precast installation. *Autom. Constr.* **2015**, *49*, 163–174. [CrossRef]
99. Delgado, J.M.D.; Oyedele, L.; Ajayi, A.; Akanbi, L.; Akinade, O.; Bilal, M.; Owolabi, H. Robotics and automated systems in construction: Understanding industry-specific challenges for adoption. *J. Build. Eng.* **2019**, *26*, 100868. [CrossRef]
100. Iuorio, O.; Wallace, A.; Simpson, K. Prefabs in the North of England: Technological, Environmental and Social Innovations. *Sustainability* **2019**, *11*, 3884. [CrossRef]
101. Pan, W.; Gibb, A.G.F.; Dainty, A.R.J. Leading UK housebuilders' utilization of offsite construction methods. *Build. Res. Inf.* **2008**, *36*, 56–67. [CrossRef]
102. Cappellazzi, J.; Konkler, M.J.; Sinha, A.; Morrell, J.J.J.W. Potential for decay in mass timber elements: A review of the risks and identifying possible solutions. *Wood Mater. Sci. Eng.* **2020**, *15*, 351–360. [CrossRef]
103. King, D.T.; Sinha, A.; Morrell, J.J.J.W.; Science, F. Effect of wetting on performance of small-scale shear walls. *J. Soc. Wood Sci. Technol.* **2015**, *47*, 74–83.
104. Safe Work Australia. *Work-Related Traumatic Injury Fatalities Australia 2019*; Safe Work Australia: Canberra, Australia, 2019; p. 18.
105. QSR International. ABOUT NVIVO, A Place to Organize, Store and Analyze Your Data. Available online: https://www.qsrinternational.com/nvivo-qualitative-data-analysis-software/home (accessed on 1 February 2021).
106. Hickory Peppers Kings Square. Available online: https://www.hickory.com.au/project/peppers-kings-square/ (accessed on 1 September 2021).
107. Lendlease New Commercial Icon for City Skyline at Melbourne Quarter. Available online: https://www.melbournequarter.com/discover/news/new-commercial-icon/ (accessed on 1 August 2021).
108. PrefabNZ. The Material Matrix. PrefabNZ, Ed. PrefabNZ, 2018. Available online: https://www.offsitenz.com/_files/ugd/4fe8d5_a254fe9b72a341fdb1ddce4e09049139.pdf (accessed on 5 May 2021).
109. prefabAUS. Types of Prefab. Available online: https://www.prefabaus.org.au/what-is-prefab (accessed on 5 May 2021).
110. Kremer, P.; Symmons, M. Mass timber construction as an alternative to concrete and steel in the Australia building industry: A PESTEL evaluation of the potential. *Int. Wood Prod. J.* **2015**, *6*, 138–147. [CrossRef]
111. Builtoffsite Modular Construction Code Board Handbook: A Guide to Offsite Construction. Available online: https://builtoffsite.com.au/emag/issue-04/modular-construction-code-board-handbook/ (accessed on 3 March 2021).
112. Clarke, C. Toyota and Holden factories to close, end of the line for autoworkers. *ABC News*, 2 October 2017.
113. Robertson, J. Modular Construction—Making Payment Terms Work. Available online: https://www.charlesrussellspeechlys.com/en/news-and-insights/insights/constuction-engineering-and-projects/2020/modular-construction--making-payment-terms-work/ (accessed on 5 May 2021).
114. Molavi, J.; Barral, D.L. A Construction Procurement Method to Achieve Sustainability in Modular Construction. *Procedia Eng.* **2016**, *145*, 1362–1369. [CrossRef]
115. Tam, V.W.; Tam, C.M.; Ng, W.C. On prefabrication implementation for different project types and procurement methods in Hong Kong. *J. Eng. Des. Technol.* **2007**, *5*, 68–80. [CrossRef]
116. Adinyira, E.; Ayarkwa, J.; Aidoo, I. Knowledge and usage of the seven basic quality control tools by producers of precast concrete products in Ghana. *J. Constr. Proj. Manag. Innov.* **2014**, *4*, 966–975.
117. Alaa, A.-S.; Pasławski, J.; Nowotarski, P. Quality Management to continuous improvements in process of Ready Mix Concrete production. In *Proceeedings of the IOP Conference Series: Materials Science and Engineering, Wuhan, China, 10–12 October 2019*; IOP Publishing: Bristol, UK, 2019; p. 022019.
118. Şimşek, B.; Pakdil, F.; İç, Y.T.; Güvenç, A.B. Building a graphical user interface for concrete production processes: A combined application of statistical process control and design of experiment. *Arab. J. Sci. Eng.* **2019**, *44*, 4373–4393. [CrossRef]
119. Valero, E.; Adán, A. Integration of RFID with other technologies in construction. *Measurement* **2016**, *94*, 614–620. [CrossRef]
120. Li, X.; Shen, G.Q.; Wu, P.; Fan, H.; Wu, H.; Teng, Y. RBL-PHP: Simulation of lean construction and information technologies for prefabrication housing production. *J. Manag. Eng.* **2018**, *34*, 04017053. [CrossRef]
121. Davila Delgado, J.M.; Oyedele, L.; Beach, T.; Demian, P. Augmented and virtual reality in construction: Drivers and limitations for industry adoption. *J. Constr. Eng. Manag.* **2020**, *146*, 04020079. [CrossRef]
122. Kong, L.; Li, H.; Luo, H.; Ding, L.; Zhang, X. Sustainable performance of just-in-time (JIT) management in time-dependent batch delivery scheduling of precast construction. *J. Clean. Prod.* **2018**, *193*, 684–701. [CrossRef]
123. Ocheoha, I.; Moselhi, O. Impact of Building Information Modeling on Just-In-Time Material Delivery. In Proceedings of the International Symposium on Automation and Robotics in Construction, Montreal, QC, USA, 11–15 August 2013; p. 1.

124. Safe Work Australia. *Guide to Managing Risk in Construction: Prefabricated Concrete*; Safe Work Australia: Canberra, Australia, 2019.
125. Masood, R.; Lim, J.B.P.; González, V.A. Performance of the supply chains for New Zealand prefabricated house-building. *Sustain. Cities Soc.* **2021**, *64*, 102537. [CrossRef]
126. Tam, V.W.Y.; Tam, C.M.; Zeng, S.X.; Ng, W.C.Y. Towards adoption of prefabrication in construction. *Build. Environ.* **2007**, *42*, 3642–3654. [CrossRef]
127. Salama, T.; Figgess, G.; Elsharawy, M.; El-Sokkary, H. Financial Modeling for Modular and Offsite Construction. In Proceedings of the International Symposium on Automation and Robotics in Construction, Kitakyushu, Japan, 27–28 October 2020; pp. 1082–1089.
128. Gan, X.; Chang, R.; Wen, T. Overcoming barriers to off-site construction through engaging stakeholders: A two-mode social network analysis. *J. Clean. Prod.* **2018**, *201*, 735–747. [CrossRef]