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Obstacles Preventing the Off-Site Prefabrication of Timber and MEP Services: Qualitative Analyses from Builders and Suppliers in Australia

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Abstract: Limited empirical and qualitative studies focus on the detailed processes and obstacles for coordinating off-site prefabrication between builders and suppliers. This research aims to identify and address the obstacles that currently prevent the further expansion of off-site prefabrication, with a research scope on timber and mechanical/electrical/plumbing (MEP) services in construction projects. The focal point of this research is to highlight their obstacles. A total of forty interviews were conducted and analyzed from four builders' organizations and four suppliers' organizations to ascertain their obstacles in coordinating the practice of off-site prefabrication. The results found the builder's obstacles were sustainability, quality assurance (QA), mass production, CAD/BIM, technological support, commercial arrangements, system building, buffering in supply, schedule monitoring, productivity, flexibility, engagement, risks, and multiple supply arrangements. The supplier's obstacles were design, financing and subcontracting, coordination, recognized practices, risks, multiple supply arrangements, and constraints. Moreover, the builders and suppliers had identified some ways to harmonize off-site prefabrication of timber. Some examples of timber prefabrication technology include joinery, doors and/or windows, structural floor/wall/roof frames, partitions, trusses, stairs, balustrades, and others. MEP services with in situ construction comprise the use of power sources and working coordination. The most important outcome of this investigation is that these obstacles can be addressed through collaboration and coordination. This is because there is a traditionally a lack of collaboration amongst builders and their suppliers. Furthermore, there is a lack of coordination between them in general. The research contributes to the improved timber and MEP services collaboration and coordination in off-site prefabrication, which can be referred to by other approaches of modular construction.

Keywords: construction; collaboration; coordination; timber; MEP; off-site; on-site; in situ; prefabrication; builder; supplier; Australia

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1. Introduction

The term "prefabrication" has been interpreted and expressed differently by previous studies as per their subtle regional, geographical, or proximal nuances. For example, prefabrication can be referred to as either off-site construction (OSC) [1] or off-site manufacturing (OSM) [2]. Meanwhile, Design for Manufacture and Assembly (DfMA) is commonly used in United Kingdom, which DfMA in construction intends to use "standardized components, sub-assemblies or assemblies that can beneficially be manufactured off site, transported to site viably, and assembled there safely, quickly and straightforwardly" [3]. David Chandler (2018) [4], in his predictions on the future of in situ construction, recognized the popularity of adding a letter "M", which denotes the term "manufacture/manufacturing", to become OSCM, which he defines *offsite* components as "manufactured . . . shipped—fully made with fitments, penetrations and lifting points". This study defines the nomenclature for off-site construction. Their issues should be considered to define fabrication in the contexts of timber and mechanical/electrical/plumbing (MEP) services. Hence, in this research, "off-site" and "prefabrication" in construction are used interchangeably, whereas the terms "off-site prefabrication" can be generally simplified as all prefabricated products, components and MEP services that are not made in situ or on-site.

A range of advantages, disadvantages, and emergent influences of off-site prefabrication have already been identified by previous studies. Most relevant to this research, Bock et al. (2015) [5], Zhong et al. (2017) [6], and Ayinla et al. (2022) [7] advocated some innovative technologies and approaches to address certain problems in off-site prefabrication including Digital Twin [8]. Despite these, there are still limited empirical and qualitative studies within the literature that address the processes and performance obstacles from the perspectives between builders and suppliers, particularly for the scope of timber and MEP services off-site prefabrication.

Timber and MEP services receive particular attention as no prior research or literature has investigated their specific coordination and implementation process in details. Johnsson and Meiling (2009) [9] studied the defects of completed timber modules that have already been prefabricated off-site. Tserng et al. (2011) [10] developed an algorithm to efficiently assemble modular MEP services, albeit on-site. Whilst these articles, in their own ways, address the integration of timber and MEP services with in situ construction, the research gap is identified as the need to address obstacles in their prefabrication processes off-site. It is based on this research gap that the foundation of the research undertaken is reported in the forthcoming justification, aim, and objectives of study.

2. Justification, Aim and Objectives of Study

The builder's role is to integrate a system that constructs a building [11,12]. The builder organization takes charge of construction activities on-site to translate the design drawings, specification, schedules, and other documentation into a built structure [11]. On the other hand, the supplier's role is to develop the requested innovations. There is widespread acknowledgement amongst builders that supplier organizations generally have greater potential to innovate due to their better efficiency [12]. The peculiarities of these roles and nature of the organizations also extends to their characteristics. In the construction industry, the business models of builders fundamentally involve purchasing. Hence, it has been the supplier organizations that normally carry most of the risks in the supply chains of construction projects [13,14].

Bildsten (2014) [15], in his previous research of supply chain relationships within the construction industry, justified that there is a traditionally a lack of collaboration amongst builders and their suppliers. Furthermore, there is a lack of coordination between them in general [16]. Integral to their working relationships is that coordination differs from collaboration. Collaboration cannot happen without the preexistence of coordination. Hence, in the relational integration stages, coordinating happens before collaborating [15]. This study aims to investigate the obstacles to achieve these.

To address this aim, the underpinning objectives are to (a) scrutinize the coordination of timber and MEP services work undertaken off-site and in situ, (b) evaluate approaches that hinder the management of timber and MEP services off-site prefabrication, and (c) simplify initiatives to integrate timber and services MEP work undertaken off-site and in situ. Interviews were conducted and analyzed comparatively from the key stakeholders, namely, builders and suppliers. These interviews focused on ways the off-site prefabricating of timber and MEP services could evolve, which follows from the study of Yunis et al. (2016) [17] that revealed deficiencies between this and in situ construction. This research contributes to the effective coordination and simplification of the operational complexities associated with off-site prefabrication in timber and MEP services.

3. Literature Review

3.1. Off-Site Prefabrication of Timber Components and MEP Services

Timber as a building material is produced from the logging of forests or plantations [18]. They are categorized as either softwoods or hardwoods [19,20]. Timber is processed either as sawn, utility poles, glue-laminated sections, plywood, veneers, particleboard, or fiberboard. Processed timber products have been used in dry and wet conditions, internally and externally [17]. Examples of off-site prefabricated timber components typically include joinery, doors and/or windows, structural floor/wall/roof frames, partitions, trusses, stairs, balustrades, and others [21].

MEP services are categorized as environmental or utility [22]. Mechanical services comprise conveyors, ductwork, heating, ventilation, and air-conditioning (HVAC) systems. Electrical services comprise the associated meter, cabling, lighting, power, and communications. Plumbing services comprise various hydraulics, drainage, or sewage installations that include the associated meter, pipes, and equipment [22,23]. Tserng et al. (2011) [10] even developed an algorithm to efficiently prefabricate modular MEP systems.

In construction projects, off-site prefabrication entails the practice of modular coordination [17]. It shares many commonalities with repetitive production [24]. Hosseini et al. (2018) [25] suggest that the ideas, approaches, and practices of off-site prefabrication may be cross-fertilized. This is primarily achieved by effective communication throughout the supply chains [13]. Focusing on such sharing is necessary in order to achieve off-site prefabrication productivity [15,25].

3.2. Advantages of Off-Site Prefabrication

Li et al. (2014) [26] previously investigated the off-site prefabrication systemic mechanisms that can help to progress their sustainability. Hu et al. (2019; 2020) [27,28] advocate off-site prefabrication as sustainable in various ways. Salama et al. (2017) [29] even established a "Modular Suitability Index" that helps to optimize the coordinating of off-site-prefabricated components and in situ construction. These comprised the connections, lifting/loading, logistics, structural requirements, and dimensions of off-site-prefabricated components [29].

Integral to coordinating on-site activities with off-site prefabrication have been technological advances [5]. For example, the introductions of RFID and GPS technologies have improved the performance of off-site prefabrication [26,30,31]. Off-site prefabrication can mass-produce better quality components than if had they been traditionally constructed in situ [32].

Integrated project delivery (IPD) better caters for off-site prefabrication than traditionally procured construction projects. IPD has recently been defined by Laurent and Leicht (2019) [33], in their study of practices for cross-functional teams, as when "multiple stakeholders from the design and construction team join a relational, multiparty contract". They found that cross-functional teams must be managed to coordinate their activities and integrate their deliverables [33].

3.3. Disadvantages of In Situ Construction/Off-Site Prefabrication Obstacles

Defects in components off-site prefabricated by timber suppliers tend to include work that is either missing, unfinished, broken, or erroneous [9]. MEP suppliers are certainly not without their obstacles. A key limitation of MEP suppliers is that they are less able to verify the designs on-site than the builder as the buyer [10]. With the exception of this, many disadvantages of in situ construction also represent the obstacles of off-site prefabrication. Off-site prefabrication obstacles normally concern the output components, optimizing planning, fundamentals of scheduling, joint connections, structures, coordinating with on-site construction and even in appraising the performance/s of suppliers [1,34]. For the builder, their necessity to coordinate and achieve common goals also exist concerns within construction project planning, designing, supplier logistics, as well as construction/prefabrication. Maintaining control has been identified as an off-site prefabrication obstacle for buyers as well [24].

4. Research Methodology

Field research entailed conducting a series of wide-ranging interviews with a valuable selection of construction organizations. The data gathered from the field was validated externally by those construction professionals employed at these organizations that were interviewed. The gather of comparative raw data from interviews is suited to this research about the off-site prefabricating of timber and MEP services [35]. This field research was to clarify the understanding by recognizing the contextual environments of actual complex off-site prefabrication situations and phenomena from the perspectives of *builders* as the main contractor (C#) and their subcontracted *suppliers* of prefabricated timber or MEP services components (P#) as construction project stakeholders and, indeed, contributors. This raises a myriad of ontological qualitative questions about the social world of the respondents and how interviews enable access to that world. Within Australia, arguably every construction company is at least in some way involved with prefabrication. There is interactivity between the subject matter and the research methods adopted in this methodology. This is because the people in them inherently articulate the processes of construction as qualitative data when they are interviewed.

The interview responses were obtained from approximately 2 research participants sampled from their respective companies, from which a total of 40 interviews were recorded and shared proportionally from four builders and four suppliers in Melbourne, Australia. These interviews were undertaken face-to-face, which enabled the interviewer to further clarify any ambiguities in the overall findings, without inputting biases into the responses of responses. The interviewer remained unbiased throughout this process of enquiring. As this field research was undertaken in Australia, these questions were qualitative and unstructured to include some Australian English lexicons and vocabulary when asked of construction industry practitioners within this region who are familiar with them. These unstructured qualitative questions fostered interactive conversations as the qualitative data [36].

Some of the qualitative questions directly pursued certain aspects of this research and others were open-ended to enable further discussion. These interviews were unstructured, which meant that they also required asking probes on certain research aspects so to obtain the data necessary for qualitative analyses. Oppenheim (1992) [37] defined probes, in the context of their use in these interviews, as "follow-up questions, after the respondent has a first answer to the main question" (p. 90). Many of these probing questions had ranged between those that were general through to the specific [37]. Therefore, the interview questions were tailored to extract responses from the builders and suppliers separately (refer to Appendix A). The gathered qualitative data were then interpreted and organized manually. Subsequently, the data were coded and analyzed using the Nvivo software (Version 12). This was undertaken to generate and understand the emerged themes for the content analysis from the perspectives of builders and suppliers, individually.

5. Data Synthesis and Analyses

This section synthesizes the qualitative data that was gathered from the interviews and analyzed them individually from the perspective of the builders and the suppliers. In the preliminary analysis of data, the interview responses were collected from the same numbers of questions and organizations. In the content analysis of data, more themes emerged for builders than suppliers. This situation is reasonable as builders have always been playing their significant roles in coordinating off-site prefabrication in construction projects. Subsequently, the data were compiled and grouped into the comparative analysis.

5.1. Content Analysis of Builders

5.1.1. Economic and Environmental Sustainability

Economic and environmental sustainability were the first emergent themes that surprised the researchers in this analysis, particularly as neither of these had been anticipated. Table 1 shows the business model of Builder C1 essentially generates revenue and profits for their shareholders. Therefore, the primary concerns of this builder are to keep their business model economically and financially efficient. These concerns were also shared by other construction companies. Despite having these economic and financial concerns, their government infrastructure construction project clients normally mandate that they uphold corporate social responsibility (CSR) and environmental sustainability, in particular. For instance, a Contract Administrator of Builder C1 felt that their wildlife protection and conservation client in Australia appreciated these combined efforts of the construction project team.

Table 1. Contractor Companies in Content Analysis of Builders.

Contractor Companies	Builder C1:	Builder C2:	Builder C3:	Builder C4:
Project Specialty:	• Residential construction; • Commercial construction.	• Commercial construction; • Industrial construction; • Government infrastructure construction.	• Commercial construction; • Government infrastructure construction.	• Residential construction and fit-out; • Commercial construction and fit-out; • Off-site prefabricated components.
Building Height Range:	4 to 60 storey buildings.	Up to 26 storey buildings.	Single storey buildings only.	20 to 60 storey buildings.
Project Cost Range:	$10,000,000 to $400,000,000 AUD.	$20,000,000 to $26,000,000 AUD.	$58,200,000 to $150,000,000 AUD.	Any contract sum in the millions of AUD.

Builder C1 expressed concern with their subcontracted suppliers when they prefabricate components in overseas countries with looser environmental regulations and lower standards for them to uphold, particularly as the supplier's greater commercial priority would otherwise be on their economic interests. Moreover, Builder C1 would incorporate CSR and environmental sustainability as part of their processes to achieve their construction project objectives.

5.1.2. Quality Assurance

Both Builders C2 and C3 claim to maintain associations with component suppliers by also regularly visiting them to monitor and scrutinize their off-site prefabrication processes. On the other hand, the in-house integration of off-site prefabrication, as well as in situ construction, of Builder C4 enabled them to better streamline the design, fabrication, construction, and testing of their components. According to Builder C1, errors significantly influenced the nonconformance of components that they received. They admitted that the repetitive reading of tape measures in the off-site environments of suppliers had led to some oversights whilst undertaking prefabrication routines. Despite such setbacks, Builder C1 had respectful, yet professional, working relationships in openly communicating with each of their suppliers so to maintain productivity and meet critical path scheduled deadlines.

5.1.3. Mass Production Off-Site and On-Site

Builder C1 was concerned about the quality of off-site-prefabricated components delivered on-site. Builder C2 undertook a similar risk assessment, but also believed in the necessity of mass-producing components to maximize the value of off-site prefabrication.

Contrastingly, there are also contractors found to prefer in situ construction. A Project Manager of Builder C3 provided very significant insight that engaging subcontractors for conventional in situ construction had often proved of greater benefit than off-site prefabrication. For example, their previous project precluded the option of mass-producing precast concrete panels, primarily due to each of their intricate designs (see Figure 1).

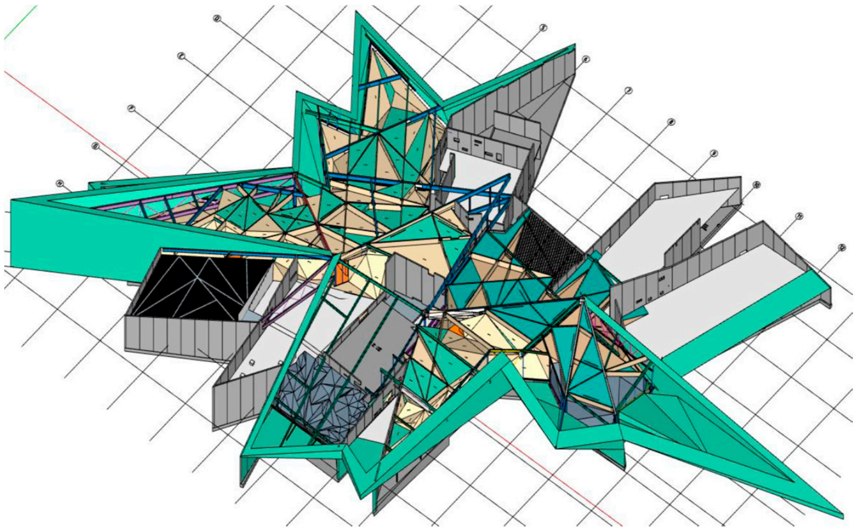

Figure 1. Building Information Model of Builder C3 (Adapted from Phillip Island Nature Parks, 2022).

5.1.4. Computer-Aided Design and Building Information Modeling

In BIM implemented projects, both Builders C2 and C3 instead merely administered each of their off-site prefabrication suppliers with IFC files, which they then diligently used to address the requirements. The implementation of BIM specifically for off-site prefabrication is increasing throughout the construction industry. What Builders C1, C2, and C3 had in common was that they had set procedures for reporting situations and evaluating the requirements of the construction site itself, as well as component sizes, deliveries, lifting, and loading. A general understanding exists throughout the construction industry that each of its projects is uniquely complex, which makes the availability of design support for off-site prefabrication suppliers a critical control measure to address the unforeseen risks of disruptions (see Figure 2).

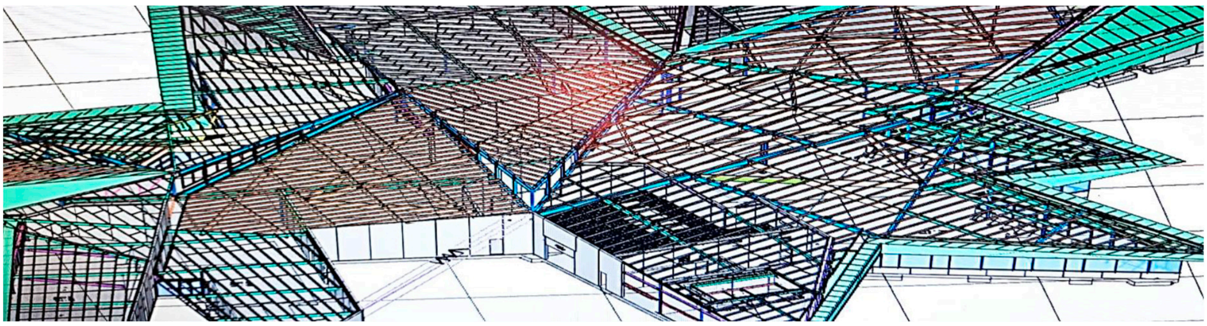

Figure 2. Steelwork and Precast Design of Builder C3 (Adapted from Phillip Island Nature Parks, 2022).

5.1.5. Technological Support by Builders

Builder C1 had been open about their minimal adoption of technologies to support off-site prefabrication suppliers as the expense and effort necessary to implement them were seldom worthwhile. Despite their reluctance, they contended that some of their off-site prefabrication suppliers themselves already have the automation or robotics to specialize in planning, design, manufacture, storage, and tracking and tracing logistics, as well as delivery of their components to the construction site. Contrastingly, Builders

C2 and C3 have experienced projects where they needed to interactively coordinate with VDC disciplines amongst other stakeholders to clarify, as well as updating, when necessary, their comprehensively designed models to reflect the eventual apportionment and logistics of components. Both of these builders were also accustomed to using tablet-enabled applications for real-time monitoring, communicating, as well as synchronizing of the off-site prefabrication and in situ construction works.

5.1.6. Commercial Arrangements with Prefabrication Resources

Builders C2 and C3 include clauses in their contracts with suppliers. Bank guarantees allow the builders to deposit payments, which helps them obtain materials, plant and/or equipment necessary for contending with construction project-specific risks. Builder C2 stressed that this arrangement—for them to submit monthly progress payment claims for the project client to approve—is contentious because such approval sometimes happens when deemed acceptable by a third-party quantity surveyor (QS). Therefore, Builder C3 innovatively obtains an additional insurance certificate of currency, which covers both themselves and their off-site prefabrication suppliers, specifically for the cash flow risks associated with this arrangement.

5.1.7. Integrating System Building

In the previous experiences of Builders C1 and C3, the capabilities of prefabricating modular components differed between construction projects. For these reasons, Builder C1 performs a cost-benefit analysis (CBA) to determine the feasibility of off-site prefabrication and in situ construction in delivering the requirements for each of their projects, before they administer subcontracts onto the relevant suppliers. At the other end of this spectrum, Builder C2 had previously found it economical to administer subcontracts onto suppliers to mass-produce off-site-prefabricated components for larger-scale apartment buildings and prison infrastructure. This need to subcontract can be bypassed by Builder C4, who had previously demonstrated their capability of systemically prefabricating comprehensive modular "pods" in-house from their overseas operations.

5.1.8. Buffering in Supply of Off-Site Prefabricated Components

Builders C1 and C3 both implied having similar buffers that proactively anticipated a tightening of the construction project schedule by preempting delays in the off-site prefabrication of components and aggressively pushing for their earlier supply on-site. The Construction Manager of Builder C1 had expressed that larger off-site prefabrication suppliers were capable of attaining components from their competitors as well, particularly if their output productivity is otherwise inadequate to meet demand. He also noticed that buffering also occurred in the off-site prefabrication of standardized components.

5.1.9. Off-Site Prefabrication's Schedule Monitoring

Builder C1 divulges their construction productivity in real-time by displaying this information to the rest of the project team via an automated, collaborative dashboard. Builders C2 and C3 also coordinate their construction activities between locations using real-time information, but from applications in their smartphones, tablets, or other devices. As the off-site prefabrication functions of Builder C4 are in-house departments; they are capable of parleying classified yet accurate information on their productivity, quality, testing, and supply directly to where they are needed. It is primarily due to these capabilities of their competitors Builder C1 had expressed concern that between 90% and 95% of their fellow project stakeholder companies were small to medium enterprises (SMEs), despite them yielding average end of financial year (EOFY) turnovers of between AUD 10,000,000 and AUD 50,000,000.

5.1.10. Supplier Productivity

Builder C1 expressed understanding and empathy toward their off-site prefabrication suppliers who have been hampered by the supply chain from meeting expectations. Both Builders C2 and C3 have extended grace and assisted their off-site prefabrication suppliers with the work if they promptly report any disruptions. Every builder in this content analysis had expressed willingness, as well as empathy, to assist their off-site prefabrication suppliers that share common working relationships and objectives in the construction project with obtaining the necessary materials, plant, or equipment.

5.1.11. International Supplier Flexibility

Builder C1 observed from engaging supplier companies situated in China and Scandinavian countries that they tended to have refined processes and are more experienced at prefabricating similar components for construction yet had QA predicaments to contend with. In the experience of a Project Manager of theirs, every construction company normally has unique QC standards to them achieving QA in their outputs. Builder C2 were inclined to trust engaging, integrating, and coordinating with supplier companies situated in the Republic of Ireland, Italy, as well as Japan, due to their reputedly steeped history of prefabricating reliable components for the construction industry. The previous experiences of Builder C3 with their international supplier companies have also been largely in contrast to those benefits experienced by Builders C1 and C2.

Two different forms of flexibility are presented, each of which could innovatively be used to help the other. The construction specialists at Builders C1 and C3 insisted that those international supplier companies who pioneered mass-producing components to meet increasing demands for economic alternatives must have designed and prefabricated them with adequate flexibility to incorporate them with the in situ construction works. As an example, the Planner at Builder C2 pointed out that supplier companies situated in Japan were accustomed to designing and prefabricating components with the adequate flexibility to withstand their regular earthquakes. The appeal of engaging international suppliers of prefabricated components to Builders C3 and C4 are certain areas of specialties, as well as working mechanisms, which are otherwise unable to be found amongst their counterparts locally.

5.1.12. Stakeholder Engagement

Builder C2 also has a database of their previous subcontractors but is open to the assistance, solutions, and/or supplies of other construction project stakeholders as well. Uniquely, Builder C1 use their in-house "Integrated Management System" (IMS) as a decision-making tool that helps them identify then select suppliers and trades to subcontract based on common approaches, methods, and objectives for the construction project.

5.1.13. Off-Site Prefabrication Risks to Builders

There was a belief amongst each of the builders that all design details must be provided sufficient and thorough, especially before off-site prefabrication of components starts, for them to holistically schedule, manage, coordinate, as well as control the in situ construction. Because they also believed that without the timely shop drawings with adequate information from off-site prefabrication suppliers, risks of associated unforeseen costs, delays, defects, OH&S hazards, and project client distress would ensue, which normally require remediation measures through potentially hostile negotiations. Examples of these experienced by Builder C1 included the unforeseen new need for crane/s, interferences to existing access and egress, as well as added efforts incorporating off-site-prefabricated components with in situ construction works. Builder C3 recalled a previous construction project where they competently used a single crane that successfully performed the lifting and loading for all of their subcontractors, the planning of which entailed being familiar with the site limits, engaging multiple work crews, as well as conducting routine inductions for them on-site. The years of investment and efforts by Builder C4 toward establishing their holistic in-house system afforded them the luxury of being able to bypass the abovementioned risks by undertaking all design, prefabrication, logistics, lifting/loading, construction, and fit-out themselves.

5.1.14. Builders in Multiple Supply Arrangements

The suppliers of builders in this analysis are seldom, if ever, subcontracted to undertake identical work for the same construction project. Builder C1 has previously subcontracted duplicate precast concrete and joinery trades for the construction of two mixed-use high-rise towers, yet each of these competing companies had been assigned work packages to undertake in a separate tower, as well as on alternating odd or even floor levels. Builders C2 and C3 have also previously let to competing off-site prefabrication suppliers the pre-casting of concrete panels, which includes the necessary timber for formwork, simultaneously but separated to work with different specifications of color, finish, and QA.

All builders and suppliers studied indicated that they had their guidelines for reviewing design documentation and requirements of sample prototypes for off-site prefabrication. A Contract Administrator of Builder C3 articulated that if other construction project stakeholders could not meet their subcontract obligations in the deadlines set, additional control measures would then be sought to support them beyond tolerance by effectively duplicating their efforts. As a Senior Project Manager of Builder C1 explained:

> “Costs aren’t always the most vital. If you fail in what you deliver, it might be cheaper to let in bulk . . . If you can’t deliver on time, you’ll lose more”.

The Estimators of Builder C2 and Construction Managers of Builder C3 also expressed similar sentiments to this quote, as well as the bespoke nature of every construction project.

5.2. Content Analysis of Suppliers

Table 2 shows the content analysis of timber and MEP services suppliers, representatives from four off-site prefabrication companies. Supplier P1 is a multinational company that specializes in the prefabrication of cross and laminated veneer lumber (LVL) timber components for construction projects within Australia and New Zealand. Supplier P2 specializes in the sawmilling of softwoods and prefabrication of glue-laminated timber components for construction projects within Australia. Supplier P3 specializes in the prefabrication of cross/glue-laminated and LVL timber components for construction projects within Australia. Supplier P4 is also a multinational company that specializes in the prefabrication of MEP services for construction projects in Australia, UAE, UK, or USA. The findings from Supplier P4 in the context of MEP are justified as this company is currently a major employer that holds the local market monopoly for their capability to provide all of these off-site prefabricated services from the same entity.

Table 2. Prefabrication Companies in Content Analysis of Suppliers.

Prefabrication Companies	**Supplier P1:**	**Supplier P2:**	**Supplier P3:**	**Supplier P4:**
Component Specialty:	• Cross-laminated timber; • LVL timber.	• Sawmilling; • Glue-laminated timber.	• Cross-laminated timber; • Glue-laminated timber; • LVL timber.	• Mechanical services; • Electrical services; • Plumbing services.
Project Locations:	• Australia; • New Zealand.	• Australia only.	• Australia only.	• Australia; • New Zealand; • UAE; • UK; • USA.

The builders sampled have engaged these suppliers to prefabricate components for them on their previous and/or current construction projects. Most of their off-site prefabrication practices are found to involve timber-related work and there were multiple suppliers of this type in the Australian market. Supplier P4 represents the outlier of the sample inasmuch that they were the only company of their kind in this local market. Their business model is innovative, as MEP services tend not to be combined and prefabricated off-site given their bespoke configurations in the majority of construction projects.

5.2.1. Design, Collaboration, and Testing

To attain clarity before preparing their shop drawings, Supplier P1 undertook at least four iterations of their in-house design maturity and feasibility system, which the builders who engaged them have valued. Suppliers P1 and P2 are both similarly diligent in the way they prefabricate, as well as deliver, heavy timber components due to their wider range of risks working with this material, including lead times of between 3 and 4 months if imported from a European country. Supplier P1 described their struggle and persistence to acquire succinctly clear drawings, as well as the continual toil prefabricating timber components and coordinating their installation on-site, as follows:

> "Enormous when compared to traditional in situ building".

Of particular concern in the off-site prefabrication of timber components, a Structural Engineer of Supplier P1 insisted that each variation order (VO) by the project client inevitably changed their cycle of preparation, resources invested, QC, as well as coordination, thereby jeopardizing the functions of logistics, scheduling, meeting deadlines, constructability, and installation efficiency. All of the prefabrication suppliers in this analysis acknowledged in their way that advanced timbers, as well as composite materials, are increasingly being sought after by project clients and architects. For instance, Supplier P2 recalled needing to educate the project client and end-users of the benefits, shortcomings, as well as considerations, of different timbers before configuring the prefabrication of components for a zoo infrastructure refurbishment. When it comes to intellectual property (IP) sharing, Supplier P2 protects their interests in generally preferring to provide verbal information, rather than documents like shop drawings, as they are cautious of the risk of losing future work to a competitor who has managed to get hold of their designs.

Having received thorough cost planning advice on different options proposed by the architect and each of the engineering consultants throughout the design phase has helped to negate the cost impacts of VOs. Decisions to substitute familiar structural steel or concrete with alternate materials have impeded economic design in the past, yet Supplier P1 has been dedicated to transparently providing a set of requirements and limitations of different timber species, just falling short of divulging their cost information straight away. The latter is a measure to protect their IP, which would only be divulged if the builder proceeds to subcontract their shop drawing design and off-site timber prefabrication. Supplier P2 was also happy to provide their timber component designs exclusively for off-site prefabrication to the project client upon request.

5.2.2. Financing and Subcontracting Conditions

The parent organization of Supplier P2 has been assisted by the Australian Government to establish glue and cross-laminated timber component prefabrication plant facilities in the Australian states of Queensland and Victoria, respectively. As an off-site pre-fabricator of timber components, Supplier P1 had the following opinion of risk-averse, large-scale builders who had previously subcontracted them under their onerous terms and conditions:

> "Tier One (1) builders mightn't budge ... There's no excuse because those contracts blindly say you will deliver".

Project clients then normally became upset whenever the supply of off-site-prefabricated components was disrupted. Supplier P2 is unique inasmuch that they regularly open a short-term joint trading account with the builders or construction project clients to whom they supply off-site prefabricated timber components. The construction project client would then engage the builder, with Supplier P2 included as a Nominated Subcontractor. Suppliers P1 and P2 transparently encouraged, as well as promoted, tours of their facilities to closely inspect and understand the meticulous procedures and machinery involved to prefabricate timber components. They both normally provide samples and prototypes of their prefabricated timber components, more so for construction project clients to confirm the aesthetics of connection detailing than their structure.

5.2.3. Coordinating Suppliers

Whilst often expected to meet demands for off-site-prefabricated components, as well as deliver them inside unrealistic timeframes, the transparencies of both Suppliers P1 and P2 in communicating pragmatic information have helped unfamiliar construction project clients learn about extended lead times required to allow for materials like timber. It is for this reason that Supplier P1 affirmed the following regarding the satisfaction of their customers:

> "Unfortunately, the world revolves around economics and time . . . Make it work and plan".

Supplier P1 preferred to prepare their shop drawings using CAD software to prefabricate their timber components from and share with the project team. Both Suppliers P1 and P2 believed in the necessity of buffering the supply to prefabricate their timber components at full productivity. According to Supplier P1, coordination failings were likely if communication transparency was unclear, as additional components have previously been requested that could not easily be incorporated within the same prefabrication deadline.

5.2.4. Internationally Recognized Practices

There is a shared understanding throughout the construction industry that suppliers situated in Canada, Japan, China, Singapore, the USA, and European countries have advanced practices in the prefabrication of components for construction. Supplier P1 added suppliers situated in New Zealand, as they had the benefit of direct access to the raw materials available there. Both Suppliers P1 and P2 understood that the dispersed expanse of populations in Australia as an obstacle to their prospects of business expansion. Supplier P2 admitted that Australian suppliers of prefabricated timber components were deficient relative to their counterparts within European countries. They asserted this as largely due to the extremely cold winters in many European countries that prevented construction during those times of the year, the environmental factors around which prefabrication suppliers there need to operate. Supplier P2 also believed that the innovative technologies embraced by off-site prefabrication have been catalysts towards addressing the existence of skilled labor shortages in the construction industry everywhere, including these countries.

As a multinational company, the experience of Supplier P4 in the UAE and European countries was that builders there, by default, scrutinized construction projects to distinguish between what could be prefabricated off-site and the work that must be done in situ. For example, these MEP services were precisely embedded inside the off-site prefabricated modular walls for the construction of hospital facilities and infrastructure in the UAE. Supplier C4 have off-site prefabricated their system building modules in Australia as well. In delivery, Supplier C4 has also been capable of lifting and installing two (2) of their completed bathroom pods at a time.

5.2.5. Off-Site Prefabrication Risks to Suppliers

Supplier P1 was content with familiar construction operations, experiencing risks which rarely pushed them beyond their comfort zone. In the experience of Supplier P2, builders were sometimes unable to match the degree of precision that their off-site prefabrication, coordination and integration demanded. Supplier P2, who operate in Japan, specifically recalled needing to engage a Concreter within Australia to smooth out fluctuations on the in situ floor slab surfaces and precisely accommodate their prefabricated timber components. Both Suppliers P1 and P2 are aware of construction companies who intentionally provided quotes, which did not quite conform with the design documentation such that, if selected, they would then retreat to their conventional methods of using concrete or steel in place of timber for instance.

Supplier P2 wants earlier involvement in projects, ideally within the planning and/or design phases. Much of this is because, as Suppliers P1 and P2 declared, they have worked for builders who were perturbed by, or reacted with procrastination against, their necessary lead times for materials. For Supplier P4, similar time-related risks have often been exacerbated by the international divide between their prefabrication location and the construction site.

5.2.6. Suppliers in Multiple Supply Arrangements

Whilst builders typically leave work to off-site prefabricate components as individual subcontracts, Suppliers P1, P2, and P4 are accustomed to being part of multiple supply arrangements with other competing suppliers as well. Supplier P2 has previously been in multiple supply arrangements to prefabricate components with different types of timber for construction projects on an Antarctic island and a sporting stadium in Sydney, Australia. Supplier P1 has previously been in a multiple supply arrangement to prefabricate different timber components for the construction of a mixed-use, high-rise tower in Melbourne, Australia. Their General Manager, who benefitted from combining the default technologies they used, expressed the following:

> "Both using the same process, same data, same intelligence to be able to produce".

5.2.7. Off-Site Prefabrication Constraints

In the construction of multistorey buildings, where working space is limited, Supplier C4 has been content to hasten their involvement with the internal finishes and fit-out by progressively loading their off-site prefabricated components directly onto the same floor level where they are to be incorporated into the works. Their Director has high regard for the advanced competencies of practitioners in the Australian construction industry to complete a floor level every 4 to 5 days. In prioritizing their shop drawing and off-site prefabrication processes, Supplier C4 had intertwined their internationally dispersed operations. Contrastingly, Supplier P1 operates three (3) shifts per day, with only 12 staff across Australia and 75 in New Zealand. After inputting algorithms resembling their knowledge into the settings, the robotic technology of Supplier P1 was then skilled to undertake timber component prefabrication:

> "That robot now has the intelligence within one (1) machine. It's automated . . . has agency from both".

The approach of Supplier P2 involved programming their off-site mass production of timber components based on the resources available to them locally, such as sawmills. In their case, expanding production also involved loaning the required minimal additional finance:

> "It certainly has a measure of constraint . . . So certainly, there's a financial consideration to [Supplier P2′s] planning. Which may or may not translate as being quick or rapid enough, but when done, it's done well . . . Responsibly and we've all still got jobs and . . . A very strong future".

5.3. Comparative Analysis

Table 3 presents the collective benefits and shortcomings of the off-site prefabrication of timber and MEP services that have been conferred by the first-hand accounts of representatives from the contractor and supplier companies interviewed. The data were summarized and organized into a couple of generic indicators from the project management perspective, which the associated findings were compiled for the benefits and shortcomings in off-site prefabrication. This would provide a holistic view of the results of the comparative analysis. It would also help readers and practitioners to grasp certain information and references that are suitable for them in managing or coordinating off-site prefabrication in the future.

Table 3. Conferred Collective Off-site Prefabrication Benefits and Shortcomings.

Generic Indicators	**Content Analysis**		**Comparative Analysis**	
	Builders:	**Suppliers:**	**Benefits:**	**Shortcomings:**
Time Constraints:	• Off-site prefabrication's schedule monitoring.	• Off-site prefabrication time constraints.	• Off-site construction is manufacturing that can operate twenty-four hours a day, seven days per week (24/7); • Quicker than on-site construction, which can result in time savings; • Reduces waste in time, materials and transportation; • Reduces on-site management, workforce and mess; • Unites procurement of building components in bulk; • Optimizes staging of construction work.	• Lead times are more necessary in off-site prefabrication; • Earlier tendering deadlines restricts analyses of off-site pre-fabricators to after tenders are won, albeit within set budget; • Slower to rectify off-site prefabricated components during Liquidated Damages.
Cost Constraints:	• Economical sustainability; • Environmental sustainability; • Commercial arrangements with prefabrication resources.	• Financing conditions; • Subcontracting conditions.	• Mass production economies of scale possible; • Advantages of repetition; • Addresses productivity loss; • On-site quantities can be handled by a crane; • Reduces on-site costs.	• Time savings are sometimes inadequate to offset costs of material deliveries and storage; • Changes to off-site prefabricated components are not as transparent, so discounts to trade packages are often not realized.
Quality Constraints:	• Quality assurance (QA).	• Off-site prefabrication quality constraints.	• Easier to monitor, which enhances quality assurance (QA); • Enables Six Sigma productivity; • The systemic production line in off-site prefabrication; • Enables off-site controls; • Able to consistently control the working environment; • Prototyping and sampling; • Reduces damage, pilfering, and vandalism.	• Inadequate or poor quality in off-site prefabricated components need to be rectified; • Difficult to justify off-site prefabricating components at lower volumes.

Table 3. *Cont.*

Generic Indicators	**Content Analysis**		**Comparative Analysis**	
	Builders:	**Suppliers:**	**Benefits:**	**Shortcomings:**
Planning and Labor:	• Technological support by builders; • International supplier flexibility; • Stakeholder engagement; • Off-site prefabrication risks to builders.	• Coordinating suppliers; • Off-site prefabrication risks to suppliers.	• The program is considered from the outset; • Sequencing is improved; • Consistency in the supply chains; • Network of suppliers in manufacturing; • Rigorous worker training and adoption; • Collaboration between multiple trades; • Enables worker cross-skilling; • Improves employment longevity, morale, productivity, security, and injury rehabilitation; • Fosters gender equality and career advancement.	• Comprehensive decision making before off-site prefabrication; • Earlier planning and engaging requires discipline; • Lacks on-site flexibility, relative to the dynamism of traditional construction; • Tolerances in off-site prefabrication require precision; • More difficult and time-consuming to fix any errors; • Greater clarity is required in earlier planning.
Design:	• Computer-aided design (CAD); • Building information modeling (BIM).	• Design collaboration; • Design testing.	• Enables sharing of information and building information modeling (BIM); • Earlier design team engagement and collaboration; • Design can be comprehensive; • Drawings can be as-built earlier.	• Design errors tend to only be identified on-site, which adversely affects planning; • Signing-off designs are more difficult; • Designs are frozen once agreed, reducing contract variations; • When the concept/feasibility drawings provided are of poor standards.
Construction:	• Mass production off-site; • Mass production on-site; • Integrating system building; • Supplier productivity.	• Internationally recognized practices.	• Construction concurrency can sometimes address high costs by reducing time; • Off-site prefabrication environments enhance safety.	• Builders tend to have less grasp of off-site prefabrication operations; • Builders are normally averse to change from familiar operations.
Logistics:	• Buffering in supply of off-site prefabricated components; • Builders in multiple supply arrangements.	• Suppliers in multiple supply arrangements.	• Better tracking and tracing; • Savings in procurement through bulk deliveries; • Savings in on-site deliveries and storage; • Reduces vehicle traffic around the site; • Reduces working at heights; • Dispersion of trades in off-site prefabrication improves access and egress.	• Challenges in coordinating the crane and delivery times; • Pressures on crane use and loading bays; • Limited opportunities for deliveries; • Environmental constraints.

6. Discussions and Implications

The research highlights and contributes three key implications for the implementation process of timber and MEP services in off-site prefabrication. Although the implications are quite practical and specific to the practice of off-site prefabrication in Australia, they are generalizable and can be referred to by other countries and modular constructions, particularly through the new and in-depth understanding in improving timber and MEP service coordination in off-site prefabrication. This can be achieved by managing hindrances to off-site prefabrication, as well as coordinating and integrating work done off-site and in situ.

6.1. Hindrances to Management of Off-Site Prefabrication

The construction industry itself is competitively difficult to thrive in, the industry's strained timeframes sometimes causing the hasty preparation of quotes and tender bids. Builders and suppliers traditionally focus on communicating their approaches to the construction project as a quote or tender bid, in the hope that theirs will be selected. Once selected, construction management would then uphold their objectives in the project when appraising and dissecting to optimize value for money, as well as constructability [38]. For example, Builder P1 normally acts to counteract any losses by setting a narrow profit margin to make their tender bids competitive and exploit the likely project client preference for a low cost by seeking value gains elsewhere.

When all avenues to find gains from the design documentation for a project have been exhausted, they are then likely to focus on dynamically compressing their schedule, usually through adopting concurrent construction by way of off-site prefabrication [39]. These practices have made communications with project clients contentious, who sometimes initiate contract variations during construction, the extra costs of which they are willing to finance. Whilst the off-site prefabricated timber and MEP service suppliers, as professionals, tolerated contract variations, each of them tended to raise their angst, particularly when contracts exclude the necessary extra time for material deliveries and project client intervention/s. As such, off-site prefabricated timber and MEP services suppliers can become anxious and less productive.

Whilst a trend exists amongst the design disciplines of embracing new materials or technologies in place of traditional practices, such as the extremely cantilevered roof shown in Figure 3, the reluctance throughout the industry to deviate from what is familiar remains an obstacle in making the off-site prefabrication of timber and MEP services a seamless fit with in situ construction. A paradox also exists, whereby some of the above disruptions are necessary for the construction industry to progress beyond traditional practices to foster new design standards, proactive decisions, and realistic timeframes [39]. Tier 1 commercial builders, in particular, have both initiated and been receptive to the changes necessary for their construction projects to benefit from off-site prefabrication [40]. Amongst them, Builders C3 and C4 gallantly advocate embracing off-site prefabrication for its diverse benefits.

6.2. Coordination of Work Done Off-Site and In Situ

The construction industry is fast-paced and inclusions to off-site prefabrication processes tend to first undergo appraisal based on supplier needs, quantities required, constraints on-site, as well as coordination necessities [42]. Builders generally feel assured by the returns to these investments in solutions that will realize future benefits. QC measures have ensured that the majority of off-site prefabricated timber components in particular were found to comply with specifications and inside precise tolerances [43]. Whilst differences in QC exist amongst off-site prefabrication suppliers, the consensus amongst the research participants was that the majority of them were indeed producing quality components. For example, when the QA of Builder C2 was able to notice that their floor fall gradients were inverted within the off-site prefabricated bathroom pods, they then arranged for this predicament to be rectified by the Carpentry trade. The meticulously precise tolerances of most off-site prefabrication suppliers are often not matched by many builders who subcontract and coordinate with them, which have sometimes hampered the incorporation of their components into the in situ construction work. Off-site prefabricators of timber components in particular are dedicated and would openly assist the builder by providing the information necessary to support construction, which they see as a way to optimize their uptake for future projects.

Figure 3. Cantilevered Roof and Box Gutters of Builder C3 (Adapted from Phillip Island Nature Parks [41]).

The Construction Manager of Builder C3 was willing to do whatever it took to engage with and integrate all of the other project stakeholders, including those in their off-site prefabrication supply chains so that remarkable deliverables could be achieved. This resolve was necessary to construct the building. In particular, its unorthodox ceiling and internal walls, which feature many haphazard triangles, were challenging for their project team to visualize before construction and underwent several design revisions for clarification (see Figure 4).

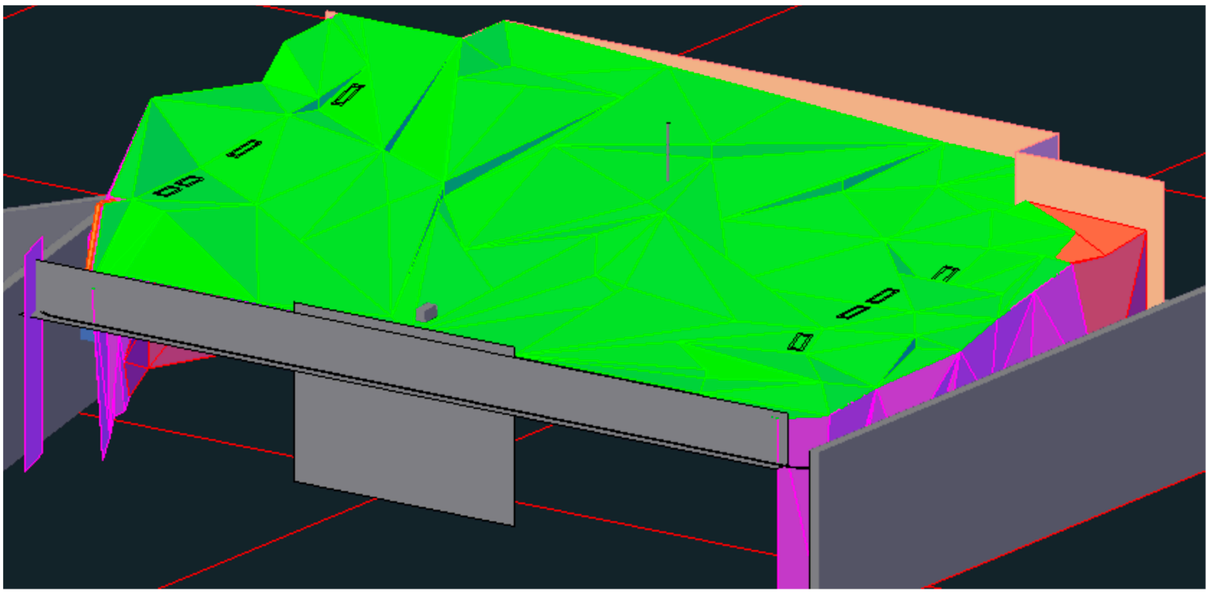

Figure 4. Complex Suspended Ceiling and Internal Walls of Builder C3 (Adapted from Phillip Island Nature Parks [41]).

6.3. Initiatives to Integrate Work Undertaken Off-Site and In Situ

An ingrained belief amongst the off-site prefabricated timber and MEP services suppliers was that engineers could promote and improve their coordination with in situ construction. This was largely due to the difficulties experienced by construction management in pausing, deliberating, as well as ingesting, unfamiliar processes into their trusted traditional activities that are otherwise easier to schedule and track the QC of. The result of this has been prevalent apprehension amongst commercial builders in particular, as well as off-site prefabricated timber and MEP services suppliers, toward their investments to implement innovative technologies. Some off-site prefabrication suppliers situated in European countries have obtained additional funds to finance their advanced mass prefabrication plant facilities to produce components for the construction industry where demands for them are greatest. Supplier P2 strives for engagement in those more collaborative, non-traditionally procured projects as early as possible to foster better communications, clarifications, and outcomes between their off-site prefabricated timber components and the design and construction teams. Conversely, Builder C4 strives for self-sufficiency by reducing their volume of construction projects to develop separate system building departments in-house, thereby potentially removing the need for off-site prefabrication suppliers.

6.4. Internal and External Validation of Findings

The performance obstacles and recommendations found for off-site prefabricated timber and MEP services in construction projects that are presented within this paper were validated. Those obstacles and recommendations were identified by construction industry practitioners employed at four builders and four suppliers, based on their first-hand experiences. Both internal and external validation has been undertaken. Internally, this involved the identification of converging information between the literature review and what was valid academically. The theories presented had generally been supported through this research.

Externally, the opinions of experts involved in this research were provided on the real-world validity of the performance obstacles and recommendations. Their assessment of these generic obstacles and recommendations has been presented by the research participants themselves at presentations that were organized by construction industry professional bodies, the Chartered Institution of Building Services Engineers [44] and Chartered Institute of Building [45]. In their presentations, these performance obstacles and recommendations for off-site prefabricated timber and MEP services were collectively identified as valid within real-life construction projects.

7. Conclusions and Limitations

7.1. Conclusions

The research found and addressed performance obstacles for off-site prefabricated timber and MEP services in construction projects through the literature review and field research of interviews. The *theoretical* contributions provided by the literature review were the prefabrication production, processing, off-site advantages, as well as on-site disadvantages/obstacles, of timber components, and MEP services from the perspectives of their buyer and seller stakeholders in the supply chains of construction projects. The content and comparative analyses were then conducted from two sets of key construction stakeholders, specifically the builders (buyers) and suppliers (sellers) of timber and MEP services, who addressed their identified obstacles through different and innovative off-site prefabrication practices.

The *managerial* contributions provided by the field research were specifically the *builder*-focused obstacles of off-site prefabricating timber components and MEP services. The builders' obstacles were sustainability, quality assurance (QA), mass production, CAD/BIM, technological support, commercial arrangements, system building, buffering in supply, schedule monitoring, productivity, flexibility, engagement, risks, and multiple supply arrangements. The *practical* contributions provided by the field research were specifically the *supplier*-focused obstacles of off-site prefabricating timber components and MEP services. The suppliers' obstacles were design, financing and subcontracting, coordination, recognized practices, risks, multiple supply arrangements, and constraints. Overall, this research contributes new and in-depth understanding of obstacles that prevent the widespread adoption of off-site prefabrication methods as well as directions for improved timber and MEP service coordination in off-site prefabrication. Particularly, the described coordination in off-site prefabrication processes may offer substantial improvements, which can be referred to by other modular construction professions.

Masood et al. (2021) [46] has recently studied the supply chains of prefabricated houses. In this study, they recently reported the key prefabrication challenges or obstacles from the perspectives of suppliers in New Zealand. The most important of these were crane usage, competitive pricing, poor delivery systems, international competition, skills shortages, slow technology adoption, off-site facility inadequacies, as well as imprecise and under-optimized manufacturing processes. The supplier market in New Zealand is similar to that of Australia [46]. Indeed, similar in both of these markets are those obstacles of competitive pricing, international competition, and technology adoption, in particular. In Australia, builders face obstacles in the ways suppliers competitively price the work within their commercial arrangements. Both builders and suppliers face obstacles with international competition that having multiple supply arrangements bring. Builders in Australia have found the adoption of technology, such as CAD/BIM [47], to be another obstacle for which they require support.

Thus, consistent with the findings of Masood et al. (2021) [46], it is recommended that earlier engagement of the builder and suppliers of timber and MEP services in involvement in the digital design phase would strategically enhance project integration, common understanding, and coordination of work methods. The suppliers of off-site prefabricated timber and MEP services involved in this research generally seemed to be aware of this yet were content with educating others on the benefits of their working methods, operations, environments, QC, QA, components, and/or system building. Complementarily, the Tier 1 builders were proactively and continuously exploring ways to integrate off-site prefabrication advances into their construction projects. Overall, the builders and suppliers involved in this research had identified ways to harmonize certain practices of off-site prefabrication of timber and MEP services with in situ construction, of which the findings render a new and in-depth understanding in improving the coordination of off-site prefabrication within construction projects.

7.2. Limitations

It is speculated that this study could have delved further into qualitative engagement and comparison between builders by their volume rather than project type specialty. In particular, the research methodology adopted could have case studied how opposing builder entities would embrace collaborative construction procurement and contracting, engage suppliers earlier, clearly define the project objectives, better utilize virtual design technologies, and provide environments that facilitate off-site prefabrication. These systems may then be streamlined without necessarily enveloping most of their processes internally. This study could have also benefitted from additional analysis of emerging opportunities for off-site prefabricated timber components in existing buildings. This could reveal improvements in coordination between off-site prefabrication and existing buildings, potentially extending their usable lifecycle where they may otherwise be considered redundant.

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Appendix A. Questions

1. What strengths and weakness between off-site prefabrication integration with in situ construction would you consider the most impactful to decision making of incorporating prefabricated componentry into construction builds?
2. What impacts or what do off-site prefabricators consider the biggest impact of your client's Construction Management decision-making process most when choosing to opt for off-site prefabrication componentry over in situ construction? In addition, how do the economic, environmental, and socially sustainable objectives compete in your or to sell your business/products to their organization?
3. To what extent does your firm or clients carry out testing and quality control measures of off-site-prefabricated componentry in controlled off-site locations to ensure or confirm your components adhere to specifications, code, quality, and integration connection points under construction or that they require on your or their physical construction sites?
4. If off-site prefabrication could not be mass produce the same component, would your company always opt to construct in situ, or is repetitive, quantitative, off-site production mandatory to alleviate coordination implications of production and installation of off-site-prefabricated componentry?
5. What level of design assistance and specifications are provided or do your clients, to aid off-site prefabrication, ensure elements prefabricated off-site meld seamlessly into your or for their in situ construction environments? E.g., off-site prefabricated component optimization via a 'Modular Suitability Index', which may categorize discussion into compartments akin to module components, transport-dimensions, logistics, crane-costs, and additional structural footing requirements.
6. To what extent is technology to support off-site prefabrication mechanisms employed prefabricated elemental inclusions into your site's relevant predicaments, and how does it assist your firm to reduce waste and assembly times, accelerating your building practices? E.g., robotics, advanced computer animations/simulations and 'control systems', plus intelligent manufacturing arrangements. Or what technological systems does your factory use to enhance off-site prefabricated component manufacture to collect data aiding the coordination of elements with in situ operations?
7. Do your firm's contractual arrangements prepare/allow for bespoke contract clauses permitting payment of off-site-prefabricated elements prior to their delivery and installation on site? If so, are there stipulations included to regain materials should suppliers go into administration? Would the ability to seek some financial assistance from your customers or how has prohibitive costs in capital investment required to 'tool-up' with and/or procure plant and equipment that surpasses the current low-tech environment, and pushes your efforts towards the future operations or automations restricted your firm's growth ambitions, plus large material stocks assist your firm to economically establish supply of custom/bespoke/unique/superior products?
8. The intertwining of off-site prefabrication and in situ construction methods have been referred to as 'hybrid' activities. Do you think this terminology clearly defines/progresses these collaborative efforts of heightened construction effort? Why/why not?
9. Modular Coordination must be linked to off-site prefabrication, *often termed as IBS 'Industrialised Building Systems' in overseas locations*, to enhance construction integration. To what extent does your role with your organization coordinate (*plan/prepare/design/schedule*) Modular Construction to realistic outputs achievable by off-site prefabrication concerns? Other innovations, such as GPS (Global Positioning Systems), and Radio-Frequency-Identification (RFID), have been effectively applied in off-site pre-

fabrication realms, does your company utilise these methods at present? If not, are you considering the adoption of these or other such innovations?

10. To what extent are off-site prefabricators or your construction clients able to deliver as scheduled or provide a realistic construction program that your off-site prefabrication manufacturing is able to deliver as scheduled? Do you think off-site prefabricators intentionally 'buffer supply' to ensure they are able to meet schedule deadlines and meet client service expectations?
11. What if any leeway or 'product sequencing strategy' is nominated to monitor off-site prefabrication manufacture/rs by clients on or to observe performance metrics in order to record the order and time constraints or restraints to proactively plan for delays/complications?
12. Are there regions of Australia or globally that you understand to have better practices and arrangements to elevate the use of off-site prefabricated elements/components?
13. Does your firm embrace or actively seek formal measures to designate and/or engage off-site prefabrication suppliers, and/or is there a robust strategy/protocol to shortlist participants based on their ability to better provide accurate coordination or accurately coordinate fabrication plans to complement in situ construction operations utilized?
14. There are some opinions that off-site prefabrication and in situ coordination inevitably leads to insufficiencies that have ramifications which elevate costs and time allocations, compromise quality, affect OH&S, create technical issues, and diminish client satisfaction? Would you agree with their summation, and what could be added? Or does your off-site prefabrication operation permit enhanced opportunities to multi-skill staff and encourage a great inter-disciplinary sharing of construction tasks/roles/trades in the manufacturing setting, that is only conceivable because of your controlled and stable employment environment?
15. Has your company engaged in duplicated off-site prefabrication supply arrangements to mitigate risks, and/or does your client deem this noteworthy to safeguard against bottlenecking, delay, or disruption of component supply?

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