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Lean and BIM Implementation Barriers in New Zealand Construction Practice

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Abstract: The construction sector is lagging behind other industries in terms of efficiency and value achievement. Several building sector initiatives are introduced to improve productivity and project value enhancement. Significant developments such as Lean principles and BIM tools have been applied in the construction sector to achieve efficiency and enhanced productivity while minimizing waste. Lean principles in construction practice are a developing research area, and BIM tools have been widely used in construction project delivery and communications. Although these concepts are beneficial, barriers to their integration and joint implementation have not previously been explored. The paper investigates barriers to implementing Lean and BIM and their interrelationships in the New Zealand construction industry. A three-step triangulation methodology was used in the study to validate the findings. The study used an extensive literature review process, case studies, and expert interviews to consolidate the findings. Barriers to Lean and BIM implementation in construction practice were identified, which include strong cultural resistance, lack of Lean-BIM understanding, resistance to change, lack of knowledge of the Lean-BIM method, and lack of support from senior staff in New Zealand organizations. The effect of implementing Lean-BIM principles is discussed, as are recommendations for implementing the method in construction practice.

Keywords: Lean-BIM; case study; modern construction; management practice; subject matter expert

Citation: Likita, A.J.; Jelodar, M.B.; Vishnupriya, V.; Rotimi, J.O.B.; Vilasini, N. Lean and BIM Implementation Barriers in New Zealand Construction Practice. *Buildings* **2022**, *12*, 1645. https://doi.org/10.3390/buildings12101645

Academic Editor: David J. Edwards

Received: 20 July 2022
Accepted: 29 September 2022
Published: 10 October 2022

1. Introduction

The construction industry underperforms other industries in terms of productivity, cost reduction, and project duration; it is also one of the largest waste-producing industries globally [1–3]. Construction practices have changed considerably by including technologies and digitization tools such as Building Information Management (BIM), automation, prefabrication, new manufacturing concepts, artificial intelligence, 3D printing, etc., for higher efficiency [4,5]. However, productivity is still an issue due to non-value-adding activities, and even though much potential exists in reducing construction waste at all stages of construction, these processes still generate substantial waste [6,7]. Therefore, there is a need to identify the sources of waste and delays earlier in the construction phase and implement measures sooner to eliminate the occurrences. Implementing lean construction processes has been proven beneficial for speedy project completion [8].

Lean principles eliminate waste in process activities to reduce process cycles, improve quality, and increase efficiency [1,9,10]. The critical purpose of Lean principles in construction includes establishing a clear set of objectives for the delivery process aimed at maximizing performance for the customer at the project level, as well as concurrent product and process design [3,11]. When lean principles are applied to construction, it takes on a new dimension as participants consider the project's entire lifecycle when deciding what to build and how to build it [12]. Studies evidence sustainable outcomes regarding reduced waste, effort, and time as well as increased productivity by implementing lean construction projects [13]. However, it is sometimes viewed as a non-value-generating activity [13,14]. Modern construction management practices include proper planning and design to reduce construction time and cost while maintaining overall project sustainability [15–17]. Lean improvements are better realized through an integrated information system such as BIM [18–20].

Building Information Management (BIM) is a collective digital representation of any built object's physical and functional characteristics, which serves as a reliable basis for decisions and processes. It is a tool for delivering construction projects with collaboration by sharing information to avoid delays [21]. BIM is seen as the process of producing and managing information on a construction project by making visible the reality on the ground, and sharing that data and information in a digital format [22]. It is also regarded as a modern information technology tool that solves issues in the construction management process [23]. Collaboration between different stakeholders at various levels can support lean implementation in BIM [24–26].

There is an increasing need for a lean-focused integrated information center that focuses on reducing waste, which can be made possible via information interchange and exchange within BIM tools and technologies [27]. There are efforts to apply lean processes and principles in construction projects to enhance efficiencies. However, much of this application is not integrated with modern tools such as BIM [28]. The integrated application of Lean-BIM in a construction project will significantly enhance the value of the construction sector [29]. The improvement in productivity and waste minimization resulting from the integrated application of BIM and Lean is confirmed by numerous studies [18–20]. Implementing Lean and BIM in a construction project is becoming an emerging research area as a section of information technology development in the architecture, engineering, and construction (A.E.C.) industry [4,30,31].

There is an increasing need for a lean-focused integrated information Centre that focuses on reducing waste which can be made possible for information interchange and exchange within the BIM tools and technologies [27]. are efforts to apply lean processes and principles in construction projects in order to enhance efficiencies. However, much of this application is not integrated with modern tools such as BIM [29]. The integrated application of Lean-BIM in a construction project will significantly value the construction sector[29]. The improvement in productivity and waste minimization resulting from the integrated application of BIM and Lean is confirmed by numerous studies [18–20]. Implementing Lean and BIM in a construction project is becoming an emerging research area as a section of information technology development in the architecture, engineering, and construction (A.E.C.) industry [4,30,31].

Table 1 is the amalgamation of the findings from existing literature and demonstrates a good prospect for enhancing the productivity of construction project management practices through the integration of Lean-BIM [32]. BIM tools and Lean construction principles are used diversely and dynamically for multiple purposes and, as indicated, they can also support the delivery of sustainability values in construction management practices [33]. As the dominant and common mode of communication in modern construction practices, BIM platforms are deemed essential to maximize those benefits obtained through Lean principle implementation. Although BIM and Lean principles are used concurrently, there is not enough of an organic link or integration between the tools being applied to enhance their respective principles. This demonstrates the gap in effectively integrating BIM and Lean principles in modern construction practices.

Table 1. Benefits of integrating Lean, and BIM in construction management practice.

	Integration Benefits	BIM	Lean	BIM +Lean	Reference
Process	Ensure better planning, as well as a collaborative, integrated, and visible construction process.	⚜✓	✓⚜	⚜✓	[12,32,34]
	Allow for the best project delivery process possible. Effectively enable each other's use in construction projects.			⚜✓	[16,33]
	Resolve more issues during the project (cost, constructability, schedule, quality, sustainability, waste, and so on).			⚜✓	[20,33]
	Increase productivity and efficiency while providing more value to the client.		⚜✓	⚜✓	[35]
	Reduce the amount of data that isn't necessary.	⚜✓			[36,37]
	Allow information sharing and improve project relationships.	✓		⚜✓	[26]
	Show significant progress in prescribed and legal matters.			⚜✓	[16]
	Enable risk and reward to be shared with the project team.	✓		⚜✓	[38,39]
People	Encourage closer collaboration from the start of the project. Integrate suppliers into the construction industry's processes.		✓	⚜✓	[7,31]
	Assist work teams in performing more effectively.		⚜✓	⚜✓	[22,39]
Tools	BIM is an excellent team-building tool that accelerates the formation and implementation of Integrated Project Delivery (I.P.D) strategies.	⚜✓		✓	[31]
	BIM offers data storage exchange services.	✓		⚜✓	[12,32,34]

Integrating Lean principles and BIM tools in the construction project will be beneficial in terms of productivity and performance [33]. BIM software can be integrated for solid communication within construction projects, while the Lean principles can be used to smooth out all non-valuable activities [40]. Despite the benefits gained from Lean and BIM implementation, the limitations and gaps in current construction practices and implementation strategies create barriers to successful Lean-BIM implementation [41,42]. This study aims to investigate Lean and BIM implementation barriers and their interrelationships in the New Zealand context. Three objectives of this research are: (1) to identify the barriers to Lean implementation; (2) to identify the barriers to BIM implementation; and (3) to assess the interrelationships between these barriers. The findings will provide insights into the reasons for the slow uptake of integrated BIM and Lean applications in New Zealand.

2. Methodology

The methodology philosophy adopted in this study is exploratory and inductive. The study aims to investigate Lean and BIM implementation barriers in New Zealand construction practices through an extensive literature review and case studies, and expert interviews to provide a theoretical basis and methodological approach to achieve triangulation [43]. Accordingly, a three-step methodology was designed and implemented to achieve research aims which include, Step 1: Extensive literature review; Step 2: Case studies; and Step 3: Expert interviews. The findings of the literature review and case studies are used as inputs to develop the themes of questions for the expert interviews. Case studies are used, and also a semi-structured interview approach is adopted to reduce bias. Therefore, minimal information from the literature findings is exposed to interviewees [13]. The triangulation approach was used to capture multiple facets of this qualitative research [43]. An extensive literature review was conducted to obtain input construction data and provide a global understanding of BIM and lean practices and shortcomings. The case study approach was conducted to obtain structured and practical information on BIM and lean implementation, especially within the New Zealand construction sector. For appropriate comparison, the case studies methodology framework contains the following themes in the three cases: context, management practice, lean principles, BIM functionality, lean barriers, BIM barriers, BIM in digital applications, and software tools. Finally, interviews verified and completed the intended triangulation of findings through input industry expertise [43].

2.1. Extensive Literature Review

A comprehensive literature review is applied to summarize the critical points of current knowledge of the barriers to BIM and Lean implementation around the world. Further scoping of the literature shows the relationship between the barriers, common issues, and gaps in knowledge relating to Lean-BIM integration barriers. This extensive literature review uses the concept of de-contextualization and re-contextualization to identify different faces of barriers to the implementation of Lean and BIM in construction management practice globally. Assessing the findings provides insight into problems relevant to the New Zealand construction industry. Contextualization shows the process of putting information into context, making sense of the information from the situation or location in which the information was found. BIM and Lean barriers were identified to aid in the development of interview questions. The following keywords were included in the review criteria: Lean construction, principles, BIM, Lean implementation, barrier, BIM implementation barrier, management practice, and construction project. The timeframe for inclusion of selected publications was 2000–2022, and articles were chosen from relevant journals in the Q1 and Q2 rankings. The relevant articles were chosen from journals and sources such as the Journal of Construction Engineering and Management, Engineering Construction and Architectural Management (ECAM), Journal of Management in Engineering (ASCE), Computer-Aided Civil and Infrastructure Engineering, Automation in Construction, Architectural Engineering and Design Management (AEDM), Journal of Construction Innovation, Canadian Journal of Civil Engineering, and Project Management Journal. The sources are all recognized and acknowledged by building project management across the world.

2.2. Case Studies

An exploratory and comparative case studies approach was undertaken to develop a comprehensive knowledge base of Lean-BIM applications. Case studies are used in this study to better understand the efficacy of using BIM and Lean in infrastructure projects. Case studies from three different infrastructure projects in New Zealand were selected to gain comprehension of the generalized application and practice of BIM and Lean in NZ construction. In addition, the selected cases featured strategic initiatives to follow and implement both Lean principles and BIM tools. The cases were selected from New Zealand infrastructure projects where access to project information and documentation was available. These three case studies were considered because they represent the complex nature of construction and infrastructure development projects and different sectors within the construction industry. The detailed examination of the cases provides more data and specific details on implementing BIM and Lean in construction practices, which may appear difficult to capture using other data collection methods [44]. A thorough case study review can provide coverage of complex projects from different perspectives and can confirm or contradict the findings of the literature review studies [45].

A framework or guidelines is necessary for extracting case study information for the three case studies and for classifying project information [15]. Figure 1 illustrates a comparative case study framework used in this research. This case study framework for comparative case study analysis was developed based on Yinian perspective on a case study. This perspective states that a case study must be based on multiple data sources and triangulation of findings must be performed [35]. This framework is essential for the replication of logic and meeting the burden of proof [46]. This enables systematic documentation of information plus a meaningful comparison of the three cases. The method is based on standard replication of analysis for the three cases. The replication is possible with the development of a standard case study framework [4,47]. This is a well-established method of case study design selection and execution [35]. The multiple and comparative case-study analysis was used to provide analytical replication and create a basis for the validation of findings [48].

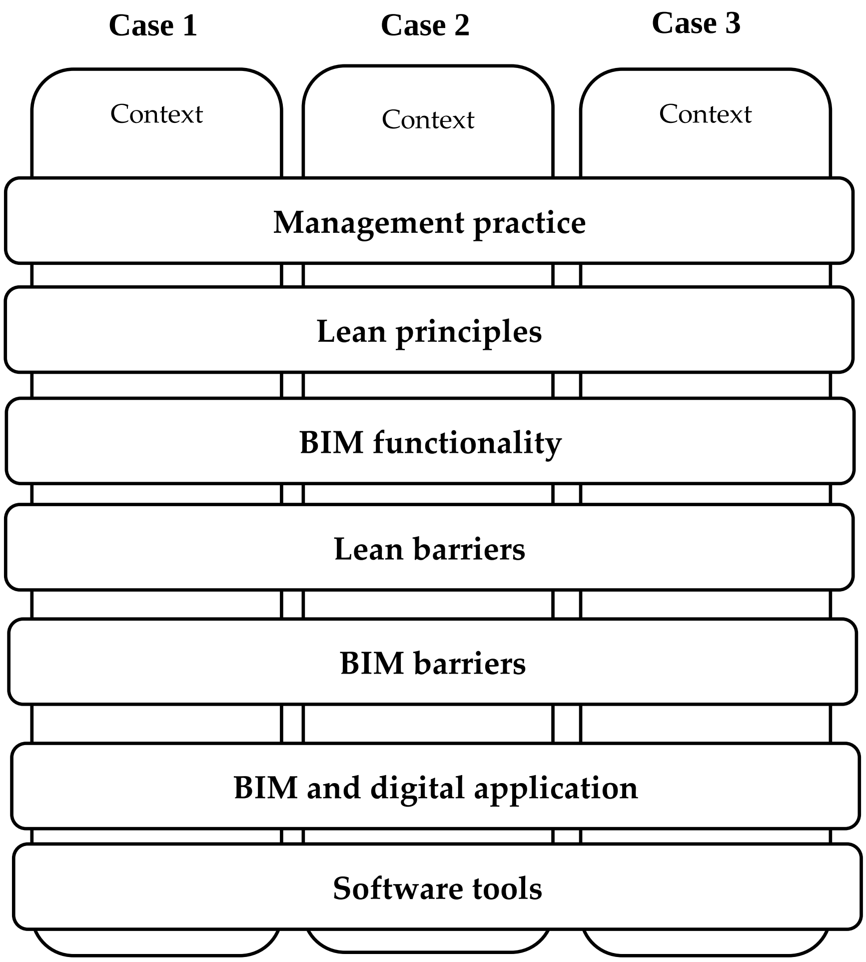

Figure 1. The case study framework used for comparative case study analysis.

The framework breaks down the project information for each case into management practices, lean principles, BIM functionality, lean barrier, BIM barriers, BIM and digital applications, and software tools, which form the units of analysis. Because project information is highly contextual, certain units of analysis are required to classify the information and analyze each case. In addition, a comparison of the cases will be very difficult without standard units of analysis.

The case studies were chosen to identify common barriers to BIM and Lean implementation in construction practice and management. Furthermore, information about the actual project, its context, the benefits and functions of using specific BIM tools, and the Lean principle approach is recorded and classified as common comparable information among the cases. Document reviews and publicly available data were primarily used as inputs to the case studies. Upon review of these documents, further information was requested, and data obtained from the cases were compared to enrich the discussion and tool applications.

2.3. Expert Interviews

After identifying different barriers to BIM and Lean implementation in construction projects both globally and from a New Zealand viewpoint, to ascertain the challenges, an interview was needed to be conducted so as to acknowledge the opinion of the subject matter experts in the relevant field. Interviews are most effective for qualitative research as they help participants explain their opinions and experiences. Open-ended interview questions help collect in-depth information if there is little objective evidence for an idea or fact [40,49,50]. Subject matter experts (S.M.E.s) in the field of BIM and Lean/last planner were interviewed in a semi-structured manner. Semi-structured interviews assist in confirmng and verifying the barriers identified from the literature review and case studies while providing a 'deeper' understanding of the cultural, technical, and economic aspects associated with Lean and BIM integration. The interviewees' profiles are tabulated in Table 2. Appendix A includes a copy of the questions asked during the interview.

Table 2. The S.M.E. participant's profile**.**

S.M.E.'s	Position Description	Year of Experience
SME1	Senior Fellow Institute Civil Engineer/Expert Lean/Last Planner	Over 25 years
SME2	Senior Project Manager/Data Analyst	Over 20 years
SME3	Senior Project Analyst/Planner/Quantity Surveyor/Estimator	Over 18 years
SME4	Senior Engineer Planner	Over 17 years
SME5	Senior Innovation Manager (BIM)	Over 23 years
SME6	Senior Digital Engineering Manager (Lean)	Over 24 years
SME7	Transformation Manager (Lean Expert)	Over 15 years

3. Results

3.1. Findings from Literature Review

A total of 267 articles were initially identified, and 64 articles were chosen for the full review of this study based on their relevance to the study objectives. These articles generally cover the fundamentals of construction project management. This was done to identify barriers to Lean principles and BIM implementation in various construction projects worldwide and New Zealand.

Table 3 shows the identified barriers to lean principle implementation within the general construction literature, which considered global sector-related issues. Generally, these barriers are related to technology, management, resistance to change, poor performance, and lack of awareness. In addition, Table 4 shows the key barriers identified in implementing BIM tools. These identified barriers to BIM implementation in construction practice are also considered global issues, and are related to lack of BIM knowledge, lack of specified standards, traditional methods, and high cost. The NZ-specific barriers identified in the literature review are underlined in Table 4.

Table 3. Lean principle implementation barriers in construction management.

Barriers	Descriptions	Reference
Technology-related • High cost of software • Inadequate resources • Lack of funds • <u>Unawareness of technology</u>	Technical barriers affect and shorten project duration by improving construction order, and there will be communication issues and a lack of collaboration.	[1–3,51]
Management-related • Poor management • <u>Lack of top management commitment</u> • Leadership characteristics • <u>Organizational management issues</u> • Lack of inter-department practices	Due to insufficient lean principles and experience on the team, there will be performance issues and poor productivity improvement.	[3,14,41,52]
Resistance to change-related • Traditional culture • Unwillingness to change the existing culture • Culture and philosophy issues • Client's traditional practices	Construction industry attitudes and reluctance to change, as well as other types of barriers, have an impact on project management performance and monitoring efficiency. Lean construction principles are used by practitioners to improve supervision and performance.	[1–3,51,52]
Poor performance-related • Unstable political environment • Lack of knowledge of Lean principles • Lack of customer involvement • Lack of standardization	Due to resistance to change from traditional working practices, Lean lags far behind other countries such as the United Kingdom and the United States. The lack of a stable policy explains the lack of standardization.	[25,37]
Lack of awareness-related • Lack of awareness and skills • Lack of knowledge of lean construction philosophy • Training and lean principles	Most construction workers lack the fundamental skills required to apply Lean principles in a construction project. A solid understanding of lean awareness is required. Issues concerning information reuse and overall client satisfaction have an impact on what the construction industry could achieve.	[3,33,53]

Table 4. BIM implementation barriers in construction management practice.

BIM Implementation Barriers	Descriptions	Reference
Lack of BIM knowledge-related • Poor knowledge about the benefit of BIM • Workflows required for BIM and sustainability • Lack of skilled personnel • Unawareness of the technology • Lack of demand for BIM use • Inadequate organizational support to execute BIM	Barriers of this kind show negative outcomes in a construction project. BIM is used as a tool to help reduce project costs and reveal important impacts on the construction industry.	[20,26,41,54]

Lack of specified standard-related • Lack of understanding of the process • Lack of contractual standards around BIM models • Lack of tangible benefits • Unavailability of standardized tools	Failure to obtain the appropriate standard in BIM adoption in the construction industry contributes to negative productivity in the construction project and sector.	[13,15,55–59]
Traditional methods-related • Lack of quality in-house staff • <u>Lack of support from top management</u> • <u>Poor management</u> • Lack of awareness about BIM • Lack of BIM implementation • Lack of teamwork mentality	BIM is being used as a tool to help reduce project costs and have a greater impact on the construction industry. Acceptance of BIM implementation and proper application fosters a positive teamwork mentality.	[2,14,60]
High cost-related • High cost of implementation • Training expenses • Lack of training • Lack of BIM experts • Cost of BIM software	The logic of this emphasis, i.e., on process cost reduction, is problematic in New Zealand from the standpoint of BIM implementation. The budget savings sought by New Zealand clients are primarily in the construction process cost.	[20,26,37,54,61]

Practices of Lean principles in construction projects have become more complex due to weakness in the regulatory processes, outdated construction management models, lack of government efforts, strong cultural resistance, and lack of the lean adoption process [34,36]. Although the construction industry is transforming with the application of modern technologies, the change is slow when compared to the manufacturing industries [47,55,62–64]. A similar trend of slow uptake of integrated Lean-BIM applications has been observed in New Zealand [3,61]. The unfamiliarity with or misunderstanding of Lean concepts was an issue observed by researchers [53], along with technological difficulties [12] in proper Lean implementation in construction projects in New Zealand.

Based on the literature review, BIM barriers generally include a lack of: understanding of the BIM implementation process, capable personnel, specified standards, quality in-house staff, training, expertise, support from management, etc. [37,55,58]. Similarly, poor management, a lack of top leadership support, management and organizational issues, cultural and philosophical issues, client-related traditional practice, material-related and cost-related barriers, and a lack of performance and knowledge were identified as barriers to Lean implementation from the literature review [2,14].

The number of studies reporting on the implementation of both Lean and BIM or integration of the BIM tools in Lean principles is scarce in construction. Lean construction and BIM are instrumental for both academics and practitioners in the Architecture, Engineering, and Construction (A.E.C.) industry [46]. When the appropriate BIM tools are integrated into modern construction processes, achieving the desired level of Lean principles is significantly enhanced [59]. Lack of training, which would be cost-related, a lack of knowledge, a lack of management, poor management, and a lack of support from senior management are identified as barriers in New Zealand construction organizations [6,42,45].

While a review of the literature identified implementation barriers to Lean and BIM implementation separately, some of the barriers to Lean-BIM integration have also been identified for the construction sector. These barriers include a lack of mentoring from BIM and Lean professionals, issues with current BIM and Lean practice, operational tools and Lean methodologies that are not generally recognized and understood, and an unwillingness to change the existing culture [3,13,15].

3.2. Case Studies Results

Case study 1 considers one of New Zealand's largest transport infrastructure projects involving metro rails and underground networks. Once completed, it will allow the transportation of up to 54,000 passengers per hour to travel more easily across the network. A water and wastewater treatment facilities project is studied as Case study 2. Table 5 shows a summary and the context of the three case studies selected for this study.

The water and automation teams were responsible for several successful outcomes, including designing and constructing the TeAnau, Mossburn, Otautau, and Winton Water Treatment Plants. Case study 3 is also a major rail infrastructure project involving double-tracking of 2.7 km rail to enable trains to travel in both directions at the same time. The detail of each case is included in Table 5.

Table 5. Summary of case studies.

Case Studies	Context/Challenges	Issues and Solutions	Key Outcome
Case Study 1: Transport Infrastructure Projects, New Zealand	The City Rail Link (C.R.L.) $4.4B projects will improve and connect Auckland's entire rail network and support a growing population. It will enable up to 54,000 passengers per hour to travel more easily across the network. For the construction consisting of two 3.45-km-long tunnels and two new underground stations, accurate locating and mapping of existing key utility infrastructure was essential to success.	In such invasive construction activities, knowing where the existing utility infrastructure is located is essential to success. Technicians used a combination of Ground Penetrating Radar (GPR) and electromagnetic location (E.M.L.) to pinpoint the location of this key infrastructure in advance of construction works.	BIM process provides the construction team with full As-Built drawings pinpointing the exact location of critical infrastructure. It also supports marking out the construction site with visible markers. The process increases safety outcomes for workers and minimizes the risk of service strikes and disruption during construction.
Case study 2: Water and Wastewater Reticulation and Treatment Operation and Maintenance **(O&M)**	Southland District Council (S.D.C.) is required to undertake repairs and maintenance for an extensive network consisting of sewerage schemes, wastewater pump stations, stormwater networks, and urban and rural supply schemes. The contract value is a $4M p.a. contract starting in 2010 and will carry through to 2023. This includes: • 13 water treatment plants • Reservoirs • 4000 valves and hydrants • 623 km of water mains • 10,000 service connectors • 18 wastewater treatment plants • 80 wastewater pump stations	24/7 availability and response to customer requests. O&M services for water and wastewater reticulation systems and treatment facilities. Assistance in overcoming issues relating to drinking water through the upgrade of the water treatment plants. Skilled system users who can troubleshoot and transfer learnings to the S.D.C. team. Monitoring ensures the safety and quality of water.	The upgrade was done without interrupting existing operations and ensured the treatment plants were in line with the 2008 drinking water standards. Over the past three years, project execution achieved an excellent rating of 93% across 14 Key Performance Indicators (KPIs). Monitoring ensures the correct levels of safety and water quality are provided. The organization team was also able to apply the lessons learned to other areas of business provision. The contract has been delivered on time and within budget using the BIM approach.

	• 225 km of sewerage • 1600 manholes		
Case study 3: Trentham to Upper Hutt rail Project (T2UH)	T2UH involved double-tracking of 2.7 km of the Hutt Valley line between Trentham and Upper Hutt stations to enable trains to travel in both directions at the same time and deliver more frequent and reliable services. There is a real motivation for partners on the project to engage and learn together on the digital transformation team.	BIM development is the basis of design and encouraging collaborative processes at each stage of the project lifecycle (purchasing, design, construction, and asset management). This led to: • Reduced individual requests for information by 88% • Reduced individual notices to the contractor by 83% • Reduced the forecasted contract cost by 55% • Reduced the program timeframe by 62%	Digital tools developed d on T2UH contribute to a more resilient, productive rail sector, and enhance outcomes on other infrastructure projects. The Trentham to Upper Hutt project and BIM pilot program have changed the way KiwiRail approaches projects in the railway corridor. Collaboration and standardizations were implemented for reduced errors. In comparison to traditional delivery methods, it was found that for a complex project in a live transport corridor, there was a significant financial benefit.

The initial observations of these case studies indicated that all projects implemented BIM tools and applied Lean principles in the projects. All three case studies implemented BIM applications which are given in Table 6. Some of the key examples of Lean application in the projects are explained below.

Table 6. Case studies comparison results.

	Case 1	**Case 2**	**Case 3**
Project Information	Transport Infrastructure New Zealand	Water and wastewater reticulation and treatment O&M	Trentham to upper Hutt project
Management practice	Estimates developed and followed in line with internal process, procedures, and the client's pricing schedule	Schedule and basis of schedule were frozen and any changes from the initial baseline were reported	A clear and traceable plan for the scheduling architecture
Lean principles	Flow Process Value generation process Problem-solving	Flow Process Value generation process Problem-solving Developing partnership	Flow Process Value generation process Problem-solving Developing partnership
BIM functionality	Design Design and fabrication detailing Preconstruction and construction	Design Design and fabrication detailing Preconstruction and construction	Design Design and fabrication detailing Preconstruction and construction
Lean barriers	Technology-related: inadequate resources; unavailability of experts and skilled professionals Management-related: lack of top management commitment and managerial consistency; multi-organizational challenges	Technology-related: lack of skills and unawareness of technology; lack of funds for technology adaptation; high cost of software	Technology-related: lack of skills and unawareness of technology; lack of funds for technology adaptation; unavailability of experts and skilled professionals
BIM barriers	Human and skills shortage-related	Finance-related	Human resource-related

	Poor management of technical resources Lack of standards	Human resource/skills shortage-related Technology-related Lack of standards	Technology-related Lack of standards
BIM & digital applications used	BIM and CAD Planning and Project Management Estimating and Takeoff Software Accounting	BIM and CAD Planning and Project Management Estimating and Takeoff Software Accounting	BIM and CAD Planning and Project Management Estimating and Takeoff Software Accounting
Software tools	Adobe Acrobat Aconex AutoCAD Planswift Trimble Accubid	Adobe Acrobat Not used AutoCAD Trimble Accubid Trimble Accubid	Adobe Acrobat Aconex AutoCAD Deltek Vision Not used

In Case study 1, the construction team marked the construction site with visible markers to minimize disruptions. Labeling and marking are Lean approaches to increase visibility for improved workflow and performance [64,42]. In Case study 2, continuous monitoring ensured appropriate safety and water quality levels. A monitoring plan is a Lean approach that helps keep an eye on the ongoing processes to ensure a project's continued success [45]. Case study 3 demonstrated reduced construction risks by collaboration and increased team productivity by increasing digital capabilities. When faced with errors during the construction phase, the team addressed the issues through discussions and standardizations. Collaboration and standardizations are both Lean approaches used in construction for the safest, easiest, and most effective achievement of project goals [35].

Table 6 summarizes the case study comparisons based on the framework in Figure 1. The comparison is done based on the eight units of analysis included in the case study framework, demonstrating the theoretical replication logic required for the case studies [48]. The context of each case is broken down into the units of analysis-documented in each row of Table 6—to achieve conclusive outcomes [48]. The cases provide a broader view of the problems faced in the industry. The comparison identifies each case's management practices, BIM functionality, and application. In addition, the Lean principles identified in the literature are also associated with each case.

Case study 1 identifies some of the core Lean-BIM implementation issues in projects. The document for case study 1 states that capability issues and lack of technical knowledge can hinder a project. Lack of formal process was also a barrier to achieving Lean values, leading to errors and rework. Budget constraints, time pressures, and resource shortages are also noted as some of the other challenges. The review of Case study 2 identifies the lack of skilled users and knowledge transfer as a barrier. 'Perceived Value for Money' and lack of collaboration were also addressed in Case study 2.

A comparison of lean principles throughout the three cases demonstrates that the initial adoption of these principles is not often structured. However, themes such as lack of resources, funds, cost of technology adaptation, and unavailability of experts and skilled professionals are the underlying themes of the three cases for Lean implementation barriers. In addition due to the multi-project portfolio nature of Case 1 management-related issues such as lack of both top management commitment and managerial consistency, and multi-organizational challenges, were also considered as Lean barriers. BIM implementation barriers were also compared among the three cases and again, Case 1 involved barriers such as consistency of practices and especially, shortage of skills. Accordingly, the common underlying themes of BIM implementation barriers were human resource/skills shortage, technology and also a lack of standards.

The case studies also highlighted the advantages of Lean-BIM implementation of the projects. The BIM approach led to several breakthrough innovations that could deliver significant productivity improvements for New Zealand's rail network. The project team believes these improvements could not have been made under traditional methods of delivery. These cases all involved BIM applications and Lean processes even though they may have not been directly or deliberately implemented.

3.3. Expert Interview Results

According to the findings of the subject matter expert, despite the advantages and benefits of BIM and Lean implementation in the New Zealand construction industry (NZCI), there are still issues and limitations. The following sections show the most typical barriers encountered and discovered while implementing Lean and BIM integration: Challenges in implementing BIM in NZCI; Lean application in NZCI and possible barriers; and Requirements for Lean and BIM integration in NZCI. The interview findings complemented the literature review and comparative case studies and provided a measure of internal validity for the study findings [48,41].

3.3.1. Challenges in Implementing BIM in NZCI

According to S.M.E. 1, implementing BIM in the NZCI is quite expensive, and small and medium-sized projects have not been identified as having a clear understanding of how to use BIM tools. S.M.E. 1 also did mention a lack of an integrated supply chain, a lack of work continuity, a lack of information transfer from concept to design, from construction to subcontractors, and from construction to operations, and difficulty transitioning from one job to the next. One of the most frustrating challenges, according to S.M.E. 6, is the interoperability of different design packages. They primarily use civil 3D or 12D in plant design and construction, but these packages do not integrate well. S.M.E.6 added that when something not native to that environment is introduced, it takes a lot of effort to get it accepted. According to S.M.E. 4, S.M.E. 5, S.M.E. 1, S.M.E. 3, and S.M.E. 2, the barriers to implementing BIM in the New Zealand construction industry are cost, lack of proper training, poor management, lack of top leadership support, lack of mandatory standards for Lean-BIM construction industry, managerial and organizational issues, material-related, and lack of performance and knowledge.

3.3.2. Lean Application in NZCI and Possible Barriers

According to S.M.E. 6 and S.M.E. 7, Lean application in NZCI is primarily for defining value and is thus similar to that in the construction industry globally. Lean principles assist a client in knowing what needs to be implemented at the right time in the construction process. This implementation of the process sometimes depends on a client, and they may have different drivers; notably, some clients are purely trying to speed up the construction process, reduce variations in cost, and are unconcerned about data. According to S.M.E. 1, the level of maturity for Lean construction adoption in the New Zealand construction industry has dropped significantly in the last three or four years due to a lack of practitioners using Lean tools in construction.

According to S.M.E. 1, it only exists on sites where it has been introduced, as well as among those operators who had previously taken it up and are encouraged to continue to use it. S.M.Es 3 and 7 argued that using Lean in a construction project saves money and improves quality; however, NZCI is facing a shortage in skilled Lean construction operators. According to S.M.E.s 1 and 7, Lean construction only exists on paper in New Zealand, not in practice, and although most businesses practice it, they may not call it Lean construction. S.M.E. 1 distinguished between organizational and project-level barriers, stating that construction at the project level is very focused on the project, to be handled by people who want to start right away but are terrible at finishing. S.M.E. 7 regards Lean principles as an extended period, a longer period of implementation before a project begins, and then using the early start to organize a slower mobilization pace to run construction projects more efficiently.

3.3.3. Requirements for Lean and BIM Integration in NZCI

According to S.M.E. 1, construction companies are comparative but have failed to pick up those lead ideas and adapt quickly, especially from leading sectors overseas. New Zealand's construction industries fail to imitate and implement productive ideas implemented by other industries in New Zealand. This includes the integration of new technology such as BIM and digitization in established construction processes such as Lean. According to S.M.E.s. 1–7, the most valuable feature of BIM is its ability to reduce risk, coordinate, and prevent variations on-site. Lean construction, on the other hand, establishes and encourages value achievement in construction practice.

According to S.M.E. 1, the most obvious Lean implementation barriers are overspending, waste, cultural resistance, a lack of knowledge, and a lack of standardization. This claim was also supported by S.M.E. 2, who believes that a lack of adoption is the main reason for the slow improvement of Lean implementation in New Zealand, and S.M.E. 3 concurred. S.M.E. 4 says there are numerous challenges, including a lack of training to gain more knowledge on tool operations, culture, and inadequate top management decision-making; and S.M.E. 6 says that the cost of digital management is outrageously high. S.M.E. 1 identified the top four barriers to Lean implementation to be industry fragmentation, a lack of understanding of Lean principles, a lack of practical Lean process in construction, and not understanding the real value that can be added. The barriers to Lean-BIM implementation in NZCI identified by the S.M.Es are included in Table 7.

Table 7. S.M.E.-identified barriers to Lean-BIM implementation in NZCI.

Interviewee	Lean-BIM implementation barrier in NZCI
S.M.E. 1	Over budget, wastage, lack of cultural resistance, lack of knowledge, and lack of standardization
S.M.E. 2	Lack of adoption of Lean understanding
S.M.E. 3	Lack of human collaborations
S.M.E. 4	Lack of training to acquire more knowledge on tool operations, culture, and inadequate top management decision-making
S.M.E. 6	Cost of digital management
S.M.E. 7	Lack of experience in Lean adoption, Lean still at an early stage, cultural resistance

Table 8 demonstrates the common barriers to BIM and Lean implementation in New Zealand. These barriers were documented through the literature review, case studies, and interview stages of the study.

Table 8. Common barriers to BIM and Lean implementation.

Barriers to BIM and Lean	Barrier Item	Literature Review	Case Studies	Interviews
Traditional method-related	Lack of mentorship from a BIM and Lean professional	✓	×	✓
	Lack of support from senior staff in New Zealand organizations	✓		✓
	Lack of support from the government	✓	⚜✓	✓
	Lack of BIM educational provision	✓	⚜✓	✓
	Issues in current BIM and Lean practice	✓	××	✓
Management -related	Poor management	✓	×	✓
	Lack of top management commitment	✓	×	✓
	Leadership characteristics	✓	×	✓
	Lack of support from the government	✓ ⚜	✓	✓
Resistance to culture change-related	Traditional culture	✓	✓	⚜✓
	Unwillingness to change the existing culture	✓	✓	✓
	Client's traditional practice	✓	✓	✓
	Cultural resistance in companies hinders its effectiveness	✓	✓⚜	✓
Technolo-gy-related	Technology adaptation			
	Operational tools and techniques for lean principles not well-recognized and understood	✓	✓	✓
	Lack of an electronic standard for coding BIM software to a standard method	✓	✓	✓
	Unawareness of the technology	✓	✓	✓
High cost-related	Too expensive	✓	×	✓
	High cost of software	✓	✓	✓
	Lack of funds	✓	×	✓
	Lack of investment in hardware	✓	✓	✓
Lack of knowledge-related	Lack of BIM and I.T. knowledge	✓	✓	✓
	Lack of knowledge of Lean construction	✓	✓	✓
	Lack of training and Lean principles	✓	✓	✓
	Lack of collaboration and coordination	✓	✓	✓
	Lack of understanding	✓	×	✓

4. Discussion

This study makes three broad conceptual contributions: it investigates the barriers to successful Lean construction implementation, the barriers to successful BIM implementation, and the barriers to the successful integration of Lean and BIM implementation and their interrelationships in the New Zealand context. The study identified a lack of support from senior staff in New Zealand organizations, an unwillingness to change the existing culture, lack of technology awareness, a lack of investment in hardware, a lack of training, and a lack of Lean principles as the most significant barrier in the New Zealand construction sector. Figure 2 shows common barriers in New Zealand at a macro level, and the challenges that can occur at different project layers [62].

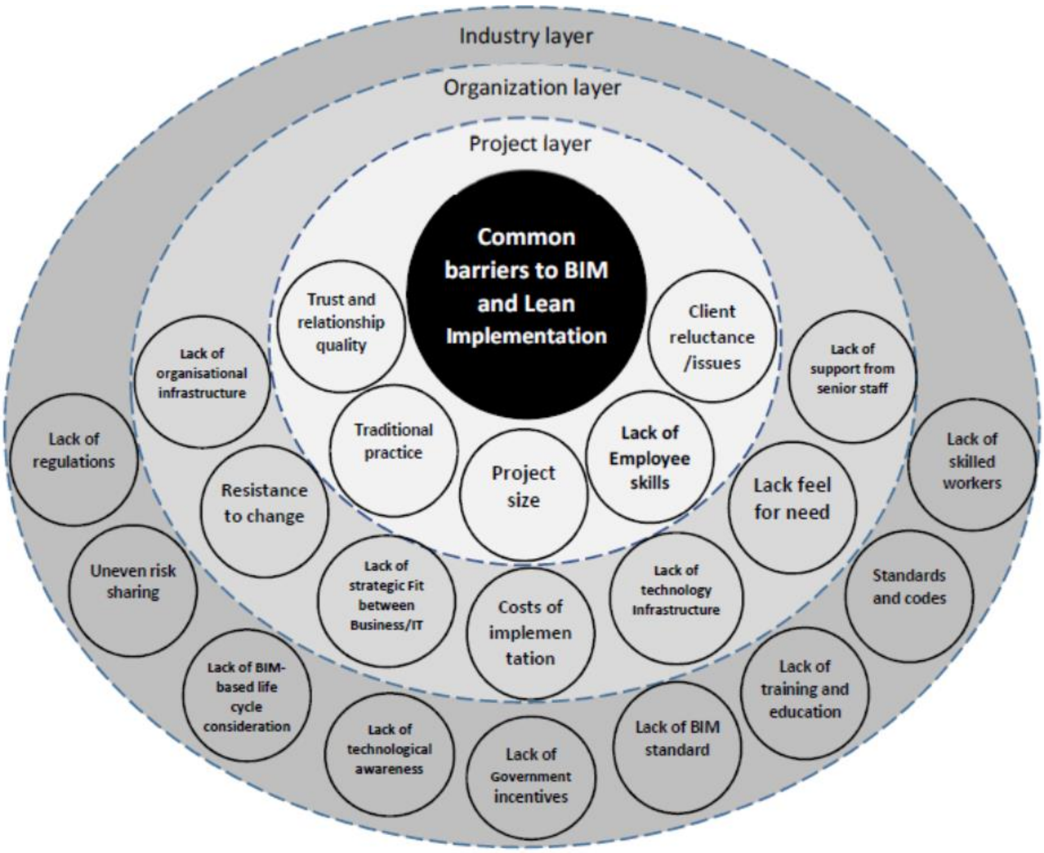

Figure 2. Common Barriers to BIM and lean construction solutions According to [62].

As identified in previous stages, the principles of Lean construction and the application of BIM tools have greatly impacted the construction sector, and their synergy and potential for the construction industry have been identified [26]. BIM provides the opportunity for the A.E.C. industry to improve the process, people, and productivity by linking the core construction processes. Similarly, case studies adopted for the current study show that adopting and applying Lean principles to construction projects lead to reduced risk in construction and increased team productivity. It shows the significance of Lean principles applied in a construction project and proves contract correspondence was significantly reduced with time savings equivalent to a year's full-time employee's wage. However, the S.M.E.s mainly identified Lean principles application in NZCI as a means for adding value, which is in line with the global construction industry.

The application of BIM tools in construction projects is intended to improve communication, coordination, interoperability, and productivity. These are also the direct or indirect outcomes of Lean principles in construction. Accordingly, the full achievement of integration between the two concepts faced multiple barriers which were identified. These common barriers affect the expected goals in the construction sector worldwide; unsurprisingly therefore, their presence in New Zealand's construction sector was also found.

This study also identified various levels of barriers that were working against the required goal at the industry level, organization level, and project levels. Moreover, the case studies comparison found that, despite the barriers identified, BIM and Lean principles adoption and implementation in construction have a significant financial benefit. Figure 2 demonstrates the common barriers to BIM and Lean construction solutions at different levels in construction project practices, such as barriers at the industry layer, organizational layer, and project layer, with each layer having its unique issues and implications. Thus, some of them contribute to their outer layers, and some have a systematic effect on inner layers, which could trigger the cause and effects of the cycle.

Barriers to BIM and Lean implementation in construction projects have been identified in previous studies using a range of methods, including the adoption of evaluation of published articles, questionnaires distributed throughout the New Zealand construction industry, structured interviews with quantity surveyors within the New Zealand construction sector, and selected literature consisting of published case studies related to Lean and BIM.

The outcomes of the literature review, the theoretical replication logic provided through case studies, and the analysis of the expert interviews have provided triangulation of knowledge and a measure of internal validity [43,48]. As a result, the current study identified barriers to BIM and Lean implementation using the following methods: a review of the literature on Lean and BIM implementation barriers in construction; case studies related to the use of Lean and BIM in a construction project to identify challenges; and subject matter expert (S.M.E.) interviews with New Zealand construction professionals with extensive experience with the Lean and BIM approaches, to gain their perspective on the challenges and lack of performance. These common barriers are also barriers to the effective integration of BIM tools for Lean principles.

The triangulation highlighted the core issues of Lean-BIM implementation. This study also identified some other barriers relevant to NZ not reported in previous literature such as lack of collaborative practices, perception of cost, lack of awareness of Lean principles, etc. As observed in the results, there are still challenges in implementing Lean principles and BIM at the project level. Currently, the implementation of Lean values is generally unintentional due to a lack of awareness, as observed by the interviewees, which may be causing difficulty in the uptake of Lean values at project level. The need for planning Lean into a project at an early stage is required for successful Lean implementation, as demonstrated by case studies. The marking approach was planned and communicated to the entire project, raising awareness and collaboration. Similarly, for BIM, the tools are not integrated fully into a project, making it inaccessible to each individual involved in the project. Thus, the knowledge gap and management issues can cause resistance to the acceptance of the tool. By improving training and availability of the appropriate BIM tools, these issues can be negated. Training of staff or involving experts can improve the positive perceptions and uptake among the staff. Although not previously recognized as a major barrier according to the literature review for NZ, from the current case studies, a perception of the high cost of Lean and BIM tools was identified. This is particularly true for small to medium size construction companies and projects, according to the interview findings.

Some of the globally-faced challenges such as political environment, lack of tangible benefits, unavailability of standardized tools, lack of contractual standards, and lack of customer involvement were not particularly evident.

5. Conclusions and Recommendations

BIM and Lean implementation barriers were investigated using extensive literature reviews, case studies, and interviews to achieve the study's aim and consolidate the findings. Based on the findings of this study, only a few studies have shown joint implementation in public construction projects. The case studies revealed the advantages of implementing Lean construction jointly with BIM tools in construction projects.

According to the literature, the interaction of Lean principles and BIM tools in construction improves project management practices and significantly facilitates efficiency, including time and cost savings. In line with the case studies, in the New Zealand construction sector, implementing BIM and Lean principles in construction projects has resulted in significant financial savings and a reduction in the occurrence of future challenges. Subject matter experts (S.M.E.s) report a low level of acceptance and application of integrated Lean and BIM in the New Zealand construction sector, citing a lack of trained personnel, a lack of research focus, a lack of awareness among professional stakeholders, and a lack of support from senior management. Even though the implementation of Lean and BIM in the construction sector is facing challenges due to inconsistency of construction processes and products, a better understanding of Lean concepts and BIM methods is required in the construction sector, which would promote enhancement at each level of the construction organization. Due to a lack of trained personnel, a lack of focus on research, a lack of awareness among professional stakeholders, and a lack of support from senior staff, research revealed a low level of acceptance and application of integrated Lean-BIM in the New Zealand construction sector. Thus, adequate attention is needed to Lean-BIM integration in the construction sector in New Zealand. Table 8 documents all the barriers identified in the three stages of this study. In addition, the barriers were associated with different layers of a project, organization, and industry which have interactions and causal effects on each other (Figure 2). The case studies indicate that, without the partnership, acceptance, and the right attitudes from the contractor's team, achieving innovations—and accordingly efficient and lean outcomes—would have been impossible.

The study provides practical and valuable knowledge on the nature of the barriers to BIM and Lean implementation. Industry stakeholders can use the information to direct resources and provide training to overcome these barriers. Training requires high-quality national and worldwide construction industry training and consulting in areas such as project control, accountability, and responsibility, as well as improved functions in the organizations and project management. Considering the major barriers found in the literature review, case studies, and opinions of S.M.E.s, this study suggests that the New Zealand government investigates and supports the implementation and acceptance of Lean and BIM in the construction sector, and create a regulation that might lessen and eliminate the recurrence of such identified barriers in the construction sector. According to the study findings, implementing BIM and Lean jointly in construction was shown to be significantly better than when the two methods were implemented individually. We thus recommend that both Lean principles and the BIM approach be implemented jointly in construction management practices in New Zealand. This is the first study of its kind, a three-step approach of literature review, case study, and subject matter expert interviews to consolidate the outcomes of the literature review and case studies as a method for identifying barriers affecting Lean principles and the BIM approach implementation flow in construction practice in New Zealand. This study recommends that stakeholders in the construction industry globally, including New Zealand, focus on resources and give more suitable training to overcome the many difficulties limiting effective Lean-BIM implementation in construction practice. The study suggests future research to confirm the findings.

Author Contributions: Conceptualization, A.J.L., M.B.J., J.O.B.R.,V.V. and N.V.; methodology, A.J.L., M.B.J., J.O.B.R., V.V. and N.V.; formal analysis, A.J.L., M.B.J., J.O.B.R., V.V. and N.V.; investigation, A.J.L., M.B.J., J.O.B.R., V.V. and N.V.; resources, A.J.L., M.B.J., J.O.B.R.,V.V. and N.V.; data collection, A.J.L., M.B.J., J.O.B.R., V.V. and N.V.; writing—original draft preparation, A.J.L., writing—review and editing, A.J.L. M.B.J., J.O.B.R., V.V. and N.V.; visualization, A.J.L., M.B.J., J.O.B.R., V.V. and N.V.; supervision, M.B.J., J.O.B.R., V.V. and N.V. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: This study has been evaluated by peer review and judged to be low risk by Massey University Human Ethics Committee. The Ethics notification number is 4000023940.

Informed Consent Statement: Informed consent was obtained from all the subjects involved in the study.

Data Availability Statement: The data shown in this study are available on request from the corresponding author. Data is not openly available due to confidentiality matters.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

DEPARTMENT OF CONSTRUCTION MANAGEMENT
SCHOOL OF BUILT ENVIRONMENT
Massey University, New Zealand

Dear Esteemed Respondent,

This is an interview schedule to identify barriers to Lean-BIM implementation in New Zealand (NZ) construction projects. The literature review has indicated that the integration of both BIM and Lean principles within construction would benefit management practices within the construction industry. In this study I intend to investigate:

- How well BIM and Lean principles have been implemented in the NZ construction industry (NZCI)
- If the integration of BIM and Lean is feasible within the NZCI
- What are the likely barriers to integrating BIM and Lean in practice
- What aspects of current construction project management practices could be enhanced by the integration of BIM and Lean

I kindly request your participation in answering this questionnaire. Be assured that your responses will remain confidential and be used strictly for academic purposes. Your answers will be of great help! However, I would be extremely grateful for your valuable time and input if you agree to participate.

Thank you
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Topic: Identify Barriers to Lean-BIM Integration in New Zealand Construction Projects

Questioner: There are three (3) sections in the questionnaire following the initial question regarding the participant's demography: Section A, Lean/Last planner; Section B, BIM; and Section C, BIM and Lean integration.

Introduction question:

Can you please provide a brief background of yourself in the construction industry (your roles and responsibility, years of experience, projects, and type of work you have been involved in)?

Section A: Lean

1. What is your view concerning Lean application in the New Zealand construction industry (NZCI), and does the construction sector have sufficient Lean practices?
    a. Follow-up question: Are you satisfied with the level of Lean awareness and implementation in NZCI?
    b. Follow-up question: What are the priority Lean principles in your view?
2. Can you give some examples of Lean implementation within your organization or the construction industry in general?
3. From your experience, what are the possible challenges to Lean implementation in NZCI?
    a. Follow-up question: How many of these challenges have you experienced within your organization?
    b. Follow-up question: Do you think there is a distinction between barriers at an organizational level and project level?
4. What do you consider to be the most important ingredients to making Lean successful within NZCI?
5. Does an organization need to update leadership commitment and engagement to achieve Lean practices?
    a. Follow-up question: if yes, can you provide some details on the skills required?

6. How does a Lean expert participate in handling key challenges in a construction project? Can you explain how?
7. How can you handle resistance to an effective Lean principle? Can you provide a brief description of this?
8. Do organizations need to apply a guide to learn techniques for material and waste reduction? if yes, can you provide reasons?
9. I have a list of potential barriers to Lean implementation: can you briefly explain how many of these barriers you have experienced in your construction projects and organization? If you think any of the items are not a barrier to Lean implementation in construction projects, explain the reasons and provide evidence for that.
    - poor management
    - lack of top leadership support
    - lack of mandatory BIM and Lean construction industry standards
    - managerial and organizational issues
    - traditional culture
    - culture and philosophy issues
    - client-related traditional practice
    - material-related barriers
    - cost-related barriers
    - lack of performance and knowledge

Section B: BIM

The general philosophy of BIM is in terms of collaboration, information sharing/communication, stakeholder management, supply chain integration, shared values/commitment, etc.

1. Why is BIM important in the construction industry?
2. In your opinion, what are some of the barriers to the industry implementing BIM?
3. Is BIM being effectively used and is it delivering its full potential?
4. What should be included in a BIM execution plan?
5. Why is a BIM execution plan so important?
6. I have a list of potential BIM implementation barriers: can you briefly explain how many of these barriers you have experienced in your construction projects and organization? If you think any of the items are not a barrier to BIM implementation in construction projects, explain the reasons and provide evidence for that.
    a. lack of knowledge of the BIM adoption process
    b. lack of skilled personnel
    c. unawareness of the technology
    d. lack of specified standard
    e. lack of BIM industry standard
    f. unavailability of standard tools
    g. lack of quality in-house staff
    h. high cost of implementation
    i. lack of training
    j. lack of BIM expertise in top management

Section C: Lean-BIM integration

1. What are the requirements of Lean and BIM integration? Please provide your views on the following:
    a. People and organizational requirements
    b. Resources
    c. Technology transfer
    d. Regulation and policy
2. Does integrating Lean-BIM ensure active improvement in construction management?
    a. Follow-up question: If not, what else is required?

3. Does integrating BIM and Lean impact design management and collaboration-related issues?
4. In your opinion, what benefits do you understand that using BIM and Lean construction as an integrated approach would bring into a construction project that is not effectively achieved by implementing them separately?
5. How compatible are Lean principles with modern BIM tools?
6. What features do BIM tools have that allow better implementation of Lean principles in construction?
    a. Follow up: what are BIM's capabilities to integrate with other concepts and philosophies?
    b. Follow up: Have you experienced any integrated BIM practices with Lean principles or other principles?
    c. What are the Lean principles that you prioritize for any integration with BIM?

THANK YOU FOR YOUR TIME

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