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Blockchain and Information Integration: Applications in New Zealand's Prefabrication Supply Chain

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Abstract: New Zealand's rising demand for new and affordable homes is driving innovative and effective methods for project delivery. Prefabrication or off-site construction is considered an innovative approach to project delivery that eliminates the limitations of traditional construction methods. However, the prefabrication industry struggles with several challenges, including poor coordination and low supply chain integration amongst its partner organisations. There has been previous literature on improving the prefabrication supply chain integration, but few studies about the role of technology in this sector. Therefore, this article provides intuitions into the applicability and benefits of advanced technologies, namely blockchain, for improving supply chain integration in the context of prefabrication in New Zealand. A questionnaire survey was used to identify the channels used for information exchange between clients and contractors. Moreover, the questionnaire ascertained the positive effects of blockchain on enhancing supply chain integration between the two partners. Blockchain has proven to be a secure information integration instrument that can improve the integration of the prefabrication supply chain by fostering collaboration between organisations.

Keywords: prefabrication; supply chain; communication channels; information integration; blockchain; New Zealand

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1. Introduction

Supply chain management concepts are effectively used in various industries. However, in the prefabrication industry, these concepts are relatively new [1]. The rising demand for affordable and newly built houses in New Zealand urges modern and efficient project delivery systems [2]. Construction organisations that perform roles in the highly competitive market of New Zealand consider supply chain management a critical part of success for their overall performance [3].

Prefabrication is recognised as a means of improving conventional construction procedures [4]. Some benefits of prefabrication technology include shortened lead time, reduced costs and enhanced quality and sustainability [1,5]. However, prefabrication in New Zealand needs specific consideration concerning the factors inhibiting its performance. Poor supply chain integration is perceived to be a substantial problem preventing the efficient performance of this sub-sector in the construction industry [6]. Supply chain management consists of the management of two key flows: Information and material [7]. Integration of these flows amongst supply chain partners, commonly referred to as Supply Chain Integration (SCI), is considered a crucial contributor to the effective management of supply chains [8]. Within the prefabrication sub-sector, co-operative interaction amongst supply chain allies is a fundamental driver of supply chain integration [9]. However, inadequate information exchange systems, little adoption of advanced technologies and low transparency in the diffusion of work at isolated sites are viewed as obstacles to prefabrication supply chain integration [1,10,11]. The origin of the explained impediments can be attributed to the low level of information integration amongst organisations [7,12].

A supply chain with integrated information ensures swift and efficient design, fabrication, construction and assembly processes [13]. Additionally, trust amongst different prefabrication stakeholders is improved [14]. Therefore, using an information integration tool such as blockchain, the supply chain participants in prefabrication projects benefit from improved trust and integration [15]. The main advantage of Blockchain technology over other advanced technologies is the anonymity and decentralisation of its stored data [16]. Unlike other technologies, information/data on blockchain is processed and stored across different isolated computers, giving organisations an opportunity to have their information tidily stored in multiple locations [17].

Blockchain, a new era in the field of information technology, is revolutionary. This technology enables integration in the prefabrication sub-sector and offers a distributed and secure database, helping supply chain partners to communicate their project information efficiently [18]. As a secure communication platform, blockchain provides a reliable and transparent information-sharing setting for supply chain stakeholders [19].

In New Zealand, blockchain-based systems can positively influence business growth, especially in the prefabrication sub-sector of the construction industry. Innovation and technology are being adopted as part of New Zealand's resilience towards business development [20]. One of the most prominent benefits of blockchain in New Zealand's prefabrication supply chain is its ability to provide traceability for clients/customers wishing to trace the origins of their materials [21]. Supply chain organisations demand this ability since prefabricated construction is complicated with various stakeholders and suppliers involved [9]. Moreover, with the help of blockchain technology, supply chain organisations can exchange information in an organised manner, resulting in better transparency in information sharing and better distribution of accountability of each partner with regards to their contribution to project deliveries in New Zealand [10,22].

Previous literature has explored the integration of prefabrication supply chains and the advantages of utilising information technology. For example, Bakhtiarizadeh, Shahzad and Rotimi [21] developed a process map, showing different stakeholders' interrelationships in 12 development phases of prefabricated projects. Other studies have focused on client-contractor relationships and their engagement in specific phases of construction projects [23,24]. Moreover, a few studies have shown the importance of information exchange amongst supply chain partners in the design and construction phases of projects [3,13]. Nevertheless, little research has been conducted in the prefabrication industry of New Zealand, and there is limited knowledge of the use and benefits of blockchain technology. In this study, blockchain technology is considered an information-exchange mechanism for improving integration in the prefabrication supply chain of New Zealand's construction industry. The benefits of this technology are explored to address the lack of investigation in this area.

Exploring communication channels amongst partner organisations helps evaluate the impact of blockchain technology on the integration and performance of the prefabrication supply chain. As such, in this research, a questionnaire survey was used to identify (1) the channels used for information exchange between clients and contractors in three phases: Detailed design, construction and handover, and (2) critical information attributes. The findings from the survey helped to strengthen arguments around the potential benefits of blockchain in the prefabrication supply chain in New Zealand. We contend in this current study that blockchain technology can play a crucial role in enhancing information integration amongst partner organisations.

2. Literature Review

2.1. Overview of Prefabrication Supply Chain

According to Čuš-Babič, Rebolj, Nekrep-Perc and Podbreznik [13] and Luo et al. [25], supply chain management plays a vital role in accomplishing the successful delivery of prefabrication projects. Different industries use different supply chain configurations to achieve their desired environmental, social and economic outcomes [14].

A supply chain is a network of organisations that produce value for the end consumer by linking the upstream and downstream flow of materials and information [26]. The primary principles of supply chain management can be discovered in systems thinking, where it is crucial to consider every single individual involved in the product/services delivery lifecycle to be an important contributor to a larger system [27]. Supply chain management is observed to be highly dependent on innovation and information technology [28].

In prefabrication, supply chain management requires more consideration. While prefabrication helps to reduce construction duration by transferring on-site activities to an off-site plant [20], it lags in supply chain practices [25]. Due to the broken working sites, complexities in prefabrication supply chains are higher than traditional ones [29], which intensifies the necessity of effective integration and communication. In addition, managing information flow and acting promptly in response to any variation to the design or customers' requests needs dynamic integration strategies amongst the prefabrication supply chain partners [30].

In the prefabrication supply chain, unique products are primarily designed and constructed for distinctive projects. Therefore, the recurring pattern of supply chain methods for one project may not fit another, and can cause the loss of information, fragmentation and instability [31]. The current principles of supply chain management preclude the adoption of innovation, causing a slow usage of supply chain information technology in the prefabrication industry [1,32]. Increasing the knowledge of prefabrication and its supply chain techniques through investigation and implementation of technological tools will help the industry expert to benefit from innovation and integration.

2.2. Prefabrication in New Zealand

Different synonyms are interchangeably used for defining prefabrication technology, such as off-site fabrication, off-site manufacturing, off-site construction, pre-assembly and prefabrication [33]. All these synonyms are attributed to the process of constructing a portion/component/structure of a larger structure or a building remotely [34].

There is a critical necessity for employing innovation in lieu of traditional construction approaches in New Zealand since a significant housing shortage is observable in the country [35,36]. Moreover, due to New Zealand's geographical isolation along with high material/human resource costs, the supply of affordable homes is insufficient [37]. Despite the resilience of New Zealand's construction industry in adopting innovations, the present utilisation of prefabrication, which is considered an innovative approach of construction in New Zealand, is relatively low [4].

Prefabrication delivers several practical benefits, including improved recycling of wastes, decreased on-site efforts, improved quality control and enhanced health and safety measures [9,38]. However, utilising prefabrication methods in New Zealand hinges on industry experts' perception of prefabrication and their collaboration techniques within the prefabrication supply chain [3]. Close-knit stakeholders' relationships in New Zealand's construction industry address the interrelated nature of the perceptions/challenges that affect the market's demand and hinder the expansion of prefabrication [37].

The prefabrication sub-sector of New Zealand's construction industry has more complexities in comparison with traditional construction [5]. In the prefabrication supply chain, information integration can be more intricate since the number of stakeholders involved in prefabrication projects is higher. The multiplicity of stakeholders imposes a hefty challenge on the construction partners to share their knowledge or information quicker and with higher accuracy [39]. Besides, obtaining statutory approvals (e.g., resource or engineering consents) is difficult in prefabrication projects, owing to the multiplicity of workplaces and complicated inspection procedures [1]. Additionally, quality-related matters such as reworks and defects in prefabrication projects typically stem from inefficient information sharing or collaboration amongst the supply chain allies [40]. These complexities can adversely impact the development of supply chain integration within this sub-sector. Trust is another issue in prefabrication. Most contradictions and trust-related disputes arise from poor transparent information exchange [41]. The absence of trust in prefabrication hinders future interactions, negatively impacts stakeholders' relationships and weakens stakeholders' viewpoints on adopting innovations [21,42].

Most of the impediments to the uptake and effective use of prefabrication technology in New Zealand's construction industry can be addressed using advanced information-based technologies [43]. For instance, blockchain technology could be helpful for creating information integration and therefore supply chain integration within this sub-sector. Blockchain has the potential to directly address the issues related to transparency of information sharing, traceability of products' provenance and security of information-sharing platforms used for stakeholders' communications.

2.3. Blockchain Technology in New Zealand's Prefabrication

Web-based supply chain management systems have recently gained popularity worldwide to integrate supply chain networks [44,45]. Information technology systems such as Customer Relationship Management (CRM) or Enterprise Resource Planning (ERP) are being challenged by cloud/web-based technologies, e.g., drones, GPS, RFID and Internet of Things (IoT) [46]. Using these technologies, information exchange between supply chain partners has been made faster and more efficient [47].

Despite the additional value of cloud-based technologies, there are still a few issues associated with them. Chou et al. [48] describe that information/data security can be deemed a substantial issue associated with these technologies since hackers' risk of manipulating or altering the stored contents is high. Meanwhile, these supply chain management systems provide cross-organisational access to the information repository [16]. This accessibility can be hazardous in the construction supply chain since all project information would be prone to change by any user, randomly or deliberately [49]. These issues, in turn, will harmfully disturb trust and market competitiveness amongst supply chain organisations.

On the contrary, Blockchain technology can perform prominently better regarding cyber security. Distributed Ledger Technology (DLT) or commonly recognised as "Blockchain", is a secure and consensus-based transactional register that streamlines connections amongst its users [50]. This technology offers a peer-to-peer (P2P) network where a digital signature is attached to all transactions to prevent alteration to the original transactions [44].

Blockchain is analogous to a centralised cloud data centre. Yet, the main distinction is that blockchain is decentralised, meaning that there are multiple sources/databases of information that are simultaneously accessible by dissimilar users from dissimilar locations [22]. Moreover, blockchain works by proof-of-work, which means that for making any changes to the contents saved in the database, users need a consensus-based agreement [15]. This can assist organisations in obstructing malicious attacks on their information repositories.

There are other benefits to using blockchain, as identified by different researchers. For example, supply chain information/data recorded in blockchain will yield long-term transparency and trust by conserving the knowledge gained in the project [51]. In addition to this, the immutability of details saved in blockchain fosters a secure atmosphere, within which supply chain organisations can distribute their assets or information without being concerned about scams [50].

This study aims to ascertain the impact of blockchain technology as an information integration tool on New Zealand's prefabrication supply chain integration. Identifying information exchange channels will assist in assessing the benefits of using this technology for improving the integration of the prefabrication supply chain in New Zealand. Figure 1 portrays the process model of this study.

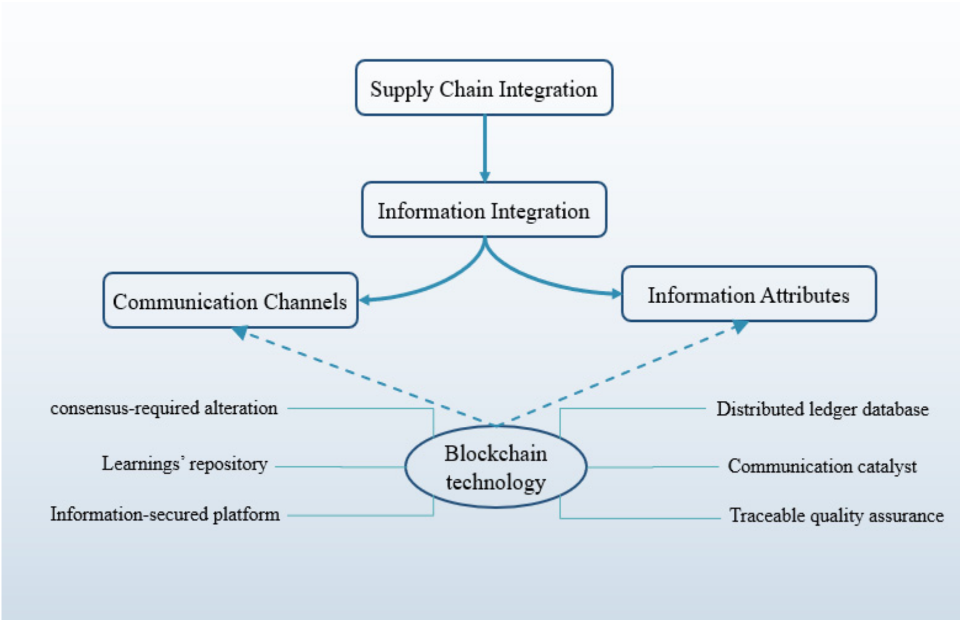

Figure 1. Knowledge gap design.

3. Research Design

This study uses an exploratory approach for identifying the communication channels in the prefabricated construction supply chain of New Zealand. A questionnaire survey was utilised to (1) identify the modes of information exchange between prefabrication projects' clients and contractors, and (2) explore the qualities of information critical for the enhancement of the prefabrication supply chain.

Many studies have utilised questionnaire surveys for collating experts' perspectives and ideas on the construction supply chain [9,52]. The questionnaire survey comprised three sections. A summary of the definitions was provided to the respondents in the opening statement. The next section obtained the preliminary demographic information of the participants. It is worth noting that respondents were requested to identify which major sector they belonged to, whether clients or contractors. Subsequently, participants were asked to respond to a number of questions associated with channels of information exchange and attributes of information. Multiple-choice questions were incorporated in the questionnaire survey to gain respondents' answers regarding the types of information technology used for communication with other stakeholders. This was followed by five-point Likert scale questions to measure the participants' degree of agreement with the importance of information attributes to the success of New Zealand's prefabrication supply chain. Responses ranged on a scale of 1 (strongly disagree) to 5 (strongly agree). Respondents were also given an extra "Other" option with a textbox to provide their comments/other information.

After pre-testing of the questionnaire survey, it was sent to PrefabNZ which has about 350 members across the design and construction sector (https://www.prefabnz.com/Membership, accessed on 1 April 2021). The study uses a convenience sampling strategy by first targeting a few familiar PrefabNZ members and using snowball approach to recruit future respondents amongst their acquaintances. This snowball sampling method was utilised because of the challenges associated with accessing all PrefabNZ members. Snowball sampling is efficient and cost effective [53], and mainly helpful for conducting surveys in which respondents are required to have relevant experience or knowledge on a particular subject [54]. Forty-one valid responses were obtained from experts who received the questionnaire. The demography of respondents can be viewed in Table 1.

Table 1. Participants' demographics.

Category	Sub-Category	% of Respondents
Stakeholders	Client Contractor	46% 54%
Prefabrication experience	0–4 years 4–8 years 8–12 years Over 12 years	59% 20% 17% 5%

In this study, a descriptive analysis technique was employed. Two steps were taken for the analysis: (1) Communication channels and (2) critical information attributes. First, the multiple-choice responses regarding the channels used for information exchange were split into three groups (detailed design, construction and handover) and the frequency of each response was counted and divided by the total number of responses in each phase. Then, the analysis for the second step was conducted based on the respondent's answers to the questions set out in the Likert scale. An average value of greater than or equal to 2.6 for each question was deemed significant.

Errors and biases were lessened by sequencing and writing the questions precisely and succinctly without authors' interpretations, ensuring the reliability and validity of the findings. Moreover, as using subjective data in the questionnaire survey may increase the researcher's bias [55], we avoided that by promising confidentiality of data to the respondents, highlighting the importance of the subject and emphasising the significance of the accuracy of data that they provide. Moreover, as internal validity is commensurate with measuring what an author expects a measurement tool (e.g., questionnaire survey) to measure [56], the questionnaire survey delivered satisfactory results of the questions, ensuring abated distortions in the data collected from the participants. The internal consistency between two groups of respondents, clients and contractors, was measured using a Cronbach's Alpha test (Table 2). A score of 0.751 was returned as a result of this test, which is within acceptable ranges (Cronbach's Alpha > 0.70), thus a high internal consistency of the variables according to the participants' responses.

Table 2. Result of Cronbach's Alpha.

Construct	Variables	α
Information Exchange	Transparency Traceability Security (Reliability)	0.751

4. Results and Discussion

In geographically dispersed construction sites, prefabricated construction is more suitable [20]. However, the complexity of the supply chain in prefabrication is more than that in traditional construction [57]. When information is exchanged effectively throughout prefabricated projects, this complexity can be decreased significantly [10]. Information technology will streamline complex information exchange processes and facilitate the construction supply chain for prefabricated projects [43].

4.1. Communication Channels

Previous studies have shown that the types of information exchanged across the entire supply chain in a prefabricated project can substantially affect the outcome of the project [58]. A large number of documents, including design and construction drawings, quality assurance (QA) documents, requests for information (RFIs) and governmental permits/approvals are exchanged within the prefabrication supply chain on a daily basis [21,59]. Effective integration of this abundance of information results in a positive future collaboration amongst supply chain partners [43].

Various industries have benefited from the use of technologies in their supply chains. Information Technology (IT), firstly, has made collaboration within the production team easier, thereby decreasing the timeframes for the development of products [9]. Additionally, it has resulted in lower production costs [7]. Finally, it has improved customer satisfaction by improving products' quality [44,48].

While collaboration has been streamlined through information technology, the best technological tool to be used has remained the major challenge of researchers and industry experts, triggering different approaches and technologies to be investigated thoroughly [60]. Information integration is a prerequisite for effective collaboration [61], and in order to integrate information, it is necessary to identify the channels of communication amongst stakeholders [61,62].

Communication channels in prefabrication supply chains have been studied in various ways. However, information technology has never been the focus of these studies. For instance, Evborokhai and Shittu [63] studied different channels of communication for improving communication management approaches and reducing disputes in the design phase of construction. Moreover, Achar, Chebii and Mugo [59] classified the channels of communication amongst different organisations in the construction industry and evaluated the role of these channels in the execution of housing construction projects. Traditional ways such as intranet/extranet-based emails, faxes and phone calls were studied by Wang, Wang, Hu, Gong, Ren and Xiao [10], revealing the lack of automatic information-sharing systems and the importance of technological adoptions. Others identified different channels such as video/audio conferences, face-to-face conversations, blogs, text messages and letters [59].

Communication channels in this study were clustered into 11 categories and incorporated in the questionnaire survey: Email, meeting, telephone, cloud database or applications, intranet or extranet, GIS systems, Building Information Modelling (BIM) software, video conference, verbal communication, workshops and social media. The questionnaire survey sought to determine the main channels (platforms) for exchanging information between clients and contractors in the prefabrication sector. The response to the questionnaire survey is presented as a clustered bar chart in Figure 2. According to the respondents, the traditional and most commonly used modes of communications in the prefabrication supply chain are email, meeting, telephone and internet-based applications (e.g., SharePoint) with an average of 90, 80, 50 and 50 percent, respectively.

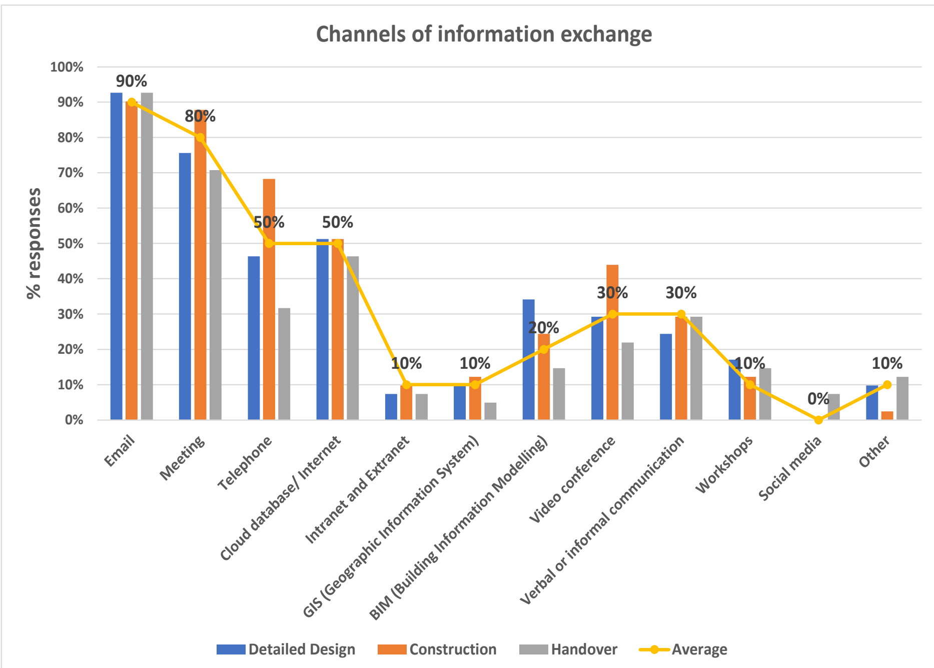

Figure 2. Channels of information exchange.

These channels have been investigated in three phases: Detailed design, construction (off-site and on-site) and handover. The difference between the percentage of responses in these phases is commensurate with the concentration of actual construction works for a given prefabrication project. Depending on which phase the project is at, the communication channels switch their use case dominance. For instance, in the construction phase, the use of face-to-face applications such as meetings and video conferences or phone calls for quick actions to be taken on-site is dominant. Conversely, internet-based applications or formal communication channels such as emails are frequently used in the modelling or detailed design phase when acquiring statutory approvals and engineering consents is taken place. The identified channels are representative of the views of contractors (54%) and clients (46%), showing relatively equal participation of both stakeholders. Moreover, 61% of participants indicated that IT (in general) is utilised in their organisations, and 83% suggested that technological tools could facilitate effective information integration.

4.2. Attributes of Information

Logistics integration, trust and collaboration occur in the supply chain as a result of information integration [24]. However, when information exchange is not quite streamlined, supply chains experience uncertainty [64]. The absence of efficient information integration has been proven to cause several drawbacks in literature, including fragmentation, distrust and scepticism in supply chains [65]. Essential qualities of information affecting information integration are transparency, traceability and security [10,13,21]. Information transparency is interpreted as a decrease in the level of uncertainty or a reduction in the expectation heterogeneousness amongst the participants in an uncertain circumstance [66]. Transparency is acknowledged to be one of the most critical attributes of information affecting the success of supply chains [13]. In the prefabrication supply chain, transparent information exchange enhances collaboration and trust amongst partner organisations [10]. Traceability is another important quality of information contributing to the enhancement of supply chains. In prefabricated construction projects, where a vast number of materials are used to finalise a project, the characteristic of services and quality of materials give rise to the necessity of developing a traceable information integration system in which all the information regarding the origin of materials can transparently be traced [44].

Moreover, prefabrication is a method of construction aiming to reduce waste materials, energy consumption and carbon emissions by using green products to ensure the preservation of social and environmental elements [1]. These sustainability measures are acquired through mutual learnings from in-development projects. A project's knowledge is primarily made up of the information collated and stored throughout the project, which is practically impossible to condense into words [67]. This kind of knowledge is mostly communicated through person-to-person interactions, where the possibility of forgetting parts of it is high [68]. New IT systems can help capture the knowledge and convert it to data that is easy to be stored [67]. Konukcu [31] states that some of these new IT systems are electronic bulletin boards, decision-making computer systems, web/online databases and knowledge gateways. These systems are being substituted for decentralised systems where information security is assured [19]. The ability to trace the information flow for prefabricated materials used in construction projects ascertains the sustainability metrics and significantly improves clients-customers' views on the genuineness of products, which helps supply chain partners build up better collaborative and trustworthy partnerships [17].

The last information attribute investigated in this study is security. Information security refers to the long-term preservation of the authenticity of records and the integrity of the data [69]. Information communicated in an organisation varies from reports or technical drawings to contracts and statutory documents [70]. These forms of information need a protected information-sharing engine to enable the secure preservation of learnings for future use. Thus, adequate information security systems are required to ensure the safe transition of one project's learnings to the next, assisting the integration in the construction supply chain.

In this study, the questionnaire survey determined to what extent transparency, traceability and security (system reliability) were, respectively, significant to the success of the respondents' organisations. These information qualities were tested using a five-point Likert scale to obtain experts' opinions on the importance and impact of each attribute on the success of the prefabrication supply chain in New Zealand. The result is presented in a clustered bar chart in Figure 3. A high percentage of respondents strongly confirmed that the identified attributes are crucial to the performance of prefabrication supply chain. These three aspects can be connected to the strength of blockchain technology and the benefits it offers for integrating organisational information.

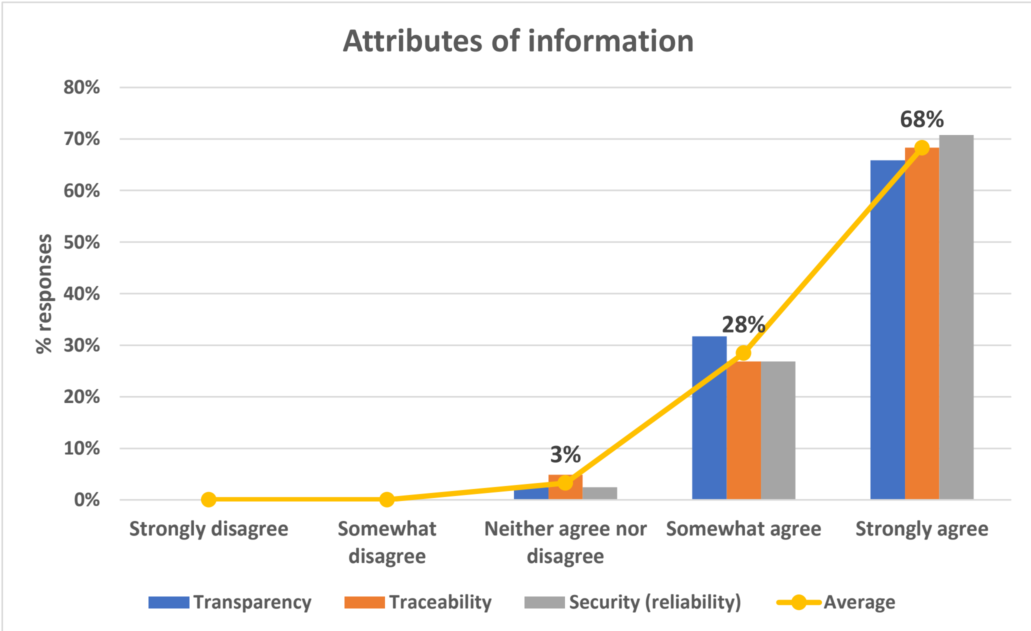

Figure 3. Important attributes of information.

4.3. Blockchain in the Prefabrication Supply Chain

Historically, the construction industry in New Zealand has been primarily based on traditional construction methods [1]. Prefabrication is relatively a newer approach that is becoming more popular, and industry experts are better discovering its benefits. However, the adoption of IT systems is relatively low in the prefabrication sub-sector of New Zealand's construction industry [57]. This is mainly due to the lack of awareness of prefabrication practitioners about the benefits of information technology [37]. Moreover, poor understanding of information integration strategies and lack of technical knowledge or expertise is predominant across supply chain parties [71], inhibiting the effective utilisation of technology, and conceivably, limiting the steps towards supply chain integration.

Information integration has a close relationship with blockchain technology as an enabling mechanism for providing a secure information-sharing database. Researchers have demonstrated that blockchain technology is capable of storing a wide variety of data or information such as sustainable building construction/design data, building performance information and equipment records [62]. Similarly, they have confirmed that data/documents in various formats, e.g., images, models, drawings and videos, can be uploaded and saved on blockchain [72,73]. Thus, the information of all transactions (such as manuals, handbooks, standards, specifications and regulatory compliance certificates) from different stakeholders in supply chains can be recorded and tracked on blockchain [10,62]. This information integration will bring many benefits to the construction sector, including reduced fragmentation of supply chain partners, enhanced scalability, reduced time/cost, high transparency, traceability and data security.

Blockchain's central novelty lies in its capacity to authorise, distribute and record transactions in unalterable registers. For blockchain to obtain ubiquitous popularity in prefabrication, it should address some of the fundamental challenges in this sub-sector, such as fragmentation, deficient quality products, security of information, bureaucracy, lack of trust leading to disputes and transparency [17].

The fragmentation of prefabrication construction needs enhanced integration in the supply chain for effective performance [24]. From a wider perspective, the structure and governance of supply chains in the construction industry as well as trust, which is the underlying factor for fragmentation [74], is highly affected by integration and innovation across supply chain actors [10]. Blockchain's contributing characteristics, namely, transparency, traceability and security/immutability, have the innovative potential to introduce better integration and make a bridge between traditional and technological practices within the construction industry, allowing the industry to efficiently promote trust and reduce resources and administration costs, durations and disputes. Moreover, from the governmental perspective, blockchain can provide the same services offered by statutory authorities and the corresponding private sectors in a decentralised and automated manner whilst preserving the same validity [75]. Examples of such services in the construction industry are Engineering Plan Approvals (EPAs), resource consents and Construction Compliance Certificates (CCCs), which are all deemed bureaucratic and time-consuming processes in the New Zealand context.

Whilst New Zealand's government has strict border control measures and import/export regulations, the number of counterfeit products imported into New Zealand is of major concern. A study by Building Research Association New Zealand (BRANZ) revealed that most construction products are often tested and certified overseas before being shipped to New Zealand, and problems with these products may take many years to emerge, and by the time that the issues arise, the suppliers of products may no longer exist in the market [76]. Therefore, prefabrication supply chain organisations rely on suppliers/manufacturers products specifications to satisfy the Building Consent Authorities (BCAs) as well as their customers that the products used in their projects comply with regulatory requirements and are fit for the purpose.

Blockchain can play a significant role in the transmission of quality assurance and certification information. The traceability function of blockchain can allow New Zealand's prefabrication supply chain organisations to conduct their products testing and shipment tracking in a real-time and consensus-based manner. This, in return, increases the visibility and control over the history of products from their origin to their final location. Moreover, instead of having the source of technical information generated by the supplier company and uploaded to their company website for tracking, all partner organisations can simultaneously trace and verify the provenance of information in a flexible fashion. Enhanced visibility and control associated with this flexibility lead to better trust and transparency between organisations involved in the project.

Nevertheless, there are some challenges towards the practical implementation of blockchain technology in the prefabrication supply chain. Energy consumption is deemed as one of the biggest concerns associated with blockchain's requirement of electricity usage for its computational process [16]. Legal matters such as ownership rights, standardisation, corruption and risk allocation are also other types of concerns attributed to blockchain where the intervention of centralised legal authorities is limited [44]. Readiness of industry experts, lack of skilled blockchain professionals, technological status-quo of the construction industry and the cost of change are some other challenges towards the adoption of blockchain technology [15,44,62]. As blockchain grows and matures, different aspects of using this technology will be discovered, and its potential opportunities/risks can be practically examined.

5. Conclusions

The construction supply chain is viewed as a network/system of activities providing value and services to stakeholders [77]. This value-generating network inherently confronts many challenges and complexities, reducing collaboration and growth opportunities [78]. Modern prefabrication practices appear to have resolved the majority of concerns associated with traditional construction regarding economic, social and environmental limitations. However, little attention has been given to the integration of information, which is a significant driver of supply chain integration, in this subset of the construction industry [4]. In an integrated supply chain, information is traded swiftly and securely amongst the stakeholders without alterations [10]. The prefabrication supply chain can gain benefits from the transparency and visibility connected to information integration.

New Zealand is confronting a lack of affordable housing, high resource and material cost, defects and low-quality products and lack of integration amongst the supply chain partners [20,36,76]. Adopting information technology (in general) and information integration mechanisms (in particular) have been the primary focus of studies targeting the increase of efficiency and performance of supply chains [21,43,47]. However, blockchain technology has not been viewed as a feasible option yet.

As an innovative information integration instrument, blockchain technology has the potential to enhance supply chain structures by ensuring traceability, transparency and security [17]. New Zealand's prefabrication industry can benefit from adopting this technology for improving the transparency of information exchange, traceability of construction products' provenance and protecting technical information while allowing visibility for partner organisations' analyses. Exploring communication channels between prefabrication organisations is a starting point for assessing the impact of blockchain technology on the supply chain integration.

This study identifies information sharing channels between clients and contractors and contends the strength of blockchain technology in New Zealand's prefabrication supply chain. By adopting a questionnaire survey as the data collection tool, several communication platforms for transmitting information inter-organisationally between prefabrication clients and contractors in detailed design, construction and handover phases of projects were identified. Then, the importance of the critical attributes of information needed for the success of the prefabrication supply chain was verified. Finally, the significance of adopting blockchain technology, an effective information integration tool, in place of traditional communication methods was explored.

The results demonstrated that traceability, transparency and security of information exchange across organisations are of great importance and blockchain technology has the potential to improve integration in prefabrication projects by fostering collaboration and trust amongst partner organisations. The findings provide an understanding of blockchain technology and prefabricated supply chain integration, which will assist stakeholders in enhancing their managerial decisions and supply chain strategies. Industry experts and managers could use the result of this study for understanding the essential attributes of information and current communication practices dominant in the prefabrication supply chains. Moreover, the impact of blockchain technology on the prefabrication supply chain in New Zealand, as described in this paper, can be understood. Future research will be conducted on providing a practical framework for employing blockchain technology as a means of information integration and, therefore, supply chain integration for New Zealand's prefabrication industry.

Data was collected from the experts within a specified time frame, which limits the extensive findings of this study. The low response rate of the questionnaire survey is acknowledged, which is a result of the small-sized prefabrication sub-sector of New Zealand's construction industry and the lack of industry professionals' knowledge on the topic. The majority of the participants had limited knowledge of blockchain technology or had not practically used it as an instrument in their professional practices. The findings of this research can feed into the prefabrication supply chain frameworks developed by other researchers. As blockchain technology evolves and becomes widely accepted, stakeholders' outlook on the blockchain or similar cutting-edge information technology systems can be improved.

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References

1. Shahzad, W. Comparative Analysis of the Productivity Levels Achieved through the Use of Panelised Prefabrication Technology with Those of Traditional Building System. Doctoral Dissertation, Massey University, Albany, New Zealand, 2016.
2. Bell, P. *Levers for Prefab*; PrefabNZ: Wellington, New Zealand, 2015; pp. 3–5.
3. Samarasinghe, A.; Tookey, J.; Rotimi, J. Supply chain collaboration in New Zealand house construction. In Proceedings of the 38th AUBEA, Auckland, New Zealand, 20–22 November 2013; pp. 11–22.
4. Shahzad, W.; Mbachu, J.; Domingo, N. Marginal Productivity Gained through Prefabrication: Case Studies of Building Projects in Auckland. *J. Build.* **2015**, *5*, 196–208. [CrossRef]
5. Jaillon, L.; Poon, C.S. Design issues of using prefabrication in Hong Kong building construction. *Constr. Manag. Econ.* **2010**, *28*, 1025–1042. [CrossRef]
6. Zhai, X.; Reed, R.; Mills, A. Factors impeding the offsite production of housing construction in China: An investigation of current practice. *Constr. Manag. Econ.* **2013**, *32*, 40–52. [CrossRef]
7. Prajogo, D.; Olhager, J. Supply chain integration and performance: The effects of long-term relationships, information technology and sharing, and logistics integration. *Int. J. Prod. Econ.* **2012**, *135*, 514–522. [CrossRef]
8. Power, D. Supply chain management integration and implementation: A literature review. *Supply Chain Manag. Int. J.* **2005**, *10*, 252–263. [CrossRef]
9. 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]
10. Wang, Z.; Wang, T.; Hu, H.; Gong, J.; Ren, X.; Xiao, Q. Blockchain-based framework for improving supply chain traceability and information sharing in precast construction. *Autom. Constr.* **2020**, *111*, 103063. [CrossRef]
11. Li, X.; Shen, G.Q.; Wu, P.; Yue, T. Integrating building information modeling and prefabrication housing production. *Autom. Constr.* **2019**, *100*, 46–60. [CrossRef]
12. Cai, S.; Jun, M.; Yang, Z. Implementing supply chain information integration in China: The role of institutional forces and trust. *J. Oper. Manag.* **2010**, *28*, 257–268. [CrossRef]
13. Čuš-Babič, N.; Rebolj, D.; Nekrep-Perc, M.; Podbreznik, P. Supply-chain transparency within industrialized construction projects. *Comput. Ind.* **2014**, *65*, 345–353. [CrossRef]
14. Bankvall, L.; Bygballe, L.E.; Dubois, A.; Jahre, M. Interdependence in supply chains and projects in construction. *Supply Chain Manag.* **2010**, *15*, 385–393. [CrossRef]
15. Casino, F.; Dasaklis, T.K.; Patsakis, C. A systematic literature review of blockchain-based applications: Current status, classification and open issues. *Telemat. Inform.* **2018**, *36*, 55–81. [CrossRef]
16. Li, J.; Greenwood, D.; Kassem, M. Blockchain in the built environment: Analysing current applications and developing an emergent framework. In Proceedings of the Creative Construction Conference 2018, Ljubljana, Slovenia, 30 June–3 July 2018; pp. 59–66.
17. Li, J.; Greenwood, D.; Kassem, M. Blockchain in the built environment and construction industry: A systematic review, conceptual models and practical use cases. *Autom. Constr.* **2019**, *102*, 288–307. [CrossRef]
18. Wang, J.; Wu, P.; Wang, X.; Shou, W. The outlook of blockchain technology for construction engineering management. *Front. Eng. Manag.* **2017**, *4*, 67–75. [CrossRef]

19. Li, Z. Toward open manufacturing. *Ind. Manag. Data Syst.* **2018**, *118*, 303–320. [CrossRef]
20. PrefabNZ. *Good Offsite Guide*; PrefabNZ: Wellington, New Zealand, 2018; pp. 9–14.
21. Bakhtiarizadeh, E.; Shahzad, W.; Rotimi, O.B.J. A process map for supply chain relationships in prefabricated construction. In Proceedings of the 43rd AUBEA Conference, Noosa, Austrailia, 6–8 November 2019; pp. 112–123.
22. Chowdhury, M.J.M.; Colman, A.; Kabir, M.A.; Han, J.; Sarda, P. Blockchain Versus Database: A Critical Analysis. In Proceedings of the 2018 17th IEEE International Conference On Trust, Security and Privacy in Computing and Communications/12th IEEE International Conference on Big Data Science and Engineering (TrustCom/BigDataSE), New York, NY, USA, 1–3 August 2018; pp. 1348–1353.
23. Kadefors, A. Client-contractor relations: How fairness considerations and interests influence contractor variation negotiations. In Proceedings of the IGLC, Berkeley, CA, USA, 26–28 July 1999; pp. 231–240.
24. Jagtap, M.; Kamble, S. The effect of the client–contractor relationship on project performance. *Int. J. Prod. Perform. Manag.* **2020**, *69*, 541–558. [CrossRef]
25. 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*, 05020001–05020015. [CrossRef]
26. Christopher, M. Logistics and Supply Chain Management: Strategies for Reducing Costs and Improving Services. *J. Oper. Res. Soc.* **1994**, *45*, 1341.
27. Moon, S.A.; Kim, D.J. Systems thinking ability for supply chain management. *Supply Chain Manag.* **2005**, *10*, 394–401. [CrossRef]
28. Papadonikolaki, E.; Vrijhoef, R.; Wamelink, H. The interdependences of BIM and supply chain partnering: Empirical explorations. *Archit. Eng. Design Manag.* **2016**, *12*, 476–494. [CrossRef]
29. 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]
30. Gibb, A.; Isack, F. Re-engineering through pre-assembly: Client expectations and drivers. *Build. Res. Inf.* **2010**, *31*, 146–160. [CrossRef]
31. Konukcu, S. A Knowledge Chain Framework for Construction Supply Chains. Doctoral Dissertation, Loughborough University, Leicestershire, UK, 2011.
32. Zhai, Y.; Zhong, R.Y.; Li, Z.; Huang, G. Production lead-time hedging and coordination in prefabricated construction supply chain management. *Int. J. Prod. Res.* **2016**, *55*, 3984–4002. [CrossRef]
33. Gibb, A.G. *Off-Site Fabrication: Prefabrication, Pre-Assembly and Modularisation*; John Wiley & Sons: Hoboken, NJ, USA, 1999.
34. Kaufmann, M.; Remick, C. *Prefab Green*, 1st ed.; Gibbs Smith: Layton, UT, USA, 2009; p. 176.
35. Gordon, G.; Curtis, M. *Building-Quality Issues: A Literature Review*; SR375; Building Research Association of New Zealand (BRANZ): Wellington, New Zealand, 2018; pp. 12–13.
36. Shahzad, W.M.; Hassan, A.; Rotimi, J.O.B. The challenges of land development for housing provision in New Zealand. *J. Hous. Built Environ.* **2021**, 1–19. [CrossRef]
37. Burgess, J.C.; Buckett, N.R.; Page, I.C. *Prefabrication Impacts in the New Zealand Construction Industry*; SR279; Building Research Association of New Zealand (BRANZ): Wellington, New Zealand, 2013; pp. 41–45.
38. Blismas, N.G.; Pendlebury, M.; Gibb, A.; Pasquire, C. Constraints to the Use of Off-site Production on Construction Projects. *Archit. Eng. Design Manag.* **2005**, *1*, 153–162. [CrossRef]
39. Shojaei, A. Exploring applications of blockchain technology in the construction industry. In Proceedings of the International Structural Engineering and Construction, Chicago, IL, USA, 20–25 May 2019; pp. 1–7.
40. Bell, P. Kiwi Prefab: Prefabricated Housing in New Zealand: An Historical and Contemporary Overview with Recommendations for the Future. Master's Thesis, Victoria University of Wellington, Wellington, New Zealand, 2009.
41. Handfield, R.B.; Bechtel, C. The role of trust and relationship structure in improving supply chain responsiveness. *Ind. Mark. Manag.* **2002**, *31*, 367–382. [CrossRef]
42. Höök, M. Customer value in lean prefabrication of housing considering both construction and manufacturing. In Proceedings of the Annual Conference of the International Group for Lean Construction, Santiago, Chile, 25–27 July 2006; pp. 583–594.
43. Darlow, G.; Rotimi, J.O.B.; Shahzad, W.M. Automation in New Zealand's offsite construction (OSC): A status update. *Built Environ. Proj. Asset Manag.* **2021**. ahead of print. [CrossRef]
44. Saberi, S.; Kouhizadeh, M.; Sarkis, J.; Shen, L. Blockchain technology and its relationships to sustainable supply chain management. *Int. J. Prod. Res.* **2018**, *57*, 2117–2135. [CrossRef]
45. Papetti, A.; Marconi, M.; Rossi, M.; Germani, M. Web-based platform for eco-sustainable supply chain management. *Sustain. Prod. Consum.* **2019**, *17*, 215–228. [CrossRef]
46. Xing, K.; Qian, W.; Zaman, A.U. Development of a cloud-based platform for footprint assessment in green supply chain management. *J. Clean. Prod.* **2016**, *139*, 191–203. [CrossRef]
47. Sundram Veera Pandiyan, K.; Bahrin Atikah, S.; Abdul Munir Zarina, B.; Zolait Ali, H. The effect of supply chain information management and information system infrastructure: The mediating role of supply chain integration towards manufacturing performance in Malaysia. *J. Enterp. Inf. Manag.* **2018**, *31*, 751–770. [CrossRef]
48. Chou, D.C.; Tan, X.; Yen, D.C. Web technology and supply chain management. *Inf. Manag. Comput. Secur.* **2004**, *12*, 338–349. [CrossRef]

49. Tse, D.; Zhang, B.; Yang, Y.; Cheng, C.; Mu, H. Blockchain application in food supply information security. In Proceedings of the 2017 IEEE International Conference on Industrial Engineering and Engineering Management (IEEM), Singapore, 10–13 December 2017; pp. 1357–1361.
50. Zhao, J.L.; Fan, S.; Yan, J. Overview of business innovations and research opportunities in blockchain and introduction to the special issue. *Financ. Innov.* **2016**, *2*, 28. [CrossRef]
51. Lu, Q.; Xu, X. Adaptable Blockchain-Based Systems: A Case Study for Product Traceability. *IEEE Softw.* **2017**, *34*, 21–27. [CrossRef]
52. Black, C.; Akintoye, A.; Fitzgerald, E. An analysis of success factors and benefits of partnering in construction. *Int. J. Proj. Manag.* **2000**, *18*, 423–434. [CrossRef]
53. Ghaljaie, F.; Naderifar, M.; Goli, H. Snowball sampling: A purposeful method of sampling in qualitative research. *Strides Dev. Med. Educ.* **2017**, *14*. [CrossRef]
54. Walliman, N. *Research Methods: The Basics*, 2nd ed.; Routledge: London, UK, 2017; p. 208.
55. Bell, E.; Bryman, A.; Harley, B. *Business Research Methods*, 5th ed.; Oxford University Press: Oxford, UK, 2019; p. 642.
56. Saunders, M.; Lewis, P.; Thornhill, A. *Research Methods for Business Students*, 5th ed.; Pearson Education India: Edinburgh, UK, 2009; p. 872.
57. Shahzad, W.M.; Mbachu, J. Prefabrication as an onsite productivity enhancer: Analysis of impact levels of the underlying constraints and improvement measures in New Zealand construction industry. *Int. J. Proj. Organ. Manag.* **2013**, *5*, 334–354. [CrossRef]
58. Briscoe, G.; Dainty, A.R.J.; Millett, S. Construction supply chain partnerships: Skills, knowledge and attitudinal requirements. *Eur. J. Purch. Supply Manag.* **2001**, *7*, 243–255. [CrossRef]
59. Achar, M.; Chebii, P.; Mugo, J. The Role of Communication Channels on Implementation of Housing Construction Projects in Nairobi County, Kenya. *Afr. J. Educ. Sci. Technol.* **2021**, *6*, 265–281.
60. Lee, K.; Lim, C. Technological regimes, catching-up and leapfrogging: Findings from the Korean industries. *Res. Policy* **2001**, *30*, 459–483. [CrossRef]
61. Costa, A.A.; Tavares, L.V. Social e-business and the Satellite Network model: Innovative concepts to improve collaboration in construction. *Autom. Constr.* **2012**, *22*, 387–397. [CrossRef]
62. Yang, R.; Wakefield, R.; Lyu, S.; Jayasuriya, S.; Han, F.; Yi, X.; Yang, X.; Amarasinghe, G.; Chen, S. Public and private blockchain in construction business process and information integration. *Autom. Constr.* **2020**, *118*, 103276. [CrossRef]
63. Evborokhai, M.; Shittu, A. Assessment of Communication Channels in Use by Professionals on Construction Projects in Abuja, Nigeria. In Proceedings of the 5th Research Conference of the NIQS (RECON 5), Minna, Nigeria, 9–10 November 2020; pp. 467–480.
64. Zhou, H.; Benton, W.C., Jr. Supply chain practice and information sharing. *J. Oper. Manag.* **2007**, *25*, 1348–1365. [CrossRef]
65. Awasthi, A.; Grzybowska, K. Barriers of the Supply Chain Integration Process. In *Logistics Operations, Supply Chain Management and Sustainability*; Golinska, P., Ed.; Springer International Publishing: Cham, Switzerland, 2014; pp. 15–30.
66. Angeletos, G.-M.; Pavan, A. Transparency of information and coordination in economies with investment complementarities. *J. Am. Econ. Rev.* **2004**, *94*, 91–98. [CrossRef]
67. Kazi, A.S. *Knowledge Management in the Construction Industry: A Socio-Technical Perspective*; Khosrow-Pour, M., Ed.; IG Global: Greenville, SC, USA, 2005; p. 384.
68. Zhang, C.; Xiao, H.; Gursoy, D.; Rao, Y. Tacit knowledge spillover and sustainability in destination development. *J. Sustain. Tour.* **2015**, *23*, 1029–1048. [CrossRef]
69. Lemieux Victoria, L. Trusting records: Is Blockchain technology the answer? *Rec. Manag. J.* **2016**, *26*, 110–139. [CrossRef]
70. Sahin, F.; Robinson, E.P. Flow coordination and information sharing in supply chains: Review, implications, and directions for future research. *Decis. Sci.* **2002**, *33*, 505–536. [CrossRef]
71. Harland, C.M.; Caldwell, N.D.; Powell, P.; Zheng, J. Barriers to supply chain information integration: SMEs adrift of eLands. *J. Oper. Manag.* **2007**, *25*, 1234–1254. [CrossRef]
72. Devine, P. Blockchain learning: Can crypto-currency methods be appropriated to enhance online learning? In Proceedings of the ALT Online Winter Conference, Online, 7–10 December 2015; pp. 1–7.
73. Chen, S.; Wang, H.; Zhang, L.-J. Blockchain-ICBC 2018. In Proceedings of the First International Conference on the Services Conference Federation, Seattle, WA, USA, 25–30 June 2018.
74. Cheng, J.C.P.; Law, K.H.; Bjornsson, H.; Jones, A.; Sriram, R. A service oriented framework for construction supply chain integration. *Autom. Constr.* **2010**, *19*, 245–260. [CrossRef]
75. Tezel, A.; Febrero, P.; Papadonikolaki, E.; Yitmen, I. Insights into Blockchain Implementation in Construction: Models for Supply Chain Management. *J. Manag. Eng.* **2021**, *37*, 04021038. [CrossRef]
76. Allison, N.; Warren, M. *Applying Blockchain to Product Compliance and Assurance in the Construction Industry*; ER042; BRANZ: Porirua, New Zealand, 2019.
77. Mentzer, J.T.; DeWitt, W.; Keebler, J.S.; Min, S.; Nix, N.W.; Smith, C.D.; Zacharia, Z.G. Defining supply chain management. *J. Bus. Logist.* **2001**, *22*, 1–25. [CrossRef]
78. Bidabadi Zahra, T.; Hosseinalipour, M.; Hamidizadeh Mohammad, R.; Mohebifar, A. Supply chain collaboration within the Iranian construction industry. *Organ. Technol. Manag. Constr. Int. J.* **2016**, *8*, 1437–1445. [CrossRef]