Causes of Delay in Smart and Complex Construction Projects

Kambiz Radman[1]; Mostafa Babaeian Jelodar, Ph.D.[2]; Eghbal Ghazizadeh, Ph.D.[3]; and Suzanne Wilkinson[4]

Abstract: From the economic value and contribution point of view to gross domestic product (GDP), it is highly important to find efficiency through new technology and digital tools as modern practices in the New Zealand construction industry. This requires coordinated efforts and greater alignment in using technology and information technology (IT) infrastructure provisions in complex and smart construction projects and operations. However, construction projects experience indicates delays as a recurring issue that requires constant assessing of these delays' causes and impact. Many delay analysis methods and causal factors are being recognized, but none has considered whether information and communications technology (ICT) infrastructure such as software and smart platforms affect these delay causes and events. This paper aims to identify and rank the causes of delay, which happened through using software and ICT platforms in smart and complex construction projects in New Zealand. Initially, the delay causes were classified, and 15 executed smart construction projects were identified and studied. The projects were selected based on purposive sampling from the different contracting organizations. Accordingly, the project managers and engineers involved participated in a survey on the actual delay causes in these projects. This study utilized the correlation coefficient and ranking of relative importance index (RII) to prioritize the causes of delay. The result presented a list of 20 factors in three classes of design/engineering (DE), client (CL), and contractor (CO). The results revealed that issues such as retrieving information, gathering and screening real-time data on the site, and lack of multicommunication channels between parties and stages (pre- and postconstruction) could be significant causes of delay in smart projects with the expansion of smart tools and techniques in construction. Meanwhile, consents and ethics can potentially become another potential cause of delay, which requires further attention. **DOI: 10.1061/(ASCE)LA.1943-4170.0000501.** © *2021 American Society of Civil Engineers.*

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Introduction

Often in construction projects, uncertain and uncontrolled events caused delay situations deemed an inevitable part of these projects. Lost productivity, increased costs, termination, extension of time, and acceleration are critical impacts of delay in the construction area (Shahinmoghadam and Motamedi 2021). All involved parties are responsible for recovering significant delay impacts such as time, cost within the project, and some force majeure and nonhuman intervention causing unforeseen conditions. Most of the time, the delay process is complicated because many root causes might contribute to the formation of other delays (Wu and Liu 2019).

On the other side, construction projects are developing very quickly, and computer aid in construction areas that initially started by drawing tools such as computer-aided design (CAD) has been growing and deploying to three- and four-dimensional (3D and 4D) programs such as Revit. Concurrently, scheduling and budgeting software such as Primavera and Microsoft Project have been essential parts of construction projects. The application of Internet of Things (IoT) and digital transformation in safety, real-time supply chain, and project management are also some of the remarkable growth of technology throughout the construction environment (Al-Saeed et al. 2019).

Smarter construction processes need intelligent tools and processing power, and research has shown that artificial intelligence (AI) and business intelligence (BI) will be making a significant revolution in the digitalization approach (Lee and Yu 2012). For instance, a hot topic in the field is a visualization of construction projects to detect clashes; it is estimated to reduce reworking in preconstruction and construction phases by 65% on average (Lee and Yu 2012). Project analysts can provide schedule analysis with the critical path method (CPM) to utilize float consumption, critical effects, and lost opportunities as a useful tool to evaluate the impact of delays; this can be integrated with other tools such as Primavera and Microsoft Project as well as building information management (BIM).

In terms of the state of the national knowledge report, implementing technological approaches captures barriers such as financial risk, technology adaptation by industries, succession planning, cultural complexity, and risk of being rejected by workers (National-Science-Challenge-Report 2017). Furthermore, a combination of the smart concept with construction is vital for the growth of urban areas to enhance the capability of the sector for New Zealand's future population growth in these areas. Projections to 2043 show the main cities' population will increase rapidly, so 75% of the growth of

[1]Ph.D. Student, School of Built Environment, Massey Univ., Albany Campus, Auckland 0632, New Zealand (corresponding author). ORCID: https://orcid.org/0000-0001-6905-5817. Email: k.radman@massey.ac.nz

[2]Senior Lecturer, School of Built Environment, Massey Univ., Auckland 0632, New Zealand. ORCID: https://orcid.org/0000-0003-1956-7384. Email: M.B.Jelodar@massey.ac.nz

[3]Lecturer, School of Computer and Mathematical Sciences and Computer Science, Auckland Univ. of Technology, Auckland 0632, New Zealand. Email: eghbal.ghazi@aut.ac.nz

[4]Professor, School of Built Environment, Massey Univ., Auckland 0632, New Zealand. Email: S.Wilkinson@massey.ac.nz

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New Zealand's total working-age population would be over the next 30 years (National-Science-Challenge-Report 2017). Therefore, information technology (IT)–based infrastructures (software, applications, devices) are being utilized to manage projects for changes, delays, and variations that may occur. Nevertheless, this research contrasted the mentioned approaches and technologies with their failure in delays from technologically or managing points of view (MBIE 2017).

PricewaterhouseCoopers (PWC) reported that the construction sector had delivered almost as much of New Zealand's gross domestic product (GDP) only in the Auckland region, and this contribution is rapidly growing. As the core industry in New Zealand, the construction sector has had more than 19% GDP growth, overtaking wholesale trade-off in the top five of the most significant contributing sectors to GDP. Furthermore, the construction industry has supported the highest job ranking in the industry and related activities contribute one out of every five new jobs in New Zealand. For example, between 2012 and 2017, construction provided around 330 new jobs (BRANZ 2016; Stats NZ 2020).

The study aims to develop a framework to classify and prioritize key delay elements in modern smart and complex construction projects in New Zealand.

The study will focus on a megaproject where modern tools and smart systems are utilized to manage and monitor the construction project. The framework will be tested with actual data acquired from systems applied in these complex construction projects.

Background

The Project Management Institute (PMI) has proposed a relatively recent definition of *project* that should be inclusive and exclusive. *Inclusive* means it should not be possible to identify any undertaking generally thought of as a project that does not fit the definition. In contrast, *exclusive* points out that it should not be possible to describe any undertaking that satisfies the definition and is not generally thought of as a project (Craig and Sommerville 2006).

According to the project concept defined by PMI, a construction project (e.g., residential, commercial, industrial, and heavy) is essentially a temporary endeavor with a specified time and cost, initiated to create a unique product, service, or result, and tends to be limited. Furthermore, the involvement of advanced technologies and owner-desired changes makes it even more challenging to keep a project on the scheduled track (Pritchard 2015). Therefore, changes, delays, and variations are common in construction projects. Control measures and management of these events require different strategies as project complexity increases and smart tools and technologies are used.

However, variations such as addition, omission, deletion, or substitution or changes are the nature of projects; even the work scope is initially specified in the contract. Moreover, sometimes variation is referred to as a change. The precise nature of the construction process makes the subject of variations important. Inevitably, because the parties cannot anticipate everything that may happen or where a contract is agreed before the design/scope of works is fully finalized, frequent changes are often required (Tang et al. 2020). Unless a variation is instructed, a contractor is required to follow the works as initially specified; otherwise, it would be in breach of contract (Hwang et al. 2018).

As mentioned, variations are an inevitable aspect of construction projects. Seldom are projects completed without any changes being requested or enforced. Some key steps that ensure variations do not drain the profitability out of a project are listed, such as plan in advance (forecast revenue versus actual revenue) and the importance of comprehensive budgeting at the outset cannot be overstated, check the project key data as often as possible (e.g., labor, material, and installation progress), monitor subcontractor behavior for late costs, and do not presume variations will deliver a profit.

These considerations and measures are required to effectively manage variation orders in construction projects (Ding et al. 2019; Hwang et al. 2018).

Generally, a delay means to be late or behind in movement or progress. The delay implies a holding back, usually by interference, from completion or arrival. For instance, bad weather delaying braking suggests reducing speed without actually stopping (Shahsavand et al. 2018).

In construction, delay can be defined as the extra time required or incurred either beyond the stipulated completion date or beyond the project stakeholders' date to complete the project. In other words, construction delays are considered as the time lag in completion of activities from its specified time as per the contract or can be defined as late completion or late start of activities to the baseline schedule, directly affecting specified cost (Yap et al. 2017).

Furthermore, some key recognized reasons could delay a project, such as a change in project scope, project complexity, inadequate planning, design variation, inaccurate engineering estimate, inefficient technological tools, payment methods, lack of or less communication among parties, and weather, strikes, and governmental or owner interference (Bucchiarone et al. 2019). As a result, there will be extensions of time required, resulting in subtly increased cost due to inflation, termination of the contract, court cases, or combinations of these factors, resulting in delay damages. The larger the scale of projects, the more severe these issues; therefore, large-scale management with higher-value investment requires more intense monitoring and modern tools for delay control.

Ultimately, large-scale projects comprise complexity and value more than $1 billion, and substantial completion takes longer to develop. These projects have multiple public and/or private stakeholders who are impacted by and/or impact many people, and they are closely related to high-tech requirements, critical attributes as same as multidisciplinary construction projects (Construction Leadership, UK Council 2018; Niu et al. 2016).

Smart construction is building design, construction, and operation that, through collaborative partnerships, uses digital technologies and industrialized manufacturing techniques to improve productivity, minimize whole life cost, improve sustainability, and maximize user benefits. This way of working can transform the construction industry and maximize the benefits of projects for the occupants and provide them with a better quality of life. Furthermore, smart construction is defined as using IoT and information and communications technology (ICT) approaches to support the realization and management of dynamic and adaptable applications specifically suitable for construction sites (Bucchiarone et al. 2019; Construction Leadership, UK Council 2018).

Moreover, the literature investigation shows that no research has been undertaken into smart construction projects. This study reviewed 50 construction delay and technology studies to bridge this gap, such as cyber-physical systems (CPSs), BIM, big data, cloud computing, and Microsoft Project and Primavera literature into the construction process (Anumba et al. 2020; Fabiano and Maciel 2018). From a technologist point of view, technological infrastructure in the construction area must mitigate many of the critical challenges. It means that frequent changes and variations cause remarkable delay challenges during the project life cycle, so they must be identified and prioritised. So, decision-makers can analyse those challenges to optimise risks and increase productivity (e.g., minimising delays) by using appropriate site tools (e.g. software and ICT infrastructure) (Ferrari et al. 2018; Xu et al. 2018; Wu and Liu 2019).

Literature Review

Delay in construction is inevitable and a well-established topic of discussion among many researchers (Bajjou and Anas 2018; Basak et al. 2019; Bonga and Wellington 2017; Serdar et al. 2018; Su et al. 2020; Zhao et al. 2019; Zidane and Andersen 2018). In the US, Canada, and Singapore construction industries, especially in managing big projects, assessing time and cost are key points and maintaining high-quality performance is often considered (Barbosa and César 2020; Gholamzadeh et al. 2019; Jergeas 2008; Ramazani and Jergeas 2015).

Studies showed that the main factors, such as financial, complicated planning, inappropriate scheduling, owner change order, and frequent design changes, would cause a significant delay in the construction industry. Improper feasibility study, risk management, budgeting, and time forecasting can cause construction project delays (Zarei et al. 2017; Abbasi et al. 2020). Moreover, studies show that rushing to the execution phase will mean carelessness and less consideration in the planning phase; therefore, some failure factors include: project reworking, frequently re-scheduling, multi-baseline, multiple testing and less configuration management (Camacho et al. 2018). Construction is a high-risk business because schedule management has a high risk for owners and contractors. Losing project task opportunities may incur significant cost on construction projects (Xu et al. 2018; Muizz et al. 2020). Furthermore, focusing on delay causes in the preliminary stage of the design phase revealed that the most important cause of delay is changes in the client's requirement or uncertainty perspective of the project from the client's perspective (Sepasgozar et al. 2019).

According to Serdar and Hosseini (2019), Jalali-Yazdi et al. (2018), and National-Science-Challenge-Report (2014), construction delays frequently occur on projects; however, the governmental and public projects have been experiencing and reporting the worst of these delays and disruptions. About 85% of all construction projects with common problems and causes of delays are those tagged under the government/public sector. Public projects generally follow government management methods, legislation, and policies. Therefore, as a common main problem, significant causes of delay are driven from top to bottom (e.g., from the government to subcontractors).

On the other side, automated progress tracking is used to increase the efficiency and effectiveness of construction monitoring, where reducing traditional time-consuming tracking systems in smart construction areas is critical to construction management (Moselhi et al. 2020). Moreover, construction project management uses modern technologies to monitor and control software (labor) and hardware (plant and material) throughout the project to supervise and track activities and productivities on the site (Amare et al. 2017; Safwan et al. 2014; Khair et al. 2017; Ferrari et al. 2018; Moselhi et al. 2020; Serdar and Hosseini 2019; Muizz et al. 2020; Lee and Yu 2012). As a result, tools or software such as Primavera and Microsoft Project are used to minimize delay through stages of planning, scheduling, and monitoring (Ashwini and Rahul 2014; Elfi et al. 2020; Khair et al. 2017). For modeling, BIM use in construction projects, either pre- or postconstruction, will be increasingly a key factor of success, such as efficiency and quality of construction projects deliverables (Gamil and Ismail 2019).

Generally, the construction sector's acquisition of information is one of the key, and most challenging, steps. Therefore, IoT-based technologies such as BIM, geographic information system (GIS), radio frequency identification (RFID), and combination with scheduling tools are suggested to minimize delay and create a smarter construction setting. It is well documented that decreasing the risk of misunderstanding by clarified data is key to evaluating construction project progress (Alizadehsalehi and Ibrahim 2018; Fan et al. 2020; Haupt et al. 2019; Zeng et al. 2018). Studies show that suitable and adequate devices such as wearable watches, mobiles, drones, laptops, sensors, and cameras might increase the chance of minimizing delay in construction projects (Khair et al. 2017; Zidane and Andersen 2018; Huang et al. 2018). This is because ICT-based technology is being widely used and expanding different construction work aspects (Haupt et al. 2019; Elfi et al. 2020).

The authors analyzed and evaluated relevant and state-of-the-art studies over the past 6 years. The most significant delay factors/criteria have been identified and classified; in addition, the measure and methods recommended and identified for minimizing them have been captured in Table 1.

From Table 1, providing a clear and detailed enough drawing and schedule of quantity (SoQ) earlier, defining an understandable scope of work, proper planning, and scheduling either through software or design tools can be recognized as the root cause of delays that can affect resource, design, and project management stages. In contrast, some research has recommended depth studies to develop combined SoQ methods such as BIM with IoT-based devices, BIM and scheduling, Primavera web-based and Microsoft Project alongside Microsoft Office analytical tools. However, no evidence has dealt with the advantages, requirements, and disadvantages of developing methods. In this study, two main criteria of minimizing delay factors in construction areas have been selected through literature reviews from the contractor's perspective. The first is a technology and the second is technical and management skills. All factors comprise a different type of construction project that belongs to either private or governmental projects. Finally, those factors have been applied and assessed in smart construction projects. The role of using technology and management skills in orchestrating delay management into a smart construction project is divided into the construction and preconstruction phases.

Research Methodology and Data Collection

To further explore delays in smart and complex construction projects, mega construction projects were selected as the focus of this study. The selection of these projects was based on the smart systems and technologies they use for multiple purposes. They have ICT-based systems, methods, and techniques within their construction practice to collaborate with involved parties such as design, contractor, and subcontractor from preconstruction to practical completion stages for sharing their information and experience.

The current study's research methodology includes five steps: (1) identifying and choosing relevant causes of delay with significant effects; (2) using purposive sampling (emphasis on similarity); (3) assessing the established facilitated workshops; (4) comparing approach through correlation coefficient; and (5) analyzing data in conjunction with causes and effects of delay through a relative importance index (RII) (Khatib et al. 2020; Gebrehiwet and Hanbin 2017).

For determining the current study's data collection, three facilitated workshops were performed. The respondents were chosen among experienced construction experts who were representatives of companies involved in pre- and postconstruction project phases in New Zealand. All these companies were involved in applying smart methods of construction and digital tools. The selection criteria were based on smart construction involvement:

- Auckland Waikato region–based projects.
- ICT infrastructure–based projects such as Microsoft Project or Primavera for scheduling and project control, SiteDocs

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Table 1. Delay factors and methods grouped into five classes

Class	Method for minimizing
Schedule management	• Specification of a realistic duration to execute the project (Safapour and Kermanshachi 2019; Sacks et al. 2010; Shuquan et al. 2020; Abbasi et al. 2020) • Proper planning and scheduling (Jalali-Yazdi et al. 2018; Camacho et al. 2018; Zarei et al. 2017) • Case studies in Hong Kong construction projects and the Malaysian construction industry (Mrugenkumar and Bankim 2020)
Monitor and control management	• Obtaining the required approvals of the project from authorities (Khair et al. 2017; Gholamzadeh et al. 2019; Su et al. 2020; Berlinda et al. 2017) • Development of an exemplary system for site management and supervision (Goutom et al. 2019; Fallahnejad 2013; Eadie et al. 2013; Basak et al. 2019; Bajjou and Anas 2018; Abdullah et al. 2018) • Case studies in Nigerian construction projects and building construction projects in Egypt (Arditi et al. 2017)
Administration	• Construction management companies to help minimize delays or their impacts (Fan et al. 2020; Ferrari et al. 2018; Huang et al. 2018; Newsham et al. 2017) • Joint efforts of participants in the construction (Abbasi et al. 2020) • Site conditions must be improved (Jalali-Yazdi et al. 2018; Syed et al. 2018)
Resource management (e.g., financial, software, and hardware)	• Payment to the contractor on time for the work being carried and finished based on contract (Heap-Yih and Diamantopoulos 2020; Purba and Prastowo 2020) • Ensure adequate and available source of finance (Gholamzadeh et al. 2019; Gebrehiwet and Hanbin 2017) • Improving cash flow and plan the cash flow before start project (Kelm et al. 2013; Newsham et al. 2017; Aaron et al. 2015) • Employ employer based on their work/skills speciation in a construction project (Project Management Institute 2017) • Work scope needs to be well defined (Su et al. 2020; Zidane and Andersen 2018; Pritchard 2015; Sievert 1998)
Technical aspects (e.g., engineering and design)	• Prepare an accurate, clear, and adequate detail drawing and bill of quantity (BoQ) (Korzun et al. 2015; Acampora et al. 2013; Barrett and Baldry 2003) • Accurate initial study and design (Mrugenkumar and Bankim 2020; Zeng et al. 2018; Bajjou and Anas 2018; Nazmus et al. 2020)

web-based documentation app, Aconex as a contractual communication channel and documents control, partial BIM for clash detection, and Microsoft Outlook for email and correspondence.

- The data source within construction projects includes correspondence, workflow reports, progress claims report, contracts, timelines and work breakdown structure at medium level, variation, and delay registers.

To organize and establish the facilitated workshops, this study listed all potential companies with the attributes mentioned as the smart construction in New Zealand (Auckland Waikato region). Ultimately, 27 companies were chosen in the Auckland Waikato region due to location and access restriction. These included the main contractor, subcontractor, consultant (design, engineering), or companies with multiple roles. All 27 companies were contacted and invited to participate in this research: four did not respond, three project managers and two companies were unwilling to collaborate, and the rest initially agreed to participate in the facilitated workshops. Finally, 15 of the original 27 participated.

The respondents' feedback was collected through the mentioned facilitated workshops (e.g., focus groups), where existing applications, tools, and methodologies used in their projects were discussed and documented. Furthermore, all processes of the facilitated workshops were clearly explained and managed for every participant involved in the data collection process such as setting a clear goal, defining the purpose, sharing an agenda, understanding ground rules, and collaborating with all people, so that the results could be analyzed from all construction projects expertises' points of view. Finally, based on the literature review and project dossiers, an equitably complete table of delay causes was formed.

To further explore the delay causes and minimization methods identified in Table 2, three facilitated workshops that included project managers, project engineers (from design and construction site), and contract managers were organized. As a result, all of the items in Table 2 were screened and scrutinized and remarkable causes were identified; consequently, some items and details were added, and some were excluded. Accordingly, the RII and the correlation coefficient were used to analyze causes and effects of delay into smart construction projects (Wood 2017; Abdollah and Taghipour 2019; Anumba et al. 2020; Su et al. 2020; Gebrehiwet and Hanbin 2017). Meanwhile, the owners' engineering team and construction supervisors checked the facilitated workshops' results as an audit process.

The literature that has captured the RII and Spearman's rank correlation coefficient for computation and ranking factors used a similar formula. Babar et al. (2020), Basak et al. (2019), Fallahnejad (2013), Huang et al. (2018), Goutom et al. (2019), and Sambasivan and Soon (2007) all used and agreed on the following formula, which is used as the basis of this study too:

$$\mathrm{RII} = \frac{\sum_{k=0}^{n} W_k F_k}{A \times N} \quad \text{and} \quad \mathrm{RII}\epsilon]0,1] \tag{1}$$

where k = class index; W_k = respondents' weight; weight factor F_k = frequency of responses; A = highest weight; and N = total number of respondents. Eq. (1) computes the higher value of RII that presents the important cause or effect of delay using a 5-point Likert scale. The results of the test are presented in Table 3. Therefore, the relationship between variables should be assessed (Baskar et al. 2019; Makowski et al. 2020). Therefore, Eq. (2) is used to compute Spearman's rank correlation coefficient as follows:

$$R = 1 - \frac{6\sum d^2}{n^3 - n} \quad \text{and} \quad R \in [-1, 1] \tag{2}$$

where d = rank difference; n = number of ranks; and $R = 0$ means no correlation. The results of the test are illustrated in Table 4.

Table 2. List of delay coded causes and classes

Class	Cause	Code	ICT view
Design/engineering	1. Frequently variation on drawings	DE1	BIM
	2. Number of nonresponsive requests for information	DE2	Microsoft Project
	3. Waiting time for approval/comments on shop drawings and drawings	DE3	Aconex
	4. Using a different source of information	DE4	Outlook
	5. Cultural diversity between design and client team	DE5	
	6. BIM program is behind project schedule	DE6	
	7. Low experience in using main features of Aconex and BIM	DE7	
	8. Passive meetings (even frequently)	DE8	
Client	9. A load of RFI workflow	CL1	Navisworks Freedom 2020
	10. Technology for getting real-time data from the site	CL2	Primavera (only planner)
	11. Inconsistency among project managers	CL3	Microsoft Project
	12. Using multiple project scheduling softwares (Microsoft Project, Primavera, or Excel)	CL4	(most of the departments)
	13. Lack of coordination skills between various parties working on the project	CL5	Aconex
	14. The delay between what happens on-site and what will return from involved parties	CL6	Outlook
	15. Using BIM, Aconex, Microsoft Project, P6 but no clue of integrity among them	CL7	
	16. Long and mistaken process of assessing progress claim even using Aconex and BIM	CL8	
	17. Low experience in using at least the main features of Aconex and BIM	CL9	
	18. Inconsistency between submitted and assessed progress claims (not integrated database)	CL10	
Contractor	19. No lining-up between contractor and client programs	CO1	Navisworks Freedom 2020
	20. Low experience in using main features of Aconex and BIM	CO2	Microsoft Project
			Aconex
			Outlook

Table 3. Relative importance indexes and rankings

		Preconstruction		Construction		Average	
Classes	Codes	RII	Ranking	RII	Ranking	RII	Ranking
Design/ engineering	DE1	0.18	20	0.21	20	0.195	20
	DE2	0.61	6	0.58	13	0.595	14
	DE3	0.37	19	0.42	19	0.395	19
	DE4	0.7	1	0.65	2	0.675	1
	DE5	0.5	17	0.56	15	0.53	16
	DE6	0.68	3	0.6	11	0.64	4
	DE7	0.62	5	0.57	14	0.595	9
	DE8	0.65	4	0.47	17	0.56	15
Client	CL1	0.5	17	0.45	18	0.475	18
	CL2	0.57	9	0.75	1	0.66	3
	CL3	0.52	14	0.62	7	0.57	12
	CL4	0.6	7	0.62	7	0.61	5
	CL5	0.52	14	0.62	7	0.57	13
	CL6	0.54	13	0.5	16	0.52	17
	CL7	0.69	2	0.64	4	0.665	2
	CL8	0.55	11	0.6	11	0.575	11
	CL9	0.52	14	0.63	6	0.575	10
	CL10	0.59	8	0.62	7	0.605	7
Contractor	CO1	0.57	9	0.64	4	0.605	6
	CO2	0.55	11	0.65	2	0.6	8

Results and Discussion

The results of facilitated workshops were the primary source of data collection. A set of design/engineering, client, contractor, and owner representatives participated in this study to identify the causes of delay in smart construction projects. The participant classes and their identified causes of delays were coded and are summarized in Table 2. A code was assigned to each delay causes, where DE represents design/engineering-related cause, CL is for client-related causes, and CO is for contractor-related causes. Furthermore, the results of the RII analysis are included in Table 3. As mentioned, Eq. (1) is used to scale a value somewhere between $1/X$ and 1, where X is the number of response categories. Therefore, Eq. (2) may also just compute the mean score for each code of Table 3, and that will sort the items from most to least in precisely the same way as would the RII values. For instance, Table 5 illustrates a sample of RII calculation for clause 4.

To present different parties' points of view, the general ranking of the essential factors and classes is extracted and included in Table 4. This table illustrates that causes of delay are not the same

Table 4. General ranking list of essential factors and classes

Code	RII (average)	Ranking in stage		
		General	Construction	Preconstruction
DE4	0.675	1	2	1
CL7	0.665	2	4	2
CL2	0.66	3	1	9
DE6	0.64	4	11	3
CL4	0.61	5	7	7
CO1	0.605	6	7	8
CL10	0.605	6	4	9
CO2	0.6	8	2	11
DE7	0.595	9	13	6
CL9	0.595	9	14	5
CL8	0.575	11	11	11
CL3	0.575	11	6	14
CL5	0.57	13	7	14
DE2	0.57	13	7	14
DE8	0.56	15	17	4
DE5	0.53	16	15	17
CL6	0.52	17	16	13
CL1	0.475	18	18	17
DE3	0.395	19	19	19
DE1	0.195	20	20	20

within different classes and shows the degree of importance of typical causes of delay at each stage of smart construction projects. For instance, retrieving information, gathering and screening real-time data on-site, lacking multicommunication between parties, and crossed functions between parties and stages have been highlighted as critical items of delays.

Table 3 indicates relative importance indexes and rankings through a 5-point of Likert scale ranging from 1 to 5, where 1 is significantly low impact and 5 is a very significant impact to design and structure causes of delay in the smart construction area. Furthermore, by using Eq. (2) and statistical computer-based programming, Tables 6 and 7 present degrees of correlation between classes and stages as well as the degree of agreement between each of the classes, respectively. For instance, from Table 6, the presented values determine that the preconstruction stage has correlated 42% with the contractor's class while the construction stage from the client's point of view has a 97% correlation. In contrast, a 53% correlation between the design/engineering class and the construction stage can be reported. This means that the portion of the collaboration of the contractor in the preconstruction stage is significantly low. Furthermore, Table 7 shows a low degree of correlation between the design/engineering and contractors, indicating that even though the design/engineering class has used high spec tools such as BIM and the combined ones, the correlation between them and contractor class is lower than other classes, e.g., 23%. Significantly, multiple crossed relations between classes need to be paid more attention.

Generally, Tables 3 and 4 illustrate RII calculation results based on Eq. (2), so using high-tech and expensive smart construction tools can be a bottleneck to cause delays, especially if the necessary skills and requirements are not available. This may be because of using a different source of information (more than 67%), lack of integrity information systems (more than 68%), ignoring or less-attending real-time data flowing throughout the site for all parties, insufficient training, or less-skilled employees using critical features of the software and communication devices.

The correlation between client and contractor is more than 83%, potentially signifying knowledge sharing and good communication. However, the contractor and design team struggle to communicate

Table 5. Sample of RII calculation

Cause#	Cause	RII factors					Computed values, given the five frequency entries			
		Frequency of 5 responses (P1)	Frequency of 4 responses (P2)	Frequency of 3 responses (P3)	Frequency of 2 responses (P4)	Frequency of 1 responses (P5)	Total respondents (N)	Weighted total (WT)	RII	Item mean
4	Using different source of information	1	2	5	4	1	= SUM(P1:P2)	$= 5 \times \text{P1} + 4 \times \text{P2} + 3 \times \text{P3} + 2 \times \text{P4} + 1 \times \text{P5}$	$= N/(5 \times \text{WT})$	$= N/\text{WT}$

Table 6. Spearman importance rank correlations between classes and stages

Class/stage	Preconstruction (%)	Construction (%)
Design/engineering	95	53
Client	62	97
Contractor	42	95

Table 7. Spearman importance rank correlations between classes

Class/class	Design/engineering (%)	Client (%)	Contractor (%)
Design/engineering	100	—	—
Client	60	100	—
Contractor	23	83	100

and share the project knowledge mindset, which is demonstrated by the significantly lower correlation of 25%. A big data management circulation gap appears in the project in which the client needs to take on all responsibilities. This research's essential contribution is to perform and recognize the state-of-the-art review and experimental study on the current literature and executed projects categorized in the smart level of the construction industry in New Zealand. Furthermore, the presented method can measure the correlation between variables in large-scale projects where the number of delay factors might be more.

Conclusion

While previous literature has considered the common and general causes of delay, this study introduced a new perspective into delays at the preconstruction and construction stages of smart and complex construction projects. Generally, the effects of delay are dictated on time, cost, and even quality of deliverables in construction areas, but when smarter methods are introduced, the projects are expected to become nimble or at least have much more controllable delays. This study focused on presenting how and why smart construction projects suffer from delays, even using high-tech and smart tools. For instance, retrieving information, gathering and screening real-time data on-site, lacking multicommunication channels between parties, and crossed functions between parties and stages have been highlighted as critical items of delays. This study classified the leading significant causes and effects of delays in smart construction projects in New Zealand; the results can be considered in other industries or locations with the same features and attributes. The causes of delay have been categorized into three classes: design/engineering, client, and contractor, where coded with 20 causes.

Also, the RII and Spearman's rank correlation coefficient were used to prioritize the causes of identified delay. RII also presented the acute effects of delay investigated, retrieved information gathered and real-time data screened on-site, and lack of multicommunication channels between parties and stages (pre- and postconstruction) as the most severe causes. In other words, the lack of an integrity system between the used technological tools and encountering different data sources illustrates a 70% impact on project delay. Moreover, the correlation between the contractor and design team decreased dramatically to less than 25%, while the correlation between the main contract, client, and design is reasonable, 60%. In contrast, client and contractors have more than 80% satisfaction, which shows a weak management cycle is running across the project (design to construction and vice versa) through the client's side.

Considering that in only the first 9 months a variation of around NZ$ 8 million for electrical services was recorded, the projects were delayed by around 101 days. Meanwhile, those projects budgeted around NZ$ 1.5 million for Aconex to keep the projects at low risk of delays (at least design and interaction delays), but the reality is those projects still struggle with the lake of a real-time communication channel.

This research used a content validity measurement technique due to limitations in the quantity of data collection. Thus, the authors enlisted the owners' engineering team and construction supervisors to check the facilitated workshops' results as an audit process. Additionally, the authors could not get access to more than 27 projects because of two limitations: the first is that many projects of such size, value, and common features as mentioned are performed a few times a year, and second, there is not sufficient documentation regarding delays in projects accomplished before 2018.

Data Availability Statement

All data, models, and code generated or used during the study appear in the published article.

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