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"An Integrated Lean-BIM Framework for Managing Infrastructure Processes and Business Transformation in Construction SMEs"

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Alexandros Anyfantis
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DECLARATION OF ORIGINALITY

Dissertation Title:

An Integrated Lean-BIM Framework for Managing Infrastructure Processes and Business Transformation in Construction SMEs

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Supervisor: Kalampoukas Konstantinos
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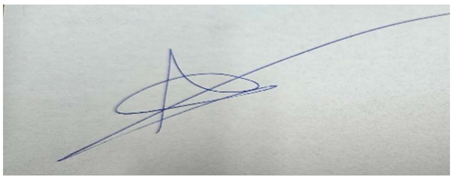

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ABSTRACT

The Greek construction sector is in recovery, yet the productivity of Small and Medium Enterprises (SMEs) remains critically low and the digital divide relative to Northern European markets continues to widen. This dissertation investigates how the strategic integration of Lean Construction and Building Information Modelling (BIM) can facilitate the business transformation of a Greek construction SME and produce measurable improvements in project management efficiency.

The study adopts a retrospective embedded case study design (Yin, 2018), with two completed projects of ATRIUM Anyfantis S.A. as sub-units of analysis: the Ammoa Luxury Hotel & Spa Resort in Khalkidhiki (Project Alpha, €335,000–€360,000, 21 months) and the luxury residential renovation known as The Ship in Vouliagmeni, Athens (Project Beta, ~€500,000, 18 months). Primary data were collected through four semi-structured interviews — with the owner-founder (INT-01), site foreman (INT-02), a long-serving external installer (INT-03), and an ALUMIL industry expert (INT-04) — and triangulated against project financial records and a structured eight-category Muda waste assessment instrument.

Chapter 3 proposes an integrated four-phase Lean-BIM framework spanning 30 months: Phase 0 (Common Data Environment, €150–200/year), Phase 1 (3D pre-production validation, €5,900 Year 1), Phase 2 (Last Planner System integration), and Phase 3 (full 4D/5D integration). The counterfactual analysis in Chapter 4 demonstrates that framework application would have prevented the principal documented failure events: an 8% cost overrun in Project Alpha and a ~15% window frame replacement rate attributable to an AlumilCal software manufacturing error in Project Beta. Break-even analysis yields a projected return on investment of approximately 6% in Year 1 for Alpha-type projects and approximately 396% for Beta-type projects, with the Year 1 investment of €10,600 recoverable within the same year for firms with a large-project portfolio exceeding €100,000.

The findings contribute original empirical evidence from a Southern European SMEs context that is under-represented in the Lean-BIM literature and demonstrate that the SMEs Innovation Paradox — strong demand, available capital, but structural inability to modernise — is resolvable through a phased, economically proportionate transformation strategy.

Keywords: Lean Construction · Building Information Modelling (BIM) · Small and Medium Enterprises · Last Planner System · Common Data Environment · Case Study · Greek Construction Industry · Business Transformation

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LIST OF ACRONYMS

Acronym	Full Definition
BIM	Building Information Modelling
CAD	Computer-Aided Design
CDE	Common Data Environment
CPI	Cost Performance Index
CSRD	Corporate Sustainability Reporting Directive
DESI	Digital Economy and Society Index (European Commission)
ECSO	European Construction Sector Observatory
ELSTAT	Hellenic Statistical Authority
EPBD	Energy Performance of Buildings Directive
ESPA / NSRF	European Structural and Investment Funds Programme for Greece — National Strategic Reference Framework
EU	European Union
EVM	Earned Value Management
GDP	Gross Domestic Product
ICAP CRIF	Hellenic Business Intelligence and Credit Risk Agency
IDSA	International Data Spaces Association
INT-01	Interview 01 — Co-owner / Founder, ATRIUM Anyfantis S.A.
INT-02	Interview 02 — Site Foreman / Civil Engineer, ATRIUM Anyfantis S.A.
INT-03	Interview 03 — External Installer / Technician (35 years with ATRIUM)
INT-04	Interview 04 — Industry Expert, Civil Engineer, ALUMIL S.A. (Northern Greece)
IOBE	Foundation for Economic and Industrial Research (Greece)
ISO	International Organization for Standardization
KPI	Key Performance Indicator
LCA	Life Cycle Assessment
LPS	Last Planner System
MEP	Mechanical, Electrical, and Plumbing (systems)
NBS	National Building Specification (United Kingdom)
PPC	Percentage Plan Complete
RFI	Request for Information
RRF	Recovery and Resilience Facility (European Union)
SME	Small and Medium Enterprise
SPI	Schedule Performance Index

Acronym	Full Definition
TFV	Transformation-Flow-Value Theory (Koskela, 1992; 2000)
TPS	Toyota Production System
4D	Fourth Dimension BIM — time / construction scheduling
5D	Fifth Dimension BIM — cost modelling and quantity take-off
6D	Sixth Dimension BIM — energy performance and sustainability
7D	Seventh Dimension BIM — facility management and asset lifecycle

1 CHAPTER 1: INTRODUCTION

1.1 Context and Industry Overview

The Greek construction sector is recovering. More than that — it is changing in ways that a simple market rebound would not fully explain. After over a decade of severe contraction following the national debt crisis, the Production Index in Construction has risen year on year from 2022 to 2024, driven mainly by capital flowing through the European Recovery and Resilience Facility (ELSTAT, 2024). Greece secured approximately €17.8 billion from the programme, with a significant portion going toward infrastructure, energy retrofitting, and digital investment (European Commission, 2023). A sector that had barely been functioning for ten years is back in motion. GDP contribution has risen steadily since 2021, the workforce grew by around 8% between 2022 and 2024, and private residential development alongside a growing pipeline of public-private partnerships has added real momentum to the picture (ELSTAT, 2024).

But the headline numbers tell only part of the story. In 2017, the McKinsey Global Institute concluded that construction was among the least productive industries in the world — labour productivity in the sector had grown at less than one-third the rate of manufacturing over two decades (McKinsey Global Institute, 2017). That gap has not closed. In Greece, Small and Medium Enterprises account for more than 90% of active construction firms (ICAP CRIF, 2025), and they are under persistent pressure: material costs rose by approximately 3.8% in the second half of 2024 alone (ELSTAT, 2024), while ongoing shortages of skilled labour undermine both quality and schedule reliability. IOBE (2024) and ICAP CRIF (2025) both arrive at the same conclusion: revenues are increasing, but margins are shrinking. According to both reports, the problem is not insufficient demand. It stems from an operational model characterised by reactive management, speculative procurement, and an almost complete absence of structured production planning.

This picture becomes more complex — and more urgent — when viewed in the European context. Two forces are reshaping the construction market across EU member states. One is the European Green Deal, with its binding decarbonisation targets for the built environment (European Commission, 2019). The other is Construction 4.0 — the push toward digital adoption as a structural feature of the industry rather than a competitive option (European Commission, 2024a). Within this context, Greece's recent output performance has been genuinely impressive: Eurostat (2024) places the country among the fastest-growing construction markets in the EU-27, with annualised Production Index growth exceeding 12% in 2023–2024 — well above the EU average.

It is necessary to clarify that growth in output, however, is not the same thing as **growth in productivity**. And the difference matters considerably. Data from the European Construction Sector Observatory (ECSO, 2024) reveals a gap in gross value added per person employed between Greek SMEs and firms in Germany, the Netherlands, and Sweden that has been widening, not closing. Those countries have embedded Lean management into their construction workflows over years of deliberate effort — reducing waste and compressing cycle times in ways that show up clearly in the numbers (Eriksson, 2010; Vrijhoef & Koskela, 2000). Greek firms have not made that shift. Most still rely on labour-intensive, poorly coordinated processes that reflect craft tradition more than industrial management discipline.

The **digital divide** runs alongside this productivity gap. Greece consistently sits in the lower quartile of EU member states on the Digital Economy and Society Index (European Commission, 2024b), and BIM adoption at the SME level remains limited and largely voluntary. In the UK, Germany, France, and across the Nordic states, BIM for publicly funded projects has already moved from encouraged to mandated (Succar & Kassem, 2015; NBS, 2023). The regulatory direction is not reversing. The revised Energy Performance of Buildings Directive (EPBD, 2024) and the Corporate Sustainability Reporting Directive (CSRD) are already changing how contractors are selected across European markets. Firms that cannot produce Life Cycle Assessment documentation or digital delivery records are being cut out — from public tenders and from the supply chains of larger contractors who must comply with these requirements. For Greek SMEs that have yet to begin the digital transition, this is not a distant risk.

1.2 Detailed Problem Statement: The SME Innovation Paradox

There is a paradox at the core of Greek construction right now. Demand is strong, European funding is available, and the case for modernisation has rarely been clearer. And yet most SMEs are structurally unable to take advantage of this moment. Their operational model — built for a different era and reinforced by years of crisis-driven management — is simultaneously the most familiar tool they have and their most significant strategic liability (Egan, 1998; Latham, 1994). This paradox has four dimensions.

Technical Fragmentation and the 2D Legacy

Most Greek SMEs still use two-dimensional CAD as their primary coordination tool. The problem is not simply that the software is dated. It is that 2D documentation creates an information environment that cannot handle modern project complexity. Eastman et al. (2011) and Sacks et al. (2010) have documented this thoroughly: 2D drawings are static, siloed, and structurally prone to coordination errors that only surface during construction — at which point, fixing errors is exponentially more expensive than catching them in a digital model. Research by Love and Li (2000) found that rework from coordination failures can account for between 2% and 15% of total contract value. In environments without digital coordination, the upper end of that range tends to be the reality, not the exception (Hwang et al., 2009). For firms already working on compressed margins, this is not an efficiency problem. It is a solvency risk.

Managerial Inertia and Waste Blindness

Lean Construction theory — developed by Koskela (1992) and extended by Ballard and Howell (1994; 2003) — treats systematic waste as the primary driver of cost and schedule overrun. There are eight waste categories that businesses could largely avoid but rarely do: waiting, overproduction, unnecessary transport, excess inventory, over-processing, unnecessary motion, defects, and the underutilisation of human talent. These are not inevitable features of construction but symptoms of poor process design (Womack & Jones, 1996). In Greek SMEs, that perspective has not taken hold. Management remains reactive — mobilising resources after problems arise rather than designing systems to prevent them. "Waiting waste" — skilled crews standing unproductive because materials have not arrived or a preceding activity remains unfinished — is routinely accepted as part of the job rather than recognised as a management failure (Koskela et al., 2002). Without structured tools that support lean management principles — such as the Last Planner System (Ballard, 2000) — workflow variability goes unmeasured, and therefore unmanaged.

Financial Vulnerability and Absence of Predictive Controls

Without 4D scheduling and 5D cost modelling, Greek SMEs are making financial decisions without reliable foresight. The commodity price shocks of 2021–2023 showed what this means in practice. Steel, timber, and insulation material prices increased by 20–40%; firms with dynamic cost models could renegotiate or redesign in time, while those relying on static budgets absorbed the loss directly (Eastman et al., 2011; IOBE, 2024). The gap between these two outcomes was not determined by firm size or market position. It was determined by whether the firm had the information systems to see the problem coming.

The Cultural and Organisational Barrier

Technology is rarely the real barrier to digital transformation; culture is. Research in innovation management consistently points to organisational norms and beliefs — not software costs — as the primary obstacle (Tidd & Bessant, 2018; Rogers, 2003). In Greek construction firms, many of which are family-owned and led by owner-managers who guided the business through fifteen years of acute economic instability, decentralising decision-making is not a technical adjustment. It is a personal and organisational shift (Gersick et al., 1997). Lean Construction requires collaborative planning — which means distributing authority to foremen and subcontractors. Arayici et al. (2011) found that BIM adoption fails most often not because the software is inadequate, but because the organisation was never restructured to use it properly. Without a clear transformation roadmap, firms that invest in BIM tools frequently find that very little changes — because nothing around the technology has changed.

The Integrated Response: Lean, BIM, and the Construction Project Management Framework

The four dimensions described above are not independent problems with separate solutions. Taken together, they exert simultaneous pressure on all three elements of the project management framework — cost, time, and quality. Technical fragmentation drives rework costs upward. Managerial inertia extends schedules beyond their planned duration. Financial vulnerability leaves firms exposed to supply chain shocks. Cultural resistance prevents the systematic improvement that would protect quality over time. The result is not a single weakness to be patched — it is a pattern of chronic, interconnected failure that affects every dimension of construction innovation and project management (Atkinson, 1999; PMI, 2021).

Figure 1.1 presents the conceptual response to this pattern. It maps the dual intervention of Lean Construction — which addresses workflow discipline and waste elimination — and BIM — which addresses information architecture and coordination quality — onto the traditional constraints of project management. Rather than accepting the Iron Triangle as a set of fixed trade-offs, the integrated framework transforms it: cost overruns become manageable through real-time 5D modelling; schedule reliability improves through structured collaborative planning; quality emerges from systematic coordination rather than post-hoc inspection. The outcome — the Transformed Triangle — is not simply the sum of two separate improvements. It represents a strategic reconfiguration of how Greek construction SMEs can deliver projects and, by extension, compete in their market.

Figure 1.1: The Lean-BIM Transformation of the Traditional Constraints Triangle

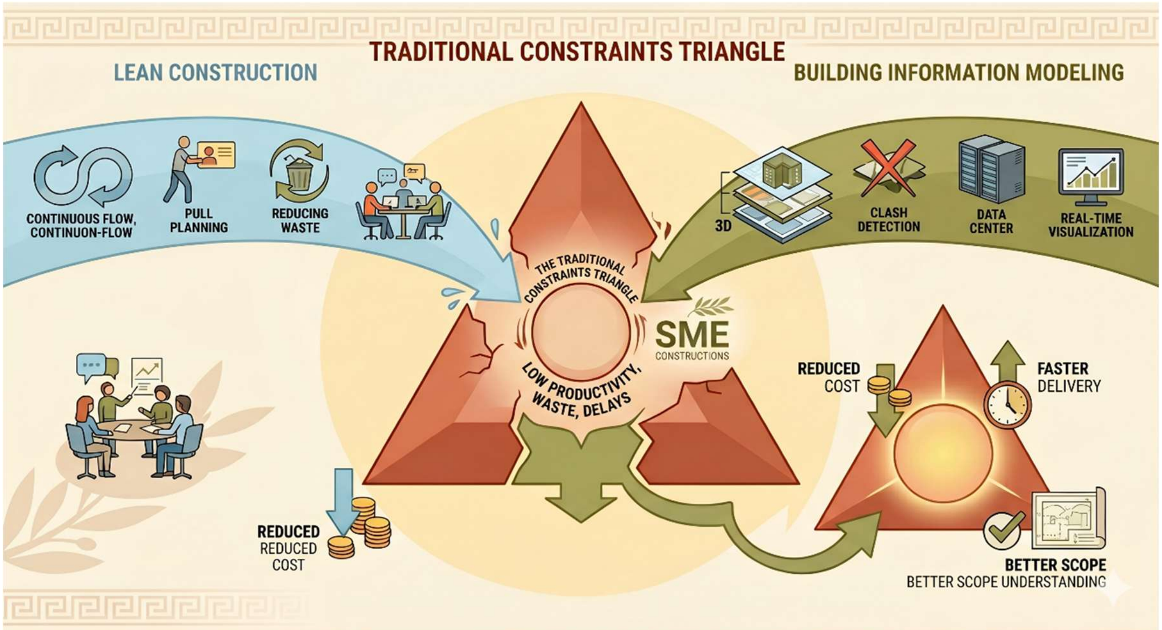

Figure 1.1. The integrated Lean-BIM framework for Greek construction SMEs: from the traditional constraints triangle to a transformed delivery model. Source: Author's own elaboration.

Figure 1.1 captures the transformation logic underpinning this dissertation. The Iron Triangle — cost, scope, and quality — is one of the oldest and most durable frameworks in project management theory (Atkinson, 1999; PMI, 2021). Adjust any one dimension and pressure shifts to the others; the job of project management is to hold the balance. For Greek SMEs in traditional workflows, however, the model does not describe a balancing act. It describes a point of simultaneous chronic failure across all three dimensions.

Lean Construction attacks this at the workflow level, stabilising production sequences through the Last Planner System and making quality a systemic outcome rather than an afterthought (Ballard & Howell, 2003; Koskela, 1992). BIM attacks it at the information level: Clash Detection moves coordination failures from the construction site to the digital model, where resolution costs far less (Eastman et al., 2011), while 4D and 5D capabilities address scheduling and cost control (Sacks et al., 2010). Together — as Dave et al. (2013) demonstrate — their integration produces compounding outcomes that neither approach achieves alone.

1.3 Purpose and Objectives

The purpose of this dissertation is to develop an integrated, lean-based construction project management framework for Greek construction SMEs. This framework draws on the convergence of Lean Construction principles and Building Information Modelling to translate their theoretical synergy into a structured, evidence-based Business Transformation Roadmap — one grounded in the empirical reality of an active Greek construction firm and calibrated to its specific operational, cultural, and financial constraints. Unlike purely theoretical contributions, the study is designed to demonstrate that such a framework is not only academically rigorous but operationally viable: implementable incrementally, within ongoing commercial activity, at an investment scale proportionate to SMEs capital.

To achieve this, five objectives structure the work:

Objective 1 looks at current practice. The aim is to assess how Greek construction SMEs actually manage their projects today, identify the dominant waste typologies, and put some numbers on their cost and schedule impact wherever the data supports it.

Objective 2 maps the synergy between Lean and BIM — specifically, how capabilities like 3D clash detection, 4D scheduling, and 5D cost modelling act as practical enablers for Lean planning tools, with the Last Planner System as the primary focus (Sacks et al., 2010).

Objective 3 concerns the roadmap itself: a phased transformation plan that treats technology, people, and process as one integrated programme rather than three separate workstreams running in parallel.

Objective 4 tests the framework against real project data. Historical records from two completed projects form the empirical basis for assessing what Lean-BIM integration would have actually meant for cost, schedule, and planning reliability.

Objective 5 turns the findings into practical guidance — for the owner-managers who will decide whether to adopt these approaches and for the policymakers who shape the conditions in which that decision is made. The framing matters: this is a strategic repositioning, not a software purchase.

1.4 Research Questions

At the centre of the investigation sits one question:

"In what ways can the strategic integration of Lean Construction and BIM facilitate the business transformation of a Greek construction SME, and what is the measurable impact on project management efficiency and market competitiveness?"

Four sub-questions give this central question its structure:

RQ1 (Analytical): What are the most prevalent forms of operational waste in the traditional workflows of Greek construction SMEs, and how do 2D-based methodologies contribute to them?

RQ2 (Techno-Managerial): How does BIM function as a catalyst for the Last Planner System, and how far can digital prototyping reduce variability in SME project delivery?

RQ3 (Strategic): What are the main organisational, cultural, and financial barriers to Lean-BIM adoption in Greek SMEs, and what strategies can realistically overcome managerial inertia?

RQ4 (Evaluative): Can the proposed framework produce a measurable reduction in delivery times and rework rates in a real-world case study?

The four questions are sequenced deliberately. RQ1 maps the problem. RQ2 asks how change becomes technically possible. RQ3 deals with the harder question — the organisational conditions that determine whether that change can actually happen inside a real firm. And RQ4 puts it to the test, not in theory but against actual project records.

1.5 Significance of the Study

This research matters on two levels. From a theoretical point of view, the Lean-BIM synergy has been studied primarily in large-project environments in Northern Europe, the United States, and Australia (Sacks et al., 2010; Dave et al., 2013). However, the research grounded in the specific constraints of Southern European SMEs remains limited, despite the fact that SMEs represent 99% of all EU enterprises and employ nearly two-thirds of the private-sector workforce (European Commission, 2024a). This gap has a negative impact on the evidence base available to both practitioners and policymakers in markets like Greece, where the structural conditions differ substantially from those studied in the dominant literature. This study generates empirical evidence from a context that is both under-represented in the research and highly representative of the broader EU construction market.

From a practical standpoint, the study provides a roadmap specifically designed for SME conditions: firms operating with limited R&D capacity, needing to see a clear return on any investment, and unable to pause commercial operations for wholesale transformation. It is structured to be implemented in stages, within live project cycles, at a scale proportionate to SMEs capital. The value of such a contribution lies in its specificity: rather than adapting large-firm frameworks downward, this study builds from SMEs reality upward. The study also connects directly to three policy areas: Greece's National Recovery and Resilience Plan priorities around digital transformation and green construction; the EU's Construction 4.0 agenda; and the European Green Deal's material waste reduction objectives (European Commission, 2019) — demonstrating that operational efficiency and environmental performance are complementary, not competing, goals.

1.6 Dissertation Structure

The dissertation consists of five chapters.

Chapter 1 sets the research context, introduces the SMEs Innovation Paradox, presents the conceptual framework of Figure 1.1, and establishes the study's objectives and research questions.

Chapter 2 reviews the literature. It traces Lean Construction from its origins in the Toyota Production System through to the Last Planner System, examines BIM across its dimensions from 3D to 7D, and makes the case for why the two work better together than either does alone. The chapter ends by identifying where the existing research falls short — specifically, the near-absence of work grounded in the conditions facing Southern European SMEs.

Chapter 3 is the framework chapter. It proposes the integrated Lean-BIM implementation methodology: a four-phase Business Transformation Roadmap, the critical success factors that determine whether it delivers the projected outcomes, and the risks that any adopting firm must plan for.

Chapter 4 applies the framework empirically to ATRIUM Anyfantis S.A. It presents the research methodology, documents the two reference projects and their waste profiles, and conducts a counterfactual analysis of what the framework would have meant for cost and schedule outcomes.

Chapter 5 draws the threads together — answering each research question, stating the contributions, offering recommendations, and reflecting on what the study means for the firm and the sector.

2 CHAPTER 2: LITERATURE REVIEW

This chapter builds the theoretical foundation for the dissertation. It begins with the origins and logic of Lean Construction, works through the dimensions of BIM, examines the documented synergy between the two, and then addresses the organisational conditions that determine whether any of this actually works in practice. It closes by identifying the specific gap in the literature that this study is designed to fill.

2.1 The Evolution and Philosophy of Lean Construction

2.1.1 From the Toyota Production System to TFV Theory

Lean Construction did not begin on a building site. The ideas that eventually found their way into construction came from the factories of post-war Japan, where Taiichi Ohno spent the better part of two decades building the Toyota Production System (TPS). At its core, the TPS was a response to scarcity. Toyota could not afford the inventories, the floor space, or the inefficiency that defined Western mass production. So Ohno built a system around two commitments: cut out every activity that consumes resources without producing value, and trust workers enough to let them stop the line when something goes wrong (Ohno, 1988). The rest of the world began paying attention in 1990, when Womack, Jones, and Roos published The Machine That Changed the World — a study that put hard numbers on the performance gap between Toyota and its Western competitors and introduced the word "lean" to the broader management vocabulary. A few years later, Womack and Jones (1996) distilled the logic into five principles — value, value stream, flow, pull, and perfection — and made the argument that none of this was specific to car manufacturing. It could work anywhere.

Koskela (1992) was the first to apply these ideas rigorously to construction. His argument was precise. The dominant project management model at the time — which treated construction as a linear sequence of input-to-output transformations — was missing something fundamental: it rendered waste invisible. Between each scheduled transformation lay a hidden accumulation of waiting, blocked materials, idle labour, and rework that consumed time and money without producing anything of value. Koskela proposed the Transformation-Flow-Value (TFV) model as an alternative, articulated in full in his doctoral thesis (Koskela, 2000). The TFV framework asks managers to see construction simultaneously through three lenses: as a transformation (producing outputs), as a flow (through which waste can be identified and removed), and as a value-generation process (in which outputs genuinely meet client requirements). A manager working within TFV does not just note that a task is running late. They ask why it failed to start, what systemic pattern keeps producing that disruption, and whether the work being produced actually reflects what the client still needs. That shift in question is the shift in management culture that Lean Construction demands — and it is precisely the shift that most Greek SMEs have not yet made.

2.1.2 The Eight Wastes of Construction (Muda)

Muda — the Japanese term for waste — means any activity that consumes resources without delivering value for the client (Womack & Jones, 1996). In manufacturing, waste is relatively visible: machines that are underproductive, mounting inventory without a plan, defective components on the line. In construction, it is more diffuse and far more culturally normalised. Much of what Lean practitioners identify as waste is simply accepted in Greek SMEs as the way building works. Liker (2004) extended the original Toyota list to eight waste categories, adding the underutilisation of human talent — a particularly significant addition in a sector dominated by centralised, owner-led firms where the expertise of foremen and trade supervisors is routinely overlooked. The eight categories, translated to the construction context:

Overproduction: executing work before the downstream process is ready to receive it — prefabricating components that then sit in storage, consuming space and cash (Formoso et al., 2002).

Waiting: crews standing without a purpose because materials have not arrived, a preceding activity is unfinished, or a design question remains unanswered. Sacks et al. (2010) identified this as one of the most prevalent waste categories on construction sites.

Unnecessary Transportation: moving materials or equipment more times than production requires — typically the result of poor site logistics and layout planning (Bertelsen, 2004).

Over-Processing: performing work to a specification higher than the task requires — applying a premium finish to a surface that will be permanently concealed (Koskela, 1992).

Excess Inventory: the 'Just-in-Case' stockpiling that ties up working capital and leaves materials exposed to damage and deterioration on site (Howell, 1999).

Unnecessary Motion: workers walking excessive distances to retrieve tools or drawings because no one has thought carefully about site layout (Koskela, 2000).

Defects and Rework: correcting work that was completed incorrectly — Love (2002) found that rework costs can reach 12% of contract value in environments without digital coordination.

Underutilisation of Human Talent: failing to draw on the practical knowledge and problem-solving capacity of the people closest to the work (Liker, 2004).

None of these waste categories can be reliably identified through observation or intuition alone. They require systematic data collection and collaborative planning — precisely what the Last Planner System is designed to provide.

2.1.3 The Last Planner System: From Scheduling to Commitment Planning

The Last Planner System (LPS) is the most practically significant tool to emerge from Lean Construction research. Developed by Glenn Ballard (2000) and refined with Howell (2003), it rests on a simple but disruptive premise: conventional project schedules describe what should happen. They say nothing about whether the conditions exist today for the planned work to actually start.

The LPS works at three planning horizons. At the project level, a Phase Schedule maps the major work packages and their dependencies—typically built in a collaborative pull-planning workshop where all parties work backward from the target completion date. Within that, a Lookahead Schedule—covering the next four to six weeks—systematically works through each upcoming activity, checking whether the conditions for its execution exist: materials ordered, subcontractors confirmed, design information complete, preceding work finished. Anything blocking an activity gets assigned to a named person responsible for clearing it before the activity reaches the next level. Only tasks cleared of all constraints advance into the Weekly Work Plan—the formal commitments that foremen and trade supervisors make for the coming week. Performance is tracked by the Percentage Plan Complete (PPC): the share of committed tasks actually completed. Projects using the LPS consistently achieve PPC above 85%; traditionally managed projects typically sit at 50–60% (Ballard, 2000). That gap is not a statistical curiosity. It represents the difference between a project under active control and one perpetually in catch-up mode.

2.2 Building Information Modelling (BIM): Concepts and Dimensions

2.2.1 Conceptual Definition and the Shift from 2D CAD

BIM is not software. That distinction is worth stating clearly, because it is the most common misconception about it. BIM is a methodology — a structured approach to creating, managing, and sharing information about a building throughout its entire lifecycle — and the software is the tool through which that methodology is implemented (NBS, 2023; Eastman et al., 2011). Firms that purchase BIM software without changing their information management processes do not get BIM; they get expensive three-dimensional drawing software.

What makes BIM fundamentally different from 2D CAD is parameterisation. In a 2D environment, every design change must be manually propagated across plans, sections, elevations, and schedules — a process that is slow under any circumstances and, under project pressure, a reliable source of inconsistency between documents. In a BIM environment, elements are defined by relationships as well as dimensions: raise a floor level and the sections, stair configurations, and door schedules update automatically. Azhar (2011) identified this automatic coordination as BIM's most significant practical value — not the visual fidelity of the model, but the structural elimination of the manual errors that come from maintaining dozens of drawings in parallel. As Succar (2009) pointed out, BIM is a progressive maturity condition: you do not need the full dimensional suite to begin capturing value.

2.2.2 The Dimensions of BIM: From 3D to 7D

BIM capabilities are commonly described through a dimensional framework that adds successive layers of analytical power to the 3D model (Smith, 2014). 3D provides automated Clash Detection — identifying geometric conflicts between architectural, structural, and MEP systems before they reach site. Eastman et al. (2011) are direct about the economics: resolving a clash in the model costs a fraction of what it costs on site. 4D attaches time to model elements, enabling day-by-day simulation of construction sequences that reveals trade congestion and access conflicts no Gantt chart could predict (Bryde et al., 2013). 5D links elements to cost data, updating quantity take-offs automatically as designs evolve — a significant advantage for SMEs without dedicated estimators (Smith, 2014; Mitchell, 2012). 6D incorporates energy simulation, supporting the Life Cycle Assessment documentation increasingly required by EU procurement rules (Love et al., 2014). 7D delivers the as-built model as a foundation for facility management; extended further, this becomes the Digital Twin — a live, data-connected virtual representation of the physical asset (Boje et al., 2020). The progression from 3D through to 7D is not a requirement but an opportunity: start where the return is clearest and build capability from there.

2.3 Historical Imperative: The Latham and Egan Reports

To understand why Lean and BIM are necessary, it helps to understand how clearly the problem they address was identified — and how long ago. In 1994, Sir Michael Latham produced Constructing the Team, a report commissioned by the UK government in response to widespread dissatisfaction with construction project outcomes. His findings were blunt: the industry was fragmented, inefficient, and culturally adversarial. Disputes were resolved in court rather than on site. His headline target — a 30% real cost reduction through better collaboration and procurement reform — was widely acknowledged and largely unmet (Latham, 1994). Sir John Egan followed in 1998 with Rethinking Construction, drawing lessons from automotive and aerospace manufacturing to argue that construction's persistent inefficiency was not inherent to the industry but a product of its management culture. He proposed annual productivity improvements of 10%, a commitment to zero defects, and the replacement of lowest-price competitive tendering with long-term collaborative relationships (Egan, 1998).

Both reports identified the Design-Bid-Build model as the structural source of what they called the rework cycle: architects designing in isolation, contractors pricing without coordination, and both discovering the gaps in the documentation only after the contract was signed (Sacks et al., 2010). What makes these thirty-year-old diagnoses still relevant is that the conditions they described have not changed in Greece. Adversarial procurement, lowest-bid tendering, and the functional separation of design and construction are still the default in the Greek SMEs sector. The problems Latham and Egan were describing in 1994 and 1998 are still the problems this dissertation is trying to solve.

2.4 The Lean-BIM Synergy and Key Performance Indicators

2.4.1 Theoretical Integration: The 56 Interactions

The most rigorous academic treatment of the Lean-BIM relationship was produced by Sacks et al. (2010), who identified 56 discrete interactions between Lean management functions and BIM capabilities. These cluster into four patterns. BIM supports Lean by providing the information transparency that reliable planning requires — a planner cannot commit to completing a task next week if the design information needed to execute it is incomplete or inaccessible. Lean supports BIM by providing the process discipline needed to act on what BIM reveals — a clash identified in the model is worthless if no one has the authority or the planning structure to resolve it before site mobilisation. BIM enables forms of Lean practice that were previously impossible without digital support, most notably 4D production simulation. And both approaches independently target the same underlying problems — information gaps, workflow variability, coordination failures — through mechanisms that reinforce rather than duplicate each other.

Dave et al. (2013) put it plainly: firms that adopt BIM without Lean process discipline capture only a fraction of the available benefit, because they lack the workflow capacity to act on what BIM tells them. Firms that pursue Lean without BIM hit information bottlenecks that limit how far workflow reliability can improve. The case for integration is not about multiplying two benefits — it is about closing the gap between what each approach can deliver alone and what they can deliver together.

2.4.2 Key Performance Indicators for the Lean-BIM Framework

Key Performance Indicators provide the quantitative basis for evaluating the impact of Lean-BIM integration on project outcomes. The construction management literature has proposed a range of KPI frameworks, which can be organised into four functional categories: planning reliability, BIM coordination quality, project performance, and waste and quality measurement.

Planning Reliability Metrics. The most widely cited Lean planning KPI is the Percentage Plan Complete (PPC), developed by Ballard (2000) as the primary measure of LPS effectiveness. PPC captures the ratio of committed weekly tasks actually completed, with a benchmark of ≥85% indicating a stable, reliable production planning environment. Ballard and Howell (2003) complement PPC with the Constraint Removal Rate — the proportion of identified planning constraints cleared before the relevant activity enters the Weekly Work Plan — and the Causes of Non-Completion analysis, which systematically identifies recurring reasons behind planning failures to create a continuous improvement loop.

BIM Coordination Quality Metrics. Within BIM environments, Eastman et al. (2011) highlight the Clash Detection Resolution Rate — the proportion of geometric conflicts between building disciplines identified and resolved in the virtual model before site mobilisation — as the most direct measure of rework prevention attributable to BIM. Succar (2009) identifies RFI Lead Time (the elapsed time from a Request for Information submission to its resolution) as a key indicator of information management quality, directly responsive to the availability and quality of a Common Data Environment. Bryde et al. (2013), in a systematic review of BIM benefits across forty-five construction studies, document consistent improvements in schedule, cost, and error reduction rates as the primary measurable outcomes of BIM adoption.

Project Performance Metrics. Standard Earned Value Management (EVM) metrics — the Cost Performance Index (CPI) and Schedule Performance Index (SPI) — are widely employed as aggregate indicators of project cost and schedule efficiency against baseline plans (PMI, 2021). A CPI or SPI below 1.0 signals cost overrun or schedule delay respectively, providing a standardised basis for cross-project comparison. These metrics have been applied in Lean-BIM research by Dave et al. (2013) and Bryde et al. (2013) to quantify performance improvements attributable to integrated adoption.

Waste and Quality Metrics. The Rework Ratio — the proportion of total project cost attributable to correcting defective or miscoordinated work — is the most directly applicable quality metric for the context of this study. Love (2002) established baseline rework rates of 2–12% in environments lacking digital coordination, providing a measurable benchmark for pre/post-BIM comparison. Hwang et al. (2009) confirm comparable ranges and document that rework rates are substantially reduced where structured coordination protocols are in place. At the operational level, material waste percentage (Formoso et al., 2002) and crew idle time as a proportion of total working hours translate directly from the Lean waste assessment framework into measurable project data.

In practice, the selection of KPIs for any given SME context must balance comprehensiveness with the data collection capacity available in a small firm without dedicated project controls staff. The five KPIs adopted for the case study analysis in Chapter 4 — PPC, Clash Resolution Rate, RFI Lead Time, CPI/SPI, and Rework Ratio — represent the subset of this broader landscape most directly measurable from the available project records of ATRIUM Anyfantis S.A. and most directly responsive to the Lean-BIM interventions proposed in the

Business Transformation Roadmap. The rationale for this selection is presented in Chapter 4, with explicit reference to the KPI landscape documented here.

2.5 Innovation Management in Construction SMEs

2.5.1 Diffusion of Innovation and the Socio-Technical Challenge

Adopting Lean-BIM in a construction SME is not a procurement decision. It is a socio-technical transformation — one that requires the simultaneous alignment of the technology itself, the organisational processes it is meant to support, and the people whose daily habits and roles it will change (Linderoth, 2010). Rogers (2003) showed that how quickly an innovation spreads through a social system depends on five perceived characteristics: its relative advantage over current practice, its compatibility with existing values and processes, its complexity, whether it can be tried on a small scale before full commitment, and whether its results are visible. In the Greek SME context, complexity and compatibility are the most significant barriers. Lean-BIM appears — from the outside — to require new software, new roles, new planning routines, and a redistribution of decision-making authority. This perception, whether accurate or not, suppresses adoption before any technical evaluation has taken place. Tidd and Bessant (2018) have shown consistently that firms achieving lasting competitive advantage through innovation do so primarily through process change, with technology serving as an enabler rather than a driver. The implication for Lean-BIM is direct: organisational change must precede — or at least accompany — the technology investment. Weick's (1984) concept of "small wins" offers a practical path: demonstrate the value of the approach in a contained, low-risk pilot before requiring wider organisational commitment.

2.5.2 Organisational Culture and the 'Lonely BIM' Phenomenon

Schein (2010) describes three levels at which organisational culture operates: visible artefacts and behaviours, espoused values and policies, and basic underlying assumptions — the deep, often unconscious beliefs that govern actual behaviour regardless of what is formally stated. It is at the third level that the most durable resistance to change resides. In a Greek SME, the assumption that "coordination problems are inevitable and resolved on site" does not dissolve when a manager attends a BIM presentation or purchases new software. It dissolves through repeated direct experience of a different outcome — which is exactly what a structured, evidence-led implementation strategy is designed to generate.

Arayici et al. (2011) showed that successful BIM adoption requires two things working in parallel: bottom-up training that gives site staff and technical personnel the practical capability to use BIM tools, and top-down strategic commitment from owner-managers willing to relinquish some direct control in favour of collaborative planning. Take away either element and the result is what Succar (2009) memorably called "Lonely BIM" — software used in isolation, for individual tasks, without ever achieving the collaborative workflow gains that integrated adoption is designed to produce. Lonely BIM often ends up confirming the sceptic's position: the firm invested, saw limited return, and concluded the technology was not worth it. The actual failure was organisational, not technological. Linderoth (2010) identified one specific indicator more consistently than any other: the absence of standardised information management protocols. Without them, BIM generates a new version of the same fragmentation it was intended to resolve.

2.6 Common Data Environments (CDE)

The Common Data Environment is the information management infrastructure through which BIM collaboration becomes real at the project level. ISO 19650-1 (2018) defines it as a shared digital workspace through which all project information is created, reviewed, approved, and distributed under controlled conditions. In practice, the defining characteristic of a CDE is not its platform but its function: every member of the project team, at any point in the project, is working from the same current, authorised version of information. In a traditional Greek SME project, information exists in multiple disconnected forms—AutoCAD files on personal laptops, design changes sent via Viber, printed drawings marked up by hand. The consequence is predictable: workers build from outdated or incorrect drawings, generating the coordination failures that Love (2002) documented consuming up to 12% of contract value. The CDE resolves this by enforcing four information states—Work in Progress, Shared (available for review), Published (approved for construction), and Archived (superseded but traceable). Only Published information is used on site (ISO 19650-1, 2018). Cloud-based platforms make this accessible at SME scale and price points (Succar, 2009).

A significant conceptual extension of the CDE principle is emerging at the inter-organisational level through the concept of data spaces, promoted by the International Data Spaces Association (IDSA, 2022). While a CDE governs information sharing within a single project team, a data space provides a broader framework of protocols and data models through which organisations can share data across organisational boundaries in a trustworthy and secure manner. A central principle of data spaces is data sovereignty — each participant retains full control over their data even while sharing it with others, with access rights defined and enforced by technical and legal governance mechanisms (IDSA, 2022). For construction SMEs operating within complex multi-tier supply chains — where data flows between designers, main contractors, specialist subcontractors, product suppliers, and facility managers — data spaces represent a meaningful evolution beyond the project-level CDE toward a sector-wide information governance architecture. As European regulatory frameworks such as the EU Data Act and the Gaia-X initiative continue to advance this infrastructure, familiarity with data sovereignty principles becomes increasingly relevant even for small firms beginning their digital transition at the CDE level.

The real investment is not financial—it is the organisational discipline to maintain the protocol consistently across every project.

2.7 Sustainability, Circular Economy, and the Role of Lean-BIM

Construction generates approximately 35% of total EU waste and accounts for close to 40% of total energy consumption — figures that place the sector at the centre of the European Green Deal's decarbonisation programme (European Commission, 2019). The Circular Economy Action Plan (European Commission, 2020) adds further pressure, prioritising resource efficiency at the design stage, waste prevention during construction, and end-of-life material recovery. Lean Construction contributes directly to these objectives through its systematic attack on overproduction, excess inventory, and the material disposal that defects generate. Formoso et al. (2002) put material waste under traditional construction management at 2–8% of total material costs; Kiviniemi and Codinhoto (2014) document higher proportions when all inefficiency categories are counted. BIM's 5D dimension complements this by enabling precise quantity take-offs that replace speculative overordering with Just-in-Time delivery calibrated to actual model quantities (Bynum et al., 2013). Osmani et al. (2008) found that the greatest leverage for material efficiency sits at the design stage — exactly where BIM's coordination capabilities are most powerful.

At the lifecycle level, 6D BIM enables energy performance modelling that supports LCA documentation increasingly required for public contracts, while 7D — extended through the Digital Twin concept (Boje et al., 2020) — turns the project handover into the starting point for lifetime asset management rather than its endpoint. The Ellen MacArthur Foundation

(2013) identified construction as one of the sectors where circular economy principles have the greatest untapped potential, precisely because the current linear model is so evidently wasteful. The Lean-BIM framework is the practical mechanism through which Greek SMEs can begin moving toward that more efficient model — not as an environmental gesture, but as a commercially rational management strategy.

2.8 Summary and Research Gap

The evidence reviewed in this chapter points consistently in one direction. Lean Construction — grounded in TFV theory and operationalised through the Last Planner System — provides a tested methodology for making construction waste visible and reducing it systematically. BIM — built up from 3D coordination through 4D, 5D, 6D, and 7D dimensions — provides the information infrastructure that makes project decision-making transparent, predictable, and collaborative. Their integration, mapped across 56 specific interactions by Sacks et al. (2010) and validated empirically by Dave et al. (2013), produces outcomes that neither approach achieves alone. The CDE operationalises the information dimension. Organisational culture — analysed through Schein (2010), Rogers (2003), and Linderoth (2010) — determines whether any of this actually happens in practice. And European regulation is steadily converting these capabilities from competitive advantages into requirements for market participation.

However, there are also limitations in the existing body of research. Almost all empirical Lean-BIM work has been conducted in large-project environments in Northern and Western Europe, the United States, and Australia — contexts with established BIM mandates, mature professional supply chains, and organisations with dedicated innovation budgets. Research grounded in the specific conditions of Southern European SMEs — and particularly the Greek construction sector — is limited (Antoniou et al., 2021). The barriers operating in Greece — owner-led management, limited R&D investment, entrenched resistance to collaborative planning, and a regulatory environment that has historically required very little digital compliance — are not adequately addressed by frameworks built for structurally different markets. This study addresses that gap by applying the Lean-BIM framework within a real Greek SME, using real project data, and generating a Business Transformation Roadmap calibrated to the conditions of the Hellenic market.

3 CHAPTER 3: A LEAN-BIM FRAMEWORK FOR CONSTRUCTION SMES

This chapter introduces the integrated Lean-BIM framework proposed for construction SMEs. Drawing on the theoretical foundations established in Chapter 2, it translates the documented synergy between Lean Construction and Building Information Modelling into a practical, sequenced implementation programme. The chapter is structured in five parts: an overview of the framework and its architecture; the Business Transformation Roadmap; the critical success factors that determine whether the framework generates the projected outcomes; the risks and constraints that any adopting firm must plan for; and a mapping of how the framework addresses the four research questions of this study.

3.1 Framework Overview and Architecture

The framework proposed here is built on a single premise: sustainable improvements in project management performance within a construction SME require simultaneous progress on two dimensions — information quality and workflow discipline. Improving one without the other produces only partial results. A firm that adopts BIM without process discipline ends up with expensive, underused software. A firm that pursues Lean planning without BIM remains constrained by the information gaps that make reliable commitment planning difficult. The integrated approach is what Sacks et al. (2010) and Dave et al. (2013) both point to as the compounding source of value.

The framework is organised into four sequential phases, each building on the preceding one. The logic is deliberately conservative: start where the return is clearest and the investment lowest, generate measurable evidence before the next commitment is required, and build organisational capability incrementally rather than demanding transformation all at once. This is the 'small wins' strategy (Weick, 1984) operationalised as a 30-month implementation programme. Figure 3.1 presents the complete framework architecture.

Figure 3.1. Lean-BIM Framework: 30-Month Implementation Roadmap for Construction SMEs

Phase	Title	Key Actions	Cost (€/yr) *
Phase 0 Months 1–3	**Information Foundation**	• Cloud-based CDE setup • 4 document workflow states • Change notification protocol • Named information roles	150–300
▼			
Phase 1 Months 4–9	**3D BIM Adoption**	• BIM platform (parametric modelling) • Role-specific training programme • Pre-production 3D validation • Clash Detection — large projects	2,500–5,000 + training
▼			
Phase 2 Months 10–18	**Lean LPS Integration**	• Structured Weekly Work Plan • 4–6 weeks Lookahead Schedule • Constraint analysis & ownership • PPC measurement (target ≥85%)	~0 (process)
▼			
Phase 3 Months 19–30	**4D / 5D Full Integration**	• 4D construction sequence simulation • 5D real-time quantity take-off • Cost dashboard for design changes • Full Lean-BIM cycle operational	500–1,500 (add-ons)

** Cost estimates are indicative and will vary by firm size, geographic market, platform selection, and available training support. They should be validated against current market pricing at time of adoption.*

3.2 The Business Transformation Roadmap

3.2.1 Phase 0 (Months 1–3): Information Foundation

Scope. The entry point of the framework establishes the firm's information management infrastructure before any BIM software is deployed. The goal is a controlled information environment in which every team member works from the same current, authorised version of project data.

Key Actions. The firm selects and configures a cloud-based Common Data Environment on an existing commercial platform. Within the CDE, four document states are defined and enforced: Work in Progress, Shared (available for review), Published (authorised for production or site use), and Archived (superseded but traceable). Named information custodians are assigned for each active project, and a change notification protocol is established: no modification to any Published document reaches production or site teams without formal written confirmation of the version and the change made.

Output. An operational CDE with enforced version control. Design changes are tracked; version conflicts are prevented by design rather than caught by luck; Information Waste is made structurally impossible.

KPIs. Version control compliance rate (target: 100% of active project documents in CDE); change notification lead time (target: same day); uncontrolled design changes reaching production (target: 0).

Resources. Cloud platform subscription (low cost — most firms already hold licences for suitable platforms). The primary investment is organisational: defining protocols, assigning roles, and enforcing compliance.

3.2.2 Phase 1 (Months 4–9): 3D BIM and Pre-Production Validation

Scope. Phase 1 introduces three-dimensional parametric modelling and automated Clash Detection. The primary application is pre-production geometric validation: all critical dimensions, interface details, and connection nodes in large or complex projects are modelled and clash-checked against the structural and architectural frame before any component is manufactured or ordered.

Key Actions. The firm selects a BIM modelling platform appropriate to its project type and supplier ecosystem. Many system manufacturers and industry associations provide training support to their authorised network members; professional BIM training programmes are also widely available. Training should be role-specific — not all staff require full modelling capability. Large projects are modelled from as-built structural dimensions before production begins. Clash Detection is applied to all identified discipline interfaces.

Output. Pre-production geometric validation for all large projects; documented clash resolution rate; reduced rework from measurement and coordination errors.

KPIs. Clash Detection Resolution Rate (target: ≥90%); Rework Rate (target: <3%); RFI Lead Time reduction.

Resources. BIM modelling platform licence; role-specific training programme. Firms should assess supplier training support before committing to commercial training expenditure.

3.2.3 Phase 2 (Months 10–18): Lean Planning Integration

Scope. Phase 2 formalises workflow discipline through the Last Planner System, targeting a Percentage Plan Complete (PPC) of ≥85% — the industry benchmark for reliable workflow (Ballard, 2000).

Key Actions. The firm's existing planning session is restructured into a formal Weekly Work Plan comprising: a) specific task commitments made by each trade supervisor for the coming week; b) explicit identification of constraints — materials, preceding work, design information, access — that could prevent any planned task from starting; c) PPC measurement: the ratio of completed commitments to total commitments, tracked weekly. Upstream of the Weekly Work Plan, a 4–6-week Lookahead Schedule is introduced to identify and resolve constraints before they reach the commitment horizon. For projects involving multiple subcontractors, a fortnightly Pull Planning session builds the programme collaboratively rather than imposing it top-down.

Output. PPC ≥85%; reduced crew idle time; systematic constraint removal; documented planning reliability.

KPIs. PPC (target: ≥85%); Crew Idle Time as percentage of working day (target: <15%); Constraint Removal Rate.

Resources. No software investment required. Facilitation time for planning sessions; basic LPS training for foremen and project managers.

3.2.4 Phase 3 (Months 19–30): 4D/5D Full Integration

Scope. Phase 3 extends the BIM model into scheduling and cost management, completing the integration of digital information with production planning discipline.

Key Actions. 4D scheduling attaches time data to model elements, enabling day-by-day visualisation of the construction sequence. 5D cost modelling links model elements to a cost database, so every design change automatically updates the quantity take-off and the project cost estimate in real time.

Output. Real-time cost dashboard; 4D production simulation for large projects; full Lean-BIM cycle operational.

KPIs. Cost Performance Index (CPI ≥0.95); Schedule Performance Index (SPI ≥0.95); Schedule Overrun (target: ≤1 month).

Resources. 4D/5D add-on modules for the existing BIM platform (indicative cost: €500–1,500/year depending on platform).

3.3 Critical Success Factors

The framework is not self-implementing. Research in Lean-BIM adoption consistently identifies organisational and process conditions as more decisive than technology selection in determining outcomes (Arayici et al., 2011; Linderoth, 2010). Five conditions are necessary for the phased roadmap to deliver the projected outcomes.

1. Leadership commitment from the owner-manager or firm principal. In small, owner-managed firms, no adoption initiative survives without the explicit and sustained endorsement of the person at the top. Arayici et al. (2011) demonstrated that BIM adoption fails most consistently when top-down strategic commitment is absent. The framework's phased architecture is designed to sustain that commitment through a sequence of low-risk, evidence-generating steps rather than requiring a single large commitment (Weick, 1984).

2. Sequential, not simultaneous adoption. Attempting to implement CDE, BIM software, and LPS simultaneously overwhelms a small SME team and increases the risk of abandonment when early difficulties arise. The phased architecture of the roadmap is a design principle, not

a suggestion: each phase must reach operational stability before the next begins. Phase 0 is the non-negotiable entry point regardless of prior technology investment.

3. Process standardisation before technology investment. CDE information protocols must be defined and operating before BIM software is purchased. Technology deployed on top of unstructured information processes does not resolve the problem — it amplifies it (Linderoth, 2010). The sequence Phase 0 → Phase 1 reflects this dependency directly.

4. Supplier and manufacturer ecosystem alignment. Firms operating within established manufacturer or system supplier networks should actively engage those partners in the BIM adoption process. Many major suppliers provide BIM object libraries, technical training programmes, and software support to their authorised networks. Leveraging this support reduces both adoption cost and the learning curve for firm-specific product applications.

5. Role-specific, not uniform, training. Not all staff require BIM modelling capability, and uniform training generates both over-investment and under-utilisation. A role-specific training matrix — developed at the outset of Phase 1 and aligned to the phasing of the roadmap — makes the training investment proportionate to the actual needs of each role: strategic literacy for firm principals; 5D skills for estimators; LPS facilitation for site supervisors.

3.4 Risks and Constraints

Six risk categories warrant explicit planning attention in any SME Lean-BIM adoption programme. For each risk, a primary mitigation strategy is identified.

1. Cultural resistance. The most pervasive risk is the tacit assumption — particularly among longer-serving staff — that coordination problems are an inherent feature of construction rather than a management choice (Schein, 2010). Mitigation: begin with Phase 0, which changes information management habits before requiring any new technology skills. The 'small wins' approach (Weick, 1984) builds confidence through incremental success.

2. Financial exposure during the adoption period. Phase 1 represents the most significant capital commitment in the roadmap, with indicative costs typically in the range of €2,500–5,000 in Year 1 for software and training, depending on platform choice and provider. These figures are indicative and should be verified against current market pricing. Mitigation: the phased model ensures each investment is validated by evidence before the next commitment is

required. A break-even analysis using actual project records should be completed before Phase 1 expenditure is authorised.

3. Skill gap in BIM-literate professionals. In many construction markets, the supply of BIM-trained technical staff at the SME level remains limited. Mitigation: role-specific training; leverage manufacturer and supplier training programmes where available; designate one internal staff member as BIM Champion, responsible for building capability progressively.

4. Interoperability with main contractors and design teams. A subcontractor's BIM model is only as valuable as the information environment into which it flows. If the main contractor does not use BIM, the specialist subcontractor must build their validation model from 2D drawings — which remains substantially more useful than no model, but limits the clash detection scope (Eastman et al., 2011). Mitigation: begin with internal CDE and self-contained 3D validation; negotiate BIM deliverables incrementally with main contractors as capability is established.

5. Time investment in BIM model preparation. Building a pre-production validation model adds technical work before manufacturing or procurement can begin. Mitigation: apply Phase 1 selectively to large and complex projects where the rework risk justifies the model preparation investment. Build model preparation time into the project schedule from initiation.

6. Dependency on supplier or proprietary software reliability. Firms that manufacture components using a single supplier's proprietary software without an independent verification layer are exposed if that software produces systematic errors. Mitigation: the BIM validation model introduced in Phase 1 provides an independent geometric check that production data must match before manufacturing is released, creating a cross-check layer independent of any proprietary production system.

3.5 Research Design for Empirical Validation

The framework proposed in Sections 3.1–3.4 is grounded in the international Lean-BIM literature. To demonstrate its validity and economic rationale within the specific conditions of a Greek construction SME, it is applied empirically in Chapter 4 through a retrospective case study of ATRIUM Anyfantis S.A. The research design — including the epistemological stance, data collection strategy, and analytical approach — is set out in full in Chapter 4, Section 4.1.

The two reference projects provide the empirical baseline against which the framework's projected outcomes are modelled.

3.6 Framework Coverage of the Research Questions

Table 3.1 summarises how the proposed framework, in combination with the literature review in Chapter 2 and the empirical analysis in Chapter 4, addresses each of the four sub-questions established in Chapter 1, Section 1.4.

Table 3.1. Research Questions and Framework Coverage

RQ	Research Question (summary)	Where addressed	How the Framework Responds
RQ1	Prevalent operational waste in Greek SME workflows	Chapter 2 (Sections 2.1.2, 2.4.2) + Chapter 4 (Section 4.2)	Eight Muda categories provide analytical lens; waste empirically assessed in Ch4 waste assessment tables.
RQ2	BIM as catalyst for LPS	Chapter 2 (Section 2.4.1) + Chapter 3 (Sections 3.2.1–3.2.3)	56 Lean-BIM interactions operationalised through Phases 0–2. CDE enables LPS commitment; Clash Detection prevents workflow breaks; 4D makes flow visible.
RQ3	Barriers to Lean-BIM adoption and strategies to overcome them	Chapter 3 (Sections 3.3 and 3.4)	Five CSFs and six risk categories with mitigation strategies address cultural, financial, technical, and organisational barriers.
RQ4	Measurable reduction in delivery times and rework rates	Chapter 4 (Sections 4.4–4.6)	Counterfactual analysis and KPI dashboard provide projected evidence. Prospective study recommended as future research.

RQ1 and RQ2 are substantially addressed through the theoretical foundations in Chapter 2 — the waste taxonomy (Section 2.1.2) and the 56 Lean-BIM interactions (Section 2.4.1) — and are validated empirically through the waste assessment instrument and counterfactual analysis in Chapter 4. RQ3 is addressed directly by Sections 3.3 and 3.4. RQ4 is answered empirically in Chapter 4, Sections 4.4–4.6, through projected outcome evidence based on the two reference projects.

4 CHAPTER 4: CASE STUDY ANALYSIS — ATRIUM ANYFANTIS S.A.

This chapter applies the Lean-BIM framework proposed in Chapter 3 to the operational reality of ATRIUM Anyfantis S.A. It opens with the research methodology that governs the empirical investigation, proceeds through a detailed analysis of the firm and its two reference projects, and then moves to the counterfactual analysis — what the framework would have meant for cost and schedule outcomes in each project. The chapter closes with a KPI dashboard, cost-benefit analysis, and a discussion of the aggregate findings.

4.1 Research Methodology

4.1.1 Research Philosophy and Design

The empirical investigation is grounded in Pragmatism — a research philosophy that selects methods based on what best answers the research question rather than on adherence to a single epistemological tradition (Saunders et al., 2019). A Mixed-Methods design follows: quantitative cost records and waste assessment scores are combined with qualitative interview data to produce a triangulated evidence base that neither source alone could provide.

The research design follows the single embedded case study approach as defined by Yin (2018), in which the focal organisation serves as the primary unit of analysis and the two completed projects serve as embedded sub-units. This design is appropriate when the researcher seeks to understand a contemporary phenomenon within its real-life context — here, the conditions for Lean-BIM adoption within a Greek construction SME — and when the boundaries between the phenomenon and its context are not clearly defined (Yin, 2018). The selection of ATRIUM Anyfantis S.A. as the focal case follows Flyvbjerg's (2006) 'typical case' strategy: the organisation is selected not because it is exceptional, but because its profile — family ownership, specialist subcontractor role, no existing digital coordination infrastructure — is representative of the majority of active construction SMEs in the Greek market. Flyvbjerg (2006) argues that typical cases are particularly valuable for generating knowledge that is transferable to comparable contexts, making ATRIUM a strategically appropriate choice for a study aimed at producing findings relevant to a broader SME population.

The study is retrospective: both reference projects were completed before the research began, and the framework outcomes are modelled through counterfactual scenario analysis rather than real-time measurement. This design choice is justified on both methodological and ethical grounds. Introducing an untested management framework into a live commercial project would expose the firm, its employees, and its clients to financial and operational risks without adequate mitigation — a violation of the non-maleficence principle that requires researchers to avoid causing foreseeable harm to the subjects of their research. Retrospective counterfactual analysis tests the framework's logic against historical data rather than against live commercial exposure (Bryde et al., 2013). It is important to note that all projected outcomes in Chapter 4 — including cost savings and waste reductions — are modelled estimates derived from counterfactual scenario analysis, not measured results from real-time implementation of the framework. They represent what the available evidence suggests would have occurred, not what has been empirically observed.

4.1.2 Data Collection Strategy

Four semi-structured stakeholder interviews were conducted, each using a structured guide developed as an appendix to this dissertation (see Appendix A, Guides INT-01 to INT-04). The father and co-owner (INT-01) provides the strategic and financial perspective of the firm's founder. The site foreman (INT-02) provides the operational workflow perspective, including the estimate that 25–30% of weekly working time is lost to waiting and re-sequencing. The long-serving external installer (INT-03), with 35 years and approximately 500 projects with ATRIUM, provides an execution-level perspective on information management. The Alumil industry engineer for Northern Greece (INT-04) provides an external expert perspective, independently confirming the <10% BIM adoption rate among Greek installers, validating the AlumilCal Ghost Profile bug that caused the frame replacement in Project Beta, and estimating that CDE adoption could reduce approximately 80% of site coordination problems. Secondary data — financial records, project correspondence, change order logs, and design drawings from both reference projects — provides the quantitative backbone for the counterfactual analysis.

4.1.3 Waste Assessment Methodology

The waste assessment instrument was developed from the eight Muda categories of Lean Construction theory (Koskela, 1992; Liker, 2004). Each category was scored on a 5-point Likert scale reflecting the severity and frequency of the waste pattern observed in the reference project. Scores were assigned through a systematic review of three independent sources: project correspondence and change order logs, direct field observations from the researcher's role as managing director on both projects, and corroborating evidence from the semi-structured interviews. Initial scores were cross validated between sources to ensure internal consistency. The scale is defined as follows:

1 — Negligible: waste in this category was not observed or had no measurable impact.

2 — Minor: occasional isolated incidents, resolved without significant cost or schedule consequence.

3 — Moderate: recurring occurrences requiring management attention, with limited financial impact.

4 — Significant: frequent occurrences materially affecting project cost, schedule, or crew productivity.

5 — Severe: persistent, systemic waste with major documented cost or schedule consequences.

4.1.4 Validity, Reliability, and Ethics

Construct validity is ensured through triangulation — the convergence of financial records, waste assessment scores, four independent interviews, and participant observation. Internal validity is strengthened by pattern-matching: causal mechanisms proposed in the counterfactual scenarios are drawn from established Lean-BIM literature, not constructed to fit the data. External validity is bounded to Greek SME specialist subcontractors sharing ATRIUM's structural profile. Reliability rests on documentation: all instruments are available for replication. The researcher's insider position (as owner-manager) is acknowledged and managed through a reflexivity journal, independent interview respondents actively asked to identify weaknesses, and quantitative records treated as primary evidence (Dwyer & Buckle, 2009; Berger, 2015). All interview participants provided informed consent. Financial figures are expressed as ratios and percentages to protect competitive data; the investor in Project Beta is not named.

4.2 Subject of Study

4.2.1 Organisational Profile: ATRIUM Anyfantis S.A.

ATRIUM Anyfantis S.A. was founded in Thessaloniki in 1994 and specialises in the design, fabrication, and installation of building envelope systems: curtain walls, composite panel facades, structural glazing, atriums, and skylights. The firm is an authorised ALUMIL system fabricator. Ownership is shared between the founder and his son, the researcher, who serves as managing director — a first-generation family business structure (Gersick et al., 1997). The permanent workforce of 12 employees is supplemented by a variable network of specialist installation subcontractors. Annual turnover is approximately €1 million, distributed across small projects (≤€50k, ~25%), medium projects (€50k–€150k, ~60%), and large projects (>€150k, ~15%) (INT-01). Production design is handled through AlumilCal (Orgadata GmbH) — a precision 2D software for aluminium system fabricators, not a BIM environment. Project information is exchanged by email, Viber, and printed drawings, with no version control and no Common Data Environment.

4.2.2 Project Alpha: Ammoa Luxury Hotel & Spa Resort, Khalkidhiki

Project Alpha covered the supply, fabrication, and installation of aluminium windows and balcony doors (Alumil S560), glass balcony railings (Alumil M8200), interior Hotelia room doors, and custom entrance doors for the Ammoa Luxury Hotel & Spa Resort in Agios Ioannis, Khalkidhiki. The client and developer was Mentekedis A.E. ATRIUM participated as specialist subcontractor alongside over 15 concurrent trade subcontractors. The initial contract value of €335,000 grew to €360,000 — an 8% overrun of approximately €25,000 — driven by client-driven metric changes, additional material procurement, and COVID-19-related labour and fuel cost inflation of approximately 10%. The project ran from June 2020 to March 2022: 21 months against an originally anticipated programme extended by COVID restrictions, archaeological permit delays, and an internal approval chain involving six engineers. The waste assessment for Project Alpha is presented in Table 4.1.

Table 4.1. Waste Assessment — Project Alpha: Ammoa Luxury Hotel & Spa Resort

Waste Category (Muda)	Score (1–5)	Evidence — Project Alpha (Ammoa Hotel)
Waiting Waste	3 / 5	COVID restrictions and archaeological permit delays caused repeated crew idle periods. Resolved through phone contact the day prior but not systematically prevented.
Rework / Defects	2 / 5	2–3 frames remeasured due to minor opening discrepancies; resolved through buffer stock. Low relative to Project Beta.
Excess Inventory	1 / 5	Deliberate buffer ordering of profiles — controlled and minimal. Not a significant operational issue.

Waste Category (Muda)	Score (1–5)	Evidence — Project Alpha (Ammoa Hotel)
Unnecessary Transportation	4 / 5	15+ concurrent subcontractors across a large resort site required high-frequency material repositioning and multi-trip crew deployment.
Information Waste	3 / 5	Design decisions delayed by a 6-engineer approval chain. Coordination via Viber and telephone only — no version control.
Crew Idle Time	4 / 5	Extended inactive periods from COVID lockdowns and permit delays, with no structured mechanism to redeploy crew to alternative activities.
Material Waste	4 / 5	Client metric changes and COVID-related cost inflation (~10%) drove unplanned additional procurement with no formal change authorisation.
Underutilisation of Talent	2 / 5	Owner–engineer disagreements limited effective use of available expertise but did not constitute a systemic management failure.

Scale: 1 = Negligible | 2 = Minor | 3 = Moderate | 4 = Significant | 5 = Severe (see Section 4.1.3 for full methodology)

4.2.3 Project Beta: 'The Ship' Luxury Residential Renovation, Athens

Project Beta covered the design, fabrication, and installation of premium aluminium window frames, curved sliding systems, and acoustic laminated safety glass (Saint-Gobain) for a landmark luxury residential building in Vouliagmeni, Athens — known as The Ship for its curved facade. ATRIUM was engaged by QProject as specialist subcontractor alongside approximately ten other trade subcontractors. The contract value was approximately €500,000 over eighteen months. Three discrete operational failures — each traceable to an information management gap — define the project's analytical significance: the AlumilCal Ghost Profile bug causing ~15% frame replacement (confirmed independently by INT-04); the undiscovered construction blackout (1 July–1 September) discovered mid-programme; and investor design changes leading to procurement of non-returnable premium materials. The waste assessment for Project Beta is presented in Table 4.2.

Table 4.2. Waste Assessment — Project Beta: 'The Ship' Luxury Residential, Athens

Waste Category (Muda)	Score (1–5)	Evidence — Project Beta (The Ship)
Waiting Waste	4 / 5	Mandatory construction blackout (1 Jul–1 Sep) not identified at project initiation. Two-month enforced stoppage disrupted the entire installation programme.
Rework / Defects	5 / 5	~15% of manufactured window frames required replacement due to the AlumilCal Ghost Profile cutting error — the highest severity rework event across both projects (confirmed: INT-04).

Waste Category (Muda)	Score (1–5)	Evidence — Project Beta (The Ship)
Excess Inventory	2 / 5	Non-returnable premium materials procured against investor specifications that were subsequently revised.
Unnecessary Transportation	3 / 5	Curved facade geometry required specialist logistics for profile delivery and on-site handling but did not constitute a persistent waste pattern.
Information Waste	4 / 5	Investor design revisions were communicated informally and without formal change authorisation, triggering procurement decisions that could not be reversed.
Crew Idle Time	4 / 5	The undiscovered blackout period and multi-contractor access restrictions generated significant periods of enforced crew inactivity during a commercially critical schedule window.
Material Waste	4 / 5	Premium non-returnable aluminium profiles and glass units procured against revoked specifications represented direct material write-off with no recovery mechanism.
Underutilisation of Talent	2 / 5	The firm deployed laser scanning as an informal geometric verification workaround — a creative application of available capability, though outside a structured BIM workflow.

Scale: 1 = Negligible | 2 = Minor | 3 = Moderate | 4 = Significant | 5 = Severe. Scores reflect documented project correspondence, researcher observation, and INT-04 expert confirmation.

Table 4.3. Comparative Project Overview: Project Alpha and Project Beta

Criterion	Project Alpha — Ammoa Hotel	Project Beta — The Ship
Location	Agios Ioannis, Khalkidhiki	Vouliagmeni, Athens
Type	Luxury Hotel & Spa Resort	Luxury Residential Renovation
ATRIUM Scope	Windows (S560), glass railings (M8200), interior and entrance doors	Premium frames, curved sliding systems, acoustic glazing (Saint-Gobain)
Contract Value	€335,000 → €360,000 (+8%)	~€500,000
Duration	21 months (June 2020–March 2022)	~18 months
Subcontractors on Site	15+	~10
Primary Waste	Transport (4/5), Crew Idle (4/5), Material (4/5)	Rework (5/5), Crew Idle (4/5), Information (4/5), Material (4/5)
Primary Causes	COVID, archaeology permits, 6-engineer approval chain	AlumilCal bug, unknown blackout, investor changes
Cost Overrun	~8% (€25,000)	Not fully quantified

4.3 Situational Analysis: As-Is State

The waste assessment scores and interview data converge on a consistent diagnostic picture. ATRIUM is a technically capable firm whose operational performance is constrained not by the quality of its workmanship but by the quality of its information management and production planning systems. The absence of a CDE is the single most consequential structural gap: confirmed by all four interview respondents, it creates the information environment in which the waste scores of 3–5 across both projects are not surprising but structurally predictable. The foreman's independent estimate of 25–30% weekly productive time loss (INT-02) corroborates the Crew Idle Time scores. The founder's acknowledgement that he had never heard of BIM before this research (INT-01) confirms the technology awareness baseline from which the framework must build. The Alumil expert's estimate of <10% BIM adoption among Northern Greek installers (INT-04) confirms that ATRIUM's profile is representative, not exceptional.

4.4 Framework Application: Counterfactual Analysis

The counterfactual analysis applies the Lean-BIM framework proposed in Chapter 3 retrospectively to each reference project. Before presenting the project-specific analyses, Table 4.4 shows how ATRIUM would instantiate the generic framework phases with firm-specific data — costs, applications, and target projects. This bridges the generic roadmap of Figure 3.1 with the specific empirical context of Chapter 4.

Table 4.4. Framework Application to ATRIUM Anyfantis S.A.: From Generic Phases to Firm-Specific Implementation

Phase	Generic Objective	ATRIUM-Specific Application	Indicative Cost (ATRIUM)	KPI Target	Target Projects
Phase 0 (Months 1–3)	Information Foundation — CDE	SharePoint CDE with 4 document states; change notification protocol; managing director as information custodian for all projects	€150–200/yr	Info Waste → 0	All projects
Phase 1 (Months 4–9)	3D BIM Pre-Production Validation	Parametric BIM platform with ALUMIL system object libraries; 3D geometric validation of all openings before production release; Clash Detection against structural drawings	€5,900 (Year 1)	Rework <3% Clash ≥90%	Large projects (> €150k)

Phase	Generic Objective	ATRIUM-Specific Application	Indicative Cost (ATRIUM)	KPI Target	Target Projects
Phase 2 (Months 10–18)	Lean LPS Integration	Formalise existing Monday planning session into structured Weekly Work Plan with PPC; introduce 4–6 week Lookahead; Friday coordination session becomes Pull Planning with subcontractors	~€500 (facilitation)	PPC ≥85% Idle <15%	All projects
Phase 3 (Months 19–30)	4D / 5D Full Integration	4D sequence simulation for large project programmes; 5D cost dashboard linked to model — enables real-time costing of client design changes	€500–1,000 (add-ons)	CPI ≥0.95 SPI ≥0.95	Large projects (> €150k)

Costs are indicative for ATRIUM's profile and verified against INT-04 estimates and current market pricing. Final costs will vary by platform selection.

The counterfactual projections are conservative — drawn from the lower end of documented improvement ranges — and external factors (COVID-19, supplier software bugs covered by the manufacturer) are explicitly separated from internally addressable failures. Savings are projected only against the latter.

4.4.1 Project Alpha Counterfactual

The €25,000 overrun was driven by client-driven metric changes, additional procurement, and COVID inflation. The counterfactual analysis identifies which phases of the framework would have prevented each internally addressable failure. CDE change order protocols (Phase 0) would have controlled the procurement-triggering metric changes. LPS Pull Planning (Phase 2) would have addressed the Crew Idle Time waste (4/5) and Transport Waste (4/5). COVID and archaeological delays remain external and non-preventable.

Table 4.5. Counterfactual Analysis — Project Alpha: Ammoa Luxury Hotel & Spa Resort

Failure Category	Actual Outcome	Lean-BIM Counterfactual	Projected Saving	Framework Phase
Client-driven metric changes	Uncontrolled changes triggered unbudgeted material procurement — part of €25k overrun	CDE change order protocol: each revision requires authorised Scope Change Notification before procurement	~€7,500–10,000	**Phase 0 (CDE)**

Failure Category	Actual Outcome	Lean-BIM Counterfactual	Projected Saving	Framework Phase
Multi-subcontractor coordination (15+ trades)	Crew Idle 4/5; ~25–30% of weekly working time lost to waiting	LPS Pull Planning with all trade supervisors; Lookahead identifies conflicts 4–6 weeks ahead	~€5,000–8,000	**Phase 2 (LPS)**
Raw material delivery delays	Reactive procurement — ordered when needed, not pre-planned	LPS constraint analysis flags lead times 6 weeks ahead	Schedule savings absorbed above	**Phase 2 (LPS)**
COVID / archaeological permits	Unavoidable — forced 3-month extension	Not preventable through Lean-BIM	€0 (external risk)	**N/A (external)**

4.4.2 Project Beta Counterfactual

Project Beta's three failure events are each traceable to information management gaps — making them the most direct test of the framework's preventive value. The framework phase column in Table 4.6 shows that the failures span Phases 0, 1, and 2, confirming that the full framework is required to address the complete failure profile of a complex project.

Table 4.6. Counterfactual Analysis — Project Beta: 'The Ship' Luxury Residential, Athens

Failure Category	Actual Outcome	Lean-BIM Counterfactual	Projected Saving	Framework Phase
AlumilCal/ERP bug (15% frames)	~15% frames replaced; confirmed and covered by ALUMIL (INT-04)	3D BIM validation model: independent geometric check before production release	~€37,500 (50% of €75k)	**Phase 1 (3D BIM)**
Construction blackout (unknown)	2-month stoppage — acceleration costs imposed	LPS Lookahead (4–6 weeks): constraint identified before commitments made	~€10,000–15,000	**Phase 2 (LPS)**
Investor design changes (non-returnable)	Premium materials procured and not required	CDE change order protocol: authorisation gate before procurement	~€5,000–10,000	**Phase 0 (CDE)**
Multi-contractor access (~10 trades)	Waiting waste; laser scanning as workaround	LPS Pull Planning + 4D simulation identifies access conflicts	~€3,000–5,000	**Phase 2 + 3 (LPS + 4D)**

4.5 On-Site Implementation: The Last Planner System

The LPS implementation proposed in Phase 2 formalises practices that already exist informally in the firm. The Monday weekly programming session becomes a structured Weekly Work Plan with PPC tracking. The long-serving installer's practice of calling the previous day to confirm site readiness (INT-03) is a functional, if informal, lookahead — Phase 2 formalises this into a systematic 4–6-week constraint analysis. The site foreman's Friday coordination session (INT-02) becomes a Pull Planning session when subcontractors are involved. PPC is tracked weekly from the outset of Phase 2. The baseline of approximately 55–60% (inferred from the 25–30% idle time estimate) targets 85%+ — a recovery of approximately one productive hour per worker per day.

4.6 KPI Dashboard and Cost-Benefit Analysis

Table 4.7. KPI Dashboard: Baseline Performance vs. Lean-BIM Projected Outcomes

KPI	Alpha Baseline	Beta Baseline	Lean-BIM Target	Source
Cost Overrun	8% (+€25k)	Significant (unquantified)	≤3%	Dave et al. (2013)
Schedule Overrun	~3 months	~2 months	≤1 month	INT-02; Ballard (2000)
Weekly Crew Idle Time	~25–30%	~25–30%	~10–15%	INT-02; PPC ≥85%
Rework / Defect Rate	~2–3%	~15% (frames)	<3%	Love (2002); INT-04
PPC (estimated)	~55–60%	~55–60%	≥85%	Ballard (2000)
RFI Lead Time	0–2 days	Variable	Same day (CDE)	Succar (2009)
Clash Detection	0 (no 3D model)	0 (no 3D model)	≥90% in model	Eastman et al. (2011)

The total first-year investment is approximately €10,600 (indicative), declining to €7,600 from Year 2 as training costs are absorbed.

Table 4.8. BIM Investment Cost Analysis — ATRIUM Anyfantis S.A. (Indicative)

Cost Item	Year 1 (€)	Year 2+ (€)	Category
BIM modelling platform licence (1 seat)	3,400	3,400	Software
Cloud CDE platform	200	200	Software
Initial BIM training — role-specific programme	2,500	0	Training
BIM model preparation — large projects (~80 hrs)	4,000	4,000	Labour
LPS process facilitation (initial setup)	500	0	Process
Total (indicative)	**10,600**	**7,600**	

Table 4.9. Break-Even Analysis: BIM Investment vs. Projected Savings

Category	Project Alpha Type	Project Beta Type	Source
Projected savings — rework	3,750	37,500	Love, 2002; INT-04
Projected savings — schedule	5,000–8,000	10,000–15,000	INT-02; Ballard, 2000
Projected savings — procurement waste	~2,500	5,000–10,000	INT-01; INT-04
Total projected saving (conservative)	~11,250	~52,500	
Annual investment — Year 1 (indicative)	10,600	10,600	Table 4.8
Annual investment — Year 2+ (indicative)	7,600	7,600	Table 4.8
Net return Year 1	**+ €650**	**+ €41,900**	
ROI Year 1	**~6%**	**~396%**	
Break-even portfolio threshold	€100,000+ annual	—	INT-04
ATRIUM actual large portfolio	~€150,000/yr ✓	—	INT-01

4.7 Discussion of Findings

The evidence in this chapter converges on a consistent picture. Both reference projects carried preventable waste — some of it substantial. Project Beta's frame replacement represents a €75,000 defect event, half of which is modelled as preventable through Phase 1 pre-production validation under the counterfactual scenario. Project Alpha's 8% overrun was partially exogenous, but the client-change and procurement components were structurally preventable through Phase 0 CDE and change order protocol. The counterfactual tables model that the failure profile of each project maps directly onto specific phases of the framework: Phase 0 is modelled as addressing information management failures; Phase 1 is modelled as addressing production validation failures; Phase 2 is modelled as addressing workflow coordination failures. No single phase would have prevented all failures — the full framework is required to address the complete risk profile of a large, multi-contractor construction project.

The break-even analysis demonstrates that for a firm with ATRIUM's project portfolio — approximately €150,000 per year in large projects, comfortably above the €100,000 threshold independently estimated by INT-04 — the investment is economically rational within the first year. The framework proposed in Chapter 3 is not merely theoretically coherent: it is financially justified against the documented project record of this specific firm.

One limitation warrants explicit acknowledgement. The outcomes in Tables 4.5, 4.6, and 4.9 are modelled projections, not measured post-implementation results. The logical next step is a prospective study that tracks ATRIUM through Phase 1 and Phase 2 implementation, generating empirical PPC data and documented rework reduction against the baseline established here.

5 CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

This chapter draws the threads of the dissertation together. It synthesises the findings from all four preceding chapters, answers each research question directly with reference to the evidence assembled, states the study's contributions to knowledge and practice, and offers concrete recommendations for the two audiences whose decisions determine whether the framework's potential is realised: the SME owner-managers who make the adoption decision, and the policymakers who shape the market conditions in which that decision is made. The chapter closes with a reflection on the emerging role of artificial intelligence in BIM-enabled construction management, an honest assessment of this study's limitations, and a final observation on what the research means for ATRIUM Anyfantis S.A. specifically.

5.1 Synthesis of Research Findings

The central argument of this dissertation can be stated directly: the performance gap between what Greek construction SMEs currently deliver and what an integrated Lean-BIM framework would enable them to deliver is both substantial and avoidable. The evidence assembled across Chapters 3 and 4 makes this concrete rather than aspirational.

Chapter 2 established the theoretical case. Lean Construction — grounded in Koskela's (1992) Transformation-Flow-Value model and operationalised through Ballard's (2000) Last Planner System — provides a tested methodology for making waste visible and reducing it systematically. BIM — progressing from 3D coordination through 4D, 5D, 6D, and 7D dimensions — provides the information infrastructure that makes project decision-making transparent and predictable. The 56 discrete interactions mapped by Sacks et al. (2010), and the empirical evidence consolidated by Dave et al. (2013), confirm that their integration produces compounding outcomes that neither approach achieves alone. European regulation, meanwhile, is steadily converting these capabilities from competitive advantages into prerequisites for market participation.

Chapter 3 translated this theoretical foundation into a practical implementation programme. The four-phase Business Transformation Roadmap — beginning with a near-zero-cost Common Data Environment (Phase 0, €150–300/yr) and progressing through 3D BIM validation (Phase 1), Last Planner System integration (Phase 2), and 4D/5D full integration (Phase 3) over 30 months — is designed specifically for the resource, cultural, and operational constraints of a construction SME. The five Critical Success Factors (Section 3.3) and six risk categories with mitigation strategies (Section 3.4) translate the framework's logic into actionable guidance. Table 3.1 (Section 3.6) provides an explicit mapping of how each research question is addressed across the chapters of this dissertation.

Chapter 4 tested the framework against the empirical record of ATRIUM Anyfantis S.A. Table 4.4 bridges the generic roadmap of Chapter 3 with the firm-specific context, showing how each phase is instantiated with ATRIUM's actual tools, processes, and costs. Project Alpha (Ammoa Luxury Hotel) recorded an 8% cost overrun — €25,000 on a €335,000 contract — driven by client-driven design changes without procurement controls and multi-contractor coordination reliant on informal messaging. Project Beta (The Ship, Vouliagmeni) was substantially more severe: approximately 15% of manufactured window frames required replacement from the AlumilCal Ghost Profile cutting error, confirmed independently by INT-04; a two-month mandatory site blackout was discovered mid-programme rather than at initiation; and premium non-returnable materials were procured against investor specifications that were subsequently revised. The waste assessments in Tables 4.1 and 4.2 document both projects systematically — Crew Idle Time, Material Waste, and Information Waste at 4/5 across both cases, with Project Beta adding a 5/5 Rework severity. The counterfactual tables (4.5 and 4.6) model a critical finding: no single phase of the framework **would have prevented** all the documented failures. Phase 1 prevents production validation failures; Phase 2 prevents workflow coordination failures; Phase 3 extends predictability into cost and scheduling. The full framework is required to address the complete risk profile of a large, multi-contractor construction project.

The four semi-structured interviews provide the qualitative dimension that the project records alone cannot supply. The founder's statement that he had never heard of BIM before this research (INT-01) places ATRIUM precisely on Rogers' (2003) adoption curve. The foreman's estimate of 25–30% weekly idle time (INT-02) gives the waste assessment scores an operational dimension. The long-serving installer's description of last-minute site decisions driven by poor information flow (INT-03) confirms the pattern from a different vantage point. And the Alumil industry expert's independent confirmation of the AlumilCal bug, her estimate that a CDE could reduce approximately 80% of site coordination problems, and her identification of the €100,000 portfolio threshold for break-even (INT-04) provide external validation that is particularly significant given her independence from both the researcher and the firm.

5.2 Answering the Research Questions

Table 5.1 provides direct answers to the Central Research Question and the four sub-questions established in Chapter 1, Section 1.4. The coverage of each question across chapters is summarised in Table 3.1 (Chapter 3, Section 3.6).

Table 5.1. Research Questions: Findings and Evidence Summary

RQ	Core Finding	Evidence Base
CRQ	The integrated four-phase framework (Chapter 3) resolves the SME Innovation Paradox by addressing information quality (CDE, 3D BIM) and workflow discipline (LPS, 4D/5D) simultaneously. Projected impacts: rework 15%→<3%; idle time 25–30%→10–15%; cost overrun 8%→≤3%; PPC 55–60%→≥85%.	Ch3 (framework, Sections 3.1–3.4 + Table 3.1); Ch4.4 (framework application + counterfactual, Tables 4.4–4.6); Ch4.6 (KPI dashboard, Tables 4.7–4.9); INT-02 (idle time estimate); INT-04 (80% CDE impact)
RQ1	Four dominant waste categories identified across both projects: Crew Idle Time (4/5 both), Material Waste (4/5 both), Information Waste (3–4/5 both), Transport Waste (4/5 Alpha). 2D CAD is the structural root enabler — making coordination errors invisible until they reach site, at which point they are exponentially more expensive to fix.	Tables 4.1 + 4.2 (waste assessments, Section 4.2); INT-01 (no CDE awareness); INT-02 (€3k rework incident, 25–30% idle); INT-03 (hasty site decisions); Love (2002); Koskela (1992)
RQ2	BIM catalyses the LPS through three mechanisms: the CDE provides the information clarity that weekly commitment requires; Clash Detection eliminates coordination surprises that break work plans; 4D simulation makes production sequences visible. As Dave et al. (2013) show, neither approach delivers full value without the other.	Ch2.4.1 (56 interactions, Sacks et al., 2010); Ch3.2.1–3.2.3 (phases 0–2); Table 3.1 (RQ coverage); INT-02 ("a 3D model would significantly reduce waiting"); Ballard (2000) PPC benchmark; Section 4.5 (LPS formalisation)
RQ3	Three barrier categories: (1) cultural — staff age and adaptability, cited by 3 of 4 respondents; (2) knowledge — the	Ch3.3 (Critical Success Factors); Ch3.4 (Risks and Constraints); Table 3.1 (Section 3.6); INT-01 (staff barrier, BIM unfamiliarity); INT-04 (knowledge gap

RQ	Core Finding	Evidence Base
	founder had never heard of BIM before this research; (3) financial — upfront investment uncertainty. Strategy: Phase 0 CDE (€150–200/yr) as a proof-of-concept entry point before any capital commitment.	exceeds cost as barrier); Rogers (2003); Schein (2010); Weick (1984)
RQ4	Yes — counterfactual analysis demonstrates measurable projected improvements. Project Beta: rework 15%→<3% (saving ~€37,500); blackout avoidance ~€10–15k; procurement waste ~€5–10k. Project Alpha: overrun 8%→≤3% (~€12,500 saving). ROI Year 1: ~6% (Alpha-type); ~396% (Beta-type). Critically, no single phase prevents all failures — the full framework is required to address the complete risk profile of a complex project.	Tables 4.5–4.9; Section 4.6; INT-04 (€100k portfolio threshold); INT-01 (ATRIUM ~€150k large portfolio); Ballard (2000); Love (2002). Caveat: projected, not yet measured post-implementation.

5.3 Contribution to Knowledge and Practice

5.3.1 Academic Contribution

This study makes three specific contributions to the construction management literature. First, it generates primary empirical evidence from a context that is simultaneously under-represented in the existing research and highly representative of the broader EU construction market. The dominant Lean-BIM evidence base — built on the work of Sacks et al. (2010), Dave et al. (2013), and Bryde et al. (2013) — is grounded in large-project, Anglo-Saxon, and Scandinavian contexts. This study demonstrates that the framework's logic and its economic rationale transfer to a structurally different environment: a Southern European, family-owned specialist subcontractor with no prior digital coordination infrastructure, operating in a market where BIM adoption at the SME level remains below 10% (INT-04; Antoniou et al., 2021).

Second, the study documents the waste profile of a specialist facade subcontractor as a distinct analytical category. The dominant failure patterns — Crew Idle Time driven by information gaps, Material Waste from uncontrolled design changes, Rework from unvalidated production data — reflect the subcontractor's structural position in the project hierarchy: dependent on others for design information, excluded from early-stage coordination, and exposed to the financial consequences of failures initiated elsewhere. This positional specificity, documented through the two-project waste assessment methodology in Section 4.1.3 and Tables 4.1–4.2, has implications for how Lean and BIM tools should be prioritised in the SME adoption context.

Third, the study provides an empirically grounded economic case for SME Lean-BIM adoption. The break-even analysis in Table 4.9 demonstrates that the framework's Year 1 investment of approximately €10,600 is recoverable within the same year for firms with a project portfolio comparable to ATRIUM's — and recoverable several times over when the most severe documented failure mode (the 15% frame replacement in Project Beta) is prevented. Table 4.4 further demonstrates how the generic framework of Chapter 3 is translated into firm-specific implementation, providing a replicable bridge between theoretical framework and operational practice.

5.3.2 Practical Contribution

The practical contribution is the integrated framework itself: Chapter 3's four-phase roadmap, anchored by the implementation architecture in Figure 3.1, the Critical Success Factor inventory in Section 3.3, the risk registers in Section 3.4, and the Research Question coverage map in Table 3.1. Unlike generic BIM adoption frameworks designed for large main contractors, this framework is built around the constraints that actually govern SME decision-making. Table 4.4 adds a further practical layer by demonstrating exactly how a firm of ATRIUM's profile instantiates each generic phase with specific tools, costs, and target projects.

The waste assessment instrument in Section 4.1.3— the five-point Likert scale applied across the eight Muda categories, triangulated across documentary records, direct observation, and interview evidence — is a replicable tool. Any comparable Greek construction SME can apply it to their own completed projects, generating the empirical baseline that makes the counterfactual analysis and break-even calculation possible without specialist consulting support.

5.4 Strategic Recommendations

Recommendations are directed at the two audiences whose decisions most directly determine whether the framework's potential is realised.

Table 5.2. Strategic Recommendations: SME Owner-Managers and Policymakers

Audience	Recommendation	Rationale / Reference
SME Owners	Begin with Phase 0 (CDE) — not BIM software. Implement version control and a change notification protocol on an existing cloud platform (SharePoint, Google Drive) before any capital commitment.	Highest return-per-euro intervention in the roadmap (Section 3.2.1). INT-04 estimated CDE alone reduces ~80% of site coordination problems. Near-zero cost removes the financial risk barrier entirely.
SME Owners	Engage the ALUMIL Academy for BIM training from Phase 1 onward. Training is available to authorised network members at minimal or no cost.	Eliminates the skill-gap barrier identified in Section 3.4 (Risk 3). ALUMIL has institutional interest in reducing manufacturing errors attributable to its own systems. Confirmed by INT-04.
SME Owners	Formalise PPC measurement alongside — not after — the Weekly Work Plan. One metric, tracked weekly, creates the improvement loop the LPS requires.	Ballard (2000): PPC is the primary diagnostic of workflow reliability. The Monday planning session already exists in ATRIUM (INT-03, INT-02); adding PPC costs nothing and validates Phase 2 investment. Section 3.2.3.
SME Owners	Use the break-even analysis in Table 4.9 when making the adoption decision. One prevented Project Beta-type failure recovers the full Year 1 investment more than three times over.	Rogers (2003): adoption requires visible relative advantage. The financial language of Tables 4.8–4.9 is more persuasive for owner-managers than technical specification. ROI ~396% Year 1 (Beta-type).
Policymakers	Introduce BIM mandates for publicly funded construction contracts above a threshold (e.g., €500,000), consistent with EU precedent in the UK, Germany, France, and the Nordic states.	Succar & Kassem (2015); NBS (2023). A regulatory mandate creates the market signal that justifies private adoption investment. Voluntary adoption at SME scale has consistently failed to scale without it.
Policymakers	Direct RRF and ΕΣΠΑ-funded training subsidies toward Lean-BIM adoption in construction SMEs, with established suppliers (e.g., ALUMIL) as designated training partners.	European Commission (2024a): SMEs represent 99% of EU enterprises. The RRF mandate is digital transformation — subsidised SME training directly serves this objective while leveraging existing supplier infrastructure.
Policymakers	Commission a Greek BIM adoption monitoring index — a sector-specific	Antoniou et al. (2021) documented the evidence gap. INT-04 estimated <10% adoption among

Audience	Recommendation	Rationale / Reference
	extension of the DESI — to track SME adoption rates and identify high-leverage intervention segments.	Northern Greek installers. Without systematic measurement, targeted policy intervention is not possible.

5.5 Future Trends: Artificial Intelligence in BIM-Enabled Construction

This dissertation focuses on the Lean-BIM framework as it currently exists — a combination of well-established tools (CDE, BIM modelling platform, Last Planner System) that is already technologically mature and economically accessible. But it is worth acknowledging, briefly, where the trajectory leads. The Alumil industry expert's unprompted closing observation — "now that the use of technology is more intense than ever, mainly with the integration of artificial intelligence, I believe we will have developments in this direction" (INT-04) — points to a second wave of construction technology that will further widen the gap between digitally capable and digitally absent firms.

Sacks et al. (2020) provide a comprehensive review of the emerging intersection between BIM and artificial intelligence. Three developments are directly relevant to the framework proposed in Chapter 3. The first is machine learning-assisted clash detection: rather than the rule-based detection that current BIM platforms provide, ML models are being trained to predict which clashes will actually cause site disruption, prioritising resolution sequences based on project type and historical data. For a small team without a dedicated BIM coordinator, this reduces the analytical overhead of working with complex facade models. The second is generative design: AI-assisted optimisation of facade system configurations against simultaneous constraints — structural, thermal, cost, fabrication tolerances. For a curtain wall specialist, the ability to evaluate multiple system configurations against fixed cost targets in minutes represents a qualitative change in the value offered at the design stage. The third is the AI-powered Digital Twin: a live, continuously updated virtual representation of a building's operational state, interpreted by an AI layer that predicts maintenance requirements and flags performance anomalies (Boje et al., 2020). These developments are not distant — the current generation of BIM platforms already incorporates several of these capabilities. For ATRIUM, completing Phase 0 and Phase 1 of the roadmap is not simply a performance improvement exercise. It is the prerequisite for participation in the next generation of construction technology value.

5.6 Limitations of the Study

Three limitations deserve explicit acknowledgement. First, the counterfactual outcomes in Chapter 4 are modelled projections, not measured post-implementation results. The savings figures in Tables 4.5, 4.6, and 4.9 are derived from literature benchmarks applied to actual financial records and validated against expert estimates from INT-04, but they represent what would have happened under the framework — not what was directly observed. The logical next step — and the most significant direction for future research — is a prospective study that follows ATRIUM or a comparable firm through Phase 1 and Phase 2 implementation, generating empirical PPC data and documented rework reduction against the baseline established here.

Second, the study draws on the records of two projects from a single firm. The external validity of the findings is appropriately bounded: to Greek SME specialist facade subcontractors sharing ATRIUM's structural and cultural profile — family-owned, 10–15 employees, authorised system installer, no existing digital coordination infrastructure. The study does not claim to represent general contractor experience, Northern European conditions, or larger firm contexts where the adoption economics and cultural barriers are materially different.

Third, the insider researcher position — the researcher as owner-manager of the firm under analysis — represents both a methodological strength and a limitation. It provides unrestricted access to project records, direct first-hand observation, and contextual depth that an external researcher could not achieve. It carries the corresponding risk that interpretations were shaped by pre-existing operational assumptions, even where mitigation strategies (reflexivity journal, external interview respondents, quantitative records as primary evidence) were applied as described in Section 4.1.4.

5.7 Final Reflection and Conclusion

There is something worth acknowledging about the nature of this research that goes beyond its academic contribution. This study was conducted by the person who runs the firm it analyses — someone who managed both reference projects, witnessed these failures directly, and signed the contracts that document the overruns. The analysis in Chapter 4 is not academic at a distance. It is a reckoning with specific operational decisions made over the course of twenty months in Khalkidhiki and eighteen months in Athens.

What makes that reckoning instructive rather than merely personal is what it reveals about the gap between capability and system. The founder of ATRIUM has been in the aluminium systems business since 1965 — sixty years of accumulated expertise about how glass and aluminium behave, how construction sites function, and how client relationships are maintained through difficulty. That expertise is real and competitive. But it has not, until now, been supported by the information architecture and planning discipline that would allow it to prevent failures rather than resolve them. The 15% frame replacement in Project Beta was not caused by ignorance of aluminium systems. It was caused by the absence of a pre-production verification step — a step that Phase 1 of the proposed framework makes standard practice. The €25,000 overrun in Project Alpha was not caused by poor workmanship or weak client relationships. It was caused by the absence of a change order protocol — a protocol that Phase 0 establishes at a cost of approximately €200 per year.

The founder's response when asked about BIM was unambiguous: "I hadn't heard of it before; Alexandros informed me and I've started thinking about how we could integrate it" (INT-01). That single response captures both the problem and the opportunity facing the Greek construction SME sector with unusual clarity. The knowledge now exists, in this firm and in this dissertation. The evidence exists. The economics — documented in Tables 4.8 and 4.9 — support the transition. The framework in Chapter 3 provides the structured entry point, and Chapter 4 demonstrates, against the records of two real projects with real financial consequences, that the investment is not only theoretically justified but practically rational.

The SME Innovation Paradox — strong demand, available capital, clear case for change, but structural inability to act on it — is not a permanent condition. It is a management problem with a management solution. This dissertation is, in its most direct sense, that solution made explicit.

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APPENDIX A SEMI-STRUCTURED INTERVIEW GUIDES (INT-01 TO INT-04)

This appendix presents the four semi-structured interview guides developed for the primary data collection stage of this research. Each guide was tailored to the respondent's role and the specific research questions their perspective was designed to address. Interviews were conducted in a flexible order, allowing respondents to expand on topics relevant to their experience. Follow-up probes (indicated by '→') were used at the interviewer's discretion to elicit deeper responses. All interviews were conducted with informed consent; the confidentiality statement in each guide was read aloud and agreed to before the interview commenced.

The four respondents were:

INT-01 Co-owner and Founder, ATRIUM Anyfantis S.A. — strategic and financial perspective
INT-02 Site Foreman / Civil Engineer, ATRIUM Anyfantis S.A. — operational workflow perspective
INT-03 External Installer / Technician (~35 years with ATRIUM) — execution-level perspective
INT-04 Civil Engineer, Technical Advisor, ALUMIL S.A. (Northern Greece) — external expert perspective

Appendix A.1 — Interview Guide: INT-01

Interview Code	INT-01
Respondent Role	Co-owner and Founder, ATRIUM Anyfantis S.A.
Research Focus	Strategic and financial perspective; digital awareness; cultural readiness for change
Estimated Duration	45–60 minutes
Format	Semi-structured, in person
Related RQs	CRQ, RQ3 (barriers and strategic vision), RQ4 (evaluation potential)

Participant Consent and Confidentiality Statement

1. The interview is being conducted for academic research purposes as part of an MSc dissertation at the Hellenic Open University.
2. Participation is entirely voluntary. You may withdraw at any time without consequence.
3. Your responses will be kept confidential. No identifying information will be disclosed in the dissertation without your explicit consent.

4. The interview may be recorded (audio) for transcription purposes only, with your permission. Recordings will be deleted upon completion of the study.
5. Anonymised findings will be used exclusively for academic analysis and publication.

Do you agree to participate and consent to the above conditions? ☐ Yes ☐ No

Part A: Background and Company Profile

These opening questions establish context and allow the respondent to speak freely about the firm's history and current position.

Q1. Can you describe the history of ATRIUM Anyfantis S.A. — when it was founded, how it has evolved, and its current position in the market?

→ How has the scope of your work changed over the past 10–15 years?
→ What types of projects do you typically take on today?

Q2. How is the company currently structured in terms of roles, responsibilities, and decision-making?

→ Who is involved in project planning and scheduling?
→ How are major decisions — procurement, subcontracting, design changes — made and communicated?

Q3. How would you describe ATRIUM's typical approach to managing a large project from contract to handover?

→ What does a 'normal' project week look like operationally?
→ What information systems or tools do you currently use to manage projects?

Part B: Operational Challenges and Waste

This section explores recurring operational problems and their perceived causes.

Q4. Thinking about projects that did not go as planned — what were the most common causes of cost overruns or schedule delays?

→ Can you think of a specific example where a problem on site cost the company significantly?
→ Was that problem foreseeable? Could it have been prevented earlier?

Q5. How do you currently manage changes requested by clients or the main contractor during a project?

→ Is there a formal process for authorising and recording changes?
→ Have you had situations where materials were procured for a specification that was later revised?

Q6. How is project information — drawings, specifications, instructions — shared between the office and the site team?

→ How do you ensure everyone is working from the latest version of a drawing?
→ Has miscommunication around information ever caused rework or wasted material?

Part C: Awareness of Lean Construction and BIM

This section assesses prior knowledge and openness to change.

Q7. Before this research began, how familiar were you with the term 'BIM' — Building Information Modelling?

→ *Had you seen it used by main contractors or other subcontractors you work with?*
→ *What was your impression of it?*

Q8. Are you familiar with the term 'Lean Construction' or the idea of systematically identifying and eliminating waste in a project workflow?

→ *Do you think the concept applies to a company like ATRIUM?*

Q9. Some of the firms ATRIUM works alongside — main contractors, designers — have you noticed any of them moving toward more digital or structured approaches?

→ *Has a client or contractor ever asked ATRIUM to provide BIM deliverables or use a shared digital platform?*

Part D: Barriers, Readiness, and Strategic Vision

This section explores the firm's capacity and appetite for transformation.

Q10. If you were to adopt a new digital management approach — such as using a cloud platform for project documents and a more structured weekly planning process — what do you think would be the main obstacles?

→ *Would you say cost, time, staff willingness, or something else is the biggest barrier?*
→ *How do you think the team would react to a change in how projects are planned?*

Q11. ATRIUM employs 12 permanent staff with varying levels of technical background. How do you think about training and capability development as the company evolves?

→ *Would you consider investing in BIM training for key staff members?*
→ *Are there members of the team who you think would embrace this kind of change most readily?*

Q12. Looking at the next five to ten years — where do you see ATRIUM? What would a successful, modernised version of this company look like?

→ *Is digital transformation part of that vision?*
→ *What would it take to make you confident that the investment was worthwhile?*

Closing

Thank you very much for your time. Is there anything you would like to add that we have not covered — about the company, the challenges you face, or the direction you would like to go? Your perspective as the firm's founder is central to this research.

Appendix A.2 — Interview Guide: INT-02

Interview Code	INT-02
Respondent Role	Site Foreman / Civil Engineer, ATRIUM Anyfantis S.A.
Research Focus	Operational workflow; waste patterns; time losses; planning practices on site
Estimated Duration	40–50 minutes
Format	Semi-structured, in person or telephone
Related RQs	RQ1 (waste typologies), RQ2 (LPS and planning discipline), RQ4 (evaluation)

Participant Consent and Confidentiality Statement

1. The interview is being conducted for academic research purposes as part of an MSc dissertation at the Hellenic Open University.
2. Participation is entirely voluntary. You may withdraw at any time without consequence.
3. Your responses will be kept confidential. No identifying information will be disclosed in the dissertation without your explicit consent.
4. The interview may be recorded (audio) for transcription purposes only, with your permission. Recordings will be deleted upon completion of the study.
5. Anonymised findings will be used exclusively for academic analysis and publication.

Do you agree to participate and consent to the above conditions? ☐ Yes ☐ No

Part A: Role and Daily Workflow

Q1. Can you describe your role at ATRIUM and what a typical working week looks like for you?

→ How much of your time is spent on site, in the office, or coordinating between the two?
→ How many active projects are you typically managing at the same time?

Q2. How does weekly planning work at ATRIUM? Is there a regular process for deciding what will happen on site each week?

→ Who is involved in that process?
→ How far ahead do you typically plan — one week, two weeks, further?

Q3. How do you receive and distribute information about a project — drawings, specifications, instructions from the main contractor?

→ Do you use any shared digital platform or is it mainly email, phone, and printed drawings?
→ Has a drawing ever been updated without the site team being notified in time?

Part B: Waste and Inefficiency on Site

Q4. Thinking about a typical week on a large project — what percentage of the working day would you estimate is actually productive versus spent waiting, re-sequencing, or dealing with problems?

→ What are the most common reasons for crews standing idle or being redeployed unexpectedly?
→ Can you give an example from a recent project?

Q5. How often does rework occur — situations where completed work has to be corrected or redone? What are the most common causes?

→ Have you been in a situation where frames or components had to be replaced because of a measurement or manufacturing error?
→ What did that cost in time and money, approximately?

Q6. How is material procurement managed? Are materials ordered in advance on a planned basis, or reactively as the need arises?

→ Have you had situations where materials arrived late, delaying work?
→ Or situations where materials were ordered but turned out not to be needed?

Q7. When multiple subcontractors are working on the same site, how is access and sequencing coordinated?

→ Is there a formal coordination meeting with trade supervisors, or is it managed informally?
→ How much time is lost because of trade conflicts or waiting for another subcontractor to finish?

Part C: Planning Tools and Improvement Potential

Q8. Are you familiar with the Last Planner System — a planning approach where each week, foremen make specific commitments about what will be completed, and track whether those commitments are met?

→ Does anything like that happen informally at ATRIUM already?
→ What do you think would change if that process were formalised?

Q9. If you had a complete 3D model of a project — showing all openings, dimensions, and interfaces with the structure — before manufacturing began, what problems do you think that would prevent?

→ Can you think of a specific situation where a 3D check would have avoided a costly mistake?

Q10. From your experience on site, what single change would make the biggest difference to how efficiently ATRIUM's projects run?

→ Is it about information, planning, coordination with other trades, or something else?

Closing

Thank you. Your direct experience of how projects work at the operational level is invaluable to this research. Is there anything else you would like to share about how ATRIUM could improve, or what you have observed on site that this interview has not covered?

Appendix A.3 — Interview Guide: INT-03

Interview Code	INT-03
Respondent Role	External Installer / Technician (approx. 35 years of collaboration with ATRIUM)
Research Focus	Execution-level experience; information flow to site; informal planning practices; cross-project perspective
Estimated Duration	30–40 minutes
Format	Semi-structured, in person or telephone
Related RQs	RQ1 (waste from execution perspective), RQ2 (informal vs. structured planning)

Participant Consent and Confidentiality Statement

1. The interview is being conducted for academic research purposes as part of an MSc dissertation at the Hellenic Open University.
2. Participation is entirely voluntary. You may withdraw at any time without consequence.
3. Your responses will be kept confidential. No identifying information will be disclosed in the dissertation without your explicit consent.
4. The interview may be recorded (audio) for transcription purposes only, with your permission. Recordings will be deleted upon completion of the study.
5. Anonymised findings will be used exclusively for academic analysis and publication.

Do you agree to participate and consent to the above conditions? ☐ Yes ☐ No

Part A: Experience and Working Relationship

Q1. You have been working with ATRIUM for approximately 35 years. How would you describe how the work — and the way it is organised — has changed over that time?

→ Has the complexity of projects increased? The number of trades on site?
→ Have there been changes in how information reaches you on site?

Q2. Can you describe your typical role on an ATRIUM project — from when you receive the job brief to when installation is completed?

→ Who do you communicate with most during a project?
→ What information do you need before you can start work on site, and how do you receive it?

Part B: Information Management and Planning on Site

Q3. How do you find out what you will be doing each week — is there a scheduled briefing, a phone call, or does it happen informally?

→ How far in advance do you usually know the plan?
→ Has it ever happened that you arrived on site and the work was not ready to start?

Q4. When you receive drawings or installation instructions, are they always the latest version? Has a drawing ever been changed without you being told?

→ Can you describe a situation where working from an outdated drawing caused a problem?
→ How was that resolved, and what did it cost?

Q5. In your experience, what are the most common causes of delays or lost time during the installation phase?

→ Is it usually about other trades not finishing before you, materials not arriving, or something else?
→ How much of a typical installation day would you say is genuinely productive?

Part C: Quality and Rework

Q6. Have you been in situations where installed work had to be corrected or redone? What was the cause?

→ Was it typically a measurement problem, a manufacturing issue, or something that happened on site?
→ How were those situations handled — was there a clear process, or was it dealt with case by case?

Q7. When you are about to start a complex installation — a large curtain wall, for example — what preparation would you ideally want to have done in advance to avoid problems?

→ Would a 3D model of the building showing the openings and structure be useful to you?
→ What would you change about how information is prepared and delivered to the installation team?

Part D: Perspective on Change

Q8. Looking at how other installation firms or main contractors you work with operate — do you see any doing things differently that seems to work better?

→ Are there practices from other firms that you think ATRIUM could benefit from adopting?

Q9. If ATRIUM introduced a more structured weekly planning process — where each week's tasks were agreed in advance, constraints were identified ahead of time, and performance was tracked — what do you think the impact would be on site?

→ Would it change how you prepare for a job?

→ *Do you think the team would adapt to it?*

Closing

Thank you very much. With approximately 500 projects over 35 years, your perspective represents a depth of experience that is central to this research. Is there anything else — about how projects are managed, what goes wrong, or what you have seen work well — that you would like to add?

Appendix A.4 — Interview Guide: INT-04

Interview Code	INT-04
Respondent Role	Civil Engineer, Technical Advisor — ALUMIL S.A. (Northern Greece Network)
Research Focus	External expert perspective; BIM adoption rates; software reliability; training support; market context
Estimated Duration	45–60 minutes
Format	Semi-structured, in person or video call
Related RQs	RQ3 (barriers and enablers), RQ4 (validation of cost estimates and savings projections)

Participant Consent and Confidentiality Statement

1. The interview is being conducted for academic research purposes as part of an MSc dissertation at the Hellenic Open University.
2. Participation is entirely voluntary. You may withdraw at any time without consequence.
3. Your responses will be kept confidential. No identifying information will be disclosed in the dissertation without your explicit consent.
4. The interview may be recorded (audio) for transcription purposes only, with your permission. Recordings will be deleted upon completion of the study.
5. Anonymised findings will be used exclusively for academic analysis and publication.

Do you agree to participate and consent to the above conditions? ☐ Yes ☐ No

Part A: Role and Market Overview

Q1. Can you describe your role at ALUMIL and your relationship with the authorised fabricator and installer network in Northern Greece?

→ *How many firms do you work with closely? What is the typical profile of a fabricator in this network?*
→ *How do you support them technically — is it project-by-project or through training programmes?*

Q2. Based on your work with the installer network, how would you describe the current level of digital maturity — specifically BIM adoption — among fabricators and installers in Northern Greece?

→ *What percentage of firms would you estimate are using BIM tools in any meaningful way?*
→ *Has that changed significantly over the past three to five years?*

Q3. What are the most common operational problems you observe among fabricators and installers — the things that most frequently cause cost overruns, delays, or quality failures?

→ Is it primarily a coordination problem, an information management problem, or something else?
→ Have you seen these patterns change as some firms adopt more digital tools?

Part B: Information Management and CDE

Q4. In your experience, how is project information — drawings, specifications, design revisions — typically managed between designers, main contractors, and specialist subcontractors?

→ Is a shared digital environment or Common Data Environment used? How common is that?
→ What happens when a design change is communicated informally — by phone or message — without a formal update?

Q5. If a fabricator were to implement a cloud-based Common Data Environment — a shared platform where all project documents are version-controlled and change notifications are mandatory — how much impact do you think that would have on the problems, you just described?

→ Is there a figure you would put on it — what percentage of coordination problems would that prevent?
→ What would be the main challenge in getting fabricators to actually use such a system consistently?

Part C: AlumilCal and Software Reliability

Q6. ATRIUM experienced a significant rework event on a recent project in Athens where approximately 15% of manufactured window frames had to be replaced. The cause was traced to an issue in AlumilCal related to a 'Ghost Profile' in the cutting optimisation. Are you familiar with this type of error?

→ How common is this type of software-generated manufacturing error in your experience?
→ Is this something ALUMIL has addressed through software updates or user guidance?

Q7. If a fabricator were to build a 3D BIM validation model of each project prior to production — using the as-built structural dimensions to verify all frame sizes before manufacturing — how would that interact with the AlumilCal production process?

→ Would the BIM model provide an independent verification layer that would catch this type of error?
→ Are there other error types in the production workflow that a 3D model would help prevent?

Part D: BIM Training and the ALUMIL Academy

Q8. ALUMIL offers a training programme — the ALUMIL Academy — for authorised network members. What BIM-related training is currently available through that programme?

→ Is there BIM object library support for ALUMIL systems in Revit or other platforms?
→ Is this training available free of charge to authorised fabricators, or is there a cost?

Q9. For a fabricator like ATRIUM — 12 employees, approximately €1 million turnover, currently using 2D AlumilCal only — what would you consider the most realistic and highest-return entry point into BIM adoption?

→ Would you recommend starting with a CDE, a 3D model for large projects, or something else?
→ At what project portfolio size does BIM investment typically become economically justified, in your view?

Part E: Market Trajectory and Policy

Q10. Looking at European regulation — the EPBD, the CSRD, and BIM mandates in public procurement — how do you expect these to affect Greek specialist subcontractors over the next five years?

→ Do you think BIM will become mandatory or effectively necessary for market participation?
→ Are there Greek fabricators in the ALUMIL network already preparing for this?

Q11. You mentioned AI and emerging technology. Do you see specific AI-enabled tools — predictive clash detection, generative design for facade systems — becoming relevant to fabricators at ATRIUM's scale within the next decade?

→ What would it take for those tools to be accessible to a small specialist firm?

Closing

Thank you very much. Your independent expert perspective on the technical, commercial, and regulatory context for BIM adoption in the Greek aluminium systems sector provides crucial external validation for this research. Is there anything further — about market trends, technology adoption, or the specific situation of ALUMIL network members — that you would like to add?