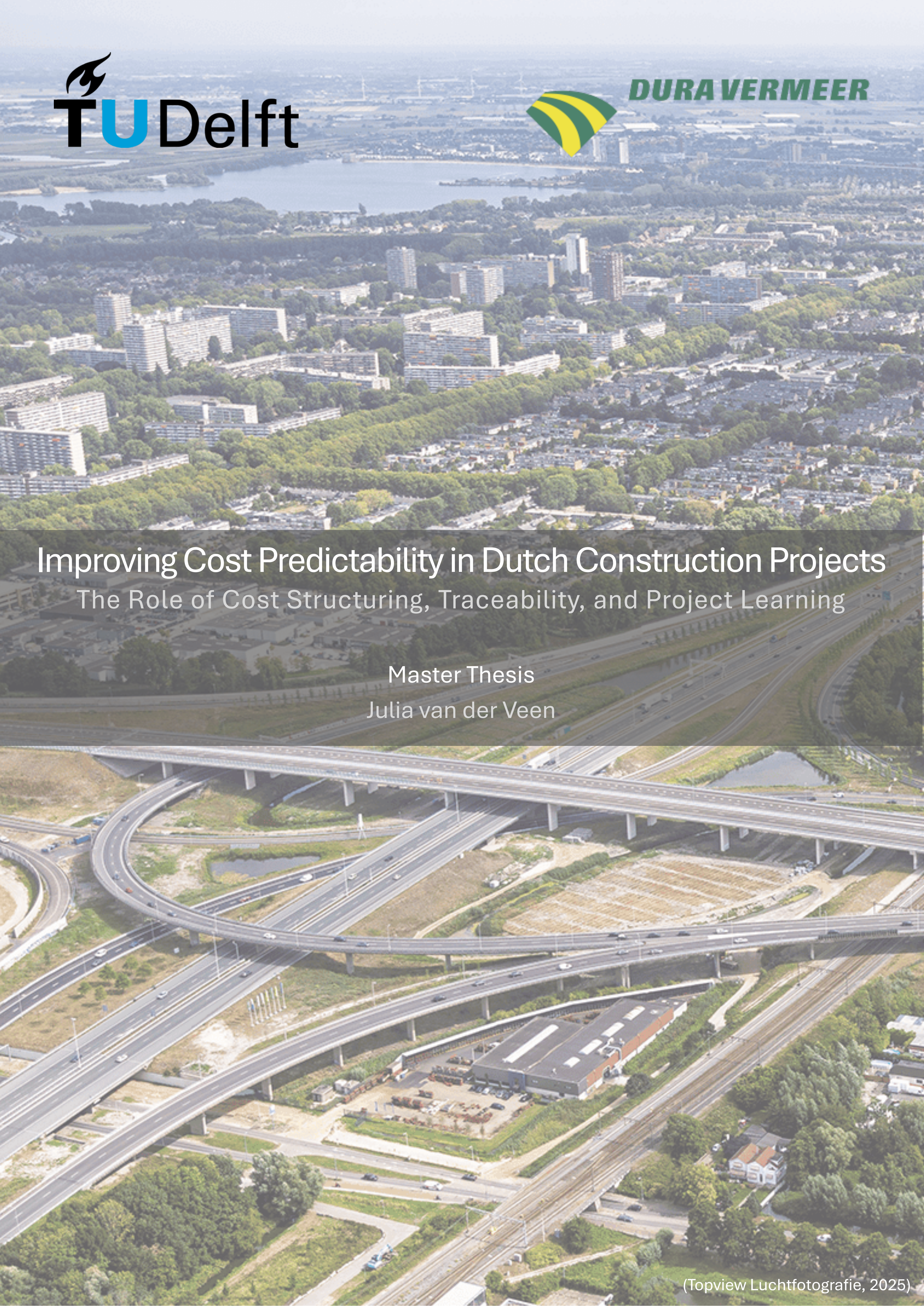
Improving Cost Predictability in Dutch Construction Projects

The Role of Cost Structuring, Traceability, and Project Learning

Master Thesis

Julia van der Veen



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Improving Cost Predictability in Dutch Construction Projects

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by

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Preface

With this thesis, my Master's programme in Construction Management and Engineering at TU Delft comes to a close, and with it, my years as a student. It feels slightly surreal to be writing the final pages of something that has occupied my mind for so many months, but I am proud of where it has ended up.

The process itself had its ups and downs, as I suspect any thesis does. There were weeks when everything fell into place and others when very little did. Looking back, both turned out to be part of the learning.

I would like to thank my supervisors at TU Delft, Daniel Hall and Erik-Jan Houwing, for their guidance, their sharp feedback, and the sparring sessions that helped me bring structure to the research. I am equally grateful to my company supervisors at Dura Vermeer, Alwin Brouwer and Joost Kuijs, for their guidance and support. I also want to thank everyone at Dura Vermeer who took the time to be interviewed for this research and shared their expertise.

Finally, I want to thank my family, boyfriend and friends for their unconditional support, and for helping me put things into perspective whenever I needed it, not only during this thesis, but throughout my entire time as a student in Delft.

With this work, my time as a student ends. I look forward to the years ahead, in which I hope to put what I have learned into practice, and I hope this thesis offers something of value to everyone who continues to work on making construction costs more predictable.

Julia Eva Fiona van der Veen
Katwijk, June 2026

Summary

Cost overruns and cost deviations remain a recurring challenge in Dutch construction and infrastructure projects. Although deviations often become visible during execution through financial reporting, their underlying causes are not always systematically traceable. This makes it difficult for project organisations to learn from cost deviations and to improve the cost predictability of future projects.

This thesis therefore investigates the following main research question:

"How can cost predictability be improved in Dutch construction projects?"

The starting point of this research is that cost predictability does not only depend on more accurate estimates or better forecasting techniques. Equally important is the way in which cost information is structured, transferred and used throughout the project lifecycle. When cost information is repeatedly restructured between tendering, work budgeting, execution, reporting and evaluation, original assumptions may become difficult to recognise or may be lost altogether. As a result, cost deviations may be financially visible, while their underlying causes are no longer causally traceable.

The research is structured in three main phases. First, a literature study was conducted to examine the relationship between cost structuring, cost traceability, project learning and cost predictability. The literature shows that cost traceability is an important condition for double-loop learning. Organisations can only learn structurally from cost deviations when they understand not only that a deviation occurred, but also why it occurred. In addition, five structuring approaches were analysed: Work Breakdown Structure, Critical Path Method, Earned Value Management, Last Planner System and Advanced Work Packaging. Each of these approaches contributes differently to structuring scope, time, cost, progress and execution readiness.

Second, the research empirically examined how cost information is currently structured and used in practice within Dura Vermeer. This was done through organisational-level interviews and three project cases: Highway A16 De Groene Boog Rotterdam, Dike Reinforcement Tiel-Waardenburg and Substation Vierverlaten. The cross-case analysis shows that the studied projects are not characterised by a lack of cost information. On the contrary, extensive information is available in the form of tender estimates, work budgets, cost reports, forecasts, risk registers, change mechanisms and evaluations. The main limitation lies in the structural continuity between these forms of information.

Across the three cases, cost structures change when projects move from tendering to execution, control, reporting and evaluation. This restructuring is often necessary to make the project manageable during execution, but it also weakens the link between original assumptions, execution conditions and final cost outcomes. Indirect costs, such as engineering, project organisation, coordination, contract management and delay-related costs, are especially difficult to trace. The cases also show that cost and physical progress are not always sufficiently integrated, meaning that financial deviations often require manual interpretation before they can be explained in operational terms.

Based on the literature and empirical findings, a Construction Project Cost Traceability Framework was developed. This framework uses the Construction Work Package as a stable

linking unit between tender assumptions, work budgets, physical progress, deviations, change mechanisms, indirect cost drivers and learning outputs. The framework does not prescribe a full implementation of Advanced Work Packaging, Last Planner System or Earned Value Management. Instead, it combines selected principles from these approaches. Advanced Work Packaging provides the lifecycle-oriented package structure, Last Planner System supports execution readiness and feedback during execution and Earned Value Management supports cost-progress measurement at package level.

The framework was subsequently validated through expert interviews with experienced practitioners at Dura Vermeer. The experts recognised the problem diagnosis and the design logic and considered the framework feasible, provided that a number of conditions are met: disciplined cost-data input, deliberate alignment of the systems used across phases, clear ownership of cross-project learning, and incremental introduction supported by change management. Their responses led to targeted refinements, in particular a clearer positioning of the Construction Work Package as a stable linking unit layered over existing procurement and work-budget structures rather than replacing them. The framework should therefore be understood as a validated design proposition rather than as a fully tested project-control intervention.

The main conclusion of this research is that within the context of the studied Dutch infrastructure projects, cost predictability can be improved by strengthening causal cost traceability across the project phases. This means that cost information should not only remain financially visible, but should also remain connected to the assumptions, scope elements, execution conditions and decisions from which cost deviations originate. When these links are preserved, project teams can explain deviations more effectively during execution, and organisations can translate project experience more systematically into future estimates, work budgets and control structures.

The proposed framework contributes to this by connecting cost structuring, cost traceability and project learning. It shifts the focus from merely registering cost deviations towards understanding and using them. Cost predictability does not improve because uncertainty is fully eliminated, but because deviations become more explainable, learnable and transferable to future projects.

Samenvatting

Kostenoverschrijdingen en kostenafwijkingen blijven een terugkerende uitdaging binnen Nederlandse bouw- en infrastructuurprojecten. Hoewel afwijkingen tijdens de uitvoering vaak zichtbaar worden in financiële rapportages, zijn de onderliggende oorzaken niet altijd systematisch te herleiden. Hierdoor wordt het lastig om van kostenafwijkingen te leren en om de kostenvoorspelbaarheid van toekomstige projecten te verbeteren.

Deze thesis onderzoekt daarom de volgende hoofdvraag:

“Hoe kan de kostenvoorspelbaarheid in Nederlandse bouwprojecten worden verbeterd?”

Het uitgangspunt van dit onderzoek is dat kostenvoorspelbaarheid niet alleen afhankelijk is van nauwkeurigere ramingen of betere prognoses. Minstens zo belangrijk is de manier waarop kosteninformatie gedurende de projectlevenscyclus wordt gestructureerd, overgedragen en gebruikt. Wanneer kosteninformatie tussen tender, werkbegroting, uitvoering, rapportage en evaluatie steeds opnieuw wordt geherstructureerd, kunnen oorspronkelijke aannames verloren gaan of moeilijk herkenbaar worden. Daardoor kunnen kostenafwijkingen financieel zichtbaar zijn, terwijl hun onderliggende oorzaken niet meer causaal traceerbaar zijn.

Het onderzoek is opgebouwd uit drie fasen. Eerst is op basis van literatuur onderzocht hoe kostenstructurering, kostentraceerbaarheid, projectleren en kostenvoorspelbaarheid met elkaar samenhangen. Hieruit blijkt dat kostentraceerbaarheid een belangrijke voorwaarde is voor dieper projectleren: organisaties kunnen pas structureel leren van kostenafwijkingen wanneer zij niet alleen weten dát een afwijking is ontstaan, maar ook waarom deze is ontstaan. Vervolgens zijn vijf structureringsbenaderingen uit de literatuur geanalyseerd: Work Breakdown Structure, Critical Path Method, Earned Value Management, Last Planner System en Advanced Work Packaging. Deze benaderingen dragen elk op een andere manier bij aan het structureren van scope, tijd, kosten, voortgang en uitvoeringsgereedheid.

Daarna is empirisch onderzocht hoe kosteninformatie in de praktijk wordt gestructureerd en gebruikt binnen Dura Vermeer. Dit is gedaan aan de hand van interviews op organisatieniveau en drie projectcases: A16 De Groene Boog Rotterdam, Dijkversterking Tiel-Waardenburg en Hoogspanningsstation Vierverlaten. De vergelijking tussen deze cases laat zien dat de onderzochte projecten niet worden gekenmerkt door een gebrek aan kosteninformatie. Integendeel, er is veel informatie beschikbaar in de vorm van tenderbegrotingen, werkbegrotingen, kostenrapportages, prognoses, risicoregisters, wijzigingsmechanismen en evaluaties. De belangrijkste beperking ligt niet in de beschikbaarheid van data, maar in de structurele continuïteit tussen deze informatievormen.

In alle drie de cases verandert de kostenstructuur wanneer het project overgaat van tender naar uitvoering, beheersing, rapportage en evaluatie. Deze herstructurering is vaak nodig om het project bestuurbaar te maken, maar verzwakt tegelijkertijd de koppeling tussen oorspronkelijke aannames, uitvoeringscondities en uiteindelijke kostenuitkomsten. Vooral indirecte en tijdsgebonden kosten, zoals engineering, projectorganisatie, coördinatie, contractmanagement en vertraging gerelateerde kosten, blijken moeilijk traceerbaar. Ook blijkt dat kosten en fysieke voortgang niet altijd voldoende geïntegreerd zijn, waardoor financiële afwijkingen handmatige interpretatie vereisen voordat ze inhoudelijk verklaarbaar worden.

Op basis van de literatuur en de empirische bevindingen is een Construction Project Cost Traceability Framework ontwikkeld. Dit framework gebruikt de Construction Work Package als stabiele koppelingseenheid tussen tenderaannames, werkbegroting, fysieke voortgang, afwijkingen, wijzigingsmechanismen, indirecte kostendrijvers en leeruitkomsten. Het framework schrijft geen volledige implementatie van Advanced Work Packaging, Last Planner System of Earned Value Management voor, maar combineert geselecteerde principes uit deze benaderingen. Advanced Work Packaging biedt de levenscyclusgerichte pakketstructuur, Last Planner System ondersteunt uitvoeringsgereedheid en terugkoppeling tijdens de uitvoering, en Earned Value Management ondersteunt kosten-voortgangsmeting op pakketniveau.

Het framework is vervolgens gevalideerd door middel van expertinterviews met ervaren professionals bij Dura Vermeer. De experts herkenden de probleemdiagnose en de ontwerplogica en achtten het framework haalbaar, mits aan een aantal voorwaarden wordt voldaan: gedisciplineerde invoer van kostendata, het bewust op elkaar afstemmen van de gebruikte systemen tussen fasen, helder eigenaarschap van het leren tussen projecten, en een stapsgewijze invoering ondersteund door verandermanagement. Hun reacties leidden tot gerichte verfijningen, met name een duidelijkere positionering van de Construction Work Package als stabiele koppelingseenheid die over de bestaande inkoop- en werkbegrotingsstructuren ligt in plaats van deze te vervangen. Het framework moet daarom worden opgevat als een gevalideerd ontwerpvoorstel en niet als een volledig getoetste beheersinterventie.

De hoofdconclusie van dit onderzoek is dat binnen de context van de onderzochte Nederlandse infrastructuurprojecten kostenvoorspelbaarheid kan worden verbeterd door causale kostentraceerbaarheid gedurende de projectlevenscyclus te versterken. Dit betekent dat kosteninformatie niet alleen financieel zichtbaar moet zijn, maar ook gekoppeld moet blijven aan de aannames, scope-elementen, uitvoeringscondities en beslissingen waaruit kostenafwijkingen voortkomen. Wanneer deze koppelingen behouden blijven, kunnen projectteams afwijkingen beter verklaren tijdens de uitvoering en kunnen organisaties projectervaringen beter vertalen naar toekomstige ramingen, werkbegrotingen en beheersstructuren.

Het voorgestelde framework draagt hieraan bij door kostenstructurering, kostentraceerbaarheid en projectleren met elkaar te verbinden. Daarmee verschuift de focus van het uitsluitend registreren van kostenafwijkingen naar het begrijpen en benutten ervan. Kostenvoorspelbaarheid verbetert niet doordat onzekerheid volledig wordt weggenomen, maar doordat afwijkingen beter verklaarbaar, leerbaar en overdraagbaar worden naar toekomstige projecten.

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Table 1: List of Abbreviations

Abbreviation	Meaning
AC	Actual Costs
AI	Artificial Intelligence
AWP	Advanced Work Packaging
BAC	Budget at Completion
BOQ	Bills of Quantities
CII	Construction Industry Institute
COAA	Construction Owners Association of Alberta
CPM	Critical Path Method
CV	Cost Variance
CWPs	Construction Work Packages
DBFM	Design, Build, Finance and Maintain
D&C	Design and Construct
EMAT	Economically Most Advantageous Tender
EV	Earned Value
EVM	Earned Value Management
EWPs	Engineering Work Packages
GWW	Earthworks, Road Construction and Hydraulic Engineering
IWPs	Installation Work Packages
CPCTF	Construction Project Cost Traceability Framework
LPS	Last Planner System
PCR	Percent Constraints Removed
PMI	Project Management Institute
PPC	Percent Plan Complete
PV	Planned Value
RFC	Request for Change
SQ	Sub-Question
SV	Schedule Variance
WBS	Work Breakdown Structure
WFP	WorkFace Planning

Glossary

Table 2: Glossary

Term	Meaning in This Research	Dutch Translation
Actual Costs (AC)	The costs actually incurred or booked for completed or ongoing work.	Werkelijke kosten/ geboekte kosten
Causal explanation	The explanation of why a cost deviation occurred, by linking it to assumptions, scope, execution conditions, productivity, planning, changes or indirect effort.	Causale verklaring
Change-driven indirect costs	Indirect costs caused by changes, RFCs, delays, disruption or additional coordination effort.	Wijzigingsgedreven indirecte kosten
Coordination effort	Time and resources spent aligning project actors, interfaces, information, planning and decision-making.	Coördinatie-inspanning
Coordination or indirect effort	A cause category for deviations arising from additional coordination, project organisation, engineering, contract management or other indirect project effort.	Coördinatie- of indirecte inspanning
Cost account	A financial control category or account to which costs are booked.	Kostenpost
Cost baseline	The approved reference budget against which cost performance is monitored.	Kostenbaseline/ referentiebudget
Cost code	A code used to organise, allocate or monitor costs.	Kostencode
Cost deviation	A difference between expected, budgeted, forecasted or realised costs. A cost deviation may be negative or positive.	Kostenafwijking
Cost information	All information used to estimate, budget, control, report, explain or evaluate project costs, including tender estimates, work budgets, cost reports, forecasts, risk registers, RFCs, change records and evaluation documents.	Kosteninformatie
Cost movement	A change in the forecast, budget position or expected final cost of a cost item, work package or project.	Kostenmutatie
Cost overrun	A situation in which realised or forecasted project costs exceed the initial, planned or contracted budget.	Kostenoverschrijding
Cost predictability	The ability to anticipate, control and improve cost outcomes by using structured information and learning from previous cost performance.	Kostenvoorspelbaarheid
Cost-progress integration	The connection between cost information and physical progress information.	Kosten-voortgangsintegratie
Cost structuring	The way cost information is organised, decomposed, aggregated, coded and linked to project elements across project phases.	Kostenstructurering

Term	Meaning in This Research	Dutch Translation
Cost traceability	The ability to link observed cost deviations to their underlying causes by connecting cost information across project phases and relating it to specific activities, assumptions, decisions or execution conditions.	Kostentraceerbaarheid
Cost variance (CV)	The difference between earned value and actual costs.	Kostenvariantie/ kostenafwijking
Cross-phase structural alignment	The extent to which cost structures remain mutually connectable when information moves from one project phase to another.	Structurele afstemming tussen fasen
CWP code	The identifier used to connect information from different systems or documents to the same CWP.	CWP-code/ koppelcode
Delay-related costs	Costs resulting from delay, prolongation, disrupted sequencing or extended project duration. These may include both direct and indirect cost effects.	Vertragingsgerelateerde kosten
Direct production costs	Costs that can be directly linked to physical production activities or discrete work scopes, such as labour, materials, equipment or subcontracted production work.	Directe productiekosten
Double-loop learning	Learning in which the underlying causes of deviations are identified and used to revise assumptions, structures, routines or future practices.	Dubbelvoudig leren
Earned Value (EV)	The budgeted value of the work completed.	Verdiende waarde
Estimating error	A deviation caused by an incorrect or incomplete assumption in the tender estimate.	Calculatiefout/ ramingsfout
Financial visibility	The ability to see that a cost deviation has occurred in financial reports or forecasts.	Financiële zichtbaarheid
Forecast movement	A change in the expected final cost reported during project control.	Prognosemutatie
Indirect cost drivers	The underlying causes or mechanisms that generate indirect costs, such as duration, coordination, engineering, project organisation, contract management, documentation, stakeholder interaction or delay.	Indirecte kostendrijvers
Indirect costs	Costs that support project delivery but are not directly attributable to one discrete production activity, such as site management, engineering support, project organisation, coordination, supervision, contract management, temporary facilities and organisational overhead.	Indirecte kosten
Knowledge owner	The organisational role or responsibility needed to maintain, retrieve and translate project lessons into reusable knowledge for future projects.	Kenniseigenaar

Term	Meaning in This Research	Dutch Translation
Package-specific indirect costs	Indirect costs that can reasonably be linked to a specific CWP, because they support or result from that package.	Pakketspecifieke indirecte kosten
Phase-related indirect costs	Indirect costs that are better linked to a project phase than to one work package, such as tender, preparation, execution or completion.	Fasegebonden indirecte kosten
Physical progress	The actual progress of work in the field.	Fysieke voortgang
Planned Value (PV)	The budgeted value of work planned to be completed at a given point in time.	Geplande waarde
Planning disruption	A disruption in the planned sequence, timing or readiness of work that affects cost performance.	Planningsverstoring
Process- and time-related drivers	Process conditions that can drive costs, such as waiting time, disrupted workflow, coordination effort, delay, readiness problems or changed sequencing. These are treated as cost drivers, not as a separate main cost category.	Proces- en tijdsgerelateerde kostendrijvers
Procurement or material issue	A cost deviation caused by procurement conditions, material availability, supplier performance or price changes.	Inkoop- of materiaalprobleem
Productivity loss	A deviation caused by lower production output than assumed.	Productiviteitsverlies
Project phases	The construction project delivery phases considered in this research: tender, preparation, execution and control, and completion and learning.	Projectfasen
Project-wide indirect costs	Indirect costs that support the project as a whole and cannot meaningfully be allocated to one work package or phase.	Projectbrede indirecte kosten
Readiness conditions	The prerequisites that must be in place before work can start.	Uitvoeringsgereedheid/ randvoorwaarden
Request for Change (RFC)	A formal change mechanism used to register and manage scope, contractual or technical changes.	Wijzigingsverzoek
Schedule variance (SV)	The difference between earned value and planned value.	Planningsvariantie/ planningsafwijking
Single-loop learning	Learning in which deviations are detected and corrected without questioning the underlying assumptions, structures or routines that produced them.	Enkelvoudig leren
Structural continuity	The preservation of meaningful links between cost information forms across project phases.	Structurele continuïteit
Time-related costs	Costs whose magnitude is strongly influenced by project duration, delays, phasing or prolonged project effort.	Tijdsgebonden kosten
Within-phase organisation	The internal structure of cost information within one project phase, such as the tender estimate, work budget or cost report.	Structurering binnen één fase

1 Introduction

1.1 Context and Background

Cost overruns continue to be a recurring phenomenon in construction projects, particularly in large-scale infrastructure developments (Flyvbjerg et al., 2003; Van Wee, 2007). Prior research shows that most infrastructure projects exceed their initial budgets. In a global dataset of 258 projects, 86% experienced cost overruns, with average overruns ranging from 20% for road projects to 41% for rail projects (Cantarelli, Van Wee, et al., 2012). Subsequent research indicates that this pattern has proven persistent over time rather than exceptional (Flyvbjerg, 2014).

Although these figures reflect international trends, similar patterns can be observed within the Netherlands. Empirical studies on Dutch infrastructure projects report average cost overruns of approximately 10% for rail projects and approximately 22% for road projects (Cantarelli, 2011). While these percentages are generally lower than global averages, they nevertheless demonstrate that cost deviations remain a structural characteristic of infrastructure delivery in the Dutch context. Taken together, these findings suggest that deviations between estimated and realised costs are not isolated incidents but rather reflect deeper and persistent challenges within project-based production systems.

Although much of the literature on cost overruns focuses on decision-making biases and megaproject governance, deviations ultimately materialise during project execution. Recent reviews of the field show that the execution phase is the stage where cost and time deviations become operationally visible and managed (Gómez-Cabrera et al., 2023). During execution, initial cost estimates are translated into engineering decisions, procurement strategies, subcontracting arrangements, and on-site production activities. It is therefore in this phase that planned assumptions are tested against operational reality.

Cost control during execution is particularly complex in construction due to the temporary and multi-organisational nature of projects (Son, 2022). Each project involves a unique constellation of stakeholders, contractual arrangements, and contextual constraints. Although significant progress has been made in the development of estimation techniques and cost management systems, the persistence of cost overruns suggests that improving predictability remains a complex challenge. The continued occurrence of deviations indicates that translating cost information into consistent improvements is not straightforward (Cantarelli, Molin, et al., 2012). Rather than being solely a matter of inaccurate initial estimates, cost performance appears to be influenced by how information is structured within projects.

A specific challenge concerns indirect costs, particularly when they are driven by process- and time-related activities. Indirect construction costs, such as site management, engineering support, coordination, supervision, temporary facilities, and organisational overhead, may represent a substantial proportion of total project expenditure (Becker et al., 2014). Unlike direct production costs, indirect costs are often less directly attributable to discrete work activities and are therefore more difficult to estimate and control (Faria et al., 2020; Chan & Pasquire, 2004). Empirical research indicates that indirect costs are frequently estimated based on professional judgement rather than systematic data-driven methods, increasing the risk of underestimation and limited recovery once deviations occur (Chan & Pasquire, 2004).

Beyond issues of estimation and control, the persistence of cost overruns has also raised questions about the extent to which learning takes place within the construction industry. Despite the development of increasingly sophisticated forecasting tools and project management techniques, improvements in estimation accuracy appear limited over time (Ahiaga-Dagbui & Smith, 2014). Earlier research has similarly suggested that patterns of cost growth have remained remarkably stable across decades of project delivery (Flyvbjerg, 2002).

Ahiaga-Dagbui and Smith (2014) argue that part of this challenge may lie in the interaction between cognition, feedback, and learning. When systematic feedback on cost performance is weak or inconsistently integrated into future decision-making, opportunities for improvement remain constrained. In project-based environments, where teams disband after completion, the capture and transfer of knowledge become complex. As a result, similar cost estimation errors may reoccur when experiences and lessons learned from previous projects are not translated into improved future estimation practices.

Against this background, persistent cost deviations suggest not only limitations in forecasting accuracy, but more fundamentally an inability to systematically understand and learn from cost performance during project execution. While deviations become visible in financial monitoring, their underlying causes often remain difficult to trace back to specific assumptions, decisions, or execution conditions. As a result, opportunities for learning remain constrained, which in turn limits the ability to improve cost predictability in future projects.

This has led to increasing attention for structuring methodologies that aim to improve alignment between estimation, planning, execution, and reporting. Rather than focusing solely on improving forecasting techniques, these approaches emphasise the way in which project information is structured and linked across project phases.

Various structuring approaches exist in both literature and practice, each aiming to improve coordination, transparency, and control. One example is Advanced Work Packaging (AWP), which introduces a hierarchical work packaging structure to better align engineering, planning, and execution activities.

While approaches such as AWP have demonstrated potential in improving coordination and execution performance, their relevance for cost traceability, project learning, and cost predictability remains insufficiently understood, particularly in the Dutch construction context.

1.2 Problem Statement

While the challenges described in the previous section are widely recognised, a more specific problem emerges when examining how cost information is structured and used across the project lifecycle. Cost deviations are often visible in financial reporting, but this visibility does not automatically explain how or why the deviation occurred. In practice, tender estimates, work budgets, execution planning and cost reports are structured for different purposes and at different levels of aggregation. When cost information is transferred between these structures, original assumptions about quantities, productivity, phasing, scope boundaries, coordination effort or risk exposure may become condensed, reclassified or disconnected from the final cost outcome. As a result, a project team may be able to see that a cost item has deteriorated but may not be able to determine whether this deterioration originated from an estimating assumption, a scope change, altered execution conditions, productivity loss, planning disruption or indirect effort.

The core problem addressed in this research is therefore not the absence of cost data, but the limited causal traceability of cost information across project phases. This limited traceability constrains the ability of organisations to learn from both ongoing and completed projects. Importantly, project learning does not only depend on whether deviations occur, but on the ability to understand why they occur. While deviations may be identified in financial monitoring, their underlying causes often remain ambiguous or only partially understood.

A key issue underlying this problem is the lack of consistent structuring of cost information across project phases. When cost information is not systematically linked between estimation, execution, and reporting, it becomes difficult to reconstruct the causal mechanisms behind deviations. As a result, feedback loops between estimation and execution may remain fragmented, not necessarily because organisations do not attempt to learn, but potentially because the causal mechanisms behind deviations cannot be clearly reconstructed.

Consequently, similar cost estimation errors or deviations may reoccur, not necessarily due to a lack of technical capability, but because experience is not effectively translated into structured and actionable knowledge. In this sense, learning is constrained not only by the occurrence of deviations, but by the limited traceability required to interpret them.

Addressing this issue requires a structuring approach that enables cost information to be consistently linked across project phases, allowing deviations to be related to specific work scopes, assumptions, and execution conditions. This implies the need for a stable and shared structuring logic that connects estimation, execution, and reporting, while limiting shifts in aggregation levels throughout the project lifecycle. Without such consistency, deviations may be visible but remain difficult to interpret and therefore difficult to translate into actionable learning.

Various structuring approaches have been proposed to improve coordination and alignment in project environments. One example is AWP, which introduces a package-based structure that explicitly links engineering deliverables, construction scope, and field execution (Ponticelli et al., 2015; Sepúlveda et al., 2023). From this perspective, AWP may be considered theoretically relevant, as it may support the alignment of information across project phases and enable a clearer connection between performance outcomes and underlying execution conditions.

However, despite this conceptual fit, the extent to which such structuring approaches can contribute to cost traceability and project learning within Dutch construction projects remains insufficiently understood.

1.3 Research Objective

The objective of this research is to examine how cost information is structured and utilised across the project lifecycle in Dutch construction projects, and how this influences cost traceability, project learning, and ultimately cost predictability.

More specifically, this study aims to analyse how cost estimation, work execution, and cost reporting are currently organised in practice, and how these are structurally connected, or disconnected, throughout the project lifecycle. While these domains are theoretically interrelated, they are often organised through different structures and levels of aggregation in practice.

Cost estimation defines the initial assumptions and expectations, execution reflects how these assumptions materialise in practice, and reporting captures the resulting performance. However, when these structures are not consistently aligned, it becomes difficult to relate observed cost deviations to their underlying causes. In such cases, deviations may be visible in reporting but cannot be systematically traced back to specific assumptions or execution conditions.

This suggests that the challenge is not primarily the absence of data, but the lack of structural alignment between different types of project information. As a result, organisations may have access to relevant data yet still lack the ability to generate actionable insights into why deviations occur.

From this perspective, the research seeks to identify the mechanisms that limit cost traceability and constrain project learning, and to explore how alternative structuring approaches may contribute to improved alignment between estimation, execution, and reporting.

By improving the understanding of these mechanisms, this study aims to contribute to stronger project learning processes and, ultimately, to improved cost predictability in construction projects.

1.4 Research Questions

Based on the identified problem and research objective, the following main research question is formulated:

"How can cost predictability be improved in Dutch construction projects?"

To answer the main research question, the following sub-questions are formulated.

Sub-Question 1:

"How can the relationship between cost structuring, cost traceability, project learning and cost predictability be conceptualised from literature?"

Sub-Question 2:

"Which structuring approaches are identified in literature, and through which mechanisms may they support cost traceability and project learning?"

Sub-Question 3:

"How is cost information currently structured and used in practice, and where do limitations in cost traceability and project learning arise?"

Sub-Question 4:

"What organisational and project conditions are needed to implement the identified structuring mechanisms in such a way that cost traceability and project learning are supported in practice?"

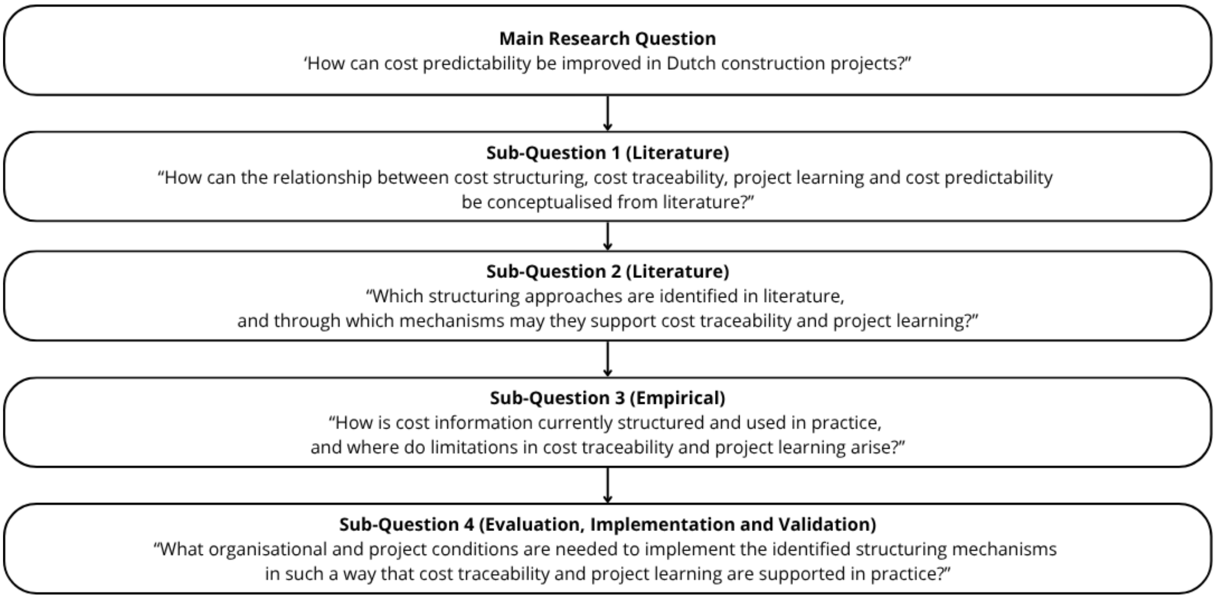

Figure 1.1: Overview Research Questions (own figure)

1.4.1 Deductive Logic of the Sub-Questions

The sub-questions are formulated to move from conceptual understanding to the identification of existing structuring mechanisms, to empirical diagnosis, and finally to implementation requirements. They therefore do not represent separate lines of inquiry, but consecutive analytical steps through which the main research question is answered.

Sub-Question 1 establishes the theoretical foundation of the research. Since the problem statement argues that cost deviations are difficult to learn from when their underlying causes cannot be reconstructed, the first step is to clarify how cost structuring, cost traceability, project learning and cost predictability are conceptually related. This sub-question does not assume a fixed causal effect between these concepts. Instead, it uses literature to define the concepts, examine possible relationships between them, and identify how cost traceability may function as a condition for learning from cost deviations.

Sub-Question 2 builds on this theoretical foundation by examining existing structuring approaches in literature. If cost traceability depends on how cost information is structured and connected across phases, it becomes necessary to examine which existing approaches in literature aim to organise project information more systematically. Sub-Question 2 therefore identifies and compares structuring approaches and analyses how they may contribute to cost traceability and project learning. This step does not yet propose a practical framework, but establishes which mechanisms are theoretically available.

Sub-Question 3 introduces the empirical diagnosis. Whereas SQ1 and SQ2 are based on literature, SQ3 investigates how cost information is structured, transformed and used in practice. The purpose is to identify what happens to cost information between tendering, work budgeting, execution, reporting and evaluation, and where the links between assumptions, scope, progress, deviations and learning outputs become weak or lost. This sub-question therefore provides the practical information needed to understand which traceability problems exist and which requirements a later framework must address.

Sub-Question 4 translates the theoretical and empirical findings into implementation requirements. Rather than asking only whether structuring approaches can improve traceability, this sub-question asks what organisational and project conditions are needed to implement the identified structuring mechanisms in a way that supports cost traceability and project learning in practice.

Together, the sub-questions form a deductive research logic. SQ1 clarifies the conceptual relationships between cost structuring, cost traceability, project learning and cost predictability. SQ2 identifies theoretically available structuring mechanisms. SQ3 diagnoses current practice and the empirical limitations that must be addressed. SQ4 translates these insights into practical implementation requirements and validates whether these requirements are feasible in practice. The implementation framework developed later in this thesis should therefore be understood as the outcome of this research sequence, rather than as a predefined solution.

1.5 Research Relevance

1.5.1 Scientific Relevance

Although cost overruns in construction projects have been widely studied, much of the existing literature focuses on macro-level explanations such as decision-making biases or governance-related factors. Less attention has been given to how cost information is structured and utilised during project execution, and how this influences cost traceability and project learning.

This research contributes to the literature by shifting the focus from explaining why cost overruns occur to understanding how cost information is structured across project phases and how this affects the ability to trace deviations and learn from them. By positioning cost traceability as a key mechanism linking cost structuring to project learning and cost predictability, this study provides a more process-oriented perspective on cost performance in construction projects.

Furthermore, while various structuring approaches have been proposed to improve coordination and alignment in project environments, their role in enabling cost traceability and supporting project learning remains insufficiently understood. This research therefore contributes by analysing how such approaches may address structural limitations in current practices.

1.5.2 Practical Relevance

From a practical perspective, improving cost predictability and strengthening cost control across project phases are of direct importance to construction firms. By analysing how cost information is currently structured and identifying limitations in traceability and feedback mechanisms, this research provides insights into why organisations may experience limited control over project costs.

Understanding where and how cost deviations emerge, and how they can or cannot be linked to underlying causes, can support practitioners in improving alignment between estimation, execution, and reporting processes. This may enable more effective decision-making during project execution and improve the ability to learn from project outcomes.

In addition, by evaluating how alternative structuring approaches may contribute to improved cost traceability and project learning, this research provides guidance on how organisations can strengthen their project information structures. These insights can support construction firms in improving both short-term cost control and long-term cost predictability.

1.6 Preliminary Conceptual Framework

Building on the deductive logic of the sub-questions presented in Section 1.4.1, the preliminary conceptual framework in Figure 1.2 organises the four central concepts of this study: cost structuring, cost traceability, project learning and cost predictability.

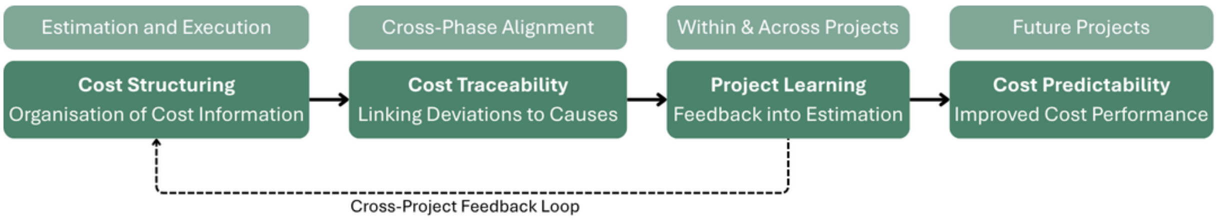

Figure 1.2: Preliminary Conceptual Framework (own figure)

The framework is grounded in the observation that cost deviations in construction projects are not only the result of inaccurate estimates but may also be influenced by how cost information is structured and used across the project lifecycle. As discussed in the problem statement, cost information is not organised through a single consistent structure, but through multiple, coexisting structuring logics that differ between estimation and execution, and within execution itself (e.g. budgeting, control, and reporting practices). These differences may introduce fragmentation and discontinuities in cost information, which could limit the ability to relate observed cost deviations to their underlying causes.

Based on this reasoning, the framework proposes a set of hypothesised relationships between four key concepts: cost structuring, cost traceability, project learning, and cost predictability. First, cost structuring refers to the way cost information is organised across the project lifecycle, particularly in estimation and execution, where different structuring logics coexist and evolve. It is assumed that the degree of alignment between these structures may influence the extent to which cost information remains consistent and connected across project stages.

Second, cost traceability refers to the ability to link observed cost deviations to their underlying causes, such as specific activities, assumptions, or execution conditions. When cost structures are fragmented or inconsistent, deviations may become visible in financial monitoring but remain difficult to interpret. Conversely, more consistent structuring may support improved traceability, potentially enabling a clearer understanding of how and why deviations occur.

Third, project learning refers to the extent to which insights from cost deviations are captured, interpreted, and translated into improved future practices. In this framework, learning is assumed to depend not only on identifying deviations, but also on the ability to trace and understand their underlying causes. Cost traceability is therefore hypothesised to act as an enabling condition for project learning, although the extent of this relationship remains to be explored.

Finally, project learning may influence cost predictability in future projects. In this study, cost predictability is therefore not treated as an isolated outcome, but as a potential result of the ability to learn from past cost performance. This is reflected in the feedback loop incorporated in the framework, where learning from completed projects informs future estimation practices and contributes to improved cost performance over time.

It is important to note that this framework represents a preliminary and conceptual interpretation of the problem, rather than a validated model. The proposed relationships are based on logical reasoning derived from the problem analysis but have not yet been systematically tested or substantiated by literature. The purpose of the literature study in Chapter 3 is therefore to critically assess and refine this preliminary framework. Existing literature will be used to examine how the identified concepts are defined, how they are theoretically related, and to what extent the proposed relationships are supported, nuanced, or challenged. Based on this analysis, the preliminary framework will be further developed into a refined conceptual framework that is grounded in literature and serves as the analytical basis for the empirical study.

As such, the framework therefore functions as an initial analytical lens, while the sub-questions define the successive research steps through which this lens is theoretically refined, empirically examined and translated into implementation conditions.

1.7 Thesis Outline

This thesis is structured into eight chapters. Chapter 1 has introduced the research context, problem statement, research objective, research questions, research relevance, and the preliminary conceptual framework that guides the study. Chapter 2 presents the research design and methodological approach. It describes the three research phases and explains how data is collected and analysed in each phase, including the literature study, empirical research, and the evaluation, implementation, and validation phase.

Chapter 3 presents the theoretical foundation of the study, examining cost structuring, cost traceability, project learning, and cost predictability as interconnected concepts. Based on this analysis, the preliminary conceptual framework is refined into an analytical lens for the remainder of the study. Chapter 4 identifies and analyses five structuring approaches from literature and examines their potential contribution to cost traceability and project learning.

Chapter 5 presents the empirical findings from organisational-level interviews and three Dura Vermeer project cases: Highway A16 De Groene Boog, Dike reinforcement Tiel-Waardenburg, and Substation Vierverlaten. A cross-case comparison identifies the mechanisms that consistently constrain cost traceability and project learning in practice.

Chapter 6 evaluates the five structuring approaches against the empirical limitations identified in Chapter 5 and proposes a three-layered configuration as the most appropriate response.

Chapter 7 translates this configuration into a practical Construction Project Cost Traceability Framework, elaborated through design principles, a CWP information model, application guidance, and a staged implementation pathway.

Chapter 8 assesses the practical relevance and feasibility of the framework through expert interviews with experienced practitioners.

The thesis concludes with an answer to the main research question, a reflection on the scope and limitations of the research, and recommendations for practice and future research.

2 Research Design

This chapter presents the research design and methodological approach of the study. Building on the research objective, research questions and preliminary conceptual framework defined in Chapter 1, it explains how the study is structured and how data is collected and analysed in each phase.

The research is conducted in collaboration with Dura Vermeer, a Dutch construction company involved in large-scale infrastructure projects. The study is embedded within the practical context of ongoing project delivery, providing access to real-world cost control practices during execution.

The study adopts a qualitative approach, combining a literature study with empirical research conducted within this organisational context. This approach is appropriate given the exploratory nature of the research, which focuses on understanding processes, structures, and underlying mechanisms related to cost structuring, cost traceability, project learning, and cost predictability, rather than measuring quantitative effects.

The research is structured into three main phases:

- Phase I: Literature Study (SQ1 and SQ2)
- Phase II: Empirical Research (SQ3)
- Phase III: Evaluation, Implementation and Validation (SQ4)

Each phase addresses specific sub-questions and builds systematically towards answering the main research question.

2.1 Phase I: Literature Study

The first phase establishes the theoretical foundation of the study by addressing Sub-Questions 1 and 2. The objective of this phase is to define the key concepts central to the research, namely cost structuring, cost traceability, project learning and cost predictability, and to conceptualise the relationship between these concepts from literature. In addition, this phase identifies structuring approaches described in literature and examines the mechanisms through which they may support cost traceability and project learning.

2.1.1 Data Collection

Academic literature is collected through structured searches in scientific databases such as Scopus and Google Scholar. Search queries include combinations of keywords related to cost structuring, cost traceability, project learning, cost predictability, Work Breakdown Structure, Critical Path Method, Earned Value Management, Last Planner System and Advanced Work Packaging.

In addition, backward referencing is used to identify relevant sources by reviewing the reference list of selected articles. The selection of literature is based on scientific relevance, number of citations, publication date, and whether sources are peer-reviewed.

2.1.2 Data Analysis

The literature is analysed using a narrative review approach combined with thematic analysis (Snyder, 2019; Webster & Watson, 2002). This allows for the identification of key concepts, recurring themes, and relationships between variables.

The analysis is guided by the preliminary conceptual framework introduced in Chapter 1, while remaining open to new insights emerging from the literature. This enables both a structured (deductive) and exploratory (inductive) analysis of how cost structuring, cost traceability, project learning, and cost predictability are theoretically related.

The outcome of this phase is a refined conceptual framework and an overview of structuring approaches and their underlying mechanisms.

2.2 Phase II: Empirical Research

The second phase addresses Sub-Question 3 and focuses on analysing how cost information is currently structured and used in practice, and where limitations in cost traceability and project learning arise.

A qualitative case study approach is adopted, with Dura Vermeer as the case organisation. Within this case, an embedded design is used, combining an organisational-level perspective with in-depth project-level analysis. This approach allows for the identification of both overarching organisational patterns and project-specific dynamics.

2.2.1 Data Collection

Data collection is conducted using multiple data sources to enable triangulation and enhance the reliability of the findings (Bans-Akutey & Tiimub, 2021). Two primary data sources are used: semi-structured interviews and project documentation.

Organisational-Level Interviews

At the organisational level, four semi-structured interviews are conducted with key stakeholders involved in cost structuring, cost control and cross-project learning, including a financial manager, project manager, cost engineer, and project controller. In this research, the organisational level refers to a cross-project perspective. This level is included because project learning is not treated only as learning within individual projects, but also as the organisational translation of project experience into future estimating, budgeting and control practices. While the project-level cases provide insight into how cost deviations are identified and interpreted within specific project contexts, the organisational-level interviews examine whether and how these insights are captured, standardised and reused across projects. This is necessary because improvements in cost predictability depend not only on project-level control, but also on inter-project feedback mechanisms through which lessons from completed or ongoing projects influence future cost structures, assumptions and reporting routines.

These roles are purposively selected because together they cover the full chain of cost information production and interpretation: estimate development (Cost Engineering), execution decision-making (Project Management), monitoring and forecasting (Project Control), and organisational financial reporting logics (Financial Management). This composition increases the likelihood of identifying mechanisms that cut across functions rather than being limited to a single discipline. These interviews were guided by semi-structured question sheets, tailored to the roles of the respondents. Appendix A provides an overview of the question sheets used.

The organisational-level interviews aim to identify:

- how cost information is structured across projects;
- how cost data is transformed between estimation, execution, and reporting;
- recurring challenges in cost traceability;
- how cost deviations are interpreted within and beyond individual projects;
- how project experiences, deviations and lessons learned are captured, transferred and reused in future estimating, budgeting and control practices.

Project-Level Case Studies

At the project level, three projects are selected for in-depth analysis. Whereas the organisational-level interviews focus on cross-project routines and feedback mechanisms, the project-level case studies examine how these routines materialise within specific project contexts. The unit of analysis at this level is therefore not the organisation, but the development of cost information within individual projects.

The project-level analysis collects information at four levels. First, at the project level, it examines the contract form, project context, organisational setting and main control structure. Second, at the phase-transition level, it reconstructs how cost information moves from tender estimate to work budget, from work budget to execution control, and from project control to reporting and evaluation. Third, at the cost-control level, it analyses the structures used to monitor and interpret costs, such as cost codes, monitoring posts, work packages, forecasts, risk registers and reporting categories. Fourth, at the deviation level, it examines concrete cost movements, RFCs, scope changes, delay-related costs, indirect costs and lessons learned to determine whether deviations can be traced back to specific assumptions, activities, execution conditions or contractual events.

This project-level analysis therefore provides information that cannot be obtained from organisational-level interviews alone. It enables the research to compare general organisational routines with the actual way cost information is structured, transformed and interpreted in practice. In doing so, the case studies show where traceability is preserved, where it breaks down, and whether project-specific deviations are translated into learning within and beyond the project.

For each project:

- two semi-structured interviews are conducted with key stakeholders (e.g. project manager, project controller, cost engineer). Appendix B provides an overview of the question sheets used;
- project documentation is analysed, including (depending on availability):
    - tender estimates;
    - work budgets, cost codes and monitoring structures;
    - cost reports and forecasts;
    - deviation analyses and narrative explanations of cost movements;
    - evaluation and lessons learned documents.

This combination enables a reconstruction of how cost information evolves throughout the project, how it changes between levels of aggregation, and how specific deviations emerge, are interpreted, and are or are not translated into learning.

Semi-structured interviews are used because they allow exploration of both formal routines and tacit knowledge how decisions are made in practice, how deviations are explained, and how lessons learned are (or are not) captured (Von Soest, 2022).

In total, ten semi-structured interviews were conducted: four at organisational level and six at the project level. This number of interviews was chosen to ensure multiple perspectives across the three projects and functions, while allowing for thematic saturation on key mechanisms (i.e., recurring explanations stabilise across interviews). All interview quotes presented were translated from Dutch to English by the author. An interview guide is developed based on the research questions, while allowing flexibility to probe project-specific practices and examples (Gill et al., 2008).

2.2.2 Case Selection

Three projects are selected using purposive sampling to ensure information-rich cases aligned with the research objective (Yin, 2018). Selecting three cases enables cross-case comparison while remaining feasible within the thesis timeframe. The comparative logic supports identification of recurring patterns as well as project-specific variation (Flyvbjerg, 2006; Yin, 2018).

Selection criteria include:

- projects that have progressed sufficiently into execution or have been completed;
- availability of both early-phase and execution-phase data;
- accessibility of relevant stakeholders and documentation.

Based on these criteria, three projects carried out by Dura Vermeer have been selected:

- Highway A16 De Groene Boog, Rotterdam;
- Dike Reinforcement, Tiel-Waardenburg;
- Substation, Vierverlaten.

Table 2.1: Overview of Empirical Data Sources

Data Source	Scope	Number / Type	Analytical Role in the Research
Organisational-level interviews	Cross-project Dura Vermeer perspective	4 interviews	Used to identify recurring routines in estimating, work budgeting, project control, reporting and cross-project learning
Project level interviews: De Groene Boog	Project-specific perspective	2 interviews	Used to reconstruct how cost information was structured, interpreted and transferred in a large DBFM combination project
Project-level interviews: Tiel-Waardenburg	Project-specific perspective	2 interviews	Used to analyse cost traceability in a D&C dike reinforcement project with parallel structures, planning pressure, EMAT commitments and variation orders

Data Source	Scope	Number / Type	Analytical Role in the Research
Project-level interviews: Vierverlaten	Project-specific perspective	2 interviews	Used to analyse cost traceability in a long-running D&C substation project with RFCs, delay-related costs and team continuity
Tender and estimating documents	Project documentation	Available per case	Used to reconstruct initial cost assumptions, estimate structures and tender logic
Work budgets and cost-control documents	Project documentation	Available per case	Used to analyse how tender information was translated into execution-phase control structures
Cost reports and forecasts	Project documentation	Available per case	Used to identify forecast movements, reporting structures and financial visibility of deviations
RFCs, variation orders, risk registers and deviation explanations	Project documentation	Available per case	Used to assess whether deviations could be linked to scope changes, contractual events or execution causes
Evaluation and lessons-learned documents	Project documentation	Available per case	Used to analyse whether project experiences were translated into reusable learning outputs

2.2.3 Data Analysis

The empirical data was analysed through thematic analysis. This approach enables identification, interpretation and reporting of patterns within qualitative data, and is well suited to exploratory research aimed at understanding processes and mechanisms (Braun & Clarke, 2006). The purpose of the analysis was not to quantify opinions statistically, but to reconstruct how cost information is structured, transformed and interpreted across project phases, and where limitations in cost traceability and project learning arise.

The analysis combined deductive and inductive coding. The deductive part was guided by the refined conceptual framework developed in Chapter 3 and the analytical lenses developed in Chapter 4. These provided the initial code groups: cost structuring, cross-phase structural alignment, cost traceability, cost-progress integration, change mechanisms, indirect cost traceability, project learning and cost predictability. The inductive part allowed additional project-specific codes to emerge from the empirical material, such as combination-specific coding structures, EMAT-related cost effects, RFC-based traceability, Excel-based interpretation and team continuity.

The analysis consisted of four steps. First, interview transcripts, interview notes and project documents were read repeatedly to become familiar with the material and to identify preliminary patterns. Second, relevant fragments were coded using descriptive labels that captured the mechanism discussed in the fragment. These codes were not treated as isolated keywords, but as indicators of how cost information moved between tendering, work budgeting, execution, reporting and learning. Third, related codes were grouped into higher-level themes. Fourth, these themes were compared across organisational-level interviews, project-level interviews and project documentation to identify recurring mechanisms and project-specific variations.

To make the analytical process transparent, the coding was organised in a structured coding matrix. This matrix linked empirical fragments and document-based observations to analytical codes, higher-level themes and the corresponding sections of Chapter 5. Code frequency was not used as statistical evidence, but recurring presence across multiple interviews, multiple cases and project documents was used as an indication of analytical salience. A theme was considered analytically important when it appeared across several data sources, was supported by project documentation, related directly to the conceptual framework, or helped explain a limitation in cost traceability or project learning. See Appendix C for the coding matrix and evidence matrix.

The organisational-level interviews were used to identify recurring cross-project routines and challenges. These interviews informed the initial empirical themes, particularly the transformation from tender estimate to work budget, the aggregation of cost information during control and reporting, the difficulty of tracing indirect costs and the limited institutionalisation of learning. The project-level cases were then used to examine how these themes materialised in specific project contexts. This explains why the case sections do not have identical subheadings: each case is structured around the mechanisms that were most empirically relevant in that project, while still being analysed through the same overarching analytical lenses.

The outcome of this phase is an empirically grounded understanding of how cost information is structured in practice, and which mechanisms limit cost traceability and project learning.

2.3 Phase III: Evaluation, Implementation and Validation

The final phase addresses Sub-Question 4 and focuses on translating the theoretical and empirical findings into organisational and project conditions for implementing structuring mechanisms in a way that supports cost traceability and project learning in practice.

This phase integrates insights from both the literature study (Phase I) and the empirical findings (Phase II).

2.3.1 Evaluation of Structuring Approaches

The evaluation is conducted by systematically comparing the characteristics of the structuring approaches identified in Phase I with the limitations identified in Phase II. By analysing how the mechanisms of structuring approaches relate to these limitations, the study assesses the extent to which they may improve cost traceability and support project learning.

2.3.2 Development of The Implementation Framework

Based on the conceptual insights from Phase I, the empirical findings from Phase II, and the evaluation of structuring approaches, an implementation framework is developed. This framework aims to identify key principles, conditions, and design considerations for improving the structuring of cost information across project phases.

2.3.3 Validation Through Expert Interviews

To assess the practical relevance and applicability of the proposed framework, it is evaluated through four semi-structured interviews with industry experts at Dura Vermeer. These experts are selected based on their experience with project management, cost control, and project structuring within construction projects.

The interviews aim to evaluate:

- the perceived relevance of the framework.
- the feasibility of implementation in practice.

- potential barriers and challenges.
- required organisational capabilities and conditions.

The use of expert interviews allows for validation of the framework in a real-world context and ensures that the proposed recommendations are grounded in practical experience (Von Soest, 2022). Appendix E provides the question sheet used.

2.3.4 Data Analysis

The data from the validation interviews is analysed using thematic analysis (Braun & Clarke, 2006). The analysis focuses on identifying recurring patterns in expert opinions regarding applicability, feasibility, and implementation challenges. Crucially, the expert responses are treated as empirical findings, not merely as input for adjusting the framework. The validation findings are reported in a dedicated validation chapter (Chapter 8), while the pre-validation version of the implementation framework is retained in Appendix F and the refined version is presented in the main thesis. Where the responses indicate that changes are warranted, the framework is refined accordingly.

The outcome of this phase is a validated implementation-oriented framework that provides guidance on how organisations can improve the structuring of cost information and strengthen alignment between project phases. By identifying the conditions under which structuring approaches can be effectively applied, this phase contributes to translating theoretical insights into practical recommendations. Ultimately, this supports improved cost traceability and project learning and thereby contributes to improved cost predictability in construction projects.

Phase I

Literature Study

3 Theoretical Foundation

This chapter presents the literature study conducted to address Sub-Question 1: *"How can the relationship between cost structuring, cost traceability, project learning and cost predictability be conceptualised from literature?"*.

Based on the preliminary conceptual framework introduced in Chapter 1, four key concepts are examined: cost structuring, cost traceability, project learning, and cost predictability. These concepts are analysed individually, drawing on existing literature to define their meaning, identify underlying mechanisms, and explore their role within construction project management. The focus of this chapter lies on understanding how cost information is structured across different project phases, and how this structuring may affect the ability to trace and interpret cost data over time.

The chapter concludes by synthesising the findings and reflecting on the relationships between the four concepts. Based on this synthesis, the preliminary conceptual framework is critically evaluated and refined where necessary. This refined framework forms the theoretical foundation for analysing structuring approaches in the subsequent chapter.

3.1 Cost Structuring

Cost structuring can be positioned within the broader concept of construction cost management, which consists of three main processes: cost estimating, cost budgeting and cost controlling (Malkanthi et al., 2017). Within this context, cost structuring refers to the way cost information is organised, broken down and linked to project elements to support these processes throughout the project lifecycle. A well-structured cost system enables the translation of project scope into measurable and controllable cost elements, forming the basis for planning and monitoring.

Cost structuring is not only a technical decomposition process but also reflects managerial decisions regarding the level of detail, aggregation and allocation of costs. As noted by Holm and Schaufelberger (2021), the way costs are structured directly influences how they can be controlled and interpreted during project execution. This implies that structuring choices made early in the project, for example, regarding the level of detail in an estimate or the logic used to group cost items, have consequences that extend throughout the project lifecycle. When structuring decisions are made without considering how information will be used in later phases, discontinuities may arise that reduce the usability and interpretability of cost data.

3.1.1 Cost Estimating and Early Structuring

Cost structuring originates in the estimating phase, where project costs are initially defined and organised. Estimating involves developing cost predictions based on the required resources, activities and scope of work (Malkanthi et al., 2017). In construction projects, this process is strongly supported by the measurement and quantification of work. Instruments such as bills of quantities (BOQ) translate design information into structured, measurable work items, linking quantities and descriptions to cost rates (Towey, 2012).

By decomposing a project into discrete elements, estimating provides an initial structure in which costs are allocated to specific parts of the project. This decomposition is essential, as it determines how costs are later aggregated, analysed and controlled. Without a clear structure at this stage, the consistency of cost information throughout the project lifecycle may be compromised.

A particular challenge in the estimating phase concerns indirect costs. Unlike direct production costs, indirect costs, such as site management, engineering support, coordination and organisational overhead, are often less directly attributable to discrete work activities and are therefore more difficult to estimate and structure (Becker et al., 2014; Chan & Pasquire, 2004). Empirical research indicates that indirect costs are frequently estimated based on professional judgement rather than systematic data-driven methods, which increases the risk of underestimation and limits the ability to trace and control these costs during execution (Chan & Pasquire, 2004). This makes the structuring of indirect costs in the estimating phase a particularly important, yet underexplored, aspect of cost management.

3.1.2 Cost Budgeting and Aggregation

Following estimation, cost structuring continues in the budgeting phase, where individual cost estimates are aggregated into an overall project budget and baseline (Malkanthi et al., 2017). This aggregation process determines how detailed cost information is consolidated for financial planning and reporting purposes.

A structured budget enables the comparison between planned and actual costs, which is essential for effective cost management. However, the level of aggregation plays a critical role in determining how useful the budget is as a control instrument. While higher-level aggregation simplifies reporting, it reduces the level of detail available for analysing deviations. When cost items are grouped into broad categories during budgeting, the connection to the underlying assumptions and work scopes from the estimating phase may be weakened. As Holm and Schaufelberger (2021) note, the way in which estimates are consolidated into budgets determines the degree to which original cost assumptions remain visible and interpretable during execution. This tension between aggregation for reporting purposes and the preservation of detail for control purposes is a structural challenge that recurs across project phases.

3.1.3 Cost Control and Monitoring Structures

In the execution phase, cost structuring is operationalised through cost control and monitoring practices. Cost control involves managing and controlling factors that affect the project budget, requiring continuous comparison between planned and actual costs (Malkanthi et al., 2017). This process depends on the availability of structured cost data and appropriate monitoring mechanisms.

Effective cost control is not only determined by the techniques applied, but also by how these techniques are embedded within the project structure (Malkanthi et al., 2017). Standardised documents such as unit cost sheets, labour cost statements and cost summaries are commonly used to structure cost information and enable consistent tracking over time. These instruments support the systematic recording and comparison of costs, facilitating monitoring and reporting activities.

Advanced techniques such as earned value management (EVM) rely on a clear structuring of work and cost data, as they require the alignment of scope, time and cost dimensions within a unified framework (PMI, 2013). However, the explanatory value of such techniques depends strongly on the granularity and execution-alignment of the underlying data. When performance is tracked at relatively high aggregation levels, deviations may be visible without being diagnostically meaningful: project teams can observe that performance is off-track, while still lacking the level of detail needed to trace the deviation back to specific execution conditions or assumptions. This suggests that cost control is only as informative as the structuring logic on which it is based.

3.1.4 Integration Across the Project Lifecyle

Cost structuring is not a one-time activity, but a continuous process that evolves throughout the project lifecycle. From initial estimating to final cost control, the structure of cost information influences how data is generated, aggregated and interpreted. The integration of cost management with other project dimensions, such as scope definition and scheduling, is therefore essential for maintaining consistency and coherence in project information.

Project management literature emphasises that cost estimating, budgeting and controlling are interconnected processes, and that effective management depends on their alignment with other project management activities (PMI, 2013). This suggests that cost structuring should be understood as part of a broader system of project organisation, rather than as an isolated activity.

A key implication of this perspective is that the consistency of structuring logic across project phases matters as much as the quality of structuring within any individual phase. When different phases use different structuring logics or levels of aggregation, information may be technically present but practically difficult to connect. The relationship between cost structuring and the ability to trace, interpret and learn from cost data therefore depends not only on how well costs are structured within each phase, but on how consistently that structure is maintained and translated across phases. This cross-phase dimension of cost structuring is a central concern of the present research and is further explored in the following section.

3.2 Cost Traceability

For the purposes of this research, cost traceability is defined as the ability to link observed cost deviations to their underlying causes by connecting cost information across project phases and relating it to specific activities, assumptions or execution conditions. This definition distinguishes traceability from mere cost visibility: a project may have detailed financial reporting without providing the causal links needed to understand why deviations occur. Traceability, in this sense, is a prerequisite for learning, as it determines whether the information needed to interpret and act on deviations is structurally available.

Within the broader context of cost management, traceability is essential for monitoring and controlling project performance. It allows for the comparison between planned and actual costs and supports the identification of deviations and their root causes. Cost overrun, for instance, is commonly defined as the difference between actual costs and planned or contracted cost, highlighting the importance of being able to track costs across project stages (Ahmed et al., 2014). Without the ability to trace cost information back to its origin, such deviations remain difficult to interpret and manage effectively.

3.2.1 Traceability as Linking Cost Information

A fundamental aspect of cost traceability is the establishment of clear relationships between costs, activities and resources. Traditional cost management systems in construction projects often lack such relationships, as costs are frequently categorised based on resource consumption rather than linked to specific activities or work components (Toosi & Chamikarpour, 2021). As a result, cost information is fragmented across different systems and lacks a clear connection to physical project progress.

This separation between cost data and project activities limits the ability to identify the causes of cost deviations. While cost reports may indicate that costs have increased, they do not necessarily explain which activities or processes contributed to this increase. The absence of a causal link between cost and performance systems therefore reduces the interpretability of cost information and constrains effective decision-making.

To address this issue, more advanced cost management approaches emphasise the importance of linking costs directly to activities through cost drivers and work packages. By assigning both direct and indirect costs to specific activities, it becomes possible to track costs at a more detailed level and to analyse deviations in relation to actual project performance (Toosi & Chamikarpour, 2021). This suggests that traceability is closely dependent on the way cost information is structured and connected to project elements. Importantly, this dependency also applies to indirect costs: because indirect cost categories are often not linked to discrete activities, they are particularly difficult to trace, and deviations within them tend to remain opaque even when financial reporting indicates that a problem exists.

3.2.2 Traceability Across the Project Lifecycle

In addition to linking costs to activities, cost traceability requires consistency of cost information across different project phases. Construction projects typically involve multiple stages which may use different levels of detail and structuring logics. As cost information is transferred between these stages, changes in structure or aggregation can affect the continuity of information and reduce the ability to compare data meaningfully over time.

Literature indicates that cost control processes are often separated from scheduling and performance monitoring systems, resulting in a lack of integration between financial and operational data (Toosi & Chamikarpour, 2021). This separation creates challenges in tracking cost information over time, as cost data and progress data are not aligned. Consequently, it becomes difficult to relate cost outcomes to specific events or activities within the project lifecycle.

Furthermore, delays in accounting processes can lead to late feedback on cost performance, limiting the ability to respond to emerging issues during project execution (Toosi & Chamikarpour, 2021). This highlights that traceability is not only a matter of structuring cost data at a given point in time, but also of ensuring timely and integrated information flows across project phases. When feedback on cost performance arrives too late to inform decision-making, the practical value of traceability is significantly reduced even if the underlying data is technically present.

3.2.3 Information Quality and Accessibility

The effectiveness of cost traceability is also influenced by the quality and accessibility of information. Construction projects generate large amounts of data, but the presence of data alone does not guarantee useful insights. Research on information management in construction shows that information is only valuable to the extent that it is properly structured and contextualised (Tang et al., 2008). When information is poorly organised, difficult to retrieve, or lacks context, its usefulness for decision-making is significantly reduced.

In practice, organisations often face both information overload and a lack of high-value information simultaneously. Large volumes of data may be stored without clear criteria for relevance or usability, making it difficult to identify and retrieve meaningful information when needed (Tang et al., 2008). At the same time, important contextual knowledge, such as the reasoning behind specific estimating assumptions or the conditions under which execution decisions were made, may not be formally captured, further limiting the ability to interpret cost data after the fact.

These challenges suggest that effective traceability depends not only on the availability of data, but also on how information is structured, filtered and maintained over time. Without a clear and consistent organisation of information, cost data cannot be effectively linked or interpreted across the project lifecycle, regardless of the volume of data available.

3.2.4 Relationship between Cost Structuring and Traceability

The literature reviewed in this section indicates that cost traceability is closely related to the way cost information is structured throughout the project lifecycle. Mechanisms such as the decomposition of work, the allocation of costs to activities, and the integration of cost and schedule information all contribute to the ability to trace cost data over time.

At the same time, limitations in current cost management practices, such as a lack of integration between cost and performance data, the separation of financial and operational systems, and the progressive aggregation of cost information across phases, reduce the traceability of cost information (Toosi & Chamikarpour, 2021). As a result, cost information becomes difficult to link across project phases, limiting the ability to analyse and interpret cost performance in a consistent manner. Cost deviations may originate from incorrect estimating assumptions, planning disruptions, changed execution conditions, productivity losses or scope changes, but this research focuses specifically on whether such causes remain traceable once cost information is transferred across estimation, budgeting, execution, reporting and evaluation.

Taken together, this suggests that cost structuring plays a central role in enabling cost traceability. The way in which cost information is organised, aggregated and transferred between project phases influences the extent to which cost data can be consistently linked, compared and interpreted over time. Crucially, this also means that traceability cannot be improved by adding more data alone. Improving traceability requires improving the structural alignment between how costs are estimated, how work is executed, and how performance is reported. A challenge that extends across the full project lifecycle.

Understanding cost deviations through traceability forms an important basis for further analysis of project performance. In particular, the ability to interpret cost information creates the conditions under which project experiences can be evaluated and used to inform future decision-making. This aspect is further explored in the next section, which focuses on project learning.

3.3 Project Learning

Project-based industries such as construction rely heavily on experiential knowledge to improve performance over time. Within this context, project learning can be understood as the process through which organizations capture, interpret, and reuse knowledge derived from past project experiences to enhance future outcomes. Organizational learning has been defined as the process of improving actions through better knowledge and understanding (Salman & Sodangi, 2025). In construction projects, this learning is often driven by the analysis of deviations between planned and actual outcomes, which provide critical feedback on project performance.

3.3.1 Conditions for Learning in Project-Based Environments

A key characteristic of construction projects that shapes learning processes is their temporary organisational nature. Projects can be understood as temporary organisational structures that exist for a predefined period and are disbanded upon completion (Antoni & Sense, 2001). Unlike permanent organisations, where knowledge accumulates within stable structures and roles, project organisations dissolve at the end of each project. As a result, knowledge is not automatically retained but must be actively transferred across organisational boundaries if it is to benefit future projects. This makes the systematic capture and reuse of knowledge inherently more complex in project-based settings.

In addition to fragmentation at the project level, learning in construction is further complicated by the interorganisational nature of project networks. Construction projects are typically executed by networks of specialised firms that collaborate temporarily and reconfigure between projects. Within such project networks, knowledge creation and integration depend on interactions across organisational boundaries, which makes learning inherently more complex than within single organisations (Chen & Taylor, 2014).

Moreover, research on project networks suggests that learning processes are often disrupted by changes in network composition. When project teams vary between projects, interorganisational routines and shared knowledge cannot easily accumulate over time, limiting the development of stable learning mechanisms. This may result in slower learning curves and difficulties in transferring knowledge across projects (Taylor & Levitt, 2007).

These characteristics reinforce the argument that learning in construction is not only constrained by the temporary nature of projects, but also by the dynamic and fragmented structure of interorganisational collaboration.

For learning to occur effectively in this environment, deliberate processes and organisational support are required. Learning does not occur automatically as a by-product of project execution. It depends on the availability of structured mechanisms for capturing, interpreting and embedding knowledge within the organisation (Antoni & Sense, 2001). Where such mechanisms are absent or weakly developed, experience remains tied to individuals and is lost when project teams disband, limiting the ability to systematically translate project outcomes into improved future practices.

3.3.2 Forms of Learning and Their Limitations

Within project management literature, a distinction is commonly made between learning within projects and learning across projects. Intra-project learning refers to the development and application of knowledge during project execution, enabling teams to adjust decisions and improve performance within the same project. Inter-project learning, in contrast, concerns the transfer of knowledge between projects, allowing organisations to improve future project performance based on experience (Antoni & Sense, 2001).

Both intra-project and inter-project learning are relevant to cost performance, but the primary focus of this research is on the depth of learning rather than on project learning in general. This thesis focuses on double-loop learning from cost deviations. Single-loop learning is used as a reference category: it describes situations in which deviations are detected and corrected within a project, without questioning the underlying assumptions, cost structures or control routines that produced them. Such learning is important for short-term project control, but it does not necessarily lead to structural improvement in future cost predictability.

Double-loop learning is more central to this research because it requires the causal explanation of deviations. It involves identifying why a deviation occurred and using this insight to revise underlying estimating assumptions, budgeting structures, planning logic or cost-control practices (Wong et al., 2011). This is where cost traceability becomes critical: without the ability to link deviations back to specific assumptions, activities, execution conditions or decisions, learning remains limited to correcting the deviation itself. This research therefore examines how cost structuring and cost traceability can create the conditions for double-loop learning, both within projects and across projects.

3.3.3 The Role of Cost Traceability in Learning

Cost deviations represent an important source of learning. They reflect mismatches between expected and actual project performance and may reveal issues related to estimation, planning or execution. However, learning from such deviations is not automatic. It requires that deviations are not only identified but also interpreted and causally linked to their underlying causes. Without this causal understanding, deviations remain descriptive rather than explanatory. They indicate that something went wrong, but not why or where the breakdown originated.

This is reflected in studies on rework, which show that recurring errors and cost inefficiencies are often linked to insufficient learning from previous projects (Titov et al., 2015). Rework costs, which can represent a significant share of total project costs, are frequently associated with failures to effectively capture and apply lessons learned across projects. This highlights the importance of structured learning processes in improving cost performance.

The effectiveness of project learning is therefore not only dependent on the availability of data, but on the ability to interpret that data in relation to its underlying causes. Cost traceability plays a critical role in enabling this interpretation. When cost deviations cannot be causally linked to specific activities, assumptions or execution conditions, learning remains descriptive rather than explanatory. Organisations may recognise that a project exceeded its budget, but lack the insight required to understand why this occurred. Without this causal understanding, lessons learned cannot be translated into actionable improvements in future estimation or execution practices.

This suggests that the extent to which learning can occur is closely related to how cost information is structured and connected across the project lifecycle. When cost information is fragmented or inconsistently structured, deviations become difficult to interpret, limiting both intra-project learning and the transfer of knowledge across projects. Conversely, more consistent structuring may enable stronger traceability, thereby creating the conditions under which more effective and deeper forms of learning can take place.

3.4 Cost Predictability

In project management literature, predictability is commonly understood as the degree to which future states of a project can be forecasted with a certain level of accuracy, typically by comparing expected and actual outcomes in terms of cost and time (Aass et al., 2026). This implies that predictability is not solely concerned with achieving low costs, but rather with reducing uncertainty and deviations between planned and actual project performance.

In construction projects, achieving cost predictability remains a significant challenge due to the inherent uncertainty, complexity and variability of project environments. Empirical evidence shows that cost deviations are common, with projects frequently experiencing differences between initial estimates and final costs (Cantarelli, 2011). This suggests that, despite the availability of forecasting techniques, cost outcomes remain difficult to anticipate reliably.

3.4.1 Within-Project and Cross-Project Predictability

A conceptually important distinction can be made between predictability within projects and predictability across projects. Within-project predictability refers to the extent to which cost forecasts become more accurate as a project progresses and more information becomes available. This form of predictability is primarily addressed through forecasting techniques and cost control mechanisms that update predictions of final project cost based on actual performance data. Accurate and timely forecasts are essential for effective project control, as they enable early detection of potential cost overruns and support decision-making during project execution (Kim & Kwak, 2018). However, commonly used forecasting approaches have been criticised for their limited reliability, particularly in early project stages where uncertainty is highest and available information is incomplete (Kim & Kwak, 2018).

Cross-project predictability, in contrast, concerns the ability to improve cost estimation accuracy over time by systematically learning from past projects and applying those insights to future planning and estimation. This form of predictability is not primarily a matter of better forecasting tools but of organisational learning: it depends on the ability to capture, interpret and transfer knowledge about cost performance from completed projects to future ones. Improvements in within-project forecasting accuracy do not automatically translate into improved cross-project predictability, as the latter requires that the causes of past deviations are understood and structurally addressed.

This distinction is particularly relevant for the present research. While within-project predictability is affected by the quality of cost control during execution, cross-project predictability depends on the strength of feedback loops between project outcomes and future estimation practices. Both dimensions are ultimately constrained by the same underlying challenge: the limited traceability of cost deviations and their causes.

3.4.2 Learning as a Condition for Predictability

The relationship between learning and predictability is central to understanding why cost overruns persist despite the availability of increasingly sophisticated forecasting tools.

Forecasting methods typically rely on the assumption that past project performance provides a meaningful basis for predicting future outcomes. This implies that the quality of cost predictions depends on the ability to interpret and generalise from historical data. When past performance is not properly understood, or when underlying causes of deviations are not identified, forecasts may be based on incomplete or misleading information, reducing their accuracy.

The literature suggests that learning effects can contribute to improved cost predictability over time. Learning curve theory shows that repeated execution of similar tasks can lead to increased efficiency and reduced costs as experience accumulates and processes are refined (Salman & Sodangi, 2025). Similarly, incorporating historical performance data into forecasting processes can improve the accuracy of cost predictions, particularly when variability and uncertainty are explicitly considered (Kim & Kwak, 2018). This indicates that predictability is not static but can be enhanced through systematic learning from past project experience.

At the same time, the relationship between learning and predictability is not purely linear. While improved learning can enhance predictability, low predictability and large deviations may themselves constrain learning. Projects experiencing significant cost overruns often operate under time pressure and organisational stress, which limits the capacity for systematic reflection and analysis. The conditions required for effective learning may therefore be weakest precisely in situations where learning would be most valuable, creating a feedback dynamic that can reinforce, rather than reduce, persistent cost problems.

3.4.3 The Role of Information Structure in Predictability

Predictability is influenced not only by learning, but also by the structure and quality of available information. Forecasting models depend on performance indicators and data collected during project execution, such as cost performance metrics or progress measurements. The reliability of these models therefore depends on the extent to which available data accurately reflects project performance and can be meaningfully interpreted (Kim & Kwak, 2018). When data is incomplete, inconsistent, or poorly structured, the predictive power of these models is reduced.

This points to a structural dimension of cost predictability that is often underexposed in the literature. Improving predictability is not only a matter of applying better forecasting techniques, but also of ensuring that the information on which those techniques rely is sufficiently structured, consistent and causally linked to execution reality. In this sense, the quality of cost structuring and the strength of cost traceability are not only relevant to learning but are also direct conditions for reliable cost forecasting and, ultimately, for improved cost predictability.

Taken together, the literature indicates that cost predictability is closely related to both the availability of reliable data and the ability to interpret that data through structured learning processes. While forecasting techniques provide tools for predicting future cost outcomes, their effectiveness depends on the extent to which past performance is understood and incorporated into decision-making. Improving cost predictability is therefore not only a technical challenge but also a structural and organisational one, in which cost structuring, traceability and learning each play an interconnected role.

3.5 Conceptual Framework

The literature reviewed in Sections 3.1 to 3.4 provides a basis for critically evaluating and refining the preliminary conceptual framework introduced in Chapter 1. That framework proposed a sequential relationship between four concepts, cost structuring, cost traceability, project learning, and cost predictability, with a cross-project feedback loop connecting learning outcomes back to future estimation. While this initial framing proved directionally valid, the literature review reveals important nuances that justify several refinements and exposes a research gap that motivates the empirical phase of this study.

3.5.1 Refinements

Refinement 1: Cost Structuring is Multidimensional and Phase-Dependent

The preliminary framework treated cost structuring as a single concept. The literature shows that cost structuring operates across distinct phases, estimation, budgeting, and control, each characterised by different logics and levels of aggregation (Malkanthi et al., 2017; Holm & Schaufelberger, 2021). Crucially, it is not merely the presence of a structuring approach that matters, but the degree of consistency between structuring logics across phases. When different aggregation levels or decomposition logics are used at each stage, discontinuities arise that directly constrain traceability.

Furthermore, the literature highlights that indirect costs represent a structurally distinct challenge within cost structuring. Because indirect costs are not directly attributable to discrete work activities, they are particularly difficult to estimate, allocate and control in a traceable manner (Becker et al., 2014; Chan & Pasquire, 2004). This suggests that the challenge of cost structuring is not uniform across all cost categories but is especially acute for indirect costs with process- and time-related drivers.

The refined framework therefore distinguishes between two analytically separate dimensions of cost structuring: within-phase organisation of cost information, and cross-phase structural alignment. Both dimensions influence the extent to which cost information remains consistent and interpretable throughout the project lifecycle.

Refinement 2: Cost Traceability is Conditioned by Information Quality

The preliminary framework implied a relatively direct link between cost structuring and traceability. The literature makes clear that traceability is constrained not only by the absence of data, but by the absence of causal links between cost data and project activities (Toosi & Chamikarpour, 2021). Even when large volumes of cost data are available, poor information quality and the separation of cost systems from progress monitoring systems limit the interpretability of deviations (Tang et al., 2008).

Traceability is therefore a function of both structural alignment across phases and information quality within phases. The refined framework reflects this by positioning information quality as a conditioning factor alongside structural alignment. This also implies that traceability cannot be improved by generating more data alone, it requires improving the structural conditions under which cost data is connected to execution reality.

Refinement 3: Cost Traceability as a Necessary Condition for Double-Loop Learning

The preliminary framework treated project learning as a single process. The literature warrants a distinction between intra-project learning, the ability to detect and respond to deviations during execution, and inter-project learning, the ability to translate insights from completed projects into improved future estimation (Antoni & Sense, 2001; Wong et al., 2011).

Importantly, the refined framework does not position all forms of learning as dependent on cost traceability. Single-loop learning, the detection and correction of deviations without questioning underlying assumptions, can occur without strong traceability. It requires only that a deviation is visible: a project can register that costs have exceeded budget and respond, without needing to establish why. Double-loop learning, by contrast, involves identifying root causes and adapting the processes or assumptions that produced them (Argyris & Schön, 1978; Wong et al., 2011). This deeper form of learning requires traceability, because understanding why a deviation occurred depends on the ability to link outcomes to specific activities, decisions or execution conditions. Without that linkage, deviations remain visible but unexplained, and learning cannot progress beyond single-loop correction (Henderson et al., 2013).

The refined framework therefore positions cost traceability as a necessary condition specifically for double-loop learning, in both its intra-project and inter-project forms. Both forms contribute to cost predictability, but through different mechanisms and at different time horizons.

Refinement 4: The Feedback Loops Operate at Two Levels

The preliminary framework included a single cross-project feedback loop. The refined framework represents two feedback mechanisms: a within-project feedback loop that enables adaptive control during execution, and a cross-project feedback loop that enables improved estimation in future projects. Both loops are positioned as conditionally dependent on the strength of cost traceability.

A critical addition in the refined framework is the explicit recognition that both feedback loops return not only to estimation practices, but to cost structuring itself. This reflects the insight that sustained improvement in cost predictability requires organisations to adapt the way information is structured, not merely the content of individual estimates (Ahiaga-Dagbui & Smith, 2014).

3.5.2 Refined Conceptual Framework

Based on these refinements, the conceptual framework is restructured as follows and visualised in Figure 3.1. The framework integrates relationships that are supported by the literature with relationships that remain insufficiently empirically understood. Figure 3.1 therefore distinguishes between literature-supported relationships and research gaps that are taken forward into the empirical analysis.

Two analytically distinct dimensions of cost structuring are distinguished in the refined framework. Within-phase organisation refers to how coherently cost information is structured inside a single phase, for instance whether an estimate, a work budget, or a control report is internally consistent and clearly decomposed. Cross-phase structural alignment refers to whether these structures remain mutually connectable as information moves from one phase to the next, so that a cost item defined in the estimate can still be recognised in the budget and traced through to control and reporting.

Both dimensions condition cost traceability. The literature, however, locates the principal constraint not within individual phases but at the transitions between them, where information is re-aggregated, reclassified, or re-coded and the causal links to the original assumptions are weakened (Malkanthi et al., 2017; Holm & Schaufelberger, 2021). The refined framework therefore foregrounds cross-phase structural alignment as the primary analytical focus, while treating within-phase organisation as a necessary condition for meaningful cost information within each phase. Whether this prioritisation holds in practice is taken forward into the empirical analysis. Information quality is explicitly recognised as a conditioning factor for traceability, as it determines whether structurally present data can be interpreted and connected to execution reality.

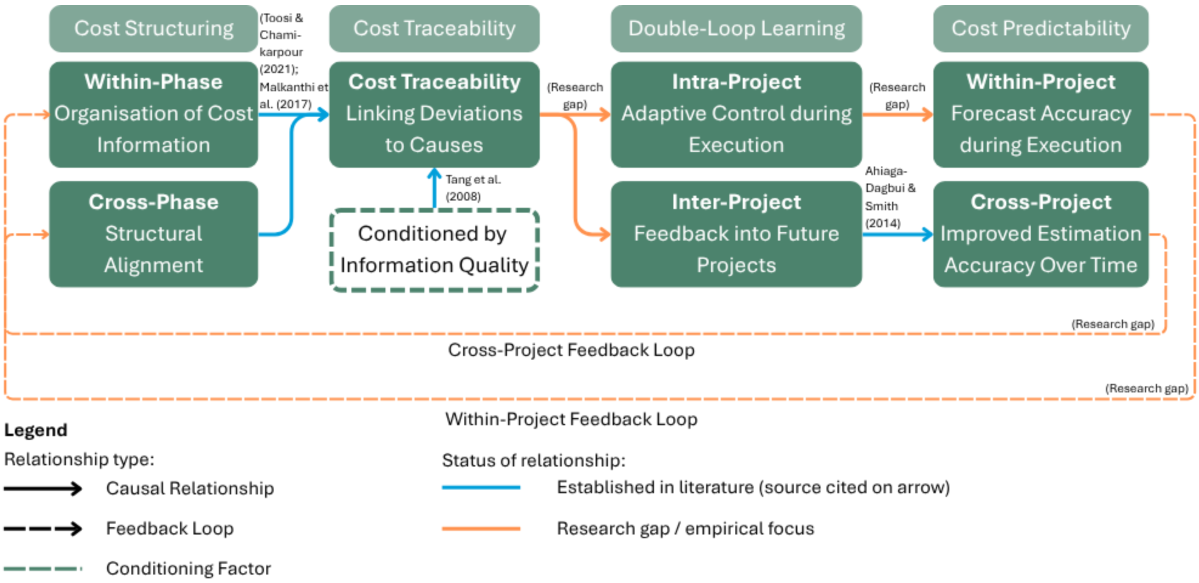

Figure 3.1: Refined Conceptual Framework (own figure based on literature synthesis; status of relationships is indicated in the legend and on the arrows)

Cost traceability, in turn, enables double-loop learning in two forms. Intra-project learning supports adaptive control and early intervention during execution, enabling teams to identify and address structural causes of emerging deviations. Inter-project learning feeds causal insights back into future estimation and planning practices. Single-loop learning, the correction of deviations without causal reconstruction, can occur independently of traceability and is therefore not represented as an outcome of cost traceability in the framework. Together, the two forms of double-loop learning contribute to improved cost predictability, although the two pathways are not equally grounded in the literature. The inter-project pathway, in which causal insight from completed projects feeds back into more accurate future estimation, is well established: weak feedback and limited inter-project learning are widely associated with persistent estimation inaccuracy (Ahiaga-Dagbui & Smith, 2014). The intra-project pathway, in which learning during execution may improve within-project forecast accuracy, is less directly established in the reviewed literature and is therefore treated as part of the empirical focus of this research. Within-project forecast accuracy and cross-project estimation accuracy are themselves established, measurable constructs (Kim & Kwak, 2018; Aass et al., 2026). A critical addition in the refined framework is the explicit recognition that both feedback loops, within-project and cross-project, return not only to estimation practices but to cost structuring itself. This reflects the insight that sustained improvement in cost predictability requires organisations to adapt the way information is organised, not merely the content of estimates.

3.5.3 Research Gap for Empirical Research

The literature reviewed in this chapter shows that cost structuring, cost traceability, project learning and cost predictability can be connected. However, the literature does not yet sufficiently explain how these conceptual relationships operate in practice. The research gap therefore lies in the interconnections between the concepts: how cost structuring affects traceability across phase transitions, under which conditions traceability enables double-loop learning rather than only single-loop correction, and how these learning mechanisms can contribute to improved cost predictability in Dutch construction projects.

Several specific gaps can therefore be identified. First, the literature acknowledges that cross-phase structural alignment is important for traceability but provides limited empirical evidence on how and where this alignment breaks down when cost information moves from tender estimation to work budgeting, execution control, reporting and evaluation. Second, the conditions under which cost traceability enables double-loop learning, rather than remaining limited to single-loop correction, are theoretically plausible but not yet empirically examined in the Dutch construction context. Third, the role of indirect costs in limiting traceability and learning during execution remains underexplored, despite their recurring identification as a problematic cost category.

These gaps directly motivate the empirical phase of this research. By analysing how cost information is structured and used in practice within Dura Vermeer’s projects, and by examining where traceability is preserved or lost, the empirical study aims to substantiate and contextualise the relationships proposed in the refined framework.

4 Structuring Approaches

This chapter builds on the theoretical foundation established in Chapter 3, where the relationships between cost structuring, cost traceability, project learning, and cost predictability were analysed. The literature review showed that cost performance in construction projects is not only influenced by forecasting techniques, but also by the way cost information is structured and connected across project phases.

Chapter 3 highlighted that cost information is often organised through different structuring logics during estimation, execution, and reporting. These differences may introduce fragmentation and discontinuities, which can affect the ability to trace cost deviations and to interpret project performance over time. As a result, the effectiveness of project learning processes may be constrained, particularly when deviations cannot be clearly linked to their underlying causes.

Against this background, various structuring approaches have been developed in both literature and practice to improve the organisation, coordination, and alignment of project information. These approaches differ in their primary focus, ranging from structuring project scope and scheduling activities to integrating planning, execution, and performance monitoring.

The aim of this chapter is therefore to identify structuring approaches described in literature and to analyse how these approaches aim to improve the organisation of project information, with particular attention to their potential to support cost traceability and project learning. By doing so, this chapter addresses Sub-Question 2: *"Which structuring approaches are identified in literature, and through which mechanisms may they support cost traceability and project learning?"*.

This study focuses specifically on approaches that explicitly structure project information related to scope, time, and cost. The selection of structuring approaches is therefore guided by their relevance to the central research problem, namely the organisation of cost information across project phases and its implications for cost traceability and project learning.

Approaches that primarily address other aspects of project management, such as contractual arrangements, collaboration, or risk management, are not included in this study, as their primary focus lies outside the structuring of cost information and its traceability. The selection is therefore not intended to be exhaustive but is based on the relevance of each approach to the mechanisms of cost structuring, cost traceability, and project learning identified in Chapter 3.

4.1 Selection and Classification of Structuring Approaches

Based on the selection criteria outlined above, five structuring approaches are identified as relevant for this study: the Work Breakdown Structure (WBS), Critical Path Method (CPM), Earned Value Management (EVM), the Last Planner System (LPS), and Advanced Work Packaging (AWP).

The five approaches were selected through theoretical purposive sampling, using the refined conceptual framework developed in Section 3.5 as the selection lens. The purpose of the selection is not to provide an exhaustive overview of all project management methods, but to compare approaches that represent different structuring mechanisms relevant to cost traceability and project learning. The refined framework positions cost structuring as a multidimensional construct, consisting of within-phase organisation and cross-phase structural alignment, and links this to cost traceability, double-loop learning, and cost predictability. The selected approaches therefore cover the main structuring dimensions required to examine this chain.

WBS is included because it represents hierarchical scope and cost decomposition. CPM is included because it represents time-based activity sequencing. EVM is included because it represents integrated cost-progress performance measurement. LPS is included because it represents execution readiness, workflow reliability, and short-cycle feedback. AWP is included because it represents lifecycle-oriented work packaging across engineering, construction planning, and execution. Together, these five approaches provide a theoretically purposeful comparison of different ways in which project information may be decomposed, sequenced, measured, stabilised, or aligned across the project lifecycle.

To clarify their relevance to the refined conceptual framework, Table 4.1 positions the five approaches according to the part of the framework they appear to address and the type of cost information they primarily support. This positioning is preliminary and literature based. It does not assume that the approaches improve cost traceability in practice but identifies where their mechanisms may be relevant for the empirical analysis and the later framework development.

Table 4.1: Preliminary Positioning of Structuring Approaches Within the Refined Framework

Approach	Main Mechanism	Part of Refined Framework Addressed	Cost Information Primarily Addressed
WBS	Hierarchical decomposition of scope and cost	Within-phase organisation of cost information	Mainly planned direct costs; limited support for indirect costs unless explicitly allocated
CPM	Sequencing of activities and schedule dependencies	Time-related structuring of execution logic	Time-related cost implications, delay exposure and activity timing; does not directly structure actual costs
EVM	Integration of planned value, earned value and actual cost	Cost-progress integration and performance visibility	Planned, earned and actual costs; strongest for measurable direct work, weaker for causal explanation and indirect costs
LPS	Readiness planning, constraint management and short-cycle feedback	Execution feedback and intra-project learning	Process- and time-related drivers such as waiting, constraints, productivity loss and disrupted workflow; indirect cost relevance is mainly indirect
AWP	Lifecycle-oriented work packaging across engineering, planning and execution	Cross-phase structural alignment and traceability	Direct work packages, package-level budgets, progress and deviations; can support indirect cost traceability if indirect effort is deliberately linked to packages

This overview shows that none of the approaches covers the full conceptual framework independently. WBS, CPM and EVM mainly provide partial structuring and measurement mechanisms for scope, time and cost. LPS adds an execution-oriented feedback mechanism, while AWP appears most directly relevant to cross-phase alignment because it introduces a lifecycle package structure. The later evaluation therefore examines not whether one approach is generally superior, but which combination of mechanisms is needed to support cost traceability and double-loop learning.

To support a structured analysis, these approaches are organised into two categories: traditional approaches and advanced approaches. This distinction is not intended as a value judgement but reflects a meaningful difference in the primary orientation of each approach. Traditional approaches, comprising WBS, CPM, and EVM, were developed as foundational instruments for project planning and control. Each of these approaches primarily addresses a single project dimension: scope decomposition, time scheduling, or integrated performance measurement (PMI, 2013). While they are well-established in both literature and practice, they were not explicitly designed to address cross-phase structural alignment or the connection between upstream planning and downstream execution.

Advanced approaches, comprising LPS and AWP, were developed in response to persistent performance challenges in construction projects, particularly those related to coordination failures, productivity losses, and the fragmentation of project information across disciplines and phases (Halala & Fayek, 2019; Jung et al., 2020). In contrast to traditional approaches, these methodologies explicitly aim to integrate multiple project dimensions and to align planning activities with execution needs. Their development reflects a recognition that improving project performance requires not only better planning instruments, but also a more consistent organisation of information across the project lifecycle.

Each approach is analysed according to the same structure: its origins and definition, its primary mechanisms for organising project information, and its potential contribution to cost traceability and project learning as defined in Chapter 3. The chapter concludes with a comparative synthesis that positions the five approaches in relation to the limitations identified in the theoretical foundation, thereby providing the analytical basis for the evaluation conducted in Phase III of this study.

4.2 Traditional Structuring and Control Approaches

Traditional structuring approaches in construction project management provide foundational instruments for organising project scope, time, and cost (PMI, 2013). These approaches have been widely adopted in both literature and practice and form the basis of most project planning and control systems. The following sections discuss three traditional approaches that are directly relevant to the organisation of cost information in construction projects: the WBS, the CPM and EVM.

4.2.1 Work Breakdown Structure

The WBS is a hierarchical decomposition of the total project scope into smaller, more manageable components. As defined by Norman et al. (2008), a WBS divides project work into discrete elements that can be planned, executed, and controlled independently, providing the organisational foundation for project management activities. The lowest level of the WBS, commonly referred to as work packages, represents the units at which cost and schedule information can be assigned and tracked.

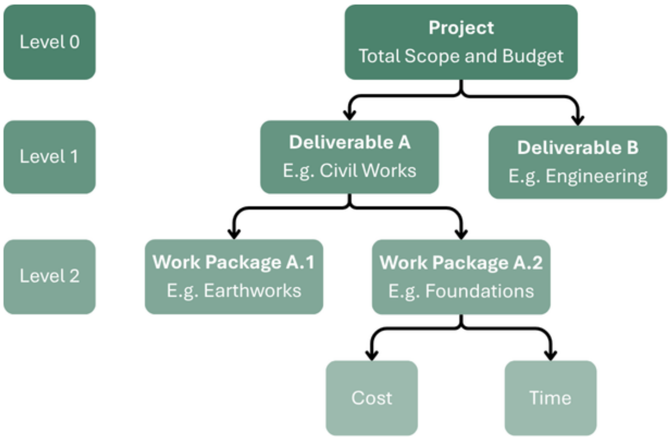

Figure 4.1: Work Breakdown Structure; Hierarchical Decomposition of Project Scope into Work Packages (own visualisation based on WBS principles described by Norman et al. (2008) and PMI (2013))

Figure 4.1 illustrates this hierarchical logic across three levels: the total project scope at Level 0, deliverables at Level 1, and discrete work packages at Level 2, at which cost and time information is assigned.

The primary contribution of the WBS to cost structuring lies in its ability to establish a consistent coding structure that links project scope to cost categories. By decomposing the project into clearly defined elements, the WBS provides a basis for allocating costs to specific parts of the project and for aggregating cost information at different levels of detail (PMI, 2013). This makes it possible to organise cost information in a structured and hierarchical manner, which supports both estimation and reporting.

However, the effectiveness of the WBS as a cost structuring instrument depends critically on how it is defined and applied. Norman et al. (2008) note that different decomposition logics, for example, functional, spatial, or deliverable-oriented, result in different representations of project scope, and these representations may not be equally useful for controlling costs during execution. When a WBS is structured primarily around deliverables or reporting categories rather than around how work is executed in the field, it may provide limited support for identifying where and why cost deviations occur.

Furthermore, while the WBS provides a stable framework for scope definition, it does not prescribe how engineering outputs should be sequenced or how work should be prepared for execution. As a result, a well-defined WBS does not automatically prevent coordination failures between disciplines or misalignments between upstream planning and downstream execution. From the perspective of cost traceability, the WBS establishes a structural basis for linking costs to scope elements but does not ensure that this linkage is maintained consistently across project phases or that deviations can be causally attributed to specific execution conditions.

4.2.2 Critical Path Method

The CPM is a time-based planning technique that models project activities and their logical dependencies to identify the sequence of activities that determines the minimum project duration. By calculating float values for each activity, CPM enables project teams to identify which activities are critical, meaning that any delay in these activities will directly affect the overall project completion date, and which activities have scheduling flexibility (Galloway, 2006). CPM is widely applied in construction project management for schedule development, monitoring, and delay analysis.

Figure 4.2 illustrates a CPM network for a project comprising seven activities. Each node displays the earliest start and finish in the upper row and the latest start and finish in the lower row, with the total float shown beneath the node. The critical path, activities A, B, C and D, is highlighted in red. Activities on the critical path have a float of zero, meaning any delay directly extends the project end date. Non-critical activities E, F, and G run in parallel with float values of 10, 5, and 10 respectively, indicating the degree of scheduling flexibility available without affecting project completion.

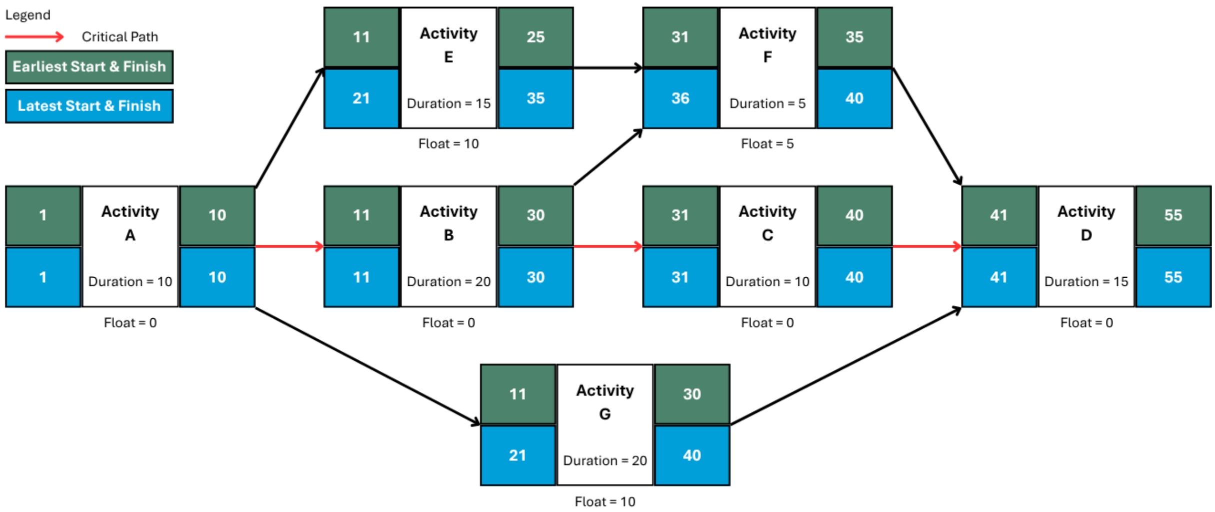

Figure 4.2: Critical Path Method; Network Showing Activity Dependencies, Float Values, and the Critical Path (own illustrative example based on CPM principles described by Galloway (2006))

From a cost structuring perspective, CPM contributes indirectly by providing a time-based framework within which cost-loaded schedules can be developed. When activities in a CPM network are assigned cost values, it becomes possible to track planned expenditure over time and to relate schedule deviations to potential cost implications. This time-phased view of costs supports cash flow planning and provides a basis for monitoring whether the project is progressing in line with financial expectations.

However, CPM has notable limitations when considered in relation to cost traceability and project learning. The primary focus of CPM is on identifying when activities are planned to occur and determining the impact of delays on project completion. It does not provide explicit mechanisms for ensuring that the prerequisites for executing those activities, such as the availability of design information, materials, or work front access, are in place at the time of execution (Galloway, 2006). This distinction is particularly relevant for cost predictability, because instability in field execution often translates into productivity losses and indirect cost growth, while the root causes may remain difficult to isolate if readiness conditions are not explicitly managed.

Moreover, as Figure 4.2 illustrates, CPM networks operate at an activity level that reflects the planned sequence of work rather than the level at which costs are estimated and reported. When cost structures and schedule structures are not aligned, relating financial deviations to specific schedule events becomes difficult. As a result, CPM supports the identification of when something went wrong but provides limited insight into why it went wrong in terms of underlying cost assumptions or execution conditions.

4.2.3 Earned Value Management

EVM is a project performance measurement methodology that integrates scope, schedule, and cost information into a unified framework for assessing project progress and performance. As defined by PMI (2013), EVM combines three core data points, Planned Value (PV), Earned Value (EV), and Actual Cost (AC), to generate quantitative indicators of both cost and schedule performance at any point during project execution. Fleming and Koppelman (2002) argue that, contrary to common assumptions, EVM is applicable across project types and contract forms, and that its fundamental utility lies in containing cost risks by providing early warning signals before problems become unmanageable.

Figure 4.3 illustrates the three core EVM curves over time. The PV (green) represents the budgeted cost of work scheduled up to a given point, ultimately reaching the Budget at Completion (BAC) at project end. The AC (red) reflects the costs actually incurred, while the EV (blue) represents the budgeted value of work completed. At the status date ("Time Now"), two key variances become visible. The Cost Variance (CV = EV − AC) indicates whether the work accomplished cost more or less than planned: in the scenario shown, AC exceeds EV, resulting in a negative CV and signalling a cost overrun. The Schedule Variance (SV = EV − PV) reflects whether more or less work has been completed than planned at this point in time: as EV falls below PV, SV is also negative, indicating a schedule delay.

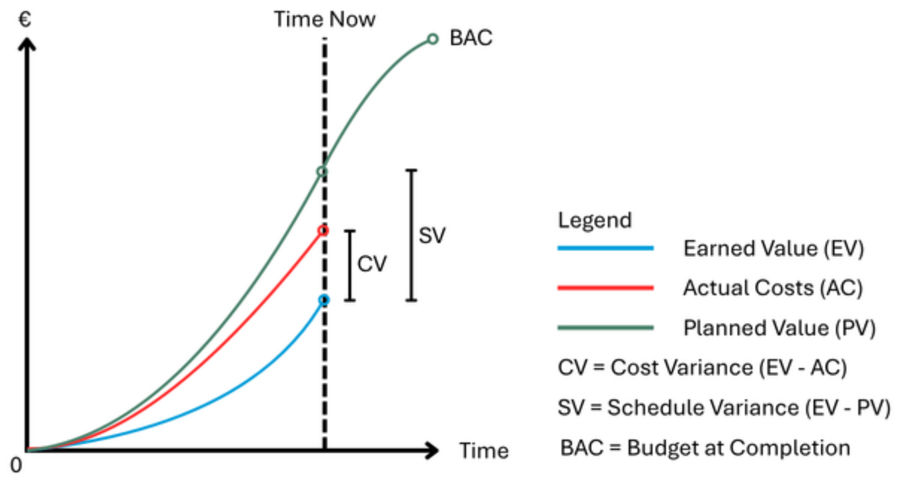

Figure 4.3: Earned Value Management; Curves Showing PV, EV, and AC (own illustrative example based on EVM concepts described by PMI (2013) and Fleming and Koppelman (2002))

The primary contribution of EVM to cost management lies in this ability to detect deviations early and to forecast the expected outcome at completion. Chin-Keng and Shahdan (2015) identify several benefits of EVM, including improved planning, clearer definition of work scope, concurrent analysis of time and cost performance, and the ability to project final cost outcomes at relatively early stages of execution. These characteristics make EVM a more integrated performance measurement instrument than either the WBS or CPM in isolation, as it explicitly connects scope, time, and cost dimensions within a single analytical framework.

Although EVM integrates multiple project dimensions, its primary function is performance measurement against a pre-established baseline rather than the structural alignment of planning and execution activities. As Figure 4.3 illustrates, EVM reveals that a deviation has occurred, through the gap between EV, AC, and PV, but does not in itself explain why that deviation has occurred or how it relates to specific execution conditions, decisions, or upstream assumptions. The explanatory value of EVM therefore depends strongly on the granularity and execution-alignment of the underlying data: when performance is tracked at relatively high aggregation levels, deviations may be visible without being diagnostically meaningful (PMI, 2013). Project teams can observe that performance is off-track while still lacking the level of detail needed to trace the deviation back to specific work scopes or underlying causes.

For this reason, EVM is classified in this study as a traditional approach. While it represents a more sophisticated instrument than WBS or CPM individually, its orientation remains primarily measurement focused. It does not explicitly address the cross-phase alignment between estimation, execution, and reporting, nor does it provide structural mechanisms for linking cost deviations to their causal origins. In this sense, EVM can signal that learning is needed but does not itself create the structural conditions under which double-loop learning, as defined in Chapter 3, can take place.

4.3 Advanced Structuring and Control Approaches

Advanced structuring approaches were developed in response to persistent performance challenges that traditional approaches proved unable to fully address. As projects grew in scale and complexity, limitations became increasingly apparent, prompting the development of approaches that explicitly aim to integrate multiple project dimensions and align planning activities with execution needs (Halala & Fayek, 2019; Jung et al., 2020).

The following sections discuss two advanced approaches that are directly relevant to the organisation of cost information and its traceability across project phases: the LPS and AWP. Despite differences in their origins and primary focus, each approach introduces mechanisms that go beyond performance measurement by structuring the conditions under which work is prepared and released to the field. Their potential contribution to cost traceability and project learning is analysed in relation to the limitations identified in Chapter 3.

4.3.1 Last Planner System

The LPS is a production planning and control method rooted in Lean Construction. It was developed as an alternative to traditional project control approaches, which often focus on monitoring deviations after they have occurred. Ballard (2000) argues that conventional project control is mainly concerned with the detection of cost and schedule variances, while production control should focus on making events conform to plan and on replanning when this is no longer feasible. In this sense, LPS shifts control from retrospective variance detection towards the active management of workflow reliability.

The central logic of LPS is the distinction between what should be done, what can be done, what will be done, and what was done. As illustrated in Figure 4.4, this logic is made explicit through four production planning filters, SHOULD, CAN, WILL, and DID, which are embedded at successive levels of the planning hierarchy. Instead of assuming that scheduled activities are automatically executable, LPS makes the feasibility of work explicit before commitments are made. Ballard (2000) describes the Last Planner as the person or group that produces assignments for direct work, translating higher-level project objectives into executable commitments while matching what should be done with what can realistically be done.

LPS is structured through multiple planning levels, as shown in Figure 4.4. Starting from project objectives and work structuring, the hierarchy progresses from master scheduling, which identifies the main milestones and overall sequence, through phase scheduling, which collaboratively structures the work for a specific project phase. As status and forecasts are incorporated, lookahead planning breaks activities into more detailed operations and identifies constraints. The make-ready process then removes those constraints and creates a workable backlog of tasks for short-term planning. Finally, weekly work planning translates executable work into short-term commitments (Hamzeh, 2011; Lagos et al., 2024).

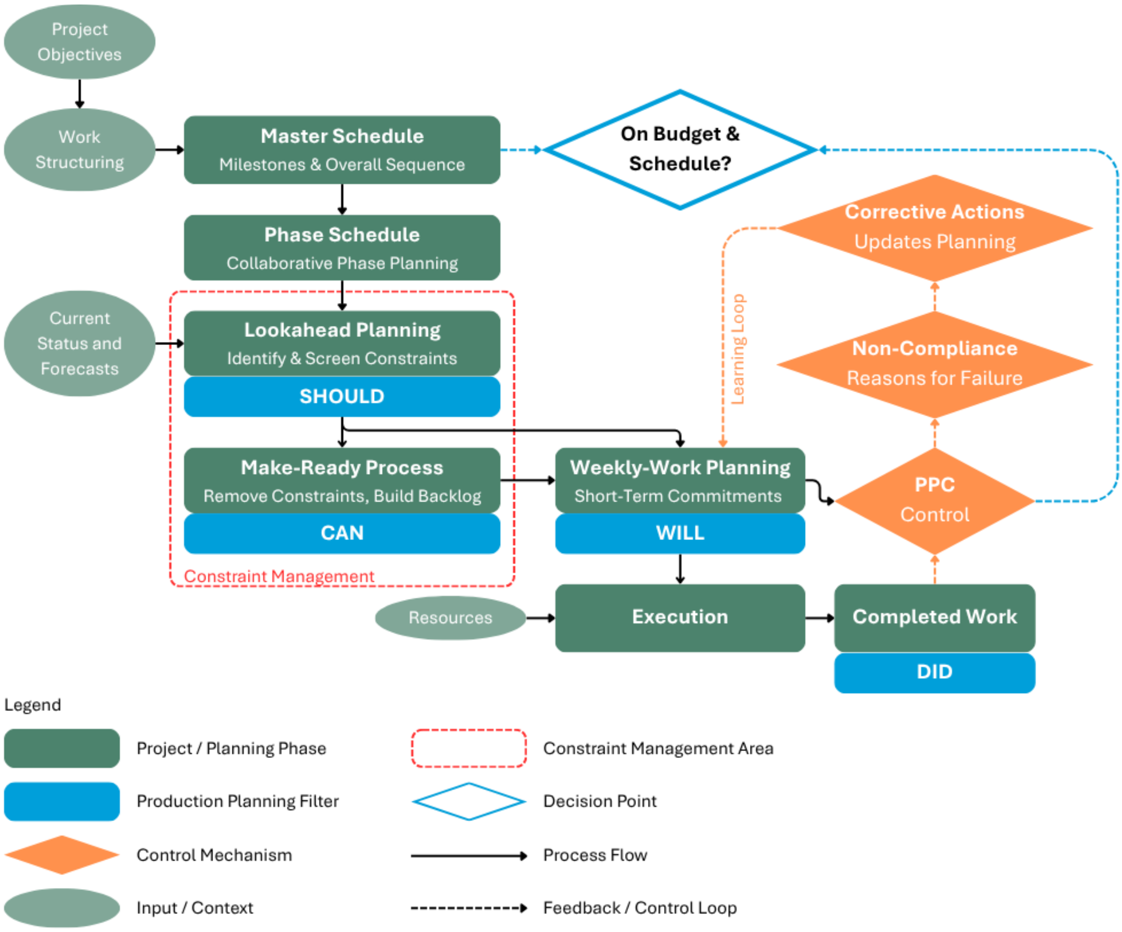

Figure 4.4: Last Planner System; Planning Levels, Production Planning Logic, and Control Loop (own visualisation based on LPS principles described by Ballard (2000), Hamzeh (2011), and Lagos et al. (2024))

A key mechanism of LPS is constraint management, highlighted in Figure 4.4 by the bounded area encompassing lookahead planning and the make-ready process. At these levels, activities are screened for readiness rather than simply pushed into execution because they appear in the schedule. This is where the SHOULD and CAN filters operate: lookahead planning identifies what should be done and screens for constraints, while the make-ready process removes those constraints to establish what can realistically be executed. As Ballard (2000) describes, lookahead planning is used to shape workflow, match load and capacity, decompose master schedule activities into work packages, maintain a backlog of ready work, and update higher-level schedules when required. Through this mechanism, LPS operates as a pull-based control system: work is released to execution only when the production system is ready to receive it.

The reliability of short-term planning is measured through the control loop shown on the right side of Figure 4.4. Once weekly work is committed (WILL) and executed, the completed work (DID) is measured against planned commitments through Percent Plan Complete (PPC). Ballard (2000) positions PPC not only as a performance indicator but also as the starting point for learning: when planned work is not completed, the reasons for non-completion should be identified and analysed so that root causes can be addressed. As shown in Figure 4.4, reasons for non-compliance feed into corrective actions, which in turn update planning and feed back into the overarching question of whether the project remains on budget and schedule. Lagos et al. (2024) further show that LPS indicators, including PPC, Percent Constraints Removed (PCR), reasons for non-compliance, and corrective actions, make the execution process measurable beyond traditional schedule progress alone.

From the perspective of cost traceability and project learning, the literature suggests that LPS contributes primarily through improving the operational transparency of project execution. LPS does not function as a cost breakdown structure in the same way as WBS or EVM and does not prescribe how budgets or actual costs should be allocated to cost accounts. Its contribution to cost traceability is therefore indirect. LPS does not directly structure or allocate costs. Its contribution lies in making execution process conditions visible, such as constraints, readiness problems and workflow disruptions, which can help explain later productivity losses, delay-related costs and indirect cost growth. By linking deviations in execution to operational causes, missing information, unavailable resources, unresolved constraints, incomplete prerequisite work, or coordination failures, LPS can improve the explanatory quality of project control information. These reasons can help account for cost deviations that result from waiting time, rework, disrupted workflow, or productivity losses.

This link between workflow reliability and project performance is supported by both foundational and recent research. Ballard (2000) argues that improved workflow reliability can reduce cost and duration because specialists can better plan their own work when they can rely on the timely delivery of drawings, materials, information, and prerequisite work. Lagos et al. (2024) extend this argument empirically, using data from 164 completed projects to show that LPS indicators can predict schedule performance with high accuracy. Although this evidence focuses on schedule performance rather than cost performance directly, it is relevant because schedule unreliability and workflow disruption are common drivers of indirect cost growth.

The effectiveness of LPS depends strongly on implementation quality. Hamzeh (2011) stresses that LPS requires commitment from management, sufficient training, involvement of the project team, and a culture of continuous improvement. Recurring implementation barriers include resistance to change, lack of leadership, limited buy-in, lack of experience with lean principles, and the absence of a clear implementation plan. These conditions matter for traceability and learning because LPS data only becomes useful when the system is consistently applied and reasons for non-compliance are captured accurately.

4.3.2 Advanced Work Packaging

AWP emerged in response to persistent coordination and productivity challenges in large-scale industrial construction projects, particularly in sectors such as oil and gas and energy infrastructure (Musarat et al., 2024). Traditional planning approaches often proved insufficient to manage the strong interdependencies between engineering, procurement, and construction activities that characterise such projects, resulting in coordination failures, productivity losses, and frequent cost and schedule overruns. In response, AWP was developed through collaborative research initiatives led by the Construction Industry Institute (CII) and the Construction Owners Association of Alberta (COAA), with the aim of providing a lifecycle-oriented execution model that integrates engineering, procurement, and construction planning through the structured definition of work packages (Hamdi, 2013; Halala & Fayek, 2019).

A key motivation behind AWP was the recognition that conventional work packaging practices were typically implemented only during the construction phase, with limited integration into earlier project stages such as front-end planning and detailed engineering. This separation frequently resulted in misalignment between engineering deliverables and construction needs, creating inefficiencies during execution. AWP therefore extends the work packaging concept across the full project lifecycle, structuring project scope from early planning through engineering and into construction execution (Ponticelli et al., 2015).

AWP can be defined as a structured planning and execution methodology that organises project work through a system of interrelated work packages. Its defining characteristic is the principle of construction-driven planning, which implies that upstream project activities, engineering and procurement, are organised with the needs of construction execution as the primary reference point. By aligning upstream decision-making with downstream construction requirements, AWP aims to reduce inefficiencies caused by incomplete information, missing materials, or poorly coordinated work sequences (Halala, 2018; Jung et al., 2020).

The AWP methodology operationalises this logic through a hierarchical work package structure comprising three interrelated package types: Engineering Work Packages (EWPs), Construction Work Packages (CWPs), and Installation Work Packages (IWPs). As illustrated in Figure 4.5, this structure spans the full project lifecycle across three phases, Planning & Design, Engineering, and Construction, and distinguishes between the overarching AWP workflow and the package hierarchy through which project scope is progressively structured and linked to execution.

EWPs organise and sequence engineering deliverables, such as drawings and material take-offs, in a way that supports specific portions of construction scope in the correct order. As shown in the engineering column of Figure 4.5, EWPs are developed during the engineering phase and function as a mechanism to prioritise and coordinate engineering output against construction execution demands, thereby strengthening the link between design information and field readiness (Ponticelli et al., 2015).

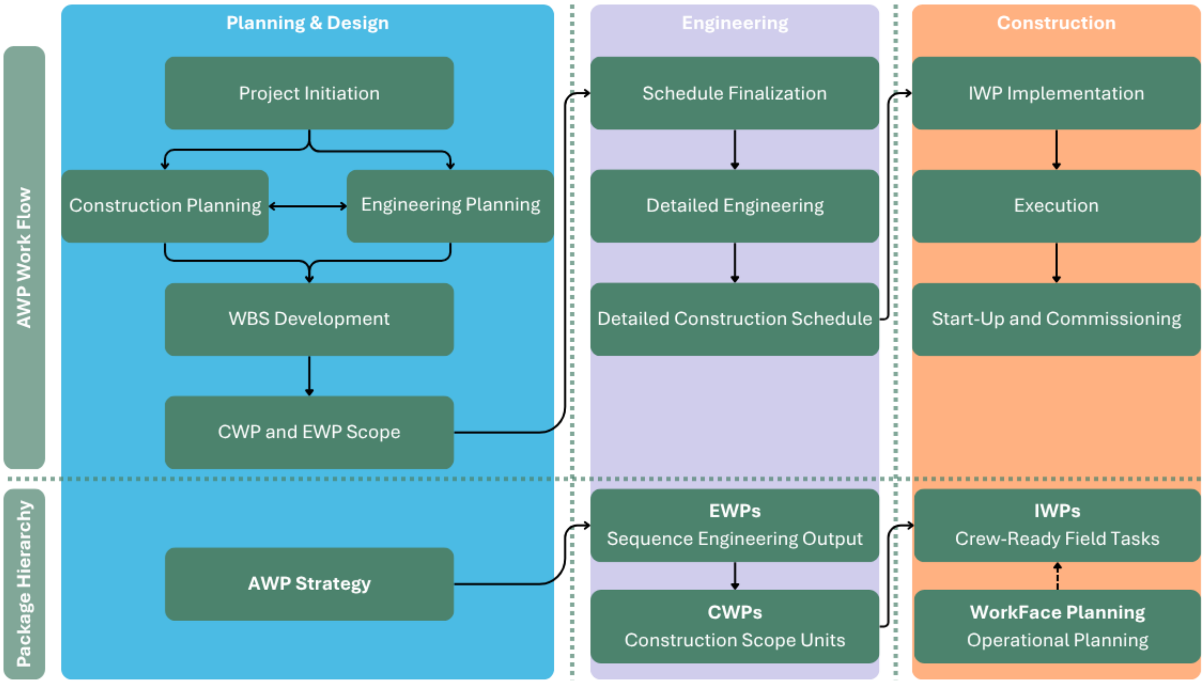

Figure 4.5: Advanced Work Packaging; Work Flow and Package Hierarchy (own visualisation based on AWP package hierarchy and workflow described by Ponticelli et al. (2015), Halala (2018), Jung et al. (2020), and Pellegrino (2017))

CWPs provide the bridge between engineering outputs and field execution planning. They assemble the relevant engineering outputs into manageable construction scope units via one or more EWPs, aligned to areas or systems, and establish targets for schedule and budget control at a level meaningful for site execution management (Jung et al., 2020). They are intended to align with the construction sequence and to provide a stable basis for coordinating procurement and installation planning. In CII-aligned descriptions, CWPs are also commonly associated with an explicit budget and schedule for monitoring actual performance, reinforcing their function as a control-relevant ‘scope-block’ that remains consistent with how work is organised on site (Pellegrino, 2017). From a project control perspective, CWPs are particularly relevant because they often become the level at which schedule and cost baselines can be aligned with how the work is organised in the execution phase. This creates a clearer basis for monitoring progress and for locating where deviations begin to emerge, especially when compared with reporting structures that aggregate performance at levels that do not reflect execution logic (Halala, 2018).

IWPs represent the most granular level of the hierarchy, as shown in the Construction column of Figure 4.5: executable units of work for field crews, containing task-specific instructions, material lists, safety requirements, and verification documentation. They are designed to contain everything required to perform a defined set of installation tasks without interruption. Complementary CII-based practitioner guidance stresses that IWPs are intended to be executable only when prerequisites are in place, and that they package the information needed to safely and efficiently complete a defined scope at crew level within a short horizon (Jung et al., 2020; Pellegrino, 2017).

Together, these package types create a vertical linkage between upstream planning outputs and downstream construction execution, while also integrating multiple information streams, design, materials, schedule, and quality, horizontally across disciplines (Jung et al., 2020; Pellegrino, 2017). When deviations occur during execution, the packaging structure provides a practical pathway to investigate whether causes relate to incomplete engineering deliverables, procurement readiness, or work front constraints affecting a specific IWP or CWP. In this way, the hierarchy supports not only coordination, but also more targeted diagnosis of deviations and improved opportunities for structured feedback and learning (Halala, 2018).

In relation to the refined conceptual framework, AWP therefore works primarily through the cross-phase structural alignment dimension of cost structuring: it provides a package-based linking logic through which tender assumptions, work budgets, execution progress, deviations and feedback can remain connected across phases. Its influence on cost traceability and double-loop learning is therefore indirect but central: AWP does not explain deviations by itself but creates the stable unit at which deviations can be localised, interpreted and later reused as learning input.

A further element of the AWP framework is WorkFace Planning (WFP), represented in Figure 4.5 as the operational planning layer beneath IWPs in the Construction phase. WFP is a short-interval planning process focused on ensuring that IWPs are sufficiently prepared before being released to the field. Central to this process is the concept of workface readiness: work is only released to construction crews once all necessary prerequisites, design information, materials, tools, and permits, are in place. This readiness-driven approach aims to increase labour productivity by ensuring that crews can focus on productive work rather than resolving planning deficiencies during execution (Porwal et al., 2025; Hamdi, 2013).

Implementation of AWP is contingent on several enabling conditions. The literature consistently identifies information standards and system interoperability, clear governance and role allocation across organisational interfaces, and training and capability development as key requirements (Jung et al., 2020; Musarat et al., 2024). A recurring challenge concerns the integration of package information across engineering tools, cost systems, and project management information systems, which requires consistent standards for numbering and data exchange. Additionally, the literature notes that AWP adoption is often framed as a maturity journey rather than a binary implementation decision, as the benefits of the approach depend strongly on the degree to which organisations have developed the capability to consistently apply its principles across project phases (Rebai et al., 2024; Halala & Fayek, 2019).

Reported performance impacts from case studies and quantitative research suggest that AWP can contribute to improved labour productivity, higher direct-work rates, reduced rework, and more predictable execution outcomes. Porwal et al. (2025) report higher mean direct-work rates in projects applying AWP and WFP relative to traditional projects, as well as tighter distributions of direct-work rates, indicating more consistent and predictable execution performance. CII research cited in Halala and Fayek (2019) suggests that AWP positively influences approximately 25% of project predictability.

From the perspective of cost traceability and project learning, AWP introduces mechanisms that differ in orientation from the traditional approaches discussed in Section 4.2. Where WBS provides a structural basis for scope decomposition, CPM organises the timing of activities, and EVM measures performance against a baseline, AWP explicitly addresses the conditions under which work is prepared and executed. By linking engineering deliverables, construction scope, and field execution through a consistent package structure, AWP creates a more stable unit of analysis at which cost and progress information can in principle be connected.

Four mechanisms through which AWP may support cost traceability and project learning can be identified. First, structural alignment: by connecting engineering, procurement, and construction planning through linked work packages, AWP improves the ability to localise and interpret deviations in relation to specific work scopes and interfaces. Second, reduced aggregation gaps: CWPs and IWPs function as execution-oriented control units that reflect how work is prepared and performed in the field, strengthening the connection between baseline assumptions and realised outcomes. Third, workface readiness as a preventive control principle: by releasing work only when prerequisites are verified, AWP reduces the execution instability that drives indirect cost growth before it materialises in productivity loss or rework. Fourth, experience codification: the package structure creates a potentially repeatable logic for documenting how work was defined, prepared, and performed, providing a more stable unit through which observations from execution can be stored and fed back into future estimation practices. Table 4.2 summarises these mechanisms. The extent to which this potential is realised remains conditional on the enabling conditions outlined above, including information standards, role clarity, and implementation maturity (Halala & Fayek, 2019; Jung et al., 2020).

Table 4.2: Summary of AWP Mechanisms Relevant to Cost Traceability and Project Learning

Mechanism	Main function within AWP	Contribution to traceability, learning, and predictability
Structural alignment	Connects planning and execution through linked work packages	Improves localisation and interpretations of deviations
Reduced aggregation gaps	Uses control units (CWPs and IWPs) that reflect execution logic	Strengthens operationally meaningful variance analysis
Workface readiness	Releases work only when prerequisites are available	Prevents disruption-related cost growth
Feedback and codification	Records deviations at package level in a reusable format	Supports project learning and future estimating improvement

4.4 Synthesis and Implications for Empirical Research

The five approaches analysed in this chapter each address a different aspect of project information organisation, but they do so from different orientations and at different levels of the project lifecycle. When these approaches are compared against the key limitations identified in Chapter 3, namely the lack of cross-phase structural alignment, the limited conditions for double-loop learning, and the insufficient traceability of indirect costs, it becomes clear that none of the approaches fully addresses these limitations in isolation.

The WBS provides a structural basis for scope decomposition and consistent coding, but it does not ensure that this structure is consistently maintained into the execution phase. CPM makes it possible to identify when activities are critical or when delays occur but provides only limited insight into the underlying causes of cost deviations. EVM integrates scope, time, and cost within a single performance measurement framework and can provide early warning signals when deviations occur. However, its explanatory value depends strongly on the granularity and execution-alignment of the underlying data. LPS improves the operational transparency of execution through workflow reliability, constraint management, and the registration of reasons for non-completion. It does not directly structure budgets or actual costs, but it provides process information that can help explain cost deviations. Its contribution to cost traceability is therefore indirect, but analytically relevant. AWP distinguishes itself from the other approaches because it explicitly addresses the cross-phase alignment that the literature identifies as a central condition for traceability. By linking engineering deliverables, construction scope, and field execution through a hierarchical package structure, AWP may provide a more stable unit of analysis for monitoring, interpretation, and feedback.

This positioning has direct implications for the empirical phase of the research. Based on the literature analysis, three analytical lenses are carried forward into Phase II. First, the empirical research examines the extent to which cost structures are consistently maintained between the tender phase, the work budget, execution, and reporting, and where discontinuities emerge. Second, it analyses the extent to which cost deviations can be traced back to specific activities, scopes, or execution conditions, and which mechanisms constrain this traceability. Third, it examines how deviations are recorded and fed back into estimating practices, and whether learning remains limited to single-loop responses rather than developing into double-loop learning. Table 4.2 summarises the five approaches and positions them in relation to these three dimensions.

Table 4.3: Overview of Structuring Approaches and Their Relevance to Cost Traceability and Project Learning

Method	Primary Focus	Unit of Analysis	Output / Deliverable	Contribution to traceability and learning
WBS	Structuring scope into manageable, controllable elements	Deliverables and scope elements (hierarchical)	Scope baseline; coding structure for budgeting and reporting	Supports consistent coding and cost aggregation across levels
CPM	Time planning and schedule logic	Activities and precedence relationships	Schedule plan; critical path; float values; delay and impact analysis	Makes schedule deviations and their timing visible; limited causal insight
EVM	Integrated performance measurement against baseline	Measurable scope and physical progress	PV, EV, AC indicators; cost and schedule variance; completion forecasts	Signals deviations early; explanatory value depends strongly on data granularity
LPS	Production planning and workflow reliability	Weekly work commitments; short-interval tasks	PPC; reasons for non-compliance; corrective actions; constraint log	Links execution deviations to operational causes; supports intra-project learning via feedback loop
AWP	Execution-oriented cross-phase structuring and alignment	Linked work packages (EWPs, CWPs, IWPs) across lifecycle	Integrated packages connecting engineering, procurement, and field execution	Improves traceability to specific scopes and interfaces; supports both intra- and inter-project learning

The comparative value of these approaches lies not in whether one method is generally “better” than another, but in how each approach strengthens a different part of the refined conceptual framework. In relation to cost structuring, WBS primarily supports within-phase organisation by decomposing scope into manageable and codable elements, while CPM adds a time-based execution logic. EVM contributes to cost traceability by integrating planned value, earned value and actual cost, thereby making cost-progress deviations visible. However, these three approaches mainly support visibility and measurement; they do not by themselves explain why deviations occur or ensure that information remains aligned across phases.

LPS contributes to the project learning side of the framework by making execution conditions more transparent. It does not structure costs directly, but it generates process information, such as constraints, reasons for non-completion and corrective actions, that can help explain operational causes of cost deviations when linked to cost accounts, work packages or progress data. AWP contributes most directly to cross-phase structural alignment, because its package hierarchy links engineering, procurement, construction planning and field execution through a more stable unit of analysis. In terms of cost scope, WBS, CPM and EVM mainly address planned scope, time, direct work and actual cost performance, whereas LPS mainly captures process- and time-related drivers behind deviations. AWP can connect direct package-level costs, progress and deviations, and may also support the traceability of indirect costs when these are deliberately linked to packages or change events.

This interpretation shows that none of the approaches independently fills the full framework. Instead, the approaches are complementary: WBS and CPM provide basic structuring of scope and time, EVM supports cost-progress measurement, LPS adds explanatory process feedback, and AWP provides the strongest basis for maintaining structural continuity across phases. These mechanisms form the analytical bridge to Chapter 6, where the approaches are evaluated against the empirical limitations identified in practice.

Phase II

Empirical Research

5 Empirical Findings

This chapter presents the empirical findings and addresses Sub-Question 3 of this research: *"How is cost information currently structured and used in practice, and where do limitations in cost traceability and project learning arise?".* The analysis focuses on how cost information develops from tender estimate to work budget, from work budget to project control, and from project control to reporting and learning, and on why deviations between these stages become difficult to trace back to their original assumptions.

In line with the embedded case study design described in Chapter 2, the empirical material combines organisational-level interviews with project-level interviews and documentation from three Dura Vermeer projects: De Groene Boog, Vierverlaten and Tiel-Waardenburg. An overview of the project characteristics of the selected case studies is provided in Table 5.1. The cases were selected based on the criteria mentioned in Chapter 2.

Table 5.1: Project Characteristics of the Selected Projects

Project	Contract Form	Client
Highway A16 De Groene Boog Rotterdam	Design, Build, Finance and Maintain (DBFM)	Rijkswaterstaat
Dike Reinforcement Tiel-Waardenburg	Design and Construct (D&C)	Water Board Rivierenland
Substation Vierverlaten	D&C	SPIE, TenneT

The chapter is structured as follows. Sections 5.1 to 5.3 describe current organisational practice based on the organisational-level interviews. Sections 5.4 to 5.6 analyse the three cases using the analytical lenses introduced in Section 4.4: (1) the continuity of cost structures between tender, work budget, execution, and reporting, (2) the traceability of deviations to specific activities, assumptions, or execution conditions, and (3) the extent to which deviations enable single-loop or double-loop learning. Section 5.7 compares the cases, and Section 5.8 concludes the chapter.

5.1 Current Cost Estimation and Budgeting Practice

Building on the theoretical distinction between cost estimation and budgeting presented earlier in this thesis, the empirical findings show that these processes are not separate steps in practice. Instead, they form a structured transformation process in which cost information is actively reorganised to support execution.

Across the interviews, respondents emphasise that the tender estimate does not function as the primary control structure during execution. The tender estimate serves as an initial representation of project scope, quantities, risks, assumptions and commercial strategy. After contract award, this information is translated into a work budget. This translation typically takes place in the first months of the project and involves close interaction between the cost engineer, project manager, project controller, and financial manager. As described by the project manager: *"First you have a tender budget, and that is translated into a work budget during the first months of the project."*

This transition is not merely a technical conversion. It is a deliberate restructuring process. Cost information is regrouped, condensed and reshaped so that it can be used for execution-phase control. The financial manager described this as *"condensing and reshaping the estimate"*, referring to the aggregation and reclassification of cost items when moving from tender to execution.

This reflects a fundamental difference between the logic of estimation and the logic of control. In line with Section 3.1, estimation is primarily structured around technical components, project objects, quantities, production assumptions and, where applicable, a work breakdown structure. The work budget, in contrast, is structured around controllable units: work packages, cost codes, budget holders, disciplines, phases or management responsibilities. This allows financial ownership to be assigned and enables project teams to monitor expected outcomes during execution.

However, this transformation also creates a traceability problem. The interviews indicate that the transition from tender estimate to work budget introduces information loss and reinterpretation. The project manager stated, *"There is always some loss of information when moving from the tender to the project phase."* The cost engineer explained that not all assumptions underlying an estimate can be fully captured in a formalised control structure. Some assumptions are explicit, such as quantities, unit rates or subcontractor quotations. Others are more implicit and experience-based, such as assumptions about working conditions, productivity, accessibility, coordination effort or risk exposure.

A key implication of this transformation is a change in aggregation level. The interviews indicate that tender estimates may be too detailed to be practically manageable during execution, while work budgets may become too aggregated to explain deviations afterwards. The financial manager described excessive detail as creating *"a false sense of precision"*. At the same time, aggregation can make it difficult to disentangle cost developments later.

This creates a structural tension between usability and traceability. A project team needs a work budget that is manageable, assignable and suited for steering. However, if the work budget no longer preserves the logic of the original estimate, the ability to explain later deviations is reduced. A cost code may show a negative development, but the project team may not be able to determine whether this resulted from an incorrect quantity, changed scope, altered phasing, lower productivity, different execution conditions, or an assumption that was never made explicit.

Taken together, these findings indicate that cost estimation and budgeting in practice are organised as a transformation process. While this restructuring is necessary to enable control, it simultaneously introduces discontinuities between initial assumptions and execution-phase cost structures. This means that limitations in cost traceability may originate before execution has fully started.

5.2 Current Cost Control Mechanisms

Based on the work budget established at the start of execution, cost control is organised as a continuous and forward-looking process of monitoring, forecasting and steering. At project level, budget holders and project controllers monitor cost developments and update forecasts on a regular basis, often weekly or bi-weekly. These updates are discussed within the project team, where project management and discipline leads evaluate progress, expected costs and possible deviations.

In addition to these ongoing activities, more formal control moments are organised monthly. During these sessions, the project team presents the current financial position, key deviations and updated forecasts to management. As described by the project manager, *"On average once a month, management joins to review performance and discuss key issues."* These meetings function as internal steering moments. Cost control is therefore not limited to retrospective registration. It is also concerned with anticipating where the project is heading.

Beyond the monthly cycle, cost control is further formalised through quarterly reporting moments. These quarterly reviews are more comprehensive and are typically used to assess overall project performance, risks, expected results and strategic developments. In joint ventures, quarterly reviews may also involve financial counterparts from partner organisations. Compared to monthly reviews, these reporting moments place stronger emphasis on validating the reliability of forecasts and communicating the project's expected position to higher organisational levels.

A central element across all levels is continuous forecasting. As explained by the financial manager: *"The project continuously reassesses where it currently stands and where it is heading towards the end."* This quote highlights that cost control is inherently predictive. The purpose is not only to understand what has already happened, but also to estimate what the outcome is likely to be.

Despite this structured approach, the interviews reveal four limitations. First, linking cost information to physical progress remains difficult. The project manager stated: *"We should be linking costs to time and progress, but in practice we are not doing this effectively."* As a result, a cost code can show expenditure or forecast movement without revealing whether work is ahead, delayed, partially completed, or reworked.

Second, indirect cost categories, such as engineering, project organisation, site management, coordination, are repeatedly identified as difficult to estimate and control. As the financial manager noted: *"In most cases, this is where deterioration occurs."* These costs are difficult because they are not directly linked to discrete production activities. The project controller, however, challenged how these costs are classified: arguing that most hours should be linked to work packages because *"everyone delivers something and has a work package, including a planner or engineer"*. In this view, treating such hours as generic overhead reduces traceability, whereas linking them to work packages could make cost development more visible.

Third, not all deviations are captured systematically. The project manager observed that *"some deviations remain under the radar and only surface at a later stage"*. This suggests that cost control tends to focus on major cost drivers, while smaller or more diffuse issues may accumulate over time.

Fourth, cost control relies on a combination of formal systems (Metacom) and Excel-based analyses. Respondents indicate that a significant part of interpretation and analysis still takes place outside the primary system. This requires manual processing and reduces standardisation across projects.

5.3 Current Cost Reporting Practices

A key characteristic of cost reporting in practice is that it operates at a higher level of aggregation than the underlying control information. While cost control is based on detailed forecasts at the level of budget holders and specific activities, reporting translates this into summarised financial overviews focused on total cost positions, major deviations, expected outcomes, and risks. The interviews indicate that this translation involves simplification. As one respondent stated: *"There is an explanation, but it is not always a real analysis."* This suggests that reporting prioritises clarity for management communication over analytical depth.

This reduction in detail is closely related to how cost information is structured earlier in the process. As emphasised by the financial manager, *"Once everything is aggregated, it becomes very difficult to disentangle it again."* The grouping of costs in the work budget and the subsequent aggregation during control directly determine what can be reported. Reporting therefore does not introduce new traceability. It reflects the traceability already embedded, or lost, in the underlying cost structure.

A further limitation is that reporting focuses primarily on financial outcomes rather than operational explanations. Deviations are usually expressed in financial terms and only selectively linked to execution activities, design decisions, scope changes or process-related causes. As a result, reporting functions mainly as an accountability mechanism rather than as a source of organisational learning. Feedback to future estimation does not occur automatically and often requires active retrieval, sometimes long after project actors have moved on. The central implication is that reporting provides financial visibility, but not necessarily explanatory traceability.

5.4 Highway A16 De Groene Boog Rotterdam

The first project-level case concerns the A16 Rotterdam, also referred to as De Groene Boog. This case represents a large-scale infrastructure project delivered through a DBFM contract. It provides rich empirical material spanning tender documentation, detailed cost estimate structures, financial control documents, quarterly reports, and interview data. The case is analysed as an example of how cost information becomes structured, transformed, interpreted, and partially disconnected across the project lifecycle.

5.4.1 Tender Estimate as a Detailed but Phase-Specific Structure

The tender documentation shows a highly detailed cost structure, organised through project objects, road sections, work zones, activities, quantities, production assumptions and cost components. For example, the detailed estimate distinguishes between road objects, earthworks, work sections, sand delivery and placement, temporary works, object-specific activities and material flows. However, this detail does not automatically imply traceability during execution. The tender structure was designed to make the project priceable, not to serve as an execution control model. It contains extensive information, but this information is organised around how the work was priced at that moment, not necessarily around how the project would later be managed, monitored or evaluated.

This distinction is central to the first analytical lens: continuity of cost structures across phases. The De Groene Boog case shows that detail in the tender phase can become less useful when the meaning of that detail is not preserved during the transition to execution. In the interview data, one respondent described the tender as *"a different level of abstraction"*, where the aim is to achieve sufficient accuracy and competitiveness under time pressure. The same respondent explained that one cannot investigate everything to the final level during tendering, because the project may not be won. This illustrates that tender estimates inevitably contain interpretation, assumptions and pragmatic choices.

The deeper issue is that tender detail and execution control require different forms of usability. When the transition between these structures is not explicitly managed, information may not be lost literally but can lose its interpretive value: the project may retain the original cost code or quantity while no longer being able to reconstruct the reasoning, productivity assumption, work method or uncertainty behind that number. In De Groene Boog, this transformation was amplified by the scale of the project and the number of objects, work fronts, disciplines and interfaces. As a result, the first traceability limitation appears before execution deviations occur: it emerges during the translation of tender logic into a control logic.

5.4.2 Cost Codes, Physical Work and the Loss of Shared Meaning

The project documentation shows that costs were structured through numerous codes, sections and work packages. At first sight, this suggests a high degree of control. However, the interview data suggests that formal coding did not always produce operational clarity. One respondent stated: *"The data is there, but actually we do not know what it says."* This captures a central paradox: the project generated a large volume of cost data, but data availability did not automatically create interpretability.

This exposes the distinction between financial traceability and causal traceability. Financial traceability means that a cost can be located in the administration. Causal traceability means that a deviation can be linked back to the activity, assumption, work condition or decision that produced it. De Groene Boog had the former to a considerable extent, but the latter remained more fragile. The issue was not the number of cost codes, but the absence of a stable shared meaning behind those codes across disciplines. A cost code meaningful to finance may be opaque to execution if it does not correspond to a recognisable geographical area, work package or production sequence. Interview data reveals that where cost codes aligned with work sections, quantities or contracts, they supported causal interpretation. Where they functioned mainly as administrative categories, their explanatory value was weaker.

5.4.3 Reporting Creates Visibility but Not Always Explanation

The quarterly reporting documents show active financial monitoring. The reports describe the status of the project, planning focus, realisation progress, risk items, financial developments and forecast movements. However, the case also shows that reporting primarily created financial visibility while the underlying causal explanation often remained dependent on contextual interpretation. A report can show that a forecast changed because of remaining works or a reclassification yet not reconstruct the full causal chain from original estimate to execution condition to financial deviation.

A concrete example can be seen in the way the earthworks, road construction and hydraulic engineering (GWW) reporting describes several developments. For groundworks, movements are explained through issues such as recovery of watercourses, remaining work on pipelines, completion of earthworks, or reclassification of expected outcomes. For roads, movements are connected to traffic measures, markings, guardrails and remaining works linked to phasing. These explanations are valuable for management because they indicate what kind of issue affected the forecast. However, they remain primarily report-level explanations: they identify the financial theme of the deviation, but not always the original assumption or execution mechanism that produced it.

Reporting is built to communicate, not to preserve causal detail. The analytical implication is that reporting cannot repair traceability that has already been lost in earlier structuring choices. If tender assumptions, work package boundaries, physical progress and cost bookings are not consistently connected during execution, the quarterly report can only summarise the resulting movement. It cannot automatically reconstruct the underlying causal mechanism. This is why a report may contain an explanation without becoming a full analysis of why the deviation emerged.

The same distinction appeared in the interview notes, where one respondent observed that reports were *"more focused on explaining losses or deviations than on how we can control them better"*. This statement clarifies the limitation of report-level explanations: they support accountability and communication, but do not automatically create a reusable causal account for future cost control or estimation.

5.4.4 Bandwidths and Reservations as Control Mechanism

The project documents show that financial uncertainty was managed through bandwidths, reservations, and risk positions. These are legitimate instruments: they allow the project team to manage uncertainty, communicate possible outcomes, and gradually harden or release expected effects. However, from a learning perspective, bandwidths have an ambiguous role. They make uncertainty manageable without necessarily making it understandable. A bandwidth can show that a cost effect is uncertain without explaining whether the issue originated from a tender assumption, design development, changed phasing, productivity loss, stakeholder interface, contractual interpretation, or administrative timing.

The interview material reinforces this ambiguity. One respondent described bandwidths and reservations as both useful and strategic: *"They help the project prepare for possible developments, but they can also function as a way of managing expectations."* A bandwidth is effective as a risk buffer, but it only generates learning if the eventual release or hardening is accompanied by a causal explanation of why the uncertainty materialised.

5.4.5 Cost, Progress and the Problem of Two Realities

A recurring theme is the misalignment between financial and physical progress. The project documentation contains production percentages, forecast positions, remaining costs and narrative explanations. The quarterly reporting also describes physical progress, such as completed work, remaining asphalt works, landscaping, water management, traffic phasing and completion activities. However, the interview data shows that cost and progress were not always experienced as the same reality. One respondent explained: *"You think you have progress, but there is no progress, or you have costs, but no progress."* The same respondent added that builders often reason from what they can see on site, while the financial administration follows a different logic: if costs have not yet been taken, they do not yet exist administratively.

For quantity-driven activities such as earthworks or road construction, physical progress could be monitored through measurable outputs (cubic metres, metres, installed quantities), making percentages informative. But when progress was inferred from cost bookings, the picture became distorted: delivered materials can appear financially complete before installation, while executed works may be physically complete before corresponding costs are booked. The case therefore shows that cost predictability requires not only progress measurement but progress interpretation: a connection between cost, planning, physical status, remaining risks, and original assumptions. This finding directly echoes the limitations of performance measurement approaches discussed in Section 4.2.3: indicators can signal deviations without explaining whether the cause lies in estimation, execution, phasing, or remaining work complexity.

A respondent made this distinction explicit when discussing production percentages: *"As soon as it was measured on the basis of costs, I found it gave less meaning."* She illustrated this with materials that could be fully delivered and invoiced while not yet installed, and with asphalt that could be placed before the related costs were charged to the project. This shows that a progress percentage only supports traceability when its basis is clear: physical production, delivery, installation, cost booking or remaining work.

5.4.6 Combination Structure and the Emergence of a Project-Specific System

The DBFM combination structure is analytically relevant because it introduced an additional layer of discontinuity. One respondent explained that different partner organisations had their own accounting principles, requiring a shared system that all parties could work with, effectively *"a system outside the system"*. This project-specific coding logic and reporting routine supported collaboration but reduced standardisation and comparability. The implication for inter-project learning is significant: knowledge generated in this structure may be difficult to transfer directly to future projects operating under different systems, risking becoming person-dependent rather than system-dependent. In other words, the combination structure may support project execution while simultaneously weakening organisational learning beyond the project.

5.4.7 Excel, Manual Interpretation, and Fragile Traceability

A significant portion of interpretation and analysis occurred outside the formal cost-control system, in Excel files used to develop, substantiate and reconcile figures. One respondent explains that this was not purely a weakness: earlier system versions could not store the reasoning behind forecast changes or the detail required for staffing forecasts, making Excel a necessary compensating mechanism. However, this flexibility introduced a structural traceability risk. The problem is not whether a final number can be found, but whether the path from source input to reported output can be reconstructed. In complex projects, information moves through invoices, production records, site input, budget files, forecasts, risk registers, progress dashboards and management reports. Each transformation can involve aggregation or reinterpretation. When these transformations occur in manual files or project-specific working documents, the reasoning behind the final figure may become difficult to verify later.

This limitation was expressed directly by one respondent. Excel lists were useful *"to roll things up"*, but the critical question remained, *"where does the input come from?"* The quote shows that the issue was not the use of Excel itself, but the difficulty of reconstructing the data lineage from original source to reported figure.

This is especially relevant for learning. If key insights are stored in the reasoning of individuals or in project-specific files, they may support control during the project but remain difficult to reuse after the project. The information exists, but its context is not always institutionalised. For De

Groene Boog, this means that traceability was partly maintained through people and supporting analyses rather than through the cost structure itself. Experienced project actors could explain why a number moved, where an assumption changed, or what happened outside. However, when that knowledge is not embedded in the system, the project's learning capacity becomes fragile. It depends on whether the right people and files are available at the moment when the organisation wants to learn.

5.4.8 From Single-Loop Control to Limited Double-Loop Learning

De Groene Boog had extensive cost control, reporting and forecasting processes, and deviations were identified, discussed, and financially managed. However, much of this learning remained single-loop: deviations were corrected or explained within the project, but the underlying structuring logic was not systematically questioned or translated into future estimating practice. One respondent reflected that learning was not absent, lessons were documented and shared with comparable projects and within the project-control community, but knowledge was shared without becoming fully embedded in formal cost-management structures. Presentations and lessons-learned documents transfer experience without necessarily changing future estimating assumptions, norm figures, or cost structures.

One respondent connected this limitation to cross-project learning by asking what an organisation has learned from *"a nice adventure with ups and downs"* and arguing that future estimating should move towards *"norm figures that have been developed through a structured process"*. This quote links learning directly to traceability: lessons only become reusable when project-specific experience is converted into structured assumptions, norms or coding principles.

Several mechanisms explain why double-loop learning remained constrained: the original tender logic was not preserved in a form allowing later comparison, deviations were reported at aggregation levels suited for management communication rather than root-cause reconstruction, combination-specific systems and Excel-based analyses reduced standardisation, and lessons depended on people who could explain the project context. Together, these mechanisms meant that the project could generate and share lessons without the organisation consistently translating them into reusable estimating assumptions, revised cost structures, or standardised control logic.

5.4.9 Case Synthesis: De Groene Boog

Applying the three analytical lenses leads to the following conclusions. On cost structure continuity: discontinuity exists between tender, work budget, execution, and reporting. The transformation was necessary for project control but weakened the continuity of original assumptions. On traceability: deviations were often financially visible but not causally traceable. Reporting could identify the financial theme of a movement, but reconstructing the underlying assumption or execution condition required contextual knowledge from individuals. On learning: learning occurred within and beyond the project, but institutionalisation remained limited. Lessons were generated and partly shared, but not consistently translated into reusable estimating assumptions, revised cost structures, or standardised control logic. De Groene Boog can be understood as a case in which extensive financial information was available, but where interpretability and learnability were constrained by fragmentation across phases, systems, and levels of aggregation.

5.5 Dike Reinforcement Tiel-Waardenburg

The Tiel-Waardenburg case concerns a large-scale dike reinforcement carried out by Combinatie Mekante Diek for Waterschap Rivierenland. The scope includes reinforcement in soil, stone revetment, roads, hydraulic structures, sheet piles, anchoring, and cable and utility works. The project is executed under a Design & Construct contract, with the structural part organised in a two-phase arrangement, and the project is also characterised by strong economically most advantageous tender (EMAT) commitments related to logistics, sustainability, optimisation of structures and collaboration. The case is especially instructive because it shows that cost information can be extensively documented while still requiring continuous interpretation to remain meaningful, with several parallel structures coexisting throughout execution.

The interview material also emphasises the organisational context of the case. One respondent described the project as a *"general partnership with three equal shareholders: Dura Vermeer, Ploegam BV and Van Oord Nederland"*. This matters for cost control because the cost structure had to be workable not only for one contractor, but for a joint venture in which reporting, responsibilities and budget ownership needed to be accepted across partner organisations.

5.5.1 Tender Cost Structure and Early Fragmentation

The tender estimate was built up in considerable detail, decomposed into clusters, dike sections, work activities, quantities, production rates, cost types, and unit prices. For example, the road works are broken down into activities such as removing asphalt, preparing foundations, applying asphalt layers, placing kerbs, and finishing verges, with each activity linked to labour, equipment, materials, subcontracting and production assumptions.

However, this structure reflected the logic of tender pricing rather than the logic of production control. This is also visible in the project's road calculation assumptions. The scope was divided into clusters, dike sections and subsections, while the works themselves were later dependent on execution phasing and the progress of earthworks. The calculation notes indicate that the road works were based on production assumptions, while the actual execution would not take place continuously because the planning was driven by earthworks. This means that cost assumptions already contained a potential mismatch between the tender structure and execution reality. As a result, the tender estimate was a structured but conditional representation: it provided a detailed financial baseline, but this baseline depended on assumptions about quantities, phasing, productivity, logistics and design information that later had to be reconsidered.

The interview data confirms this interpretation. One respondent referred to the early estimate as a *"fixed-price budget at the start of the project"*, or the *"truth of the tender"*. At the same time, the respondent noted that *"the work always turns out differently eventually"* and that *"changes occur"*. This illustrates the core tension in the case: the tender functions as an initial financial truth, while execution immediately generates conditions that require reinterpretation.

That tension became stronger as the design developed. One respondent noted that *"the design becomes much more detailed"* and that the *"price changes constantly"*. As a result, the *"detailed budget is no longer comparable with the tender budget"* because it is organised through *"other* *posts"*. This supports the analytical finding that fragmentation was not caused by the absence of a tender structure, but by the changing fit between tender logic and execution-control logic.

5.5.2 Cost Control as Reinterpretation

During execution, the financial reports show that cost control became an active process of reinterpretation rather than simple comparison with a fixed baseline. The Q4 2023 report illustrates this: the revised planning had not yet been formally accepted, the project had suffered delay from bad weather and high water, and the financial consequences of the planning impact still needed substantiation with the client. The project team had to continuously reassess the relationship between remaining work, planning impact, variation orders, risks and expected result. The same report also states that several actions had been taken to improve cost control, but that recalculating the tender estimate using design quantities would still be taken up in 2024. This is an important finding for this research, because it shows that the tender estimate did not automatically remain aligned with the execution estimate. A further translation step was required to make the cost structure suitable for ongoing project control.

By Q4 2024 this process had matured: the project organisation had gone through the figures in detail, leading to adjustments and corrections while actual production was determined and recalculated for the remaining execution sections. This supports the broader finding from Section 5.1: cost control in complex infrastructure projects requires continuous reconstruction of the financial position by connecting the tender budget, realised production, actual costs, remaining scope, risks, and forecast result.

The interview data confirms that cost control required interpretation rather than mechanical comparison. One respondent described the control task as comparing *"booked costs with forecast costs"* and then assessing whether this still corresponded with production progress. The respondent also warned that *"Excel shows whether you have spent more or less money, but that says nothing"*. This quote directly supports the distinction between financial visibility and causal traceability: a tool can show a movement in expenditure without explaining its operational cause.

The same interview material shows that tool choice mattered for traceability. One respondent described *mutations in Excel* as problematic because *"Excel is unworkable"* for synchronisation and *"error-prone"*. He contrasted this with Metacom post control, which he regarded as more stable. This distinction is relevant because traceability depends not only on the conceptual cost structure, but also on the reliability of the system in which changes are recorded and synchronised.

5.5.3 Cost Traceability and the Explanation of Deviations

The case illustrates the difference between making deviations visible and making them explainable. Financial reports contain detailed explanations of deviations, especially when the impact exceeds the reporting threshold. These explanations show that deviations are rarely caused by one isolated factor.

In Q4 2024, for example, the report explains that a section had been constructed with clay that was too wet, requiring excavation and rebuilding of approximately 10,000 m^3. The same report also links other deviations to higher traffic management costs, changed market conditions for materials, booking corrections between monitoring posts, and longer use of steel road plates due to planning delay. These examples are important because they show that cost deviations are financially visible, but their explanation requires information from outside the financial system.

This case therefore supports the argument that cost traceability should not only be understood as the ability to locate where costs were booked. For project learning and predictability, it is also necessary to understand why those costs occurred, which assumptions changed, and whether the deviation resulted from scope change, production inefficiency, technical uncertainty, market change, or booking logic.

Reporting thresholds influenced which deviations became visible as explicit explanations. One respondent noted that movements *"larger than one hundred thousand"* were explained in the difference analysis. This improved financial visibility for major deviations, but it also implies that smaller movements could remain embedded in lower-level monitoring posts until they accumulated or became strategically relevant.

5.5.4 Variation Orders as a Formal but Imperfect Traceability Mechanism

Variation orders play a central role in the Tiel-Waardenburg case. Already in Q4 2023, the project was strongly focused on variation orders and planning. The report describes many open or developing requests for change (RFC) and notes that several potential variation orders could have a significant impact on both the overall planning and the financial position of the project. The RFC register tracks changes through multiple formal statuses, from initiative phase through full agreement and incorporation into the payment schedule. This formal structure improves traceability by making visible where a change sits in the contractual and financial process.

However, variation orders often affect design, planning, procurement, and execution before they are fully agreed or incorporated into the budget, meaning the formal change structure lags the operational reality. This is also visible in Q4 2025. For several small infrastructure changes, an overview list was prepared to determine how costs would be settled, and the report notes that a substantial part of these small changes would only affect costs in the final completion phase. This indicates that even when changes are formally registered, their cost impact may remain uncertain until later in the project. Variation orders therefore function as an important traceability mechanism, but their effectiveness depends on the timing with which scope, cost and execution consequences are clarified.

5.5.5 EMAT Commitments as Cost-Structuring Elements

A distinctive feature of this case is the role of EMAT commitments, particularly regarding electric equipment and sustainable construction logistics. The tender included a structured list of required machines and responsibilities, but the EMAT obligations introduced cost categories that could not be understood through the original cost estimate alone: charging infrastructure, battery logistics, equipment availability, energy demand, operator behaviour, downtime, and productivity effects all emerged as cost-relevant factors requiring continuous learning during execution.

This is analytically important because it shows that EMAT commitments are not only performance promises but cost-structuring elements. They generate cost categories that sit uneasily within traditional direct-production cost structures, complicating both traceability and forecasting. The project had to develop new operational routines, battery transport coordination, energy planning roles, backup logistics, each with financial consequences that emerged iteratively. EMAT obligations thus exemplify a broader pattern: when new performance dimensions are introduced through contract commitments, they create cost categories requiring parallel structuring mechanisms not anticipated in the tender, and whose financial impact can only be understood through continuous learning.

The interview notes also indicate why EMAT and sustainability commitments are difficult to separate from commercial tender logic. One respondent described tendering as a *"commercial game"* in which the contractor has to offer an *"attractive price"*. In such a context, qualitative commitments made to win the project later become cost-relevant execution obligations. This reinforces the interpretation that EMAT commitments should be analysed as cost-structuring elements rather than only as qualitative tender promises.

5.5.6 Planning, Production and Predictability

The development across the reporting periods shows a gradual improvement in predictability. In Q4 2023, significant planning uncertainty remained: delays from high water, a revised planning not yet accepted, and unrecognised financial consequences. By Q4 2024, a substantial production recovery had almost fully compensated earlier delays, though the 'five to twelve' changes remained a significant financial threat. By Q4 2025, updated planning, favourable settlement periods, and a renewed EMAT assessment together improved confidence in the project outcome. This trajectory illustrates that within-project predictability improved not through the original estimate, but through repeated updating of the forecast structure based on current project knowledge.

This interpretation is also reflected in the interview material, where one respondent summarised progress measurement as inherently uncertain: *"progress is subjective"*. The respondent connected this to the need to compare booked and forecast costs with the actual production position. The relevant question was whether the financial position *"matches how far you are in production"*. If the difference becomes too large, *"you must be able to explain it"*. This quote supports the finding that predictability improved only when cost figures were interpreted together with actual production, remaining work and planning updates.

5.5.7 Project Learning during Execution

The case provides evidence of both operational and organisational learning during execution. In Q4 2023, the report states that the project focused on strengthening forecasting processes and linking variation order acceleration more directly to work preparation. By Q4 2025, the report explicitly states that lessons from earlier phases were helping manage remaining environmental interfaces. These examples show intra-project learning embedded in ongoing decisions. However, the available documents primarily evidence learning within the project. The extent to which insights were systematically translated into future estimation or tendering practices remains less visible.

In terms of the analytical framework introduced in Section 4.4, learning in this case remained primarily single-loop: deviations were recognised, explained, and financially managed within the project, but the underlying structuring logic, including assumptions about phasing, EMAT cost categories, and the treatment of indirect effort, was not systematically translated into revised estimating assumptions or standardised control structures. Double-loop learning was constrained by the same factors that limited traceability: parallel structuring systems, iterative reinterpretation of the financial position, and the dependence on individuals with contextual knowledge of how the tender logic related to execution reality.

The interview data adds an important nuance to this limitation. One respondent described the practical limits of formal lessons-learned processes by noting that there are *“too many lessons learned to share”* and that *“technology changes continuously”*. Instead of distributing all lessons as static documentation, the respondent argued that teams should *“approach people for knowledge when you encounter something* because otherwise the information *does not land”*. The respondent also emphasised that learning should be shared *“during the project and not only at the end of the work”*. This supports the conclusion that learning in Tiel-Waardenburg was mainly intra-project and actor-mediated, rather than fully institutionalised across projects.

5.5.8 Case Synthesis: Dike Reinforcement Tiel-Waardenburg

The Tiel-Waardenburg case demonstrates that limited cost predictability is not caused by a lack of data. The project contains extensive financial and technical information, including tender calculations, financial reports, risk registers, variation order registers, planning updates, and EMAT analyses. The central issue is structural alignment between these parallel systems. The tender provides a detailed baseline that does not automatically remain aligned with the execution structure. Control depends on repeatedly reconnecting financial data to production progress, planning, remaining scope, and variation orders. Deviations are financially visible, but their explanation requires reconstruction across design, site conditions, procurement, EMAT obligations, and administrative booking logic. Learning occurs during execution, particularly around planning and variation management, but its translation into reusable organisational knowledge remains limited.

5.6 Substation Vierverlaten

The Vierverlaten project concerns the civil, infrastructural, and building-related works for a new 380 kV substation and the adaptation and expansion of an existing 220 kV substation. The project was executed by Combinatie Vierverlaten Civiel, consisting of Dura Vermeer Infra Landelijke Projecten and Friso Civiel, as subcontractor to SPIE, with TenneT as the end client.

The project evolved from a clearly bounded tender and work-budget structure into a long-running, highly dynamic project characterised by numerous RFCs, delays, design changes, indexation issues, and interface discussions. The evaluation notes that the project duration increased from approximately four years to more than seven years, while the financial result improved substantially compared to the initial expected result. This indicates that its outcome was strongly shaped by how deviations, risks, claims, and RFCs were identified, structured, negotiated, and incorporated into the financial control system.

5.6.1 Transition from Tender Estimate to Work Budget

The work budget reorganised tender information into control-oriented monitoring posts: labour and equipment, purchases, subcontracting, time-related site costs, indirect project staff, engineering, financial management, contingencies, risks, scope changes, and general costs. The 2018 project budget monitoring overview already distinguishes between the work budget, approved and pending scope changes, procurement contracts, procurement result, actual costs, forecast result, and remaining budget. This structure made it possible to monitor financial performance at the level of individual monitoring posts, for example concrete piles, screw piles, project organisation, engineering, ICT costs, and risk dossiers.

The interview data shows that the conversion from calculation budget to work budget required substantial effort, as the two structures follow different logics. Once the translation was completed, however, the resulting structure was experienced as recognisable and workable, with deviations generally traceable to relevant monitoring posts. The main traceability challenge was therefore concentrated in the initial conversion, rather than in the later use of the budget. As one respondent described it: *"It was very laborious to get from the calculation budget to the work budget, and in my view that still plays up today. During the tender period you do not yet have a definitive design, so you must make assumptions, and as you progress the work budget naturally becomes more precise."* The respondent added that traceability itself was preserved, but that the budget was deliberately rebuilt the way the team wanted to monitor it.

Nevertheless, the project evaluation identifies several cases where early assumptions did not survive the transition adequately. The demarcation was insufficiently detailed for the realisation phase, the tender assumption regarding a closed soil balance proved premature, and the required low-frequency sound reduction for the transformers had been underestimated. The latter becoming one of the major deviations in the project, originating in an early technical-cost assumption that was not sufficiently tested during tendering. One respondent was explicit about the sound issue: *"When it came to the sound reduction we needed, we slipped through the eye of the needle. It had been considered far too lightly."*

5.6.2 Reporting Structure and Aggregation during Cost Control

The quarterly reports each show a formal and recurring cost-control structure: management summary, topsheet, financial details, explanations of mutations in the current result and forecast result, a bandwidth analysis, an S-curve, and references to budget monitoring, procurement, staffing, risks, and more-/less-work overviews. This indicates that project control was not absent. On the contrary, the project was monitored frequently and through multiple financial instruments.

The interview material further shows that this control structure was operationalised through recurring four-weekly reviews in which budget holders, project control and project management discussed deltas: where figures had changed, whether these changes were technically explainable, and whether they affected the expected result. This made cost control a process of continuous interpretation rather than periodic registration only. As one respondent explained: *"In those four-weekly meetings we mainly went through the deltas. Some things simply do not change over time, so we did not have to go through the whole system again. We focused on the production delivered: where are the deltas, and do they track or not? Then we moved on to risks and opportunities."* He noted that this assessment was kept deliberately informal rather than model-based: *"We kept it very simple, a lot of it we did on gut feeling."*

This recurring review cycle strengthened traceability during execution. Cost deviations were not only entered into the financial system but were discussed in relation to the remaining work and the technical logic behind the monitoring post. When uncertainty remained, the project team assessed whether the issue should be included in the forecast, treated as a risk or opportunity, or managed through a formal change mechanism. This helped maintain a relatively stable connection between financial movements, technical explanations and expected outcome.

However, the case also shows that the explanatory value of this reporting structure depended strongly on the level of detail at which deviations were analysed. The 2018 Q4 report, for example, explains that the forecast result changed only marginally at total level, but that this small net movement concealed several underlying shifts: expected gains on concrete piles, losses on screw piles, higher project controller and environmental management costs, insufficient ICT budget, positive movement in the tender risk dossier, and negative movement related to the sound insulation risk. This is analytically critical: the overall forecast result suggested stability, while the underlying monitoring posts revealed substantial reallocations and risk movements.

The same pattern appears later in the project. The final evaluation states that the financial manager built a system that provided continuous insight into costs versus revenues and that this contributed to a very positive liquidity position. It also notes that Dura Vermeer-Friso invested significant effort in payment flows and in obtaining PVs, supported by clear overviews of the status of RFCs. This suggests that cost control at Vierverlaten became increasingly dependent on complementary overviews outside the standard financial reporting structure, especially for managing RFC status, approvals, claims, and payments. The standard cost-reporting structure provided financial visibility, but the actual traceability of deviations required additional interpretive work by the project and financial management team.

5.6.3 Cost Deviations and Physical Progress

The reports repeatedly show that progress was monitored through both financial production and physical milestones. However, the project's lengthy delay period complicated cost-progress integration. Several costs, design, procurement, project organisation, ecological measures, contract management, were incurred or forecast before physical production restarted. The evaluation confirms this by stating that even during periods with less Dura Vermeer-Friso production, SPIE and TenneT still required substantial indirect project staff input. This is important, because it shows that indirect costs were not always directly linked to physical progress. They were driven by project duration, stakeholder interaction, RFC processes, design reviews, safety requirements, and delayed decisions rather than by direct construction output.

At the same time, the case also shows that some physical deviations were successfully translated into formal RFCs. For example, the overviews of more- and less-work show many RFCs connected to specific physical or technical changes, such as Tensec fencing, drainage, realisation of the sound houses, and changes to terrain finishing. In these cases, the physical cause could be linked to a contractual and financial line item. This improved traceability. However, this traceability was not automatic: it required active contract management, timely recognition of changes, and negotiation with SPIE and TenneT. The evaluation explicitly states that employees were repeatedly instructed to report changes in requirements or wishes from TenneT or SPIE in time, because this was essential to enforce an RFC.

The case therefore reveals a structural distinction: direct technical changes could become traceable once formalised as RFCs, whereas costs related to delay, coordination, documentation, safety, and stakeholder interfaces were more dependent on interpretation and negotiation.

Unlike the other cases, Vierverlaten did not rely heavily on formalised production percentages in internal cost reporting. The respondents indicated that physical progress was tracked through direct project knowledge and technical coordination within a small and stable team. This actor-dependent mechanism compensated for limited formal cost-progress integration. A finding relevant for the cross-case comparison, as such informal substitution becomes less feasible in larger or more fragmented projects. One respondent made this reliance on people explicit, noting that he leaned on continuity and mutual trust with colleagues: *"We know each other, that matters. I trusted that it was filled in well."*

5.6.4 Role of RFCs in Restoring Traceability

The RFC process became one of the main mechanisms through which traceability was restored during the project. A potential RFC was identified when the project team concluded that the required work differed from what could reasonably be considered part of the original contract. The process then required a contractual argument, a technical explanation and a financial substantiation. This made RFCs more than administrative change records: they became a structured way of linking a deviation to its contractual basis, technical cause and financial consequence. By the end of the project, virtually all RFCs had been recognised and honoured, contributing significantly to coverage of indirect project staff costs and the final financial result. One respondent described the underlying logic: *"You realise you have to do different things than in the budget sheet, and then you look: is this covered by the contract or not? If it is, you have no right to an RFC. There always had to be a ground on which you based that it was not in the contract. Then you make a calculation of what you need to charge for the extra work, and that requires substantiation."* Reflecting on the outcome, he added: *"I think we barely submitted an RFC that we did not get through."*

For larger or non-standard changes, separate monitoring codes were sometimes created because the work could not be meaningfully absorbed into the existing work-budget structure. For more routine changes, the additional budget was allocated to existing cost categories. This distinction shows that the project actively decided when a deviation required separate traceability and when it could be managed within the existing budget structure. In cases such as the sound-related works and other specific modifications, separate monitoring improved the ability to follow both the budget and the cost development of the change. The respondents illustrated this with the sound houses and the culvert, which were tracked on separate codes because, as they put it, *"those items could not really be placed within the work budget,"* whereas more routine changes were *"more of the same"* and remained within the existing categories.

However, RFC-based traceability remained conditional: the project first had to identify the deviation, determine whether it fell outside the contract, substantiate the claim, and obtain recognition from the client-side contractual chain. This required technical knowledge, contractual interpretation and negotiation. The evaluation notes that RFC negotiations were often opaque, requiring persistent management involvement. Traceability was therefore not embedded in the RFC system alone. It also depended on the organisational capability to use that system effectively. One respondent pointed to the client-side chain as part of this difficulty: *"For us it was sometimes complicated that SPIE, as main contractor, had to knock on TenneT's door. But it was also a kind of good exercise: if SPIE did not understand it, TenneT probably would not either, so you had to explain it better."*

5.6.5 Feedback Loops and Project Learning

The quarterly reports included a "Lessons Learned" section in 2018, covering informal design review with TenneT, closer contract review, the importance of a contract manager, and the positive effect of informal meetings with SPIE. This indicates that learning was recognised during the project, not only after completion. Nevertheless, many of the deeper lessons only became explicit in the final evaluation: insufficient demarcation detail, underestimated sound insulation, unclear switching moment agreements, and inadequate document management.

Several lessons also concerned negotiation and client interaction. These are forms of knowledge difficult to capture in formal documents because they depend on how project actors interpret a situation and decide when to escalate. Respondents therefore pointed to relational learning mechanisms, direct contact with experienced colleagues, as important complements to formal documentation. This confirms that feedback loops are not purely technical or administrative: even when deviations are documented and evaluated, their reuse in future projects depends on whether the underlying causal logic can be retrieved and understood. The interviews underlined how partial this reuse remains. Asked whether lessons were systematically captured for the next project, one respondent answered simply, *"not really, no,"* and another respondent reflected: *"An attempt is made, but I have been talking about this for thirty years, and it is very hard to put into practice. I think we still do not prevent making the same mistakes again. On the other hand, we make unique projects. It is never the same: the soil is different, we never build the same thing."*

In terms of the analytical framework from Section 4.4, Vierverlaten represents the clearest case in which double-loop learning became partially possible. The RFC process, combined with recurring four-weekly reviews and small team continuity, created conditions under which deviations could be traced back to their contractual and technical causes, and the project's underlying assumptions, about demarcation, subcontractor scope, and sound reduction requirements, were explicitly revisited. That this was conditional on team stability, active contract management, and available documentation suggests that double-loop learning does not emerge automatically from project complexity, but from the specific organisational and structural conditions that make causal reconstruction possible.

5.6.6 Case Synthesis: Substation Vierverlaten

The Vierverlaten case shows that cost traceability was not limited by an absence of financial data. The project had extensive budgets, monitoring posts, quarterly reporting, risk dossiers, RFC overviews, staffing plans, and a final evaluation. The main issue was that different forms of project information were structured according to different logics: the work budget was organised by cost and monitoring posts, physical progress was organised by stations, fields, transformers, cable ducts, and terrain works, contractual change was organised through RFCs and PVs, and learning was organised through quarterly lessons and final evaluation. These structures overlapped, but they were not automatically aligned.

Traceability was substantially restored through careful work-budget design, recurring four-weekly reviews, and active RFC management. However, it remained partly dependent on individual expertise and continuity. A more systematic structuring approach would need to preserve the links between assumptions, scope elements, cost codes, risks, RFC findings, and evaluation outcomes throughout the project lifecycle, while reducing dependence on individual project memory.

5.7 Cross-Case Comparison

The three project-level cases, De Groene Boog, Tiel-Waardenburg, and Vierverlaten, each show how cost information is structured, transformed and interpreted during project execution. Although the projects differ in contract form, technical scope and organisational setting, the comparison reveals a consistent underlying pattern: cost deviations are usually visible in financial monitoring, but their underlying causes are not always structurally traceable.

5.7.1 Cross-Case Overview

Table 5.2 summarises the main empirical patterns identified across the three cases. The table compares the mechanisms relevant to the conceptual framework: cost structuring, cost traceability, project learning and cost predictability.

The dimensions in Table 5.2 are derived from the coding framework described in Appendix C. They combine deductive concepts from the refined conceptual framework with inductive empirical patterns that appeared across interviews and project documents. Tender-to-execution transition, fragmentation and cost traceability reflect the core mechanism of cross-phase structural alignment. The cost-progress relationship and change mechanisms were included because the empirical material showed that deviations often became interpretable only when financial movements were connected to physical progress, planning developments or formal change records. Indirect costs were included as a separate dimension because this theme appeared across all cases and represented a recurring traceability problem. Learning and predictability were included because they connect the empirical findings back to the research objective: understanding how current cost-information practices affect the ability to learn from deviations and improve future cost predictability.

Table 5.2: Cross-Case Comparison of Empirical Findings

Dimension	Highway A16 De Groene Boog	Dike Reinforcement Tiel-Waardenburg	Substation Vierverlaten	Cross-Case Finding
Tender-to-execution transition	Detailed tender transformed into project-specific control structures with combination-specific coding logic	Detailed tender based on clusters and dike sections; not directly usable as execution control structure	Work budget reorganised tender into monitoring posts; conversion required substantial effort	In all cases, the tender estimate does not remain the primary execution control structure
Main source of fragmentation	DBFM combination structure, partner systems, project-specific coding, Excel-based interpretation	Parallel structures: tender estimate, execution sections, RFCs, EMAT obligations, and financial reports	Separation between work budget, physical progress, RFCs, claims, and final evaluation	Fragmentation occurs because different project functions use different structuring logics
Cost traceability	Financial movements visible; causal explanation depends on individual contextual knowledge	Deviations explained through production, planning, RFCs and risks; costs can split across lines	Direct technical changes traceable through RFCs; delay-related and indirect costs require negotiation	Strongest when linked to formal scope or change mechanisms; weakest for indirect costs
Cost-progress relationship	Financial and physical progress can diverge; administrative and site reality do not always align	Control increasingly depends on combining actual production, remaining work, and updated planning	Long delays and client-driven changes make cost-progress interpretation especially difficult	Progress percentages alone are insufficient; interpretation requires cost, planning, risk, and remaining-work data
Change mechanisms	Bandwidths and reservations manage uncertainty but do not explain root causes	RFCs formalise scope changes, but unresolved RFCs can temporarily distort the forecast	RFCs became a major mechanism for restoring traceability and recovering costs	Improve traceability only when timely, causally specific, and connected to execution data
Indirect costs	Staff and project-specific systems make costs difficult to transfer into lessons	Indirect project staff and EMAT-related costs visible but not always attributable to specific activities	Delay-related project staff, contract management, and documentation costs difficult to connect to progress	Indirect costs remain the most structurally difficult category to estimate, control, and learn from
Learning	Strong experiential learning; limited institutionalisation into future norm figures or structures	Learning occurs during execution around planning, EMAT, RFCs, and remaining interfaces	Strong retrospective learning through evaluation and RFC experience; many lessons visible only at end	Learning is present in all cases but often remains actor-dependent or project-specific
Predictability	Improved through ongoing interpretation of remaining works, reservations, and risks	Improves as planning, production, and risks become more stable and connected	Shaped by ability to formalise and recover deviations through RFCs	Within-project predictability improves through active control; cross-project predictability constrained by weak feedback loops

5.7.2 Cost Structuring is Detailed but Phase Dependent

None of the cases suffers from a simple lack of budgeting, monitoring or reporting. They show that within-phase structuring is generally strong: each project has structured estimates, budgets and reports. The weakness lies in the translation between phases. When tender assumptions are transformed into execution budgets, information is condensed, reclassified or reinterpreted. This enables control but weakens the ability to later trace a deviation back to its original assumption.

De Groene Boog illustrates this through the transformation from a detailed tender structure into a project-specific control system shaped by the DBFM and combination context. Tiel-Waardenburg illustrates it through the coexistence of tender calculations, dike sections, execution sections, production posts, RFCs and EMAT commitments. Vierverlaten illustrates it through the shift from work-budget monitoring posts to RFC-driven contractual and financial control. This finding directly supports the theoretical distinction in Section 3.5 between within-phase organisation and cross-phase structural alignment.

5.7.3 Financial Visibility Does Not Equal Causal Traceability

In all three cases, project teams can usually identify that a financial movement has occurred and where it appears in the budget. However, the underlying cause is not always structurally embedded in the cost system. Traceability is strongest when a deviation can be linked to a clear scope element, work package, formal change mechanism, or contractual event. It is weakest when deviations emerge gradually, relate to coordination effort, involve indirect staff costs, depend on timing effects, or cut across multiple structures.

The interview data identifies three conditions under which causal traceability is relatively strong: the cost structure aligns with execution logic, the project team has sufficient system knowledge, and the number of actors remains manageable. Where these conditions are met, as in parts of De Groene Boog's civil works or Vierverlaten's small-team environment, traceability improves. But where it depends on experienced individuals, local Excel files, or project-specific routines, it may work within a project while remaining difficult to standardise across projects.

5.7.4 Change Mechanisms Partially Restore Traceability

The three cases show that formal change mechanisms play an important role in restoring traceability after deviations occur: bandwidths and reservations in De Groene Boog and RFCs in Tiel-Waardenburg and Vierverlaten. These mechanisms create formal links between an event, a scope change, and a financial consequence, improving traceability compared to situations where deviations remain embedded in general production lines. Vierverlaten demonstrates this most clearly: the final financial outcome was substantially shaped by the project's ability to identify, substantiate, negotiate, and formalise RFCs.

However, change mechanisms are corrective rather than preventive. They operate after an operational issue has emerged, may lag execution reality, and separate contractual from production traceability. An RFC can record that a change was recognised without preserving the original tender assumption that made it necessary. Change mechanisms should therefore be understood as supplements to, not substitutes for, stronger structural alignment from the outset of the project.

5.7.5 Cost and Progress are Insufficiently Integrated

In all three cases, cost control depends on interpreting the relationship between financial data and execution reality. However, the link between cost and progress is not always direct. De Groene Boog shows the clearest conceptual divergence between site reality and administrative reality. Tiel-Waardenburg shows that forecasting becomes more reliable when actual production, remaining work, and planning updates are integrated. Vierverlaten shows that long delays and client-driven changes can make cost-progress interpretation especially difficult, as indirect costs continue even when direct production is limited.

Across the cases, progress percentages are therefore not sufficient as standalone indicators. They need interpretation alongside cost booking status, quality of completed work, remaining complexity, risks, and indirect effort. This supports the argument from Section 4.4 that explanatory value depends on the granularity and execution-alignment of underlying data.

5.7.6 Indirect Costs Remain Structurally Difficult to Trace

The most consistent cost category that remains difficult across all three cases is indirect costs: project staff, engineering, project control, contract management, planning, coordination, documentation, stakeholder management, safety, temporary facilities and other organisational costs. These costs are not inherently untraceable but become difficult to trace when treated as generic overhead without a clear relationship to responsibilities, phases, time, or change mechanisms. De Groene Boog deliberately separated staff costs from the execution structure but coordination effort cutting across disciplines could not always be neatly allocated. Vierverlaten monitored indirect costs at person or function level, making them more traceable than when absorbed into a broad overhead category. Tiel-Waardenburg shows the most complex pattern, where indirect costs are generated by cumulative coordination effort across planning, production pressure, remaining interfaces, and EMAT obligations. Indirect cost traceability improves when organisational effort is explicitly structured by person, function, phase, work package, or RFC, but this requires discipline, system knowledge, and frequent review.

5.7.7 Learning Occurs but Remains Insufficiently institutionalised

All three cases show evidence of learning. The limitation is not its absence, but the difficulty of converting situated project experience into standardised, reusable cost-structuring knowledge. Formal documents can capture what happened, but they do not always capture how project actors interpreted the situation, why certain decisions were made, or how contractual arguments were developed. As a result, learning often remains dependent on people who know the project context. This supports the refined conceptual framework's distinction between single-loop learning, correction and management of deviations within the project, clearly present across all three cases, and double-loop learning, which requires stronger causal traceability and a systematic feedback loop to future cost structuring, and is less consistently visible.

5.7.8 Implications for Cost Predictability

Within-project predictability improves in all three cases as projects progress and more information becomes available. Cross-project predictability remains more constrained: the cases generate many lessons, but these are not automatically translated into future estimating assumptions, standardised work package structures, or improved cost-control logic. Within-project predictability can be strengthened through practical mechanisms: a workable monitoring structure, recurring review meetings, clear RFC procedures, and explicit monitoring of indirect costs. However, when predictability depends on project-specific Excel files, local working methods, or experienced individuals, the learning generated within a project does not automatically benefit future projects.

The central implication is that cost predictability cannot be improved only by better forecasting during execution. Forecasting can improve the expected result of a single project, but cross-project predictability requires that the causes of deviations are systematically captured and fed back into future estimation and budgeting. The empirical comparison shows that current practice is stronger in within-project control than in cross-project learning.

5.8 Conclusion of Empirical Findings

This chapter has analysed how cost information is currently structured and used in practice, and how this affects cost traceability and the ability to learn from cost deviations. The central finding is that current practice is not characterised by a lack of cost information. Across the three cases and the organisational interviews, cost information is extensively documented through tender estimates, work budgets, cost reports, forecasts, risk registers, change mechanisms, and project evaluations. The limitation lies not in data availability, but in structural continuity between these forms of information.

Cost structures change as projects move from tendering to execution, control, reporting, and evaluation. Each transformation serving a legitimate purpose but also weakening the connection between original assumptions, execution conditions, and final cost outcomes. As a result, deviations may become financially visible while their underlying causes remain difficult to trace. Traceability is strongest when deviations can be linked to specific scope changes, contractual events, or formal change mechanisms. It is weakest for deviations that emerge gradually or cut across several domains, particularly indirect project staff, engineering effort, coordination costs, delay-related costs, and EMAT obligations.

The findings also show that learning does occur and is sometimes documented and shared beyond individual projects. However, its institutionalisation remains limited when lessons depend on personal explanation or project-specific files rather than being translated into standardised estimating assumptions, improved budget structures, or reusable control logic. Current practice is relatively strong in within-project single-loop control, and weaker in generating the double-loop learning, requiring causal traceability of deviations, that would improve cross-project predictability over time.

The cases also provide empirical grounding for the conditions under which double-loop learning becomes more or less likely, a gap identified in Section 3.5.3 as underexplored in the Dutch construction context. Vierverlaten shows that double-loop learning was partially achieved when three conditions coincided: a cost structure aligned with execution logic enabling deviations to be linked to specific scope elements, a formal change mechanism (RFC) that made underlying causes contractually and financially explicit, and sufficient team continuity to preserve contextual knowledge across the project lifecycle. De Groene Boog and Tiel-Waardenburg demonstrate, conversely, that fragmented structuring systems and actor-dependent interpretation keep learning single-loop even when data availability is high. The implication is that double-loop learning is not primarily a function of project complexity or data volume, but of the structural conditions that allow causal reconstruction to occur and be preserved beyond individual projects.

Three mechanisms consistently limit cost traceability across the cases: (1) cross-phase structural discontinuity, as the tender estimate does not remain the primary control structure and assumptions are lost or reinterpreted in translation, (2) the insufficient integration of cost and progress information, which prevents financial indicators from being diagnostically meaningful, and (3) the weak institutionalisation of learning feedback loops, which keeps improvements project-specific rather than organisationally embedded.

These findings directly inform the evaluation in Phase III. The empirical limitations identified here, cross-phase misalignment, insufficient cost-progress integration, and structurally difficult indirect cost categories, serve as the primary criteria against which the structuring approaches analysed in Chapter 4 will be evaluated. The extent to which the approaches can address these limitations in practice is the subject of the following chapter.

Phase III

Evaluation, Implementation and Validation

6 Evaluation of Structuring Approaches

This chapter contributes to answering Sub-Question 4: *"What organisational and project conditions are needed to implement the identified structuring mechanisms in such a way that cost traceability and project learning are supported in practice?"*. It does so by systematically comparing the mechanisms of the five structuring approaches identified in Chapter 4 with the empirical limitations identified in Chapter 5.

The evaluation is structured in three steps. Section 6.1 derives the evaluation criteria directly from the empirical findings. Section 6.2 evaluates each approach against these criteria. Section 6.3 synthesises the findings into a cross-approach comparison and identifies the organisational conditions under which each approach's potential can be realised.

6.1 Evaluation Criteria

The cross-case analysis in Section 5.7 identified three primary mechanisms that constrain cost traceability and project learning. For evaluating structuring approaches, these mechanisms are operationalised into five criteria. Indirect cost traceability and change mechanism support are treated as separate operational criteria because they emerged across the cases as recurring practical sub-problems within the broader traceability problem.

Criterion 1: Cross-Phase Structural Continuity

In all three cases, the tender estimate does not remain the primary control structure during execution. As cost information is transformed between phases, original assumptions are condensed, reclassified, or lost. The evaluation therefore examines whether an approach provides a stable structuring unit that can be consistently maintained from tender estimation through work budgeting, execution control, and financial reporting.

Criterion 2: Cost-Progress Integration

Financial performance indicators and physical progress were managed through separate logics in all three cases, requiring continuous manual interpretation to reconstruct their relationship. The evaluation examines whether an approach provides explicit mechanisms for linking cost expenditure to physical completion in a way that is diagnostically meaningful.

Criterion 3: Double-Loop Learning Support

Learning occurs in all three cases but remains primarily single-loop: deviations are corrected or financially managed without the underlying structuring logic being questioned or translated into improved future estimation practices. The evaluation examines whether an approach creates the causal linkages and feedback mechanisms required for double-loop learning, both within and across projects.

Criterion 4: Indirect Cost Traceability

Indirect costs emerge as the most structurally difficult category in all three cases. The evaluation examines whether an approach provides mechanisms for attributing indirect costs to specific activities, phases, or work scopes rather than treating them as undifferentiated overhead.

Criterion 5: Change Mechanisms Support

Formal change mechanisms partially restore traceability in all cases but operate correctively after operational issues have emerged, and lag execution reality. The evaluation examines whether an approach reduces the frequency of unplanned changes or improves their integration with the cost structure.

6.2 Evaluation of Structuring Approaches Against Criteria

Each approach is assessed against these five criteria using a three-level scale:

1. limited, the approach does not explicitly address the limitation;
2. moderate, the approach indirectly supports improvement under certain conditions;
3. strong, the approach directly addresses the limitation through explicit mechanisms.

The assessment draws on the literature reviewed in Chapter 4 and the empirical patterns identified in Chapter 5. The evaluation is shown in Table 6.1 below. The full justification for each individual score is provided in Appendix D. The evaluation is diagnostic and comparative rather than quantitatively validated. The scores should be read as structured qualitative judgements, grounded in the literature review and empirical findings, and not as statistically validated performance measures.

Table 6.1: Evaluation of Structuring Approaches Against Empirical Limitations

Approach	Cross-Phase Continuity	Cost-Progress Integration	Double-Loop Learning	Indirect Cost Traceability	Change Mechanisms	Total
WBS	Moderate	Limited	Limited	Moderate	Limited	7/15
CPM	Limited	Moderate	Limited	Limited	Limited	6/15
EVM	Moderate	Strong	Moderate	Limited	Limited	9/15
LPS	Limited	Strong	Moderate	Moderate	Limited	9/15
AWP	Strong	Strong	Strong	Moderate	Moderate	13/15

Limited = 1	Moderate = 2	Strong = 3

6.2.1 Evaluation of Work Breakdown Structure

The WBS contributes to cross-phase structural continuity at a moderate level by establishing a hierarchical coding structure that can serve as a consistent reference across project phases. When defined at project outset and maintained throughout estimation, execution, and reporting, a WBS reduces the fragmentation that arises when different structuring logics are applied at different stages. However, the effectiveness of this contribution depends entirely on whether the decomposition logic aligns with how work is executed in the field. De Groene Boog illustrates this limitation: extensive cost codes were present but did not always produce shared meaning across disciplines. What was meaningful to the financial administration was opaque to execution teams because the codes did not correspond to recognisable work sections or production sequences. The result is the central paradox identified in Section 5.4.2: the data was there, but the project did not know what it said.

For cost–progress integration, the WBS provides the structural basis for assigning costs to scope elements, which is a prerequisite for progress measurement, but does not prescribe how physical completion is linked to financial status. It is a skeleton without a mechanism. For double-loop learning, a consistent WBS coding structure is a necessary but insufficient precondition: it enables cross-project comparison of assumptions and actual outcomes at the work package level but provides no feedback loops or institutionalised processes for translating those comparisons into revised estimating logic.

For indirect cost traceability, the WBS offers conditional support. Indirect costs can in principle be made more traceable when activities such as engineering, project management, coordination or site support are deliberately included as separate WBS elements or linked to specific work packages. However, the WBS does not by itself define the cost drivers of these indirect activities, nor does it prevent them from being aggregated into broad overhead categories. Its contribution to indirect cost traceability is therefore moderate rather than strong. For change mechanisms, the WBS provides more limited support: scope changes can be reflected by adding or modifying WBS elements, but the WBS does not manage the contractual, technical or operational cause of the change itself.

6.2.2 Evaluation of Critical Path Method

CPM contributes indirectly to cost management through its time-based framework. When activities are cost-loaded, CPM enables time-phased expenditure monitoring and provides a basis for detecting when planned spending diverges from actual expenditure. This gives CPM a moderate contribution to cost–progress integration, specifically for the temporal dimension. However, as illustrated in Section 4.2.2 and confirmed by the empirical cases, CPM operates at an activity level that reflects planned sequencing logic rather than the level at which costs are estimated and reported. When these structures are not aligned, relating financial deviations to specific schedule events becomes difficult. The tool can identify when something went wrong but provides limited insight into why in terms of underlying cost assumptions or execution conditions. This constrains its contribution to both cost traceability and learning. For indirect costs and change mechanisms, CPM offers no direct mechanisms.

6.2.3 Evaluation of Earned Value Management

EVM represents the strongest of the three traditional approaches in terms of cost–progress integration. By explicitly combining Planned Value, Earned Value, and Actual Cost, EVM creates a structured basis for monitoring whether financial expenditure aligns with physical completion, directly addressing the divergence identified across all three cases. Its ability to generate early warning signals and completion forecasts also gives it a moderate contribution to double-loop learning: it functions as a precondition by making deviations visible and quantifiable. However, as the empirical findings consistently demonstrate, this contribution is conditional. Deviations can be visible in EVM indicators without being diagnostically meaningful when tracking occurs at high aggregation levels. A cost variance at the project level can signal that a problem exists without indicating whether its cause lies in estimation, procurement, productivity loss, or indirect cost growth. EVM signals that learning is needed but does not create the structural conditions for identifying root causes. For indirect costs and change mechanisms, EVM offers limited support: indirect categories are typically absorbed into the baseline at aggregation levels that reduce their traceability.

6.2.4 Evaluation of Last Planner System

LPS addresses a different dimension of the empirical problem than the traditional approaches. Its primary contribution is to cost–progress integration, which it addresses through a different mechanism than EVM: rather than measuring deviations after they have occurred, LPS aims to prevent the workflow disruptions that generate them. By making the readiness conditions for execution explicit before work is committed, through the SHOULD and CAN filters described in Section 4.3.1, LPS reduces the gap between financial booking and physical progress that all three cases identified as a core challenge. Indirect cost growth driven by waiting time, rework, disrupted workflow, and coordination failures is a primary consequence of poor workflow reliability, and LPS directly targets this mechanism.

For double-loop learning, LPS contributes strongly to the intra-project form through its PPC measurement and non-compliance registration, which create a structured feedback loop within the project. This corresponds to the intra-project double-loop learning pathway in the refined conceptual framework. However, its contribution to inter-project learning is more limited: LPS does not provide mechanisms for translating production-level insights into future estimation practices. For indirect costs, LPS offers a moderate contribution through its work package logic: as the project controller in Section 5.2 noted, linking indirect activities to specific work packages rather than treating them as general overhead could improve their traceability, a principle directly compatible with LPS's commitment-based planning structure. For cross-phase structural continuity, LPS's contribution is limited: it was designed for the production phase and does not address the alignment of cost information between tender estimation, work budgeting, and reporting.

6.2.5 Evaluation of Advanced Work Packaging

AWP distinguishes itself from the other four approaches by explicitly targeting the cross-phase structural alignment that the literature and empirical findings identify as a central condition for cost traceability. Its defining characteristic, construction-driven planning, ensures that engineering deliverables, construction scope units, and field execution tasks are organised through a consistent lifecycle-spanning hierarchy. CWPs provide a stable unit of analysis that can be maintained from construction planning through execution and reporting. When costs and progress are tracked at the CWP level, the connection between original scope assumptions and actual performance outcomes is structurally preserved in a manner not achieved by any of the traditional approaches individually.

For cost–progress integration, AWP's contribution is equally strong. The IWP readiness-driven approach reduces the gap between financial booking and physical progress by ensuring work is only released when prerequisites are in place, directly addressing the timing divergence identified in De Groene Boog. CWPs provide the execution-aligned level at which cost, scope, and physical completion can be integrated meaningfully. For double-loop learning, AWP offers the strongest contribution among the five approaches: the package hierarchy creates a practical pathway for tracing deviations to specific scopes, interfaces, or readiness conditions, enabling both intra-project learning (causal identification during execution) and inter-project learning (preserved package-level performance data for future estimation). Unlike more ad hoc or narrative forms of evaluation, the package structure creates a potentially repeatable basis for documenting how work was defined, prepared, and performed, providing a more stable unit through which observations from execution can be stored and fed back into future estimate practices.

For indirect costs, AWP's contribution is moderate: indirect activities can be assigned to packages if deliberately structured, engineering hours to specific EWPs, coordination effort to CWPs, but this does not occur automatically through AWP implementation and requires an explicit design decision at project outset. For change mechanisms, AWP indirectly reduces the frequency of unplanned changes through better upfront alignment, and the package structure provides a clearer basis for substantiating and integrating RFCs when scope deviations do occur.

6.3 Synthesis: Complementarity and Recommended Configuration

The evaluation confirms that none of the five approaches fully addresses all empirical limitations in isolation. The traditional approaches, WBS, CPM, and EVM, each address a specific dimension of project information organisation but were not designed to ensure cross-phase structural alignment or to create the conditions for double-loop learning. As the evaluation scores reflect, WBS and CPM each address at most two of the five criteria, and only at a limited or moderate level. EVM represents a stronger instrument within the traditional category, particularly for cost–progress integration, but its explanatory value remains dependent on data granularity, and it does not address the structural discontinuity between project phases that all three empirical cases identify as the primary constraint on cost traceability. LPS and AWP address broader sets of limitations and were both developed in response to persistent performance challenges that traditional approaches proved unable to fully resolve.

A particularly important relationship exists between LPS and AWP. The two approaches are not alternatives between which a choice must be made, but instruments that address fundamentally different dimensions of the same underlying problem. AWP provides the structural framework within which project work is organised and traced across the lifecycle: it defines what the work packages are, how they are connected across phases, and how engineering deliverables, construction scope, and field execution form a coherent unit of analysis. LPS provides the operational mechanism within that structure: it determines when packages are ready for execution and makes visible why deviations in execution occur. AWP addresses the question of structural alignment and LPS addresses the question of execution reliability. Together, they are more comprehensive than either approach alone.

The evaluation suggests a complementary relationship between AWP and LPS. This conclusion is not derived from a direct empirical comparison of projects using both approaches, but from comparing their mechanisms with the empirical limitations identified in Chapter 5. The cases showed that cost traceability is constrained by cross-phase discontinuity, insufficient cost-progress integration and weak learning feedback loops. AWP appears most relevant for the first limitation, because it provides a lifecycle-oriented package structure through which engineering, construction scope and execution can be connected across phases. LPS appears relevant for a different part of the problem, because it provides an operational feedback mechanism during execution through readiness planning, constraint management and the registration of reasons for non-completion.

Based on the evaluation, a three-layered configuration is proposed as the most appropriate response to the empirical limitations identified in Chapter 5. AWP functions as the primary structural framework, providing cross-phase alignment through the EWP–CWP–IWP hierarchy and creating the stable unit of analysis, the CWP, within which cost, progress, and deviations can be consistently connected. This directly addresses the central empirical limitation: the absence of a structuring logic that remains intact from tender estimation through execution control and financial reporting. LPS functions as the complementary execution mechanism within this structure, improving workflow reliability through constraint management and creating the short-interval feedback loop required for intra-project double-loop learning at the operational level. EVM, where already applied, is not proposed as an additional system but should be reoriented: rather than functioning as a standalone performance measurement framework disconnected from execution logic, EVM metrics are most diagnostically valuable when anchored to CWPs as the baseline unit. Tracking Planned Value, Earned Value, and Actual Cost at the CWP level transforms EVM from a signal that something is wrong into an instrument that can indicate where and why a deviation is emerging. WBS and CPM remain necessary instruments but are treated as foundational tools embedded within the AWP structure rather than as primary mechanisms for improving cost traceability or project learning.

The empirical findings further reveal the conditions under which this configuration is most likely to enable the double-loop learning that improved cost predictability ultimately requires. The cross-case analysis shows that the conditions for double-loop learning are not primarily a function of project complexity or data volume, but of three structural factors that must coincide: a cost structure aligned with execution logic enabling deviations to be linked to specific scope elements, a formal mechanism that makes underlying causes contractually and financially explicit, and sufficient team continuity to preserve the contextual knowledge required to reconstruct the causal logic behind deviations across the project lifecycle. These conditions are not external constraints on the proposed configuration but design criteria for its implementation: the configuration is only as effective as the organisational and structural conditions that allow it to function as intended.

These findings, and the three-layered configuration derived from them, directly inform the development of the implementation framework in Chapter 7.

7 Implementation Framework

This chapter translates the evaluation findings of Chapter 6 into a practical implementation framework for improving cost traceability and project learning in Dutch infrastructure projects. The framework is developed as a proposition grounded in the empirical limitations identified in Chapter 5, specifically the three mechanisms that consistently constrain cost traceability across all three cases: cross-phase structural discontinuity, insufficient integration of cost and progress information, and weak institutionalisation of learning feedback loops, and in the three-layered configuration proposed in Chapter 6.

The framework does not prescribe a full-scale implementation of AWP as applied in large-scale industrial construction. Rather, it translates selected principles from AWP, LPS, and EVM into a cost-traceability logic that is applicable to Dutch infrastructure projects of varying size, complexity, and contract form. AWP provides the lifecycle package structure, LPS provides readiness and execution feedback logic and EVM provides cost–progress measurement anchored at package level. The integrating contribution of the framework lies in organising these three logics around a single stable unit of analysis: the Construction Work Package (CWP).

The framework's central proposition is that cost predictability can only improve when cost deviations remain connected to the assumptions, scope elements, progress conditions, and execution mechanisms from which they originate. The empirical findings in Chapter 5 showed that this connection is broken because data is restructured at every phase transition without preserving the causal links between original assumptions and final outcomes. The framework is therefore designed not to eliminate restructuring, which is unavoidable and serves legitimate purposes, but to make restructuring traceable.

The framework is organised as follows: five design principles (Section 7.1) provide the normative foundation, the Construction Project Cost Traceability Framework (CPCTF) architecture (Section 7.2) and CWP information model (Section 7.3) operationalise the design, construction project application (Section 7.4), and indirect cost treatment (Section 7.5) and roles and responsibilities (Section 7.6) and the implementation pathway (Section 7.7) address organisational conditions, boundary conditions (Section 7.8) identify limitations, and a chapter synthesis (Section 7.9) integrates the framework contribution.

7.1 Framework Design Principles

The framework is structured around five design principles, each derived directly from the empirical limitations identified in the cross-case comparison in Section 5.7. Together, they provide the normative basis for the framework's design choices.

Principle 1: One Structuring Unit, Consistently Maintained

Fragmentation in the three cases does not arise from data scarcity. It arises from the use of different structuring logics by different project functions: estimation teams, execution teams, project controllers, and contract managers each organise cost information according to the logic best suited to their immediate task, without maintaining a shared reference across phases.

The first design principle is therefore to define a single execution-aligned structuring unit at project outset and maintain it throughout all project phases without restructuring at each phase transition. This unit, the CWP, serves as the common reference to which cost, progress, deviation information, and learning outputs are explicitly connected throughout the construction project phases. Maintaining the unit refers to keeping this single reference constant across phases. It does not require that the procurement and monitoring budgets organised beneath it remain unchanged, since those are legitimately structured by resource, discipline or contract package during execution. The CWP is therefore the stable linking unit layered over these structures, connecting them back to scope, assumptions and causes, rather than a replacement for them.

Principle 2: Execution-Aligned Cost Structuring

Cost codes that are administratively logical but not execution-recognisable lose their traceability even when formally present. The second principle requires that cost structures, for both direct production costs and indirect costs, are defined according to how work is executed and managed in the field. This means that cost codes should correspond to recognisable work units that can be planned, budgeted, monitored, and evaluated by the people responsible for executing them. Indirect costs should be structured according to what drives them, specific packages, project phases, time-dependent functions, or contractual events, rather than being absorbed into undifferentiated overhead.

Principle 3: Readiness as a Precondition for Execution

A recurring pattern across all three cases is the divergence between financial booking and physical reality. The third principle addresses this by requiring that work is only released for execution when critical prerequisites have been explicitly verified: design information, material availability, permits, work front access, capacity, and stakeholder constraints. This shifts cost control from a retrospective logic, recording what has been spent after the fact, towards an anticipatory logic that identifies the conditions most likely to cause future deviations before they become financial events.

Principle 4: Causal Attribution at Package Level

Financial visibility is not the same as causal traceability. Across all three cases, project teams could identify that financial movements had occurred, but the underlying causes were not always structurally embedded in the cost system. The fourth principle requires that deviations are attributed to specific causes at CWP level, not only registered as forecast movements. The cause attribution should distinguish a small set of causes: scope change (which absorbs client-driven and contractual changes), estimation error, productivity loss, planning disruption (distinguished by source: internal preparation, a neighbouring contractor, or external causes such as weather), procurement or material issue, and coordination or indirect effort. This distinction is analytically essential: each cause category has different implications for learning, and for determining whether a deviation can be recovered through formal change mechanisms.

Principle 5: Institutionalised Feedback Loops

Learning occurs in all three cases but remains actor-dependent and project-specific. The limitation is not the absence of learning but the difficulty of converting situated project experience into standardised, reusable cost-structuring knowledge. The fifth principle requires that package-level performance data and causal explanations are stored in a format that can be retrieved by cost engineers and project controllers in future tenders. The goal is not only to document lessons learned but to close the cross-project feedback loop: revised norm figures, updated risk allowances, improved package definitions, and adjusted demarcation rules that make future estimates more reliable.

7.2 Framework Architecture: The Construction Project Cost Traceability Framework

Figure 7.1 presents the overall architecture of the framework. The CPCTF positions the Construction Work Package as the stable linking unit through which cost-related information remains connected across the construction project phases. To avoid mixing project phases with process steps, the framework distinguishes between four project phases and the traceability processes embedded within them. The four project phases are tender, preparation, execution and control, and completion and learning. Budget transfer is treated as a process step within the preparation phase, because it concerns the translation of tender assumptions into an execution-ready cost baseline. Change and deviation management is treated as a control process within execution and control, because RFCs, forecast movements and causal attributions may occur throughout execution rather than in a separate phase. Reporting is likewise treated as a recurring control routine rather than as a standalone project phase. Three structuring approaches, AWP, LPS, and EVM, are integrated across these phases not as parallel systems but as complementary layers of a single coherent logic. Reflecting the validation, the figure also shows the CWP as a linking key layered over the existing procurement and work-budget structures that execution requires, rather than as a replacement for them, and distinguishes the preliminary CWP defined during tendering from the CWP baseline that is formalised at budget transfer.

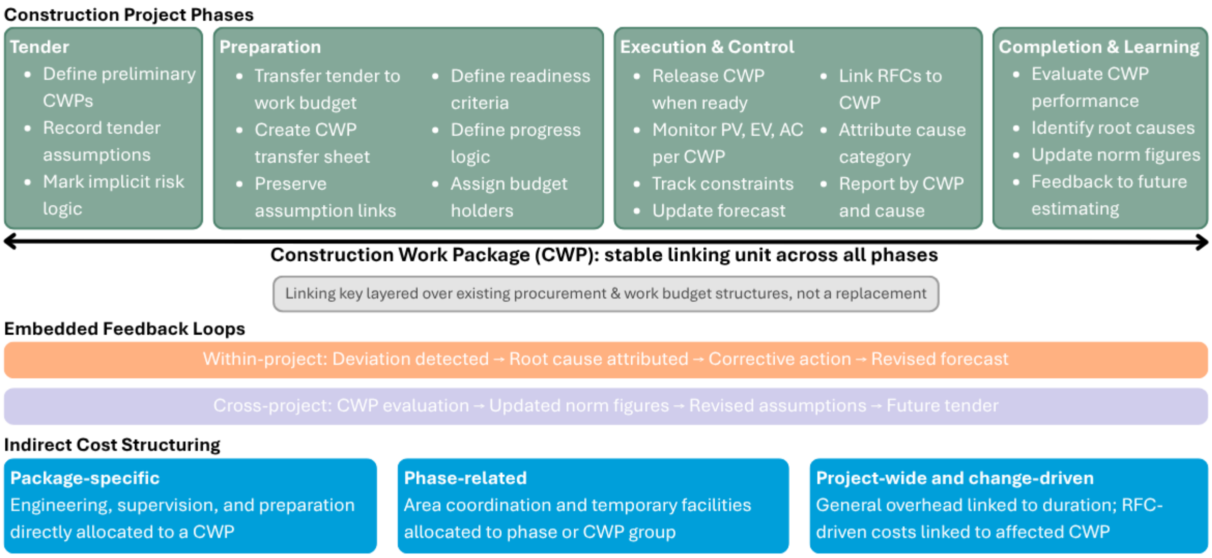

Figure 7.1: The Construction Project Cost Traceability Framework (own figure)

AWP provides the primary structural layer: it defines the CWP hierarchy, establishes the link between engineering deliverables (EWPs), construction scope (CWPs), and field execution tasks (IWPs), and ensures that the package structure defined during tender remains intact across subsequent phases. LPS provides the operational layer: within the AWP structure, it manages workflow reliability through readiness checks and constraint removal, prevents the gap between financial booking and physical progress that all three empirical cases identified, and creates the short-interval feedback mechanism for intra-project learning. EVM is reoriented from its traditional role as a standalone performance measurement system and repositioned as a cost–progress measurement layer anchored to the CWP as the baseline unit. Tracking Planned Value, Earned Value, and Actual Cost at CWP level transforms EVM from a signal that something is wrong into an instrument that can indicate where and why a deviation is emerging.

Two feedback loops are embedded in the framework architecture. The within-project feedback loop connects deviation detection at CWP level to root cause attribution, corrective action, and revised forecast, enabling adaptive control during execution and supporting intra-project double-loop learning. The cross-project feedback loop connects CWP evaluation at project completion back to future tender assumptions, norm figures, and package definitions, enabling the inter-project learning that is the ultimate condition for sustained improvement in cost predictability. Both loops are conditionally dependent on the strength of cost traceability: without causal attribution at CWP level, neither loop produces double-loop learning, as the empirical cases consistently demonstrated. Indirect costs are classified by their traceability logic: package specific, phase-related, project wide or change-driven.

7.3 The CWP Information Model

Figure 7.2 presents the information model structured around each individual CWP. The model defines what information must be explicitly linked to a CWP for it to function as a cost-traceability mechanism rather than merely as a budget container.

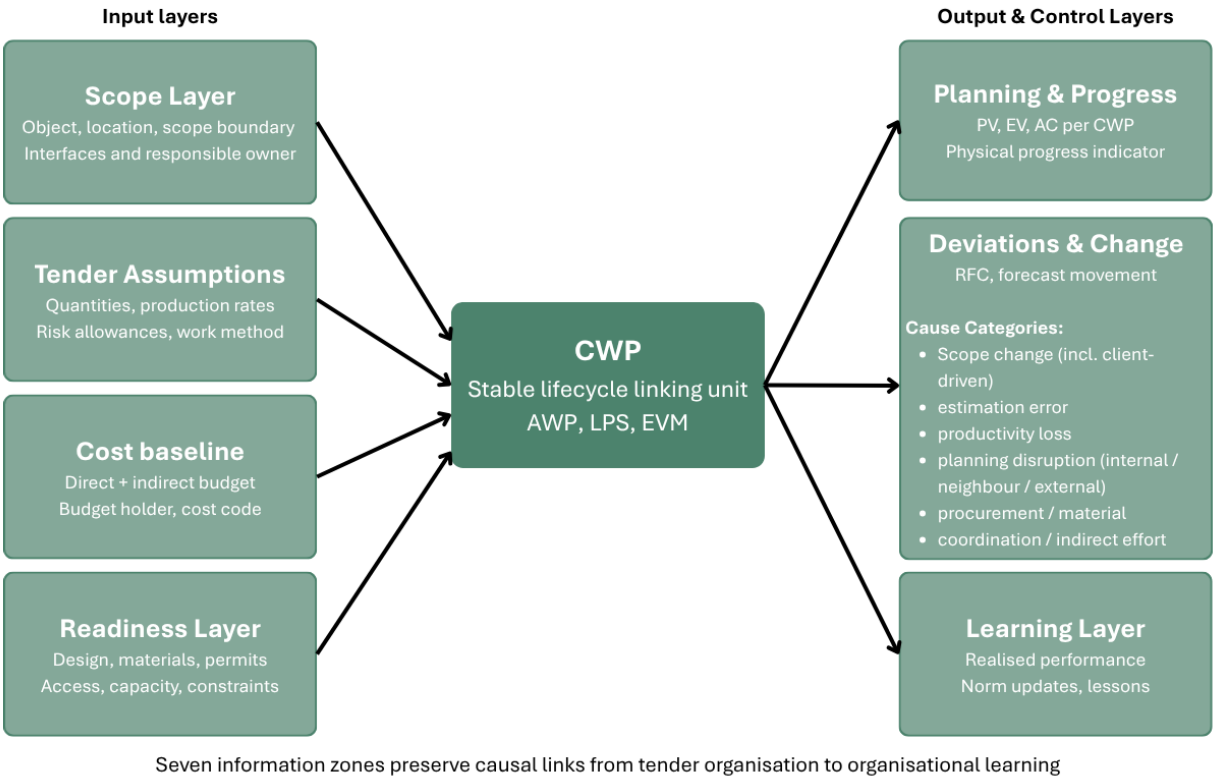

Figure 7.2: CWP Information Layer Model (own figure)

Seven information layers are structured around the CWP. The scope layer records the physical boundary of the work package: object, location, discipline, scope boundary, interface zones, and responsible owner. This layer defines what the package includes and prevents the scope ambiguity that all three cases showed to be a primary driver of untraceable deviations. The tender assumption layer records the reasoning behind the tendered value: quantities, productivity assumptions, unit rates, work method, risk allowances, and indirect cost assumptions. This layer is essential because the cross-case analysis consistently showed that deviations become difficult to interpret not because information was wrong, but because the reasoning behind it could no longer be reconstructed.

The cost baseline layer preserves the financial translation of the tender into an execution-ready budget: direct budget, indirect budget, contingency, budget holder, and cost code connection. The readiness layer records the prerequisites that must be in place before work can be released, operationalising Principle 3 in practice.

The planning and progress layer adds the time dimension: planned start and finish, physical progress indicator, planned value, earned value, and remaining work estimate. This layer links financial performance to actual physical completion rather than to cost booking alone, directly addressing the cost–progress divergence identified across all three cases.

The deviation and change layer creates the causal record of financial movements: forecast changes, RFCs, scope changes, risk and opportunity events, and cause category attributions. This layer connects financial movement to operational and contractual causes, making the deviation interpretable rather than merely visible. The learning layer closes the cross-project feedback loop: realised performance compared to tender, root cause of major deviations, lessons learned, and recommended changes to future estimating logic or package definitions.

The model does not prescribe a specific information system. It can be implemented across a combination of tools, a central ERP, project-specific dashboards, and structured evaluation templates, provided the CWP identifier serves as the common key linking all layers. The critical requirement is that layers are connected through a shared CWP code, not managed as separate parallel files with no formal linkage.

7.4 Application Across the Project Phases

The framework must be applied as a process, not as a reporting template introduced during execution. The empirical findings consistently showed that traceability limitations originate before execution deviations occur. Table 7.1 presents the main framework actions, practical outputs, and CWP information layers activated across the four project phases. Within each phase, specific process steps are nested to preserve traceability between tender assumptions, budget transfer, execution control, deviation management, reporting, and learning.

In applying the framework across the project phases, a distinction is made between project phases and process steps. Project phases describe the main temporal stages in which the framework is applied, while process steps describe the actions required to preserve cost traceability within and between those phases. This distinction is important because some elements of the framework, such as budget transfer, deviation management and reporting, are not standalone project phases. Budget transfer is a transition process within preparation, while deviation management and reporting are recurring control processes during execution. Table 7.1 therefore presents the CPCTF through four project phases, with the relevant process steps nested within each phase.

Table 7.1: Application of the CPCTF Across the Project Phases

Project Phase	Process step(s)	Main Framework Action	Practical Output	CWP Layers Activated
Tender	CWP definition and assumption capture	Define preliminary CWPs for major scope elements and register the assumptions behind the estimate	CWP assumption register	Scope layer; tender assumption layer
Preparation	Budget transfer and work preparation	Translate the tender estimate into an execution-ready work budget while preserving links to assumptions; define readiness criteria, progress logic and responsibilities	CWP transfer sheet; CWP control sheet; readiness checklist	Tender assumption layer; cost baseline layer; readiness layer; planning & progress layer
Execution & Control	Work release, monitoring, deviation management and reporting	Monitor PV, EV and AC per CWP; track readiness and constraints; link RFCs, scope changes and forecast movements to affected CWPs and cause categories; report by CWP and cause	CWP dashboard; CWP–RFC deviation log; causal deviation report	Planning & progress layer; readiness layer; deviation & change layer; all layers at summary level
Completion & Learning	Evaluation and feedback	Compare tendered and realised CWP performance; identify root causes; translate lessons into future estimating and structuring logic	CWP lessons-learned record; updated norm figures; revised package definitions for future tenders	Learning layer; feedback to tender assumption layer

Tender Phase: Creating a Traceable Assumption Baseline

In the tender phase, the framework begins with the definition of preliminary CWPs that reflect the expected execution logic of the project. These packages do not need to be final, as design and planning detail may still be incomplete. However, they should already correspond as far as possible to how the work is expected to be organised and managed in the field: geographically, by discipline, by major scope element, or by construction sequence.

For each preliminary CWP, the tender team registers the key assumptions behind the price in a structured CWP assumption register. This includes quantities, production rates, work method, risk allowances, indirect cost assumptions, relevant exclusions, and interface conditions. The purpose of this register is not to add a separate administrative document, but to make the reasoning behind the tender estimate explicit and transferable.

This step is essential because the empirical findings showed that later cost deviations are often difficult to interpret not because no information exists, but because the original reasoning behind the estimate can no longer be reconstructed. By linking assumptions to preliminary CWPs from the tender phase onwards, the framework creates an initial traceability baseline against which later budget transfers, execution performance, deviations, and evaluations can be compared.

Preparation Phase: Translating the Tender into an Execution-Ready Baseline

The preparation phase translates the tender logic into an execution-ready cost and control structure. This phase includes two process steps that were previously presented separately: budget transfer and work preparation. Treating them as process steps within preparation is more accurate, because both activities concern the transformation of the tender estimate into a structure that can be used for execution control.

The first process step is budget transfer. After contract award, the tender estimate must be translated into a work budget. This restructuring is necessary and legitimate, because the tender estimate is not automatically suitable for execution control. However, the transfer should not break the link between original assumptions and execution budget lines. The framework therefore introduces a CWP transfer sheet that maps tender items, estimate assumptions, risk allowances, and indirect cost assumptions to the corresponding CWP and work budget post. When a tender item is combined, split, or reclassified during the transfer, the sheet records how this was done and why. This makes the restructuring itself traceable: a later deviation can be compared not only with the restructured budget post, but also with the original tender assumption.

The second process step is work preparation. During this step, the CWP is enriched with planning logic, readiness criteria, progress measurement logic, and responsible actors. This activates the planning and progress layer and the readiness layer of the CWP information model. Each CWP should therefore include a clear definition of when the package is ready for execution, which constraints must be removed, how physical progress will be measured, and who is responsible for monitoring cost and progress. In this way, preparation functions as the bridge between estimating logic and execution logic. It ensures that the CWP is not only a financial coding unit, but an execution-recognisable control unit.

Execution and Control Phase: Monitoring Cost, Progress, Deviations and Reporting

During execution and control, the CWP becomes the common reference for cost monitoring, progress measurement, readiness tracking, deviation management, and reporting. This phase includes several recurring control processes rather than one linear activity. Work is released and monitored at CWP level, while deviations, RFCs, forecast movements and reporting routines are linked back to the same CWP structure.

Cost control is organised around the comparison of Planned Value, Earned Value and Actual Cost per CWP. This applies EVM logic at the level of the package, without requiring EVM to function as a separate management system. The key point is that cost-progress indicators are anchored to an execution-aligned package structure rather than to aggregated financial reporting categories. This addresses the empirical limitation that total-level financial indicators may appear stable while underlying monitoring posts shift significantly. CWP-level monitoring makes such shifts visible at the level where they can be interpreted and attributed.

The CWP dashboard should combine EVM-style cost-progress data with LPS-style readiness and constraint information. This includes readiness status, active constraints, reasons for non-completion, and corrective actions. Combining these elements allows project teams to distinguish between different causes of financial movement. A cost deviation caused by a productivity shortfall requires a different response than a deviation caused by missing design information, delayed procurement, access constraints, or a client-driven scope change.

Change and deviation management is therefore treated as a process within execution and control, not as a separate project phase. Each RFC, scope change, major forecast movement, or significant cost deviation should be linked to the affected CWP and assigned to a cause category. At minimum, these categories should distinguish a small set of causes: scope change (absorbing client-driven and contractual changes), estimating error, productivity loss, planning disruption distinguished by source (internal preparation, a neighbouring contractor, or external causes such as weather), procurement or material issue, and coordination or indirect effort. This distinction is important because each cause category has different implications for corrective action, contractual recovery, and future learning.

Reporting is also treated as a recurring control process within this phase. Rather than reporting cost movements only at total project level or through aggregated financial categories, the framework requires cost movements to be reported by CWP and cause category. The purpose is not to replace existing financial reporting requirements, but to retain the causal explanation behind financial movements. In this way, reporting becomes more than a visibility mechanism: it becomes a traceability mechanism that preserves the link between cost movement, physical progress, execution condition, and underlying cause.

Completion and Learning Phase: Closing the Feedback Loop

In the completion and learning phase, the CWP structure provides the basis for systematic project evaluation. Each CWP is reviewed against its original tender assumptions, transferred work budget, execution performance, and recorded deviations. This includes comparing assumed and realised quantities, planned and achieved productivity, allocated and actual indirect effort, readiness issues, forecast movements, RFCs, and attributed causes.

The main output of this phase is a CWP lessons-learned record. This record should not only describe what happened but should translate package-level performance into reusable estimating and structuring knowledge. Relevant outputs include adjusted productivity assumptions, revised indirect cost allowances, improved demarcation rules, updated risk allowances, refined package definitions, and standard readiness criteria for comparable future packages.

This closes the cross-project feedback loop embedded in the CPCTF. The purpose of completion and learning is therefore not only to evaluate the completed project, but to feed traceable, causally interpreted cost information back into future tender preparation and cost structuring. In this way, the framework links within-project control to inter-project learning. Cost predictability is improved not by producing more retrospective reports, but by ensuring that realised package performance and its underlying causes become available as structured input for future estimating, budgeting and control practices.

7.5 Treatment of Indirect Costs

The empirical cases show that different cost categories present different traceability challenges. Direct production costs and technical scope changes can often be traced more easily when they are linked to quantities, work packages, physical progress or formal RFCs. Indirect costs, however, proved more structurally difficult across the three cases, because they are often driven by project duration, coordination effort, engineering, contract management, documentation, stakeholder interaction and delay-related processes rather than by discrete production activities. Their treatment therefore requires explicit attention in the framework.

The classification in Table 7.2 does not attempt to force every indirect cost into a work package, which would be administratively unrealistic. Instead, it assigns each indirect cost category to the most meaningful traceability logic available. This classification reflects the finding that indirect costs should not be treated as one residual category. Some indirect effort is sufficiently close to production to be linked to a CWP, while other effort is better traced through phases, project-wide drivers or change events.

Table 7.2: Classification of Indirect Costs Within the CPCTF

Category	Definition	Framework Treatment	Example Cost Drivers
Package-specific	Indirect effort directly required to prepare, coordinate, or supervise a specific CWP	Allocate to the relevant CWP; register under the CWP cost code alongside direct costs	Engineering for a specific EWP; package-specific work preparation; package supervisor hours
Phase-related	Indirect effort related to a project phase or cluster of packages rather than one package	Allocate to phase or group of CWPs; document allocation logic in the transfer sheet	Phase planning; area coordination; temporary facilities for a construction zone; phase-specific quality management
Project-wide	Indirect effort that supports the entire project and cannot be meaningfully assigned to one package or phase	Keep as separate budget line; link to explicit cost drivers (project duration, contractual milestones, regulatory events)	General project management; contract management; stakeholder management; stakeholder engagement; financing costs; prolonged-duration overhead
Change-driven	Indirect effort triggered by RFCs, delays, scope changes, or client-driven requirements	Link to the affected CWP and/or RFC; record cause category; include in RFC substantiation where recoverable	Claim preparation; additional document management; design review cycles triggered by change; coordination overhead from scope development

The most important distinction is between indirect costs that can be meaningfully attributed to specific packages or phases and those that are genuinely project wide. Package-specific engineering effort, coordination, and supervision can and should be assigned to the relevant CWP. This is not administratively burdensome if the package structure is defined clearly at project outset: it requires allocating time registration to CWP codes rather than generic overhead codes. This is consistent with the observation from Section 5.2 that treating indirect hours as generic overhead reduces traceability, whereas linking them to work packages makes cost development visible.

Change-driven indirect effort deserves particular attention. Vierverlaten demonstrated most clearly that indirect costs triggered by contractual processes, claim preparation, additional engineering, coordination overhead from scope development, can constitute a substantial portion of total project cost and that their recoverability through formal change mechanisms depends entirely on their traceability to specific causal events. Without explicit linkage to CWPs and RFCs, these costs remain financially visible but causally opaque, reducing both within-project control and cross-project learning.

7.6 Roles and Responsibilities

The framework functions only if ownership of each information layer is clearly assigned. The CWP should not become an additional administrative object without clear responsibility. Table 7.3 presents the primary responsibility and key CWP information ownership for each project role. The project controller functions as the integrator of the cost-traceability logic rather than as the sole owner of all data.

Table 7.3: Roles and Responsibilities in the CPCTF

Role	Main Responsibility in the Framework	Key CWP Information Ownership
Cost engineer	Defines preliminary CWPs in the tender phase; records the assumptions, quantities, productivity rates, and risk allowances behind the estimate; produces the assumption register	Scope layer, Tender assumption layer
Project manager	Ensures that the CWP structure is accepted as the project control logic; ensures that deviations lead to management decisions; owns the handover of assumptions from tender to execution	Cross-layer oversight; handover process
Project controller	Maintains the CWP transfer sheet and cost baseline; connects work budget, actual cost, and forecast movements to CWPs; produces the CWP dashboard; integrates EVM logic at CWP level	Cost baseline layer, Deviation & change layer, Planning & progress layer

Role	Main Responsibility in the Framework	Key CWP Information Ownership
Work preparation	Adds planning logic, readiness criteria, constraints, and progress measurement logic to each CWP; manages LPS constraint removal	Planning & progress layer, Readiness layer
Execution team	Provides information on physical progress, productivity, constraints, reasons for non-completion, and corrective actions at CWP level	Planning & progress layer (progress data); Readiness layer (constraint reporting)
Contract manager	Links RFCs, contractual changes, and client-driven developments to affected CWPs and cause categories; substantiates claims using the assumption register	Deviation & change layer; RFC–CWP linkage
Financial management	Ensures that reporting remains connected to the CWP structure; prevents aggregation from removing causal explanation; validates forecast movements at CWP level	Cost baseline layer; deviation reporting
Knowledge owner	Receives CWP evaluation outputs; translates them into revised norm figures, productivity assumptions, and future package definitions; closes the cross-project feedback loop	Learning layer; feedback to Tender assumption layer

The most important handover in the framework is from cost engineer to project controller at the tender-to-execution transition. In all three empirical cases, this handover was identified as a primary source of information loss: the cost engineer's interpretive knowledge of the tender assumptions was not systematically transferred to the execution team, leaving the project without institutional memory of why specific assumptions had been made. A structured handover process, including a joint review of the assumption register and CWP transfer sheet before execution begins, is a minimum requirement for the framework to function as intended.

7.7 Staged Implementation Pathway

Figure 7.3 presents a staged implementation pathway for the CPCTF. In this research, the levels refer to the degree to which the cost-traceability logic of the framework is implemented and embedded in project control and organisational learning routines.

Levels 1 and 2 are primarily project-level implementation levels. They describe the extent to which a project links tender assumptions, CWPs, work budgets, progress information, RFCs, indirect cost drivers and forecast deviations during project delivery. Level 3 extends this logic to the organisational level, because cross-project learning requires that CWP evaluation outputs are reused in future estimating practices, norm figures, package definitions and control routines. The pathway therefore describes increasing implementation depth in the specific domain of cost traceability and project learning, rather than general organisational, project or individual maturity.

The pathway reflects the empirical finding that the conditions for double-loop learning must be deliberately cultivated and are not achievable in a single implementation step. Table 7.4 describes the requirements and primary benefit of each implementation level.

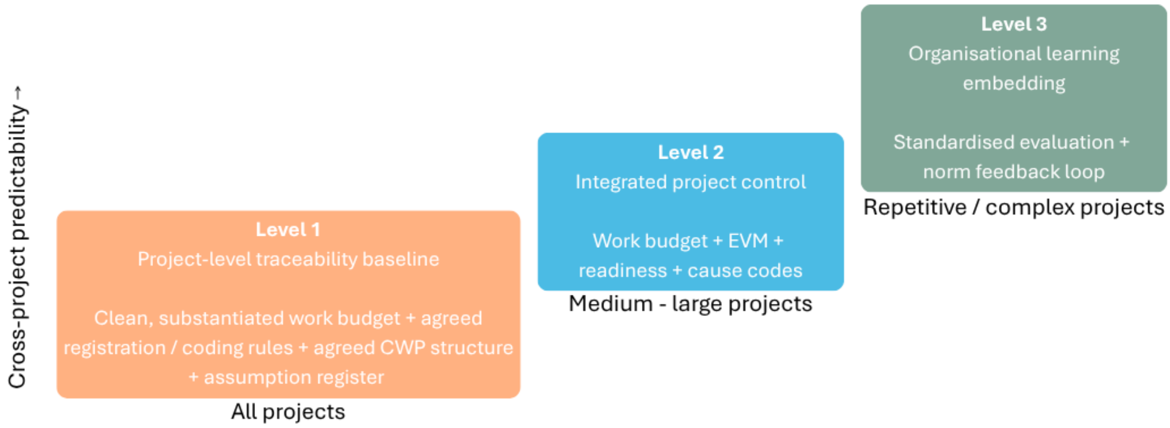

Figure 7.3: CPCTF Staged Implementation Pathway (own figure)

Table 7.4: Staged Implementation Levels for the CPCTF

Level	Description	Minimum requirements	Primary benefit
Level 1	Project-level traceability baseline	CWP structure covering major cost drivers; structured assumption registers for material assumptions; linkage of major RFCs and indirect cost drivers to CWP codes; CWP transfer sheet	Prevents the most important assumptions and deviations from becoming untraceable; applicable to all project types with existing tools
Level 2	Integrated project control	CWP-based work budget covering all direct and identified indirect cost categories; cost–progress indicator per CWP (EVM at CWP level); readiness checklist as precondition for work release; cause-coded deviation attribution for all significant forecast movements; CWP dashboard	Improves within-project predictability by linking cost movements to execution conditions; supports intra-project double-loop learning
Level 3	Organisational learning embedding	All Level 2 requirements plus: standardised CWP evaluation at project completion; feedback to estimating function; norm figure updates for recurring package types; reusable package definitions, readiness templates, and demarcation rules	Improves cross-project predictability over time; most appropriate for organisations executing multiple similar projects or managing repetitive programme work

The indication "all projects" in Level 1 refers to the intended long-term applicability of the baseline traceability requirements, not to the first step of implementation. Before Level 1 is standardised across all projects, the proposed templates, CWP links and deviation-registration routines should first be tested in a pilot project and refined based on practical feedback.

Level 1 can be implemented immediately with existing tools and minimal process change for most projects. The assumption registers and CWP transfer sheet can be implemented as structured Excel templates. RFC–CWP linkage can be added to existing change management procedures. Level 2 requires investment in aligning cost-coding and progress-reporting systems around the CWP as the common reference unit, and in introducing readiness checks as a formal gate before work release. Level 3 requires organisational commitment beyond individual project teams: standardised package templates, norm figure libraries and structured post-project evaluation only create value when they are maintained and reused across multiple projects.

The choice of implementation level should be driven by project size, available team capacity, system support and the organisation's ambition for cross-project learning. For projects with limited size or uniqueness, Level 1 may be sufficient to prevent the most important assumptions and deviations from becoming untraceable. For larger or more repetitive project environments, Level 2 or Level 3 may be appropriate because the additional structure can be reused across projects and can support organisational learning.

7.8 Boundary Conditions and Limitations

Six boundary conditions must be acknowledged before the framework can be assessed for practical relevance.

First, the CWP level must be carefully calibrated. If packages are defined too broadly, cost deviations remain aggregated and difficult to interpret at the level required for causal attribution. If defined too narrowly, the administrative burden becomes excessive and the framework loses support from project teams. The empirical cases suggest that the optimal level is the lowest level at which cost, physical progress, and responsibility can still be managed realistically by a single budget owner, typically corresponding to a scope unit of two to eight weeks of field work for a single discipline or construction sequence. Below this level, the administrative overhead outweighs the traceability benefit, above it, the causal resolution is insufficient.

Second, the framework requires adequate information system support. If CWP information is maintained only in separate project-specific Excel files, the same fragility identified across all three empirical cases will reappear under different conditions. Excel can support analysis and visualisation, but the core links between CWP, budget, progress, RFCs, and evaluation records should be maintained in a shared and controlled information environment. This does not require a single monolithic system: it requires that the CWP code serves as a consistent linking key across whichever tools are used, and that the assumption register and transfer sheet are accessible to all relevant project functions, not only to the project controller.

Third, the framework requires disciplined and sustained use by project actors. A CWP structure only creates traceability if deviations are cause-coded, readiness issues are recorded, and indirect cost drivers are made explicit. Without this discipline, the framework risks becoming a reporting layer that adds administrative effort without improving traceability. The implementation pathway addresses this risk by starting with minimum requirements and building additional layers incrementally as the team gains familiarity and as system support develops.

Fourth, the framework does not resolve all sources of cost uncertainty. Several cost drivers identified in the empirical cases, ground conditions, regulatory changes, force majeure events, and complex third-party dependencies, remain difficult to estimate regardless of how well cost information is structured. The framework improves the traceability of deviations from whatever baseline is established and improves the quality of future estimates by preserving historical performance data, but it does not eliminate estimation uncertainty as such. Improving the structure of cost information is a necessary but not sufficient condition for improving cost predictability.

Fifth, the cross-project feedback loop depends on organisational ownership of the learning function. Project teams can produce structured CWP evaluations, but inter-project double-loop learning only materialises when evaluation outputs are actively processed by a knowledge-management role that feeds insights back into future tender preparation. Without this organisational commitment, the CWP learning layer produces evaluations that are stored but not used, a risk that the empirical cases showed to be real and persistent.

Sixth, a tighter structuring regime carries the risk of undermining the very strengths it seeks to build upon. The empirical cases showed that traceability frequently depended on experienced individuals, mutual trust within small and stable teams, and the contextual judgement of cost engineers and project controllers, for instance, the actor-dependent monitoring observed at Vierverlaten and the experiential interpretation of project-specific codes at De Groene Boog. These informal capabilities are a genuine source of control, not merely a symptom of weak structure. Imposing a more prescriptive, standardised structure could erode this flexibility: it may displace professional discretion, add procedure where tacit knowledge previously sufficed, or impose a uniform logic that sits awkwardly with the singular character of individual projects. The framework is therefore intended to support rather than replace expert judgement: the deliberately low CWP granularity, the staged implementation pathway, and the principle of adopting the lowest workable level of structure are all meant to preserve room for professional interpretation while making its reasoning more traceable. Whether this balance holds in practice, whether teams experience the structure as an aid to their judgement or as a constraint upon it, is itself a question carried into the validation interviews.

7.9 Chapter Synthesis

This chapter has developed a CPCTF that translates the evaluation of structuring approaches into practical design guidance for Dutch construction projects. The framework positions the Construction Work Package as a stable linking unit across the four project phases of tender, preparation, execution and control, and completion and learning. Within these phases, process steps such as budget transfer, work preparation, deviation management, reporting and evaluation preserve the continuity of cost information. By maintaining this unit throughout the different project phases, cost deviations can be connected more systematically to the assumptions, scope elements, and execution conditions from which they originate.

The framework integrates three structuring approaches without prescribing a full implementation of any single method. AWP provides the lifecycle package structure that maintains cross-phase alignment, LPS contributes readiness and execution feedback at the operational level, EVM is reoriented to provide cost–progress measurement at CWP level. Together, these three layers address the empirical limitations identified in Chapter 5: cross-phase discontinuity, insufficient cost–progress integration, limited traceability of indirect costs, and weak institutionalisation of learning feedback loops. The three-layered configuration directly responds to the conditions under which double-loop learning was found to be possible in the empirical cases: a cost structure aligned with execution logic, a formal mechanism making underlying causes explicit, and team continuity that preserves contextual knowledge.

The practical value of the framework lies in shifting cost control from financial monitoring towards causal traceability. Deviations are not only registered as forecast movements but linked to packages, causes, readiness conditions, and future estimating implications. In this way, the framework provides the structural mechanism through which cost structuring enables cost traceability, supports double-loop learning, and contributes to improved cost predictability, the causal chain proposed in the refined conceptual framework of Chapter 3 and grounded in the empirical findings of Chapter 5. The framework's practical relevance, feasibility, and implementation barriers are assessed through expert validation in Chapter 8.

8 Validation

Chapter 7 presented the CPCTF as a proposition grounded in literature (Phase I) and in the cross-case empirical findings (Phase II). Because the framework is, at this stage, a theoretically reasoned construct rather than an implemented system, its practical relevance and applicability cannot be established from the literature and the case analysis alone. Following the validation approach set out in Section 2.3.3, the framework was therefore presented to and discussed with experienced practitioners at Dura Vermeer.

Consistent with Section 2.3.4, the validation interviews were not used solely as a mechanism for adjusting the framework. The expert responses are treated here as empirical findings in their own right: they expose the points at which a theoretically coherent framework meets the realities of execution, procurement logic, information systems and organisational behaviour. Where the responses indicate that changes are warranted, these are translated into refinements to the framework (Section 8.8).

8.1 Recognition of the Problem Diagnosis

All experts recognised the central diagnosis of the research, that cost overruns in the studied projects are not primarily caused by a lack of cost information but by the loss of traceability across phase transitions. One expert confirmed that information is lost at phase transitions *"if you are not strictly on top of it"*, precisely because one function works in one system and the next function works in another, after which the original substantiation disappears. He summarised the underlying mechanism as *"garbage in, garbage out"*: a cost item booked as a single careless line can never be reconstructed afterwards, whereas the same item booked in a disciplined way remains interpretable.

Another expert most strongly recognised the weak institutionalisation of learning. She described repeated organisational attempts to capture and broadly share lessons, work meetings, feedback sessions and standardised templates, while concluding that a single, unambiguous way of feeding lessons back so that they are usable across disciplines has not been found. She was more cautious about the claim that the causes of deviations cannot be identified: in her experience the cause of a financial setback is usually known to the people involved, most often a design that disappointed, an adverse market or indexation. Her qualification is important and is treated as a finding rather than as a correction: the problem she recognises is not that causes are unknown to those present, but that they are not structured, recorded and presented in a way that allows others, including a later analyst, to reconstruct them. This distinction between situated knowledge and transferable, structured traceability is precisely the gap the framework targets, and it sharpens rather than weakens the framework's premise.

A further expert linked this same mechanism to staff turnover across phases. Because long-running projects see personnel change roles, and because people involved in the tender phase are frequently no longer present once execution starts, knowledge is lost unless it is deliberately carried over. He observed that the handover between phases *"often lacks a good handover"*, attributing this less to unwillingness than to insufficient organisational discipline in registering and passing on what was assumed. This reinforces the framework's premise that traceability must be anchored in a stable structure rather than in the continuity of individuals.

The experts also recognised the specific empirical observation that indirect costs are frequently absorbed into an undifferentiated *"general costs"* item. One expert captured the behavioural driver succinctly: in his experience one should *"never call a cost item 'general'"*, because an ambiguous catch-all item is exactly where people prefer to book hours when they are unsure where a cost belongs, in the belief that they can then never book it wrongly. This directly confirms the empirical finding from De Groene Boog and supports the framework's principle of execution-recognisable cost codes.

8.2 The CWP as a Stable Structuring Unit

The proposal to define one execution-aligned unit and maintain it across all phases generated the most substantive discussion, and the experts approached it from their respective functional logics.

One expert reframed the CWP from her perspective in a way that proved highly informative. In current practice she estimates physically, for example a stretch of road, but during execution that stretch is broken down into several monitoring budgets, one for asphalt, one for earthwork, and so on, because procurement is organised by resource type rather than by location: asphalt for the whole project is purchased together, not per road segment. She therefore interpreted the framework not as a replacement of this procurement logic, which she considered unavoidable, but as *"adding an extra column"* that links the existing procurement budgets to a single activity or location, comparable to coupling costs to a planning line to monitor progress against cost. This reframing is significant: it confirms the CWP in its intended role as a stable linking unit, namely a single reference maintained across phases and layered over the procurement and monitoring budgets, connecting resource-level costs back to scope, assumptions and causes, rather than replacing the structures that execution requires.

Another expert confirmed that maintaining one unit across phases is *"certainly possible"* and, in fact, *"could already be done now"*. He illustrated this with the calculation of one square metre of paving, which requires stones, a paver and equipment, items that are subsequently monitored in separate places, and observed that keeping the unit (the street itself) intact from calculation through to execution is fundamentally a set-up choice that must be agreed jointly. He pointed to his own project, where two of three sub-areas share an identical set-up, as proof that such standardisation is achievable. His central qualification was behavioural and systemic: on projects *"everyone wants to do their own thing"*, producing a tangle of set-ups despite the existence of templates and standards, and a consistent unit therefore requires an explicit organisational decision, adherence, and *"a whole book of principles"*.

An expert also identified a concrete, system-level cause of phase-transition information loss that was only implicit in the framework: incompatibility between estimating and control software. Some estimators prefer to work in IBIS while infrastructure control runs in Metacom, and an estimate cannot be read directly from one into the other. Unless a deliberate conversion step is taken at handover, *"your entire substantiation is lost"*. This confirms the framework's boundary condition on information-system support and gives it a specific operational meaning: the CWP code can only function as a common key if the tools used across phases are explicitly aligned and the handover includes a controlled conversion.

One expert judged the approach workable for a large part of current practice, noting that although the budget holder for a cost item is not always known during tender, the item can still be structured and a holder assigned once identified, and that tenders already require a detailed work budget covering nearly every element the framework proposes: formalising an existing structure is a smaller step than building a new one. He located the main difficulty not in the framework's logic but in its consistent implementation across Dura Vermeer's business units and external partners, each bringing its own supporting systems, observing that this *"does not take away from the theoretical framework"* but is where the real difficulty lies. On ownership within a project, he pointed to the manager of project controls as the natural candidate, if budget holders are given a clear mandate from the project manager. Another expert confirmed that the required level of package detail is inherently project-specific, contrasting his water-treatment project, where a fine-grained breakdown is workable, with a dike-reinforcement project where the same detail would be excessive, and considered this variation a matter of practical judgement rather than a flaw in the CWP concept.

8.3 Cost Codes and the Treatment of Indirect Costs

The experts engaged in detail with the structuring of indirect costs, which the cross-case analysis had identified as the most difficult cost category. One expert set out the standard decomposition used in practice, distinguishing site costs, indirect project staff (further split into execution and engineering), process costs, conditioning, financial costs and risk. Her main objection to current practice mirrored the framework's diagnosis: staff costs that are booked under a generic *"general costs"* item are misplaced, because they belong under execution or engineering staff and, if they are to be monitored, must be split further by function and compared against the time-based staffing plan that is drawn up in almost every tender. She emphasised that the fixed company surcharge is a separate matter, a percentage levied across all projects to cover non-project overhead, to which project staff should not book at all. Conflating the fixed company surcharge with project-level indirect costs is itself a source of confusion.

One expert further argued that indirect costs are the hardest category to estimate not because quantities are wrong but because they are time-related: while the cost per week can be estimated reasonably well, a project that overruns its duration, and cannot recover that time from the client, automatically lacks budget for the additional weeks. This locates the dominant driver of indirect-cost deviations in schedule performance, reinforcing the framework's coupling of cost to physical progress and readiness, and the empirical observation that time-related costs are structurally difficult to trace.

Another expert endorsed the framework's classification of indirect costs by traceability logic (package-specific, phase-related, project-wide, change-driven) and suggested operationalising it as a checklist, because non-assignable items such as general construction equipment, or context-specific items such as parking in central Amsterdam, are frequently under-budgeted or simply forgotten. He confirmed that genuinely project-wide items, such as a site hub that remains in place for the full multi-year duration of a large project regardless of phase, cannot meaningfully be attached to a package or a phase and belong in the project-wide category. He added an important nuance regarding variation orders: additional scope does not necessarily increase indirect costs proportionally, laying a little extra paving needs no new site facilities, whereas building an additional bridge changes indirect costs substantially, and that in a RAW specification indirect costs may move automatically and proportionally with the contract sum unless the change is fundamentally different in nature. These observations support the framework's driver-based treatment of indirect costs while indicating that the classification should be applied judgementally rather than mechanically.

8.4 Cost-Progress Measurement and Readiness at Package Level

The repositioning of EVM as a cost–progress measurement layer anchored to the CWP was confirmed by an expert, who articulated, unprompted, the exact distinction the framework addresses. He observed that progress in current Excel reporting is often expressed as a percentage of booked costs, which *"says nothing"*, and that a meaningful indicator requires measuring how far the physical work has progressed in the field rather than what proportion of the budget has been spent. He judged EVM at package level to be feasible, *"simple, if you put the right information in"*, and therefore conditional entirely on data quality. He situated it within a broader practice in which Dura Vermeer monitors cost through a combination of procurement, production progress and cost-to-complete, observing that the appropriate method differs by discipline. Another expert likewise saw value in comparing committed and realised cost against physically realised work, linking this to the organisation's ongoing development of 5D BIM, while cautioning that it remains demanding of the project team because it requires coupling purchased budgets to modelled quantities.

Another expert also noted a property of the package structure that strengthens the framework's rationale: because a CWP can be formally closed, it provides a definite result at completion even on projects lasting several years, which a purely continuous indicator does not. He paired this with a caution that is directly relevant to the framework's design: while a package is in progress, attention may concentrate on its eventual close-out rather than on what is happening within it. This validates the framework's deliberate combination of EVM (continuous cost–progress measurement) with LPS (short-interval readiness and constraint tracking) as complementary layers, the latter being precisely what preserves mid-package visibility.

On readiness as a precondition for execution, an expert confirmed that work plans and similar documents are officially required before work begins but that this is not always respected in practice. He gave a current example of concrete being poured before formal approval, which the client eventually halted. Asked whether a readiness discipline would be embraced or experienced as delay, he answered that on projects where teams are *"strictly on top of things"* it would be embraced *"100%"*, while teams that prefer to *"do their own thing"* would resist it. The feasibility of the readiness principle is therefore confirmed but shown to be conditional on project culture rather than on the mechanism itself.

8.5 Causal Attribution at Package Level

One expert confirmed the empirical observation underlying the fourth design principle, that current practice typically books a forecast movement without recording why it occurred, and supported the idea of attaching a cause to each deviation at package level. His assessment of the proposed cause categories, however, produced two concrete refinements. First, he judged the "contractual or client-driven change" category to overlap substantially with "scope change", since most changes in his experience originate from the client wanting something different, and recommended treating them as effectively the same category. Second, he considered "planning disruption" too broad, because it can stem from the contractor's own organisation, from a neighbouring contractor, or from external causes such as weather. He therefore advised either merging overlapping categories or introducing sub-causes, while keeping the overall set small enough to be applied consistently. The principle of cause attribution is thus validated, but the specific taxonomy required adjustment (Section 8.8).

8.6 Feedback Loops and Ownership of Cross-Project Learning

The experts confirmed the framework's distinction between a within-project feedback loop, which they regarded as functioning, project teams detect deviations and take corrective action because the project simply has to be delivered, and a cross-project feedback loop, which they regarded as the weakest element of current practice and the hardest to institutionalise. One expert described the prevailing pattern exactly: knowledge travels with individuals to their next project rather than being transferred to others, *"unless people happen to ask for it"*. They attributed this less to system limitations than to behaviour and priority. An expert located it in the construction culture of *"running from one project to the next"*, where learning is, in effect, never the priority. Another expert observed that because the company is currently performing well, a satisfactory bottom-line result on a completed project leads everyone to move on, whereas the relevant question should be *"how much could it have been?"*. He also confirmed that end-of-project evaluations are weak partly because much of the team has already moved to other projects by the time the evaluation takes place.

On ownership, the experts converged on complementary proposals that together informed the refinement of the framework's learning role. One expert proposed that, because the within-project monitoring already produces a forecast and explanation per budget, an end-of-project synthesis, for example a concise "top five" of findings per project, need not be onerous if the budgets are well maintained, and should be owned jointly by a discipline-group manager representing the cost-estimating function, so that figures feed back into the master estimates, together with the end-responsible project manager who ensures the overviews are produced. Another expert proposed a dedicated improvement manager who moves between projects, gathering what happened and why during structured reviews and feeding it back to the estimating and bid-writing functions, on the explicit reasoning that the main reason learning is under-exploited is simply that people are too busy and move on. He judged that such a dedicated role would relieve project staff of having to compile analyses themselves, requiring only that they supply the input. The researcher's complementary suggestion of a searchable lessons database, potentially with AI-supported retrieval so that staff can find how a comparable problem was solved when they actually encounter it, was received positively, with the realistic caveat that no such mechanism is ever fully automated and that retrieval still depends on people being prompted to use it.

8.7 Implementation, Organisational Conditions and the Risk to Informal Strengths

The experts' views on implementation refined the phased pathway proposed in Section 7.8. One expert was unambiguous that the first step is data input quality: before any of the analyses the framework promises can be extracted, the work budget must be well structured and substantiated and costs must be registered cleanly, because *"analyses based on poor data say nothing"*. He coupled this with the observation that the set-up must be agreed up front, since once a path has been taken it is very hard to reverse, and that the pressure *"to get outside"* which drives premature set-up decisions is often, on closer inspection, less acute than it is presented to be.

This reframes the framework's Level 1 not merely as a minimum set of artefacts but as the establishment of a disciplined data foundation and an agreed structuring convention.

On where to begin, the experts' reasoning produced a useful distinction between where the framework delivers most value and where it should first be introduced. The framework is most needed on large and complex projects, but one expert advised piloting it on a smaller project first, because a small project allows the approach to be observed and controlled, whereas a large project simply multiplies the people and quantities involved and, with them, the resistance and the points of failure encountered when introducing something new. A small-scale pilot followed by expansion was therefore recommended as the safest introduction route, even though the eventual benefit is greatest at scale.

All experts regarded the existing organisational systems as sufficient to support the framework. One expert stated that he believed *“100%”* that the current system can accommodate it *“as long as you do it”*, and that anything genuinely missing could be built. The binding constraint is therefore organisational behaviour rather than tooling. Another expert reinforced this from the opposite direction, arguing that the existing monitoring systems should already provide adequate grip if used well, and that the recurring problem is that they are not used well, often because people are not properly informed or taken along at the start, and because work preparation is rushed. She identified avoidable failure costs as arising mainly from this lack of preparation and instruction rather than from a defective structure, which strongly supports the framework's emphasis on the preparation phase and on readiness.

Finally, the experts addressed the framework's own boundary condition that a tighter, standardised structure might undermine the informal strengths, experienced individuals, mutual trust and professional judgement, on which traceability currently depends. One expert acknowledged that people are inherently resistant to change, including himself, but judged that the organisation's relatively mature management systems mean that a new way of working can succeed if people are taken along and shown that it makes their own work easier, with the realistic expectation that a minority will resist on the grounds that *“it has been done this way for forty years”*. Another expert’s parallel point, that the structure will only deliver if people are properly instructed and engaged, frames the central condition consistently: the framework's success depends less on its design than on change management and on demonstrating reciprocal benefit to the people who must maintain it. Another expert added one caution against over-extending the framework's tender logic: the tender and execution phases are sometimes deliberately separated, and carrying tender assumptions too far into execution risks teams *“never performing outside”*. The assumption register must therefore preserve traceability without letting tender logic dominate execution.

They also endorsed the phased pathway directly against their own experience. One, reflecting on a project where staff costs had run over, singled out the ability to trace a cost overrun back to its specific cause, for example which staffing component drove a shortfall, as the framework's strongest contribution, describing the combination of the CWP structure with cause attribution as addressing exactly what current reporting fails to answer. Another stressed that this must remain lightweight in practice: project teams should not need to spend *“more than one or two hours a week”* on it, and that embedding the full evaluation and feedback loop (Level 3) is a larger step that likely requires the practice to be anchored at business-unit level, beyond what an individual project team can sustain on its own. Both observations support introducing the framework incrementally, with the heavier evaluation layer following only once the foundational layers are working.

8.8 Refinements to the Framework

The validation confirmed the framework's central proposition and its five design principles, while indicating a few targeted refinements. In accordance with Section 2.3.4, these refinements have been incorporated into the version of the framework presented in Chapter 7. The pre-validation version is retained in Appendix F. Table 8.1 summarises the principal validation outcomes and the corresponding refinement or confirmation.

Table 8.1: Validation Outcomes and Resulting Refinements to the Framework

Framework Element	Validation Outcome	Refinement / Confirmation
CWP as stable unit (Principle 1)	Feasible, but understood as a linking and aggregation layer above procurement codes, not a replacement; procurement (resource) codes remain indispensable.	Reframed as an additional linking layer; clarified that the CWP code is a common key over existing procurement budgets rather than a substitute structure.
Execution-aligned cost codes (Principle 2)	Strongly endorsed; ambiguous “general costs” items confirmed as a primary behavioural driver of untraceable cost.	Strengthened the prohibition on catch-all items; clarified separation of project-level indirect costs from the company AK surcharge.
Indirect-cost classification (Section 7.5)	Endorsed; under-budgeting and omission of items are common; variation orders do not always change indirect costs proportionally.	Added recommendation to operationalise the classification as a checklist; noted contract-dependent proportional behaviour and the judgemental application of the categories.
EVM at CWP level (Section 7.4)	Confirmed; feasibility conditional on data quality; physical progress, not percentage of cost, must drive the indicator.	Confirmed; linked explicitly to data-input quality as the precondition (see Level 1)
Readiness / LPS (Principle 3)	Confirmed; embraced where teams are disciplined, resisted where not; rail cited as exemplar.	Confirmed; feasibility reframed as culture-dependent, reinforcing the role of change management.
Cause attribution (Principle 4)	Confirmed; proposed categories partly overlapping (client-driven vs	Merged client-driven change with scope change; introduced sub-causes for planning disruption (own

Framework Element	Validation Outcome	Refinement / Confirmation
	scope) and partly too broad (planning disruption).	organisation / neighbouring contractor / external) while keeping the set small.
Cross-project learning & ownership (Principle 5, Section 7.7)	Confirmed as weakest element; ownership unclear; success masks improvement potential.	Added a dedicated improvement-manager / knowledge-owner role conducting periodic cross-project reviews, jointly anchored in the cost-estimating discipline group; proposed a searchable lessons database.
Implementation pathway (Section 7.8)	Data-input quality identified as the true first step; large projects benefit most but small projects are safer to pilot.	Recast Level 1 around a disciplined data foundation and an up-front structuring convention; added a recommendation to pilot on a small project before scaling.
Boundary conditions (Section 7.9)	Information-system incompatibility (e.g. IBIS–Metacom) confirmed as a concrete traceability break; tender logic should not dominate execution.	Sharpened the information-system boundary condition to require explicit tool alignment and controlled conversion at handover; added a caution on over-extending tender logic into execution.

Discussion

This chapter reflects on the research design, interprets the empirical findings against the refined conceptual framework set out in Chapter 3, examines the organisational and human conditions that shape implementation, and discusses the limitations and implications of the study.

Validity of the Research

Internal validity is strengthened by the combination of multiple research steps. The literature review first established the theoretical relationship between cost structuring, cost traceability, project learning and cost predictability. This theoretical foundation was then used as an analytical lens for the empirical research. The empirical phase combined organisational-level interviews with three project-level case studies and project documentation. As a result, the findings are not based on interviews alone, but on triangulation between different types of data. The cross-case comparison further strengthens the validity of the findings. The three cases differ in contract form, technical scope, organisational setting and project dynamics. Despite these differences, similar mechanisms recur across the cases. The recurrence of these mechanisms across different cases supports the analytical credibility of the results.

Reliability is supported using semi-structured interview guides, a consistent analytical structure and thematic analysis. The empirical analysis combines deductive coding based on the conceptual framework with inductive coding to capture themes emerging from practice. This reduces the risk that the findings merely confirm the initial theoretical assumptions. The use of project documentation also increases reliability, because it provides a check against retrospective interview interpretations.

External validity is more limited. The research has been conducted within one organisation, Dura Vermeer, and focuses on three infrastructure-related project cases. Therefore, the findings should not be interpreted as statistically generalisable to all Dutch construction projects. Instead, they are analytically transferable to comparable project-based construction environments where cost information is transformed between tendering, budgeting, execution, control, reporting and evaluation. The expert validation in Chapter 8 further contributes to the validity of the proposed framework by assessing its practical relevance and feasibility. However, this validation does not prove the actual performance effects of the framework. Therefore, the framework should be understood as a validated design proposition rather than as a fully tested project-control intervention. The validation moreover rests on four semi-structured interviews within a single organisation. This is sufficient to assess whether the framework is recognisable, feasible and where it would meet practical resistance, but not to establish statistical generalisability.

A further consideration concerns the independence of this validation. Because the empirical cases, the proposed framework and the validation experts all originate from the same organisation, the validation primarily establishes intra-organisational recognisability and feasibility, rather than independent confirmation. The recognition of the problem diagnosis reported in Chapter 8 should therefore be read partly as the organisation recognising a problem framed in its own terms, assessed against a framework tailored to its own processes. The four validation experts were not among the respondents interviewed during the empirical phase, which partly mitigates this concern, although it does not remove the shared organisational perspective.

Revisiting the Refined Conceptual Framework

Section 3.5.1 argued, based on Malkanthi et al. (2017) and Holm and Schaufelberger (2021), that the principal constraint on cost traceability lies not within individual project phases but at the transitions between them. On that basis, the refined conceptual framework foregrounded cross-phase structural alignment as the primary analytical focus and treated within-phase organisation as merely a necessary background condition, while explicitly leaving open whether this prioritisation would hold in practice. The cross-case analysis substantiates the prioritisation to a considerable extent. In all three cases, the tender estimate, the work budget, the cost report and the post-project evaluation were each internally coherent and fit for their own purpose, yet the connections between them were consistently the weakest link. This confirms Refinement 1's core claim that discontinuity arises primarily at the phase transitions rather than within a single phase.

At the same time, the findings qualify the original prioritisation. The case analysis shows that within-phase structuring problems can degrade traceability even before any phase transition occurs. This within-phase ambiguity is not merely a background condition in the sense the refined framework proposed. It operates as an independent constraint that can undermine traceability on its own, regardless of how well the subsequent phase transition is managed. The original framework's treatment of within-phase organisation as secondary to cross-phase alignment therefore understated its practical weight. This is a genuine refinement that the empirical work adds to the theoretical model: cross-phase alignment and within-phase organisation are both necessary conditions, and neither is sufficient on its own, but they are not hierarchically ordered in the way Section 3.5.1 implied.

Refinement 2 positioned information quality, following Toosi and Chamikarpour (2021) and Tang et al. (2008), as the condition that determines whether structurally present cost data can be interpreted. The empirical material suggests a more precise formulation than an information-quality argument alone provides. The cross-case analysis indicates that the cause of a cost deviation is usually known to the people directly involved at the time it occurs. What is typically missing is not the causal knowledge itself but its structured recording. This distinction matters, because an information-quality argument implies that better or more complete data would resolve the traceability problem, whereas the evidence here indicates that the data is often adequate but transient: it is held in the memory and informal judgement of individuals rather than in a structure that survives staff turnover or a transition between project phases. This nuances Refinement 2 by relocating the constraint from the intrinsic quality of information towards the organisational discipline of converting situated knowledge into transferable records before the people who hold it move on.

The refined conceptual framework explicitly flagged the intra-project learning pathway as “less directly established in the reviewed literature” and earmarked it for empirical investigation, in contrast to the inter-project pathway, which was already well supported by Ahiaga-Dagbui and Smith (2014). The empirical findings allow this open question to be answered directly. Intra-project double-loop learning does occur: project teams do not merely register that a deviation has occurred and correct it, which would be single-loop learning. They generally also develop an informal, shared understanding of why it occurred, and adjust their approach for the remainder of the project accordingly. This is a substantive finding, since the literature had not established whether within-project learning would reach this causal, double-loop level or remain confined to single-loop correction. However, this within-project double-loop learning proved to be cognitive and interpersonal rather than structural: it lives in the shared understanding of the project team and dissolves when that team disperses. It therefore supports within-project cost control, but without deliberate structuring it does not automatically feed the inter-project loop. This is consistent with Chen and Taylor's (2014) argument that project-based learning is vulnerable to skill decay and staff turnover, and it explains, rather than merely restates, why organisations can be effective at managing individual projects while still struggling to learn structurally across them.

Refinement 4 anticipated, following Ahiaga-Dagbui and Smith (2014), that sustained improvement in cost predictability requires both feedback loops to return not only to estimation practice but to cost structuring itself. The within-project loop was found to function reasonably well, in the sense described above, but the cross-project loop, on which Refinement 4 specifically depends for sustained improvement, was consistently reported as the weakest part of current practice, both in the case analysis and by the validation experts in Chapter 8. The persistence of this gap, despite repeated organisational attempts to institutionalise lessons-learned practices, is consistent with Wong et al.'s (2011) observation that organisational learning in construction projects is undermined not by an absence of lessons but by an "unlearning" dynamic in which structures revert once explicit reinforcement stops. This suggests that the cross-project loop cannot be closed through a single documentation exercise. It requires a mechanism that survives the unlearning tendency Wong et al. describe, which is precisely the rationale for the dedicated learning-owner role proposed at Level 3 of the proposed framework.

Becker et al. (2014) and Chan and Pasquire (2004) established indirect costs as a category that is inherently difficult to estimate, allocate and control because it is not directly attributable to discrete production activities. This is confirmed, but the empirical work goes further than these studies by showing that indirect-cost traceability differs systematically by driver type rather than behaving as a single undifferentiated problem. The classification developed in Section 7.5 distinguishes indirect effort that remains close enough to production to be linked to a Construction Work Package from effort that is better explained by phase, by project-wide drivers such as site facilities and project management, or by time itself, as in the case of costs generated by schedule overrun. Because Becker et al. (2014) and Chan and Pasquire (2004) treat indirect costs as one problematic category rather than differentiating between these driver types, this classification is an empirical contribution of the present study, and it directly answers the third research gap identified in Section 3.6.

The proposed Construction Project Cost Traceability Framework should be interpreted against this background. Its value does not lie in introducing more cost data, but in preserving the causal links between existing data across the points where the findings show those links are lost, both at phase transitions and, where cost codes remain ambiguous, within a single phase. The Construction Work Package functions as the stable linking unit that carries tender assumptions, work budgets, physical progress, readiness conditions, deviations, RFCs, indirect cost drivers and learning outputs across these points. The following section examines the organisational and human conditions under which such a framework can plausibly be implemented, since the validation findings in Chapter 8 show that these conditions, rather than the technical logic of the framework itself, will determine whether it is adopted in practice.

Organisational and Human Factors in Implementation

The interpretation above concerns what the framework needs to do analytically. Whether it can be adopted is a separate, and in practice more decisive, question. Taylor and Levitt (2007) argue that the adoption of a new coordinating structure in a project-based organisation depends on its alignment with existing incentives and routines, not only on its technical merit, and Hamzeh (2011) documents comparable cultural and behavioural resistance in the adoption of the Last Planner System. The validation findings in Chapter 8 show that this dynamic also applies to the CPCTF, and they make it possible to specify which organisational and human conditions matter most.

The first condition concerns continuity of people rather than continuity of documents. The empirical finding that intra-project double-loop learning is interpersonal rather than structural, discussed above, means the framework is competing directly with staff turnover. One validation expert linked this explicitly to phase transitions, observing that because those present during tender are frequently no longer involved once execution starts, knowledge is lost unless a handover is deliberately organised. Chen and Taylor (2014) show that this is a general vulnerability of project-based learning rather than an organisation-specific weakness, which suggests the framework's registers and assumption logs are not administrative overhead but a direct countermeasure to a well-documented mechanism of knowledge loss.

The second condition concerns capacity. Experts were explicit that adoption depends on the framework remaining lightweight in practice: project teams should not need to spend more than roughly one to two hours a week on it, and the heavier evaluation and feedback layer, Level 3, was judged to require anchoring at business-unit level because it exceeds what an individual project team can sustain on its own. This distinction between what a project team can absorb and what only the organisation can sustain is not addressed by Refinement 4, which specifies that the feedback loops must return to cost structuring but does not specify who, at what organisational level, is responsible for making that return happen. The validation findings therefore extend Refinement 4 with an organisational condition: the cross-project loop requires an owner positioned above the individual project, not only a mechanism.

The third condition concerns how the framework is introduced rather than what it contains. The validation interviews distinguished between teams that would accept added structure once they understood why it mattered and teams that would experience the same structure as bureaucracy if it were simply mandated, and on this basis the experts recommended piloting the framework on a single, smaller project rather than introducing it organisation-wide at once (Section 8.7). This recommendation reflects a broader logic of organisational change: a new way of working needs a critical mass of willing adopters before it can be mandated more broadly, and a demonstrated success is a more credible source of that willingness than an announced policy. A pilot that visibly works produces its own advocates, project staff who can explain to colleagues on other projects, in their own terms, why the structure was worth the effort, in a way that no top-down instruction can replicate.

Limitations of the Research

This research has several limitations that should be considered when interpreting the findings.

First, the study is based on a single-company context. Dura Vermeer provides a rich and relevant setting for studying cost structuring and traceability in Dutch infrastructure projects, but the organisation has its own systems, routines, project types and internal practices. The results may be relevant for comparable contractors, but they cannot be assumed to represent the entire Dutch construction sector.

Second, the empirical analysis is based on three project cases. These cases were deliberately selected because they provided access to information-rich material, including both early-phase and execution-phase cost information. This strengthens the depth of the analysis but limits the breadth of the empirical basis. Other types of projects, such as smaller regional works, building projects, maintenance contracts or alliance programmes, may show different traceability challenges.

Third, the research uses a qualitative design. This is suitable for understanding how cost information is structured, interpreted and used in practice, but it does not allow for quantitative measurement of performance effects. The study therefore cannot demonstrate that implementing the Construction Project Cost Traceability Framework will improve forecast accuracy by a specific percentage or reduce cost deviations by a measurable amount. The findings explain mechanisms and conditions, not quantified causal effects.

Fourth, part of the empirical material is retrospective. Some cost deviations, assumptions and learning processes are reconstructed through interviews and existing documentation after they occurred. This may introduce hindsight bias or selective memory. Triangulation with project documentation reduces this risk, but it cannot remove it completely. Some causal explanations may have been clearer to respondents after the event than they were during execution.

Fifth, the framework has not yet been tested longitudinally in a live project. The validation assesses plausibility, relevance and feasibility, but not actual implementation effects. The organisational and human conditions discussed above were themselves assessed qualitatively, through what four experts anticipated or had observed on other structuring initiatives, rather than through observation of the CPCTF being implemented. How project teams would actually respond over time, once early enthusiasm or scrutiny fades, remains untested. The framework should therefore be treated as a design proposition that requires further testing in practice.

Finally, there is a risk that the proposed framework creates administrative burden if implemented too rigidly. A stronger structure can improve traceability, but it may also become counterproductive if it produces excessive reporting requirements or reduces the flexibility of project teams. This limitation is important because the empirical cases show that professional judgement, informal coordination and contextual knowledge are not merely weaknesses. They are also sources of effective project control. The framework should therefore be applied at the lowest level of detail that still preserves causal traceability.

Conclusion

This thesis investigated the following main research question:

"How can cost predictability be improved in Dutch construction projects?"

This main research question was answered through four sub-questions.

Answer to Sub-Question 1

The first sub-question was:

"How can the relationship between cost structuring, cost traceability, project learning and cost predictability be conceptualised from literature?"

The relationship between cost structuring, cost traceability, project learning and cost predictability can be conceptualised as a conditional chain. Cost structuring determines how cost information is decomposed, aggregated and transferred across project phases. This affects cost traceability, because deviations can only be causally interpreted when cost outcomes remain connected to the assumptions, activities, execution conditions and decisions that produced them.

Cost traceability then forms an enabling condition for double-loop learning. Single-loop learning can occur when deviations are detected and corrected, but double-loop learning requires insight into why deviations occurred and whether underlying estimating assumptions, budgeting structures or control routines should be revised. Cost predictability can improve when these causal explanations are translated into future estimating, budgeting and control practices. The relationship is therefore not that cost structuring directly improves cost predictability. Rather, cost structuring supports cost traceability, cost traceability enables causal explanation, causal explanation enables double-loop learning, and double-loop learning can contribute to improved cost predictability over time.

Answer to Sub-Question 2

The second sub-question was:

"Which structuring approaches are identified in literature, and through which mechanisms may they support cost traceability and project learning?"

Five structuring approaches are identified in literature: Work Breakdown Structure, Critical Path Method, Earned Value Management, Last Planner System and Advanced Work Packaging. These approaches support cost traceability and project learning through different mechanisms.

WBS supports cost structuring by decomposing project scope into manageable and codable work elements. CPM supports time-based structuring by sequencing activities and making schedule dependencies visible. EVM supports cost-progress integration by relating planned value, earned value and actual cost, thereby making deviations between budget, progress and expenditure visible. LPS supports execution feedback by making readiness constraints, workflow disruptions and reasons for non-completion explicit. AWP supports cross-phase alignment by organising engineering, construction planning and execution around work packages.

None of these approaches independently supports the full chain from cost structuring to traceability and learning. WBS, CPM and EVM mainly support structuring and performance visibility. LPS adds process information that can help explain why deviations occur during execution. AWP provides the strongest basis for maintaining a stable linking unit across project phases. Their value therefore lies in the combination of mechanisms: a stable package structure, cost-progress measurement and execution feedback.

Answer to Sub-Question 3

The third sub-question was:

> "How is cost information currently structured and used in practice, and where do limitations in cost traceability and project learning arise?"

In practice, cost information is structured in multiple phase-specific forms. Tender estimates structure costs around scope, quantities, assumptions, risks and work methods. Work budgets restructure this information into controllable units such as cost codes, budget responsibilities, work packages and reporting categories. During execution, cost information is used for forecasting, financial reporting, change management and project control. During evaluation, selected deviations and lessons may be documented for future use.

The main limitation is not the absence of cost information, but the loss of structural continuity between these forms of information. Cost information is repeatedly restructured when moving from tendering to preparation, execution, control, reporting and evaluation. This restructuring is often necessary for project control, but it weakens the link between original assumptions, execution conditions and final cost outcomes.

Limitations in cost traceability arise especially at phase transitions, where tender assumptions are condensed, reclassified or disconnected from execution control structures. They also arise when financial reporting and physical progress follow different logics, making deviations financially visible but not automatically causally explainable. Traceability is strongest when deviations are linked to formal scope changes, contractual events or RFCs, and weakest for gradual deviations, coordination effort, delay-related costs, engineering effort, project organisation, contract management and other indirect costs.

Limitations in project learning arise because learning often remains project-specific or actor-dependent. Project teams do learn during execution by adjusting forecasts, managing changes and correcting deviations. However, these lessons are not consistently translated into revised estimating assumptions, improved cost structures, updated norm figures or reusable control logic. Current practice is therefore stronger in within-project control than in cross-project learning.

Answer to Sub-Question 4

The fourth sub-question was:

> *"What organisational and project conditions are needed to implement the identified structuring mechanisms in such a way that cost traceability and project learning are supported in practice?"*

The identified structuring mechanisms can support cost traceability and project learning when they are implemented around a stable, execution-aligned linking unit. In this research, the

Construction Work Package fulfils this role. It connects tender assumptions, work budgets, physical progress, readiness conditions, deviations, RFCs, indirect cost drivers and learning outputs across project phases.

Several project-level conditions are needed. First, the CWP structure must be defined early enough to preserve the link between tender assumptions and execution control. Second, cost codes, work budgets, planning information and progress data must be linked to the same CWP logic. Third, physical progress must be measured separately from financial expenditure, so that cost-progress deviations become diagnostically meaningful. Fourth, deviations must be linked to cause categories, RFCs, readiness constraints or execution conditions, rather than only being registered as financial movements. Several organisational conditions are also needed. Clear ownership must be assigned for maintaining the CWP structure, registering assumptions, linking deviations and translating lessons into future practices. Project teams need practical routines that fit existing systems, rather than a fully separate control system. Cross-project learning also requires an organisational role or process through which project-specific lessons are converted into updated estimating assumptions, norm figures, package templates or control routines.

Implementation should be staged. A basic traceability level can function as the intended long-term baseline for projects but should first be tested through a pilot project. Wider implementation is only appropriate when the templates, coding logic and deviation-registration routines have proven workable. More advanced levels of implementation require greater system alignment, data discipline, role ownership and organisational commitment to learning.

Answer to the Main Research Question

Based on the answers to the four sub-questions, the main research question can be answered as follows:

Cost predictability in Dutch construction projects can be improved by strengthening causal cost traceability across project phases. Cost deviations should not only be financially visible, but should remain connected to the assumptions, scope elements, execution conditions, progress information, change events and indirect cost drivers from which they originate.

This requires a stable structuring logic that connects cost information from tendering to preparation, execution and control, and completion and learning. The Construction Project Cost Traceability Framework supports this by using the Construction Work Package as a stable linking unit across project phases. AWP contributes the package-based structure, EVM contributes cost-progress measurement at package level, and LPS contributes readiness and execution-feedback information. Together, these mechanisms help move cost control from registering deviations towards explaining and reusing them.

Improved cost predictability does not result from eliminating uncertainty or from adding more cost data alone. It results from making cost deviations more explainable and transferable. Cost traceability creates the first condition for this improvement: it allows project teams to understand why deviations occur and allows organisations to translate those explanations into future estimating, budgeting and control practices. The actual improvement of cost predictability depends on disciplined data input, consistent coding, system alignment, clear ownership and organisational routines for cross-project learning.

Recommendations

This chapter provides practical recommendations. These are primarily aimed at Dura Vermeer and comparable Dutch construction organisations seeking to improve cost predictability through stronger cost traceability and project learning. Furthermore, this chapter gives suggestions for future research.

1. Start with project-level traceability baseline

Dura Vermeer should not start by implementing the full Construction Project Cost Traceability Framework across all projects at once. The first step should be Level 1: project-level traceability baseline. This means defining a CWP structure for the major cost drivers of a project, creating a structured assumption register for material tender assumptions and linking major RFCs, deviations and indirect cost drivers to CWP codes.

This first step is deliberately limited. Its purpose is to prevent the most important assumptions and deviations from becoming untraceable without creating excessive administrative burden. It can be implemented with existing tools and processes, provided that the CWP code becomes a consistent linking key. However, Level 1 should still be introduced through a pilot before it becomes a wider project baseline. The pilot should be understood as the first step towards the broader Level 1 baseline proposed in the implementation pathway. If the pilot confirms that the templates and routines are workable, Level 1 can subsequently be standardised across a wider group of projects.

2. Introduce a structured tender-to-execution handover

The tender-to-execution transition should become a formal traceability gate. During this handover, the cost engineer, project manager, project controller, work preparation and contract manager should jointly review the main assumptions behind the tender estimate. The output should be a CWP transfer sheet showing how tender items, quantities, productivity assumptions, risk allowances and indirect cost assumptions are translated into the work budget.

This recommendation directly addresses one of the main empirical limitations: assumptions are often lost or reinterpreted during budget transfer. A structured handover does not prevent necessary restructuring, but it makes the restructuring traceable.

3. Use the CWP as the common linking unit across cost, progress, RFCs and learning

Dura Vermeer should use the Construction Work Package as the common reference for cost control, progress monitoring, deviation explanation, RFC registration and project evaluation. This does not mean that all systems need to be replaced. It means that existing systems and documents should be connected through a shared CWP identifier.

At minimum, each relevant CWP should contain information on scope, tender assumptions, cost baseline, readiness conditions, progress logic, deviations, RFCs and learning outputs. The CWP should not be treated only as a budget container, but as a traceability unit that preserves the relationship between planned assumptions and realised performance.

4. Link cost deviations to cause categories, not only to forecast movements

Cost reports should not only show that a forecast movement has occurred. They should also identify the cause category of significant deviations. Recommended categories include scope change, estimating error, productivity loss, planning disruption distinguished by source (internal preparation, a neighbouring contractor, or external causes such as weather), procurement or material issue, and coordination or indirect effort. The set should be kept small enough to be applied consistently by project teams.

This makes deviations more useful for learning. Different causes require different responses. A productivity issue should influence future production assumptions. A scope change should influence demarcation and contract review. A coordination issue should influence indirect cost allowances and readiness criteria. Without cause attribution, cost deviations remain too generic to support double-loop learning.

5. Treat indirect costs as traceable cost drivers rather than generic overhead

Dura Vermeer should differentiate indirect costs according to their traceability logic. Package-specific indirect effort, such as engineering or work preparation for a specific CWP, should be linked to that CWP. Phase-related effort should be allocated to a group of CWPs or project phase. Project-wide effort should remain separate, but should be linked to explicit drivers such as duration, milestones or contractual events. Change-driven indirect effort should be linked to the relevant CWP and RFC.

This approach avoids forcing all indirect costs into artificial work packages, while still improving traceability. It also strengthens the ability to substantiate RFCs and understand delay-related cost growth.

6. Combine CWP-level EVM with readiness and constraint information

Where EVM-style cost-progress measurement is used, it should be anchored at CWP level. Planned Value, Earned Value and Actual Cost are most useful when they can be interpreted in relation to a recognisable execution scope. However, EVM indicators alone are not enough. They should be combined with readiness and constraint information from LPS logic, such as missing design information, material availability, access constraints, capacity problems or unresolved stakeholder dependencies.

This combination helps project teams move from “something is wrong” to “this is where and why the deviation is emerging”.

7. Make CWP evaluation part of project close-out

At completion, each major CWP should be evaluated against its original assumptions, transferred budget, realised performance, deviations and cause attributions. The evaluation should not only describe what happened but translate findings into future estimating and structuring implications.

Relevant outputs include updated productivity assumptions, adjusted risk allowances, improved demarcation rules, revised indirect cost allowances, readiness templates and package definitions for comparable future work. Without this step, project evaluations risk remaining descriptive rather than becoming useful for future cost predictability.

8. Assign organisational ownership for the learning loop

Dura Vermeer should assign a knowledge owner or equivalent organisational role responsible for processing CWP evaluation outputs after project completion. This role should translate project-specific lessons into reusable estimating assumptions, norm figures, cost codes, package templates and guidance for future tenders.

This is essential because project teams alone cannot close the cross-project feedback loop. Once a project is completed, team members move on, and lessons risk remaining stored but unused. Cross-project predictability improves only when learning outputs are actively embedded in future estimating and control practices.

9. Implement the framework incrementally through implementation levels

The framework should be implemented through three implementation levels. Level 1 should focus on assumption registers, major CWP structures and RFC linkage. Level 2 should add integrated project control, including cost-progress indicators, readiness checks and cause-coded deviations. Level 3 should add lifecycle learning through standardised CWP evaluations, norm figure updates and reusable package definitions.

Not every project needs Level 3. Smaller or less complex projects may benefit sufficiently from Level 1. Large, complex or repetitive projects, such as infrastructure programmes, substation portfolios or dike reinforcement programmes, are more suitable for Level 2 or Level 3. Regardless of the eventual target level, the framework is best introduced by piloting it on a single, smaller project first. A small project keeps the approach observable and controllable, whereas introducing it directly on a large, complex project multiplies the people and quantities involved and, with them, the resistance and the points of failure. Once the approach has proven itself, it can be scaled to the larger and more complex projects where it delivers the most value.

10. Manage adoption and take project teams along

The validation interviews indicated that the binding constraint on the framework is behavioural rather than technical: the experts judged that existing systems can already support it, and that the real risk is that people are not taken along. Implementation should therefore be accompanied by active change management. Project teams should be shown that the structure reduces later reconstruction work and makes their own work easier, the structuring conventions should be explained rather than imposed, and a degree of resistance from those accustomed to existing routines should be anticipated and addressed rather than ignored.

Reducing the effort the structure imposes on individuals is part of this. As recommended above, a dedicated knowledge owner or improvement manager should carry the cross-project analysis, so that project teams are asked only to supply clean input rather than to compile the analyses themselves. Adoption is most likely when the people who must maintain the structure experience it as support rather than as additional administration.

11. Preserve professional judgement

The framework should support experienced cost engineers, project controllers and project teams rather than replace their judgement. The empirical cases showed that tacit knowledge, trust and contextual interpretation are important sources of control. A more structured framework should make this reasoning traceable, not eliminate it.

The practical rule should therefore be: use the lowest level of structure that preserves causal traceability. More detail is not automatically better. The right level is the level at which cost, progress, responsibility and cause attribution can still be managed realistically.

Practical Next Step for Dura Vermeer

For Dura Vermeer, the most practical next step is not to introduce the full framework immediately, but to convert the recommendations into one controlled pilot. The objective should be simple: test whether a limited CWP-based traceability structure helps a project team preserve the link between tender assumptions, work-budget decisions, RFCs, indirect cost drivers, forecast movements and final learning points.

A suitable first pilot would be a small or medium-sized infrastructure project with clear scope elements, a manageable project team and sufficient involvement from cost engineering, project control, work preparation and contract management. Before execution starts, Dura Vermeer should organise one formal tender-to-execution handover in which the main tender assumptions are translated into a CWP transfer sheet. During execution, the project team should then use the CWP code only for the most important cost drivers, major RFCs, significant forecast movements and relevant indirect cost categories. This keeps the administrative effort limited while still testing the central logic of the framework.

The pilot should have one clear owner. This could be a project-control lead or project manager who is responsible for keeping the traceability structure alive and preventing it from becoming another unused template. The role of the project team should be limited to providing clean input during existing control moments, for example by linking major deviations to a CWP and selecting a cause category during forecast reviews. The owner should then translate this information into a concise learning output at the end of the project.

The success of the pilot should not be judged only by whether all templates were completed. More important is whether the project team can answer questions that are currently difficult to answer: which tender assumptions changed, which deviations were caused by execution conditions rather than scope change, which indirect costs increased because of time or coordination effort, and which findings should influence future estimates. If the pilot helps answer these questions with less reconstruction afterwards, the framework has practical value for Dura Vermeer.

After the pilot, Dura Vermeer should evaluate three things before scaling the approach: whether the CWP level was workable, whether the weekly effort remained acceptable, and whether the information produced was useful for cost engineers, project controllers and project managers. Only then should the approach be standardised more broadly. In this way, the framework becomes a realistic learning instrument. Its value for Dura Vermeer lies in making existing project knowledge less dependent on individual memory and more usable for future tenders, budgets and project-control decisions.

Suggestions for Future Research

Future research should first test the Construction Project Cost Traceability Framework longitudinally in a live project. Such a study could follow the framework from tendering through preparation, execution, control and completion. This would make it possible to observe whether the CWP structure preserves causal links over time, whether project teams use it consistently and whether it improves the quality of forecast discussions and project evaluations.

Second, future research could compare cost traceability practices across multiple contractors, clients and contract forms. This would show whether the mechanisms identified in this thesis are specific to Dura Vermeer or more widely present in Dutch construction. A comparative study could examine how traceability differs between D&C, DBFM, alliance and programme-based delivery environments.

Third, future research could quantitatively examine the relationship between cost traceability and forecast accuracy. Projects could be compared based on the degree to which cost, progress, assumptions and deviations are linked at package level. This would help determine whether stronger causal traceability is associated with fewer unexplained forecast movements, better cost-to-complete estimates or more accurate future tender assumptions.

Fourth, future research could focus specifically on indirect costs. This thesis shows that indirect costs are among the most difficult categories to trace, but also that they can be classified according to different traceability logics. Further research could develop and test practical methods for attributing engineering, project organisation, contract management, documentation and delay-related effort to packages, phases, project-wide drivers or change events.

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Statement Use of Artificial Intelligence

This thesis is written by the author with the support of artificial intelligence (AI) tools, such as ChatGPT (OpenAI) and Google NotebookLM. AI was used as a tool to support the research and writing process, primarily for language improvement, structural feedback, and brainstorming of ideas. Specifically, AI-assisted tools were used to:

- improve grammar, clarity, and readability of text.
- suggest alternative phrasings and improve academic writing style.
- support the structuring of chapters and sections.

AI was not used to generate original research findings or produce literature interpretations without critical evaluation by the author. All literature selection, interpretation of sources, methodological decisions, data analysis, and conclusions were carried out independently by the author.

All content included in this thesis has been critically reviewed, verified, and edited by the author to ensure academic integrity and accuracy. The author remains fully responsible for the final content of the thesis.

Appendix A: Question sheets organisational-level interviews SQ3

Question sheet interview with project manager

Context & Rol

1. Als je kijkt naar een gemiddeld project bij DV, hoe loopt de financiële verantwoordelijkheid vanaf tender tot en met uitvoering?
2. Waar zit projectmanagement daarin gepositioneerd?
3. Wie is binnen DV uiteindelijk verantwoordelijk voor het financiële resultaat van een project?

Van tender naar uitvoering

4. Hoe wordt de kostprijsbegroting vertaald naar het uitvoeringsbudget?
5. Wordt dezelfde kostenstructuur (bijv. WBS) gebruikt in de uitvoering? Of is er ergens een soort overgang qua inrichting tussen de verschillende projectfasen?
6. Verandert de kostenstructuur gedurende het project?
7. Zie je bij deze overgang wel eens of vaak dat informatie of aannames “verloren” gaan of verkeerd worden overgedragen?

Cost control tijdens uitvoering

8. Hoe worden kosten tijdens de uitvoering georganiseerd? En wie monitort de kosten?
9. Welke informatie krijgt de projectmanager?
10. Worden kosten gekoppeld aan activiteiten of alleen aan kostensoorten?
11. Op welk detailniveau sturen projectmanagers financieel? (Kostensoorten/werkpakketten/disciplines)
12. Houden zij het totaaloverzicht van gemaakte kosten in de gaten?
13. Hoe vaak wordt er financieel gerapporteerd? En hoe worden kosten gerapporteerd?
14. Wanneer wordt een afwijking in kosten echt zichtbaar in het project? En kun je dan nog herleiden waar de afwijking precies ontstaat? Of zie je alleen het effect?
15. Worden oorzaken van afwijkingen systematisch vastgelegd?
16. Welke kostenposten zijn het lastigst om in controle te houden?
17. Welke kosten overschrijden relatief vaak het budget?
18. Hoe worden indirecte kosten bewaakt?

Leren

19. Worden projecten achteraf financieel geëvalueerd?
20. Worden geleerde lessen structureel teruggekoppeld naar calculatie?
21. Zie jij dat vergelijkbare fouten terugkeren in projecten waardoor kostenoverschrijding ontstaat?
22. Als jij 1 structurele zwakte in de huidige kostenorganisatie mocht aanwijzen, wat zou dat zijn?

Overige vragen

23. Weet jij toevallig interessante projecten die ik zou kunnen gebruiken als case-study tijdens een latere fase van mijn onderzoek?

Question sheet interview with cost engineer

Context & Rol

1. Kun je kort uitleggen wat jouw rol is als calculator binnen een project?
2. Op welk moment in het projectproces word jij betrokken?

Opbouw van de kostprijsbegroting

3. Hoe wordt een kostprijsbegroting bij Dura Vermeer meestal opgebouwd?
4. Welke structuur gebruik je daarvoor?
5. Op welk detailniveau wordt er geraamd in de tenderfase?
6. Welke informatie gebruik je voor je raming?

Aannames en onzekerheden

7. Welke aannames zitten er meestal in een kostprijsbegroting?
8. Welke kosten zijn volgens jou het moeilijkst om goed in te schatten?
9. Zijn er bepaalde kostenposten die vaak worden onderschat?
10. Hoe worden indirecte kosten in de begroting opgenomen?

Overgang van tender naar uitvoering

11. Wat gebeurt er met jouw kostprijsbegroting wanneer een project wordt gewonnen?
12. Hoe wordt de kostprijsbegroting vertaald naar een werkbegroting?
13. Wordt daarbij dezelfde kostenstructuur gebruikt of verandert die?
14. Heb je het idee dat er bij die overgang informatie verloren gaat?
15. Word je zelf nog betrokken bij het project nadat de tender is gewonnen?

Feedback en learning

16. Krijg jij ooit teruggekoppeld hoe jouw raming uiteindelijk heeft uitgepakt?
17. Wordt er binnen de organisatie gekeken naar het verschil tussen raming en werkelijke kosten?
    → Zo ja, hoe wordt dat gedaan?
    → Zo nee, waar denk je dat dat door komt?
18. Zie jij dat vergelijkbare fouten terugkeren in projecten waardoor kostenoverschrijding ontstaat?
19. Als jij één ding zou mogen verbeteren aan de manier waarop calculaties worden gebruikt in projecten, wat zou dat zijn?

Overige vragen

20. Weet jij toevallig interessante projecten die ik zou kunnen gebruiken als case-study tijdens een latere fase van mijn onderzoek?

Question sheet interview with financial manager

Context & Rol

1. Kun je kort uitleggen wat jouw rol is als financieel manager binnen projecten?
2. Met welke projectfasen heb jij te maken?

3. Als je kijkt naar een gemiddeld project bij DV, hoe loopt de financiële verantwoordelijkheid vanaf tender tot en met oplevering?
4. Wie is binnen DV uiteindelijk verantwoordelijk voor het financiële resultaat van een project?

Kostprijsbegroting (indien betrokken)

5. Hoe wordt een kostprijsbegroting bij Dura Vermeer meestal opgebouwd?
6. Welke structuur gebruik je daarvoor?
7. Op welk detailniveau wordt er geraamd in de tenderfase?
8. Welke aannames zitten er meestal in een kostprijsbegroting?
9. Welke kosten zijn volgens jou het moeilijkst om goed in te schatten?
10. Zijn er bepaalde kostenposten die vaak worden onderschat?
11. Hoe worden indirecte kosten in de begroting opgenomen?

Werkbegroting en kostenstructuur

12. Wanneer een project start, hoe wordt de werkbegroting opgesteld? Is die gebaseerd op de kostprijsbegroting of wordt er opnieuw opgebouwd?
13. Heb je het idee dat er bij die overgang informatie verloren gaat?
14. Welke structuur wordt gebruikt voor kostenbeheer tijdens uitvoering? En op welk detailniveau zijn deze kosten ingedeeld? Is dit hetzelfde als tijdens de kostprijsbegroting?
15. Verschilt de opbouw per contractvorm? Of is er standaardisatie?
16. Kan je uitleggen hoe het werkt met samenwerkingen met andere aannemers? Hoe worden dan kosten geschat, bewaard, gemonitord? Focus alleen op DV kosten/activiteiten?

Kostenmonitoring tijdens uitvoering

17. Hoe worden kosten tijdens uitvoering gemonitord?
18. Hoe vaak wordt er naar kosten gekeken?
19. Welke systemen worden hiervoor gebruikt?

Detecteren van afwijkingen

20. Wanneer wordt een kostenafwijking zichtbaar?
21. Hoe wordt bepaald waar een afwijking vandaan komt?
22. Is het altijd duidelijk welke activiteit of beslissing de afwijking heeft veroorzaakt?

Kostenrapportage

23. Hoe worden kosten tijdens een project gerapporteerd? En naar wie?
24. Op welk detailniveau zijn deze rapporten?
25. Worden oorzaken van afwijkingen ook systematisch vastgelegd?

Moeilijke kostenposten

26. Welke kostenposten zijn het moeilijkst te controleren?
27. Zie jij dat vergelijkbare fouten terugkeren in projecten waardoor kostenoverschrijding ontstaat?

Learning en feedback

28. Worden projecten achteraf financieel geëvalueerd?
29. Worden lessen uit projecten teruggekoppeld naar calculatie/tenderfase?
30. Denk je dat organisaties in de bouwsector voldoende leren van kostenafwijkingen?

Structurele zwaktes

31. Als je één structurele zwakte zou aanwijzen in de manier waarop kosteninformatie wordt georganiseerd, wat zou dat zijn?

Overige vragen

32. Weet jij toevallig interessante projecten die ik zou kunnen gebruiken als case-study tijdens een latere fase van mijn onderzoek?

Question sheet interview with project controller

Context & rol

1. Kan je kort toelichten wat jouw rol is als project beheerser en hoe deze rol zich verhoudt tot projectteams in de uitvoering?
2. Hoe is projectbeheersing binnen Dura Vermeer organisatorisch ingericht tijdens de uitvoeringsfase van projecten?
3. Welke disciplines vallen volgens jou onder projectbeheersing in een projectteam?

Cost control tijdens de uitvoeringsfase

4. Hoe wordt cost control tijdens de uitvoering van projecten binnen Dura Vermeer georganiseerd?
5. Welke informatie wordt gebruikt om te bepalen of een project financieel op koers ligt?
6. Op welk niveau worden kosten meestal gemonitord?
7. In hoeverre zijn kosten gekoppeld aan planning of voortgangsinformatie binnen de projectbeheersing?
8. Hoe vaak worden kostenverwachtingen of prognoses geactualiseerd tijdens de uitvoering?

Cost reporting en informatieflows

9. Hoe verloopt de rapportage van kosteninformatie binnen een project?
10. Welke systemen of tools worden gebruikt voor cost control en rapportage?
11. Hoe wordt informatie uit verschillende disciplines (planning, uitvoering, financiën) gecombineerd in rapportages?
12. Waar ziet u in de praktijk uitdagingen bij het verzamelen of structureren van kosteninformatie?

Traceability van kostenafwijkingen

13. Wanneer een project financieel afwijkt van de verwachting, hoe wordt dan meestal geanalyseerd waar deze afwijking vandaan komt?
14. In hoeverre is het in de praktijk goed te herleiden waar een kostenafwijking precies ontstaat?
15. Zijn kostenafwijkingen meestal goed te koppelen aan specifieke activiteiten of werkpakketten, of blijft dit vaak op een hoger niveau?

16. Waar zitten volgens jou de grootste beperkingen in het huidige systeem om kostenafwijkingen goed te kunnen traceren?

Leren tussen projecten

17. Wanneer een project financiële afwijkingen heeft gehad, wordt deze informatie dan gebruikt om toekomstige projecten te verbeteren?
18. Hoe wordt kennis over kostenafwijkingen of financiële risico's momenteel gedeeld tussen projecten?
19. Zie je mogelijkheden om dit proces te verbeteren?

Reflectie

20. Als je kijkt naar de huidige manier waarop kosteninformatie wordt gestructureerd in projecten: waar zie je de grootste verbeterkansen?

Appendix B: Question sheets project-level interviews SQ3

Highway A16 De Groene Boog

Rol en betrokkenheid

1. Wat was jouw rol binnen De Groene Boog?
2. In welke fase(s) van het project was je betrokken?
3. Vanuit welke discipline of achtergrond was je betrokken bij het project?
4. Voor welke onderdelen of deelgebieden was je verantwoordelijk?
5. Met wie werkte je vooral samen rondom financiële beheersing en kosteninformatie?

Overgang van tender naar uitvoering

6. Hoe wordt informatie vanuit de tender vertaald naar werkvoorbereiding en uitvoering?
7. Wat verandert er in het detailniveau tussen tender en uitvoering?
8. Welke aannames uit de tender blijven bruikbaar tijdens uitvoering?
9. Waar ontstaat informatieverlies of interpretatieruimte bij de overgang van tender naar uitvoering?
10. Hoe wordt een tenderstructuur uiteindelijk vertaald naar een uitvoerbare projectstructuur?

Kostenstructuur en traceerbaarheid

11. Hoe was de kostenstructuur op De Groene Boog ingericht?
12. Hoe goed sloten kostencodes aan op de manier waarop het werk buiten werd georganiseerd?
13. Als een afwijking zichtbaar werd in de cijfers, kon je dan achterhalen waar die inhoudelijk vandaan kwam?
14. Waren afwijkingen vooral financieel zichtbaar, of ook operationeel verklaarbaar?
15. Wanneer wordt kosteninformatie te gedetailleerd om werkbaar te blijven?
16. Wanneer wordt kosteninformatie juist te geaggregeerd om nog verklarend te zijn?

Detailniveau, aggregatie en rapportage

17. Hoe bepaal je welk detailniveau zinvol is voor kostenbewaking?
18. Wat gebeurt er wanneer informatie wordt opgerold naar kwartaalrapportages?
19. Op welk niveau is informatie nog bruikbaar voor sturing?
20. Op welk niveau wordt informatie vooral geschikt voor verantwoording, maar minder voor analyse?
21. Wie bepaalt in de praktijk het niveau waarop wordt bewaakt?

Koppeling tussen kosten en fysieke voortgang

22. Hoe werd fysieke voortgang gekoppeld aan kosteninformatie?
23. Waren kosten en voortgang altijd op hetzelfde moment zichtbaar?
24. Wat gebeurt er wanneer er fysiek voortgang is, maar kosten administratief nog niet zijn genomen?
25. Wat gebeurt er wanneer er kosten zijn, maar de fysieke voortgang achterblijft?
26. Wat zeggen productiepercentages volgens jou wel en niet over de werkelijke projectstatus?

Bandbreedtes, reserveringen en risico's

27. Welke rol speelden bandbreedtes en reserveringen in de financiële beheersing?
28. Hielpen bandbreedtes om afwijkingen inhoudelijk beter te begrijpen?
29. Of functioneerden ze vooral als financieel instrument om onzekerheid op te vangen?
30. Wanneer werd iets als onzekerheid of reservering behandeld?
31. Hoe werd hierover gerapporteerd richting projectorganisatie of moederbedrijven?

Combinatieverband en organisatorische complexiteit

32. Welke invloed had het combinatieverband op de inrichting van kosteninformatie?
33. Hoe werkten verschillende moederbedrijven samen binnen één projectstructuur?
34. Waren er verschillen in boekhoudkundige principes tussen de betrokken bedrijven?
35. Ontstond er een projectsysteem naast de systemen van de moederbedrijven?
36. Hoe beïnvloedde dit de traceerbaarheid en overdraagbaarheid van kosteninformatie?
37. Speelden bedrijfsbelangen en projectbelangen soms door elkaar?

Systemen, Excel en informele informatieoverdracht

38. Welke informatie stond in formele systemen?
39. Welke informatie werd daarnaast bijgehouden in Excel of losse projectoverzichten?
40. Hoe betrouwbaar en overdraagbaar waren die aanvullende overzichten?
41. Waar kwam de input voor Excel-lijsten vandaan?
42. Wat betekende dit voor traceerbaarheid bij personele wisselingen of overdracht?

Leren, evalueren en terugkoppeling

43. Wat gebeurt er met inzichten uit kostenafwijkingen tijdens het project?
44. Worden afwijkingen tussentijds geëvalueerd?
45. Worden lessen teruggekoppeld naar calculatie of toekomstige tenders?
46. Waarom worden geleerde lessen soms niet meegenomen naar vergelijkbare projecten?
47. Hoe kan informatie uit projecten worden vertaald naar betere normgetallen?

Mogelijke oplossingsrichting: werkpakketten en geografisch labelen

48. Zou het helpen om kosten vanaf tender tot uitvoering consistenter te structureren?
49. Zou het helpen om kosten meer geografisch te labelen in plaats van alleen met codes?
50. Hoe zou de kostenstructuur beter kunnen aansluiten op hoe het werk buiten wordt georganiseerd?

Concrete voorbeelden en vervolgdocumenten

51. Kun je een voorbeeld laten zien van hoe werk in de tender werd opgeknipt?
52. Kun je laten zien hoe dit later weer werd samengevoegd of vertaald naar uitvoering?
53. Welke documenten zijn nuttig om deze dynamiek beter te begrijpen?
54. Zijn er kwartaalrapportages, tenderdocumenten of lessons learned beschikbaar?

Dike Reinforcement Tiel-Waardenburg

Rol en betrokkenheid

1. Wat was jouw rol binnen Tiel-Waardenburg?
2. In welke fase(s) van het project was je betrokken: tender, voorbereiding, uitvoering, projectbeheersing of rapportage?
3. Bij welke discipline was je vooral betrokken, bijvoorbeeld wegen, grondwerk, constructies, elektrisch materieel of projectbeheersing?
4. Met welke functies werkte je vooral samen bij het opstellen, vertalen of bewaken van kosteninformatie?
5. Was jouw rol vooral inhoudelijk-technisch, financieel-controlerend of verbindend tussen disciplines?

Overgang van tender naar uitvoering

6. Hoe is de tenderbegroting vertaald naar een uitvoerbare werkbegroting?
7. Welke informatie uit de tender bleef bruikbaar tijdens uitvoering?
8. Welke informatie moest opnieuw worden geïnterpreteerd of herverdeeld?
9. Was de tenderstructuur direct bruikbaar voor projectbeheersing, of moest deze worden aangepast?
10. Waar ontstond volgens jou het meeste informatieverlies bij de overgang van tender naar uitvoering?

Kostenstructuur en projectindeling

11. Hoe was de kostenstructuur op Tiel-Waardenburg opgebouwd?
12. Werd er gestuurd op clusters, dijkvakken, dijksecties, disciplines of activiteiten?
13. Hoe goed sloot deze structuur aan op hoe het werk buiten werd georganiseerd?
14. Waren dijkvakken en dijksecties ook de logische eenheden voor financiële bewaking?
15. Waar ontstonden verschillen tussen de calculatiestructuur en de uitvoeringsstructuur?

Traceerbaarheid van kostenafwijkingen

16. Als er een afwijking zichtbaar werd in een kostencode, hoe goed kon je dan achterhalen waar die inhoudelijk vandaan kwam?
17. Kon je afwijkingen herleiden naar een dijkvak, discipline, activiteit of specifieke aanname?
18. Waren afwijkingen vooral financieel zichtbaar, of ook inhoudelijk verklaarbaar?
19. Welke rol speelden hoeveelheden, productiesnelheden en aannames in het verklaren van afwijkingen?
20. Waar werd traceerbaarheid moeilijk: bij directe kosten, indirecte kosten, raakvlakken of wijzigingen?

Hoeveelheden, aannames en demarcatie

21. Hoe zijn de hoeveelheden in de tender bepaald?
22. Welke hoeveelheden waren gebaseerd op ontwerpdata, metingen in het werk of aannames?
23. Hoe werd omgegaan met verschillen tussen ontwerptekening, landschapsplannen, eisen en handboeken?
24. Waren de demarcaties tussen disciplines duidelijk genoeg?

25. Welke raakvlakken leverden in de praktijk de meeste discussie of onzekerheid op?

Koppeling tussen kosten en fysieke voortgang

26. Hoe werd fysieke voortgang gemeten binnen Tiel-Waardenburg?
27. Werd voortgang gekoppeld aan dijkvakken, uitvoeringsvakken, disciplines of planningsactiviteiten?
28. Hoe werd fysieke voortgang vertaald naar financiële rapportage?
29. Waren er momenten waarop kosten en fysieke voortgang uit elkaar liepen?
30. Wat zeggen voortgangspercentages volgens jou wel en niet over de werkelijke projectstatus?

Planning, fasering en uitvoerbaarheid

31. Hoe sloot de calculatie aan op de uitvoeringsplanning?
32. Waren de faseringsvakken uit de tender ook werkbaar in uitvoering?
33. Waar ontstonden problemen doordat disciplines verschillende logica's volgden?
34. Hoe werd omgegaan met activiteiten die niet netjes binnen één dijkvak of fase vielen?
35. Welke invloed had de planning op kostenbewaking en productiviteit?

Elektrisch materieel, EMVI en nieuwe kostenlogica

36. Welke rol speelde elektrisch materieel in de tender en uitvoering?
37. Hoe zijn kosten voor elektrisch materieel, laden, accutransport en energievoorziening meegenomen?
38. Waren deze kosten goed traceerbaar binnen de bestaande kostenstructuur?
39. Welke nieuwe kostenposten of activiteiten ontstonden door emissieloos bouwen?
40. Hoe werd gestuurd op EMVI-beloften in relatie tot kosten, planning en uitvoering?

Financiële rapportage en bandbreedtes

41. Hoe werd het projectresultaat periodiek gerapporteerd?
42. Welke rol speelden prognose einde werk, bandbreedtes, kansen en risico's?
43. Werden afwijkingen vooral op totaalniveau besproken of ook inhoudelijk per werkpakket/discipline?
44. Hoe werd bepaald of een afwijking aanleiding gaf tot bijstelling van de prognose?
45. Hoe bruikbaar was de kwartaalrapportage voor inhoudelijke sturing?

Wijzigingen, scopeontwikkeling en restpunten

46. Hoe werden wijzigingen geregistreerd en financieel verwerkt?
47. Waren wijzigingen goed te koppelen aan oorspronkelijke tenderaannames?
48. Welke typen wijzigingen hadden de grootste invloed op kostenbeheersing?
49. Hoe werd onderscheid gemaakt tussen scopewijziging, risico, optimalisatie en uitvoeringsafwijking?
50. Welke restpunten bleven lastig te beheersen richting afronding?

Leren en terugkoppeling naar toekomstige projecten

51. Welke lessen uit Tiel-Waardenburg zijn relevant voor toekomstige projecten?
52. Worden afwijkingen uit de uitvoering teruggekoppeld naar calculatie?

53. Welke tenderaannames zouden achteraf anders zijn gemaakt?
54. Hoe worden leerpunten rondom elektrisch materieel, planning, hoeveelheden en demarcatie vastgelegd?
55. Worden lessen tussentijds gedeeld of vooral aan het einde van het project geëvalueerd?

Mogelijke oplossingsrichting: betere structurele alignment

56. Zou het helpen om tender, werkbegroting, planning en rapportage sterker op dezelfde structuur te baseren?
57. Welke structuur zou daarvoor het meest logisch zijn: dijkvakken, werkpakketten, disciplines of activiteiten?
58. Zou een werkpakketstructuur helpen om kosten, scope, planning en fysieke voortgang beter te koppelen?
59. Waar zou zo'n aanpak juist te complex of administratief zwaar worden?
60. Welke informatie zou vanaf de tenderfase expliciet moeten worden vastgelegd om afwijkingen later beter te kunnen verklaren?

Substation Vierverlaten

Project en rollen

1. Als jullie Vierverlaten in een paar zinnen moeten typeren vanuit kostenbeheersing: wat voor project was dit dan?
2. Was het vooral technisch complex, contractueel complex, organisatorisch complex of vooral complex door de lange looptijd?
3. Hoe was jullie rolverdeling bij het bewaken en verklaren van kostenafwijkingen?
4. Hoe verliep de samenwerking tussen projectmanagement en projectcontrol wanneer er een afwijking zichtbaar werd?

Van tender naar werkbegroting

5. Hoe is de tendercalculatie na gunning vertaald naar de werkbegroting?
6. Welke structuur was daarbij leidend: inschrijfstaat, kostensoorten, bewakingsposten, objecten, activiteiten of contractonderdelen?
7. Welke informatie uit de tender was later goed bruikbaar tijdens de uitvoering?
8. Konden jullie later nog goed terugvinden waarom bepaalde bedragen, hoeveelheden of risico's waren opgenomen?
9. In de projectevaluatie staat dat de overdracht op zich netjes was, maar dat de demarcatie voor de realisatiefase niet gedetailleerd genoeg was. Hoe merkten jullie dat in de praktijk?
10. Kunnen jullie één concreet voorbeeld geven waarbij onduidelijke demarcatie tot discussie of extra kosten leidde?

Kosten volgen tijdens uitvoering

11. Op welk niveau konden jullie kosten tijdens de uitvoering het beste volgen: per bewakingspost, object, activiteit, fase, RFC of kostensoort?
12. Sloot die financiële structuur goed aan op hoe het werk buiten werd uitgevoerd?
13. Konden jullie kosten makkelijk koppelen aan onderdelen zoals het CDG, de trafo's, geluidshuizen, 220 kV, 380 kV, hekwerken of terreinafwerking?

14. Waar zat de grootste mismatch tussen de financiële structuur en de uitvoeringsrealiteit?
15. Kunnen jullie een voorbeeld noemen van een kostenafwijking die wel zichtbaar was in de cijfers, maar waarvan de oorzaak lastig te achterhalen was?
16. Waren er momenten waarop de prognose op totaalniveau stabiel leek, terwijl er onderliggend veel verschoof tussen posten?

RFC's en meerwerk

17. Wanneer besloten jullie: dit is niet meer gewone scope, maar dit moet een RFC of meerwerk worden?
18. Wie signaleerde dat meestal: uitvoering, werkvoorbereiding, projectmanagement, contractmanagement of projectcontrol?
19. Hoe werd een technische wijziging vertaald naar een financiële consequentie?
20. Welke informatie was nodig om een RFC goed te onderbouwen?
21. Heeft het RFC-proces geholpen om kostenafwijkingen beter traceerbaar te maken, of maakte het de administratie juist complexer?
22. Welke RFC was voor jullie het meest leerzaam vanuit kostenbeheersing?
23. Als voorbeelden niet direct opkomen: hoe kijken jullie terug op het geluidshuis, de overkluizing, indexatie, het opleverdossier, terreinafwerking of hekwerk Enexis?
24. Bij welke RFC moesten jullie het meest achteraf reconstrueren waar de kosten vandaan kwamen?
25. Zat de benodigde informatie vooral in systemen en documenten, of vooral bij personen?

Indirecte kosten, vertraging en prognose

26. Hoe werden indirecte kosten bewaakt, zoals UTA, engineering, projectorganisatie, contractmanagement en bankgaranties?
27. Waren deze kosten gekoppeld aan tijd, fases, activiteiten, RFC's of vooral aan algemene projectduur?
28. Welke indirecte kosten waren het lastigst te verklaren of te koppelen aan een oorzaak?
29. De projectduur is uiteindelijk veel langer geworden dan oorspronkelijk gedacht. Wat deed die lange looptijd met de begroting en prognose?
30. Welke posten kwamen door de lange looptijd vooral onder druk te staan?
31. Hoe werd de prognose einde werk opgebouwd?
32. Welke informatie had je nodig om een betrouwbare prognose te maken, maar was niet altijd beschikbaar?

Specifieke voorbeelden uit de documenten

33. De geluidsreductie van de trafo's lijkt in de tender te licht te zijn ingeschat en later via het geluidshuis een grote RFC te zijn geworden. Hoe verliep dat proces van eerste risico naar financiële claim of RFC?
34. De EMVI-weg komt meerdere keren terug als discussiepunt. Wat was hier precies lastig aan vanuit kostenbeheersing?
35. De projectevaluatie benoemt dat contractmanagement essentieel was en zichzelf zou terugverdienen. Hoe hebben jullie dat op Vierverlaten ervaren?

36. De documenten noemen dat ontwerp meer tijd kostte dan voorzien en dat sommige ontwerpen minder goed aansloten op de maakbaarheid. Hoe werkte dat door in kosten en traceerbaarheid?

Leren en afsluiting

37. Welke lessen uit Vierverlaten zijn volgens jullie het belangrijkst voor nieuwe projecten?
38. Zijn er dingen die Dura Vermeer nu anders doet door Vierverlaten?
39. Wat werkte op Vierverlaten juist goed om kosten traceerbaar te houden?
40. Als jullie één oorzaak moeten noemen waardoor kostenafwijkingen soms moeilijk traceerbaar waren, welke oorzaak is dat dan?
41. Was Vierverlaten financieel succesvol dankzij de oorspronkelijke structuur, of vooral dankzij de manier waarop jullie die structuur tijdens het project hebben aangevuld en gerepareerd?
42. Welke rol speelden individuele personen in het behouden van kosteninzicht?
43. Als jullie morgen opnieuw met Vierverlaten zouden starten, wat zouden jullie vanaf dag één anders structureren om kosten beter traceerbaar te maken?
44. Welke informatie zou volgens jullie standaard gekoppeld moeten blijven van tender tot oplevering om kostenafwijkingen beter te kunnen herleiden?

Appendix C: Coding Framework and Evidence Matrix

Table C.1: Coding Framework and Theme Development

Code group	Main codes used during analysis	Origin	Empirical indicators	Resulting theme in Chapter 5
Cost structuring	Tender estimate structure; work budget structure; cost codes; monitoring posts; budget holders; aggregation level	Deductive	Tender estimate translated into work budget; cost items regrouped; budget organised around controllable units	Current cost estimation and budgeting practice; tender-to-execution transition
Cross-phase structural alignment	Information loss; restructuring; reclassification; loss of shared meaning; system translation	Deductive	Tender logic no longer recognisable in execution; cost codes meaningful to finance but less meaningful to execution	Tender estimate as phase-specific structure; main source of fragmentation
Cost traceability	Financial visibility; causal explanation; reconstructability; data lineage; explanation of deviations	Deductive	Cost movement visible but cause not embedded; explanation depends on project memory or Excel files	Financial visibility does not equal causal traceability
Cost-progress integration	Physical progress; production percentage; booked costs; remaining work; planning update	Deductive	Costs booked before physical progress; physical progress achieved before cost booking; progress percentages require interpretation	Cost, progress and the problem of two realities; cost-progress relationship
Change mechanisms	RFCs; variation orders; bandwidths; reservations; claims; contractual substantiation	Deductive and inductive	RFC used to link scope change to cost effect; bandwidth manages uncertainty without explaining root cause	Change mechanisms partially restore traceability
Indirect cost traceability	Engineering hours; project staff; contract management; coordination effort; delay-related costs; EMAT-related indirect effort	Deductive and inductive	Staff costs visible but not always attributable to packages; delay causes continued project organisation costs	Indirect costs remain structurally difficult to trace
Project learning	Lessons learned; single-loop learning; double-loop learning; actor-dependent knowledge; organisational feedback	Deductive	Lessons documented but not translated into norm figures; learning depends on experienced individuals	Learning occurs but remains insufficiently institutionalised
Project-specific structuring mechanisms	Combination-specific system; EMAT obligations; RFC-driven project control; small-team continuity	Inductive	Themes specific to one case but relevant to traceability mechanism	Project-specific subparagraphs in Sections 5.4–5.6
Cost predictability	Forecast reliability; expected result; remaining work; risk development; future estimating	Deductive and inductive	Forecast improves during project, but cross-project estimation learning remains weak	Implications for cost predictability

Table C.2: Evidence Matrix for Empirical Themes

Empirical theme	Organisa-tional interviews	Case 1	Case 2	Case 3	Project documents	Analytical importance
Tender-to-execution transformation	Strong	Strong	Strong	Strong	Strong	Explains where traceability problems start
Fragmentation between structuring logics	Strong	Strong	Strong	Strong	Strong	Explains why financial visibility does not equal causal traceability
Cost-progress misalignment	Strong	Strong	Moderate	Moderate	Strong	Explains why cost reports require interpretation
Change mechanisms restoring traceability	Moderate	Moderate	Strong	Strong	Strong	Shows how traceability can be partly repaired
Indirect cost traceability	Strong	Strong	Strong	Strong	Strong	Recurring across all cases
Actor-dependent interpretation	Strong	Strong	Strong	Strong	Moderate	Explains why lessons remain person-dependent
Cross-project learning limitations	Strong	Strong	Moderate	Strong	Moderate	Links empirical findings to predictability
Project-specific contextual mechanisms	Moderate	Strong	Strong	Strong	Strong	Explains why case subthemes differ while analytical logic remains the same

Strong indicates that the theme was present in multiple sources within that category. Moderate indicates that the theme was present but less central. Limited indicates that the theme was only indirectly visible or appeared in fewer sources. The matrix is used to show analytical coverage rather than statistical frequency. Case 1 = Highway A16 De Groene Boog. Case 2 = Dike Reinforcement Tiel-Waardenburg. Case 3 = Substation Vierverlaten.

Appendix D: Scoring Justification for Evaluation of Structuring Approaches

This appendix provides the full justification for each score assigned in the evaluation matrix presented in Table 6.1. Scores are assigned on a three-level scale: strong (the approach directly addresses the limitation through explicit mechanisms), moderate (the approach indirectly supports improvement under certain conditions), or limited (the approach does not explicitly address the limitation).

D.1 Work Breakdown Structure

Criterion 1 — Cross-Phase Structural Continuity: Moderate

The WBS provides a consistent coding structure if defined at project outset and maintained across phases. However, its effectiveness depends critically on whether the decomposition logic aligns with how work is executed in the field. As De Groene Boog illustrates, a detailed WBS does not automatically produce shared meaning across disciplines: where codes aligned with work sections or contracts, they supported causal interpretation, but where they functioned as administrative categories their explanatory value was limited.

Criterion 2 — Cost–Progress Integration: Limited

The WBS provides the structural basis for assigning cost to scope elements, which is a prerequisite for progress measurement. However, it does not prescribe how physical completion is linked to financial status. It provides the skeleton but not the mechanism: a WBS-coded budget can register that expenditure has occurred within a code without revealing whether the associated physical work is ahead, delayed, or partially complete.

Criterion 3 — Double-Loop Learning: Limited

A consistent WBS coding structure is a necessary precondition for cross-project comparison of assumptions versus outcomes at the work package level. However, the approach provides no feedback mechanisms or institutionalised learning processes. Its contribution to double-loop learning is therefore conditional on the presence of complementary practices that translate work package performance data into revised estimating assumptions.

Criterion 4 — Indirect Cost Traceability: Moderate

Indirect cost elements can in principle be included as separate work packages or WBS elements. This means that the WBS can provide information for indirect cost traceability when indirect activities such as engineering, project management, coordination or site support are deliberately linked to work packages or responsibilities. However, the WBS does not by itself define the drivers of these indirect costs and does not prevent them from being grouped into broad overhead categories, as observed across the empirical cases. Its contribution is therefore conditional and is scored as moderate.

Criterion 5 — Change Mechanism Support: Limited

Scope changes can be reflected in the WBS by adding or modifying work packages, but the approach does not manage change processes or preserve the link between a deviation and the underlying tender assumption that it disrupted. No mechanism exists within the WBS framework for formally connecting a scope deviation to its contractual, technical, or operational cause.

D.2 Critical Path Method

Criterion 1 — Cross-Phase Structural Continuity: Limited

CPM models the timing of activities rather than the structural alignment of cost information across phases. The activity level at which CPM networks operate reflects planned sequencing logic rather than the level at which costs are estimated and reported. When cost structures and schedule structures are not aligned, relating financial deviations to specific schedule events becomes difficult, as demonstrated across the empirical cases.

Criterion 2 — Cost–Progress Integration: Moderate

Cost-loaded schedules enable time-phased expenditure monitoring and the detection of when planned spending diverges from actual. This gives CPM a moderate contribution to cost–progress integration, specifically for the temporal dimension. However, as the empirical cases demonstrate, the activity level in CPM may not align with the cost structure, complicating the attribution of financial deviations to schedule events and limiting the diagnostic value of the time-phased view.

Criterion 3 — Double-Loop Learning: Limited

CPM can identify when deviations in timing occur but provides limited insight into why they occurred in terms of underlying cost assumptions or execution conditions. The tool supports identification of timing problems but does not create the causal linkages needed for double-loop learning: it confirms that the critical path was affected without revealing whether the cause lay in estimation, design readiness, procurement, or field productivity.

Criterion 4 — Indirect Cost Traceability: Limited

Indirect costs are not represented in CPM networks and their relationship to activity timing is not modelled. No mechanism exists within CPM for attributing indirect cost growth to specific schedule positions or for relating overhead expenditure to work front conditions.

Criterion 5 — Change Mechanism Support: Limited

CPM can model the schedule impact of changes and is widely used for delay analysis. However, it does not integrate with cost change management structures and does not link contractual changes back to the original tender assumptions from which they deviate.

D.3 Earned Value Management

Criterion 1 — Cross-Phase Structural Continuity: Moderate

EVM requires a consistent scope-cost-schedule baseline, which introduces some discipline around cross-phase alignment. However, it does not in itself ensure that original tender assumptions are preserved in a traceable manner across phases. A baseline can be established without carrying the reasoning behind its components, meaning that the structural continuity EVM provides is limited to the formal baseline rather than extending to the underlying estimating logic.

Criterion 2 — Cost–Progress Integration: Strong

EVM's primary contribution lies in explicitly integrating Planned Value, Earned Value, and Actual Cost into a unified framework. This creates a structured basis for monitoring whether financial expenditure aligns with physical progress, directly addressing the divergence identified in all three empirical cases. However, the explanatory power of EVM depends strongly on data granularity: when performance is tracked at high aggregation levels, a cost variance may be visible without being diagnostically meaningful. Project teams can observe that performance is off-track while still lacking the detail needed to trace the deviation to its origin.

Criterion 3 — Double-Loop Learning: Moderate

EVM provides early warning signals and supports completion forecasting, functioning as a precondition for learning by making deviations visible and quantifiable. However, its primary function is measurement rather than causal reconstruction. EVM signals that learning is needed but does not create the structural conditions for identifying root causes. As observed in the empirical cases, deviations may remain financially visible without being causally traceable, limiting EVM's contribution to double-loop learning.

Criterion 4 — Indirect Cost Traceability: Limited

EVM typically aggregates indirect cost categories within the baseline, making deviations within those categories visible at a summary level but not causally attributable to specific activities or scopes. The Vierverlaten and De Groene Boog cases both show that even when EVM-style performance tracking is applied, indirect cost deviations remain difficult to interpret without additional contextual knowledge.

Criterion 5 — Change Mechanism Support: Limited

Baseline updates are required when scope changes occur, and EVM frameworks include mechanisms for handling authorised scope changes. However, EVM provides no inherent mechanism for linking changes to original assumptions or for distinguishing scope change from estimation error, two fundamentally different causes with different implications for future estimating practice.

D.4 Last Planner System

Criterion 1 — Cross-Phase Structural Continuity: Limited

LPS was designed for the production planning phase and does not address the structural alignment of cost information between tender estimation, work budgeting, and execution reporting. Its contribution to cross-phase structural continuity is therefore limited. The planning hierarchy it provides (master schedule through weekly work planning) operates within the execution phase rather than spanning the full project lifecycle.

Criterion 2 — Cost–Progress Integration: Strong

LPS explicitly links planning commitments (WILL) to execution outcomes (DID) through short-interval control, with constraint management reducing the divergence between financial booking and physical reality identified across all three cases. The link between workflow reliability and indirect cost growth is directly addressable through LPS constraint removal: by ensuring prerequisites are in place before work is committed, LPS reduces the execution instability, waiting time, rework, disrupted sequences, that drives cost growth in categories that traditional financial reporting cannot easily attribute to specific causes.

Criterion 3 — Double-Loop Learning: Moderate

PPC measurement and non-compliance registration create a structured intra-project feedback loop, enabling teams to identify and address recurring operational causes of deviation. This corresponds to the intra-project double-loop learning pathway in the refined conceptual framework. Contribution to inter-project learning is more limited: LPS does not provide mechanisms for translating production-level insights into future estimation practices, and the reasons for non-compliance recorded during execution are not automatically connected to the estimating assumptions that produced the baseline plan.

Criterion 4 — Indirect Cost Traceability: Moderate

The project controller perspective identified in Section 5.2 supports a moderate rating: linking indirect activities, engineering, planning, coordination, project management, to specific work packages rather than treating them as general overhead could improve their traceability. LPS's commitment-based planning structure provides a conceptual basis for this, as indirect effort can be assigned to specific package commitments rather than to a general overhead line. However, this requires deliberate application and does not occur automatically through LPS implementation.

Criterion 5 — Change Mechanism Support: Limited

LPS reduces the frequency of unplanned disruptions through proactive constraint removal, indirectly reducing the need for corrective change mechanisms. However, it does not itself manage formal change processes or integrate with contractual change structures such as RFC procedures. Its contribution to change mechanism support is therefore indirect and limited.

D.5 Advanced Work Packaging

Criterion 1 — Cross-Phase Structural Continuity: Strong

AWP is the only approach among the five that is explicitly designed for cross-phase structural alignment. The EWP–CWP–IWP hierarchy provides a stable structuring unit that spans planning, engineering, and construction execution. CWPs provide a consistent level at which original scope assumptions, execution progress, and financial outcomes can be connected. This directly addresses the structural discontinuity, between tender estimate, work budget, execution control, and financial reporting, identified as the central empirical limitation across all three cases.

Criterion 2 — Cost–Progress Integration: Strong

The IWP readiness-driven approach ensures that work is only released when prerequisites are in place, reducing the gap between financial booking and physical progress identified across all three cases. CWPs provide the execution-aligned level at which cost, scope, and physical completion can be integrated meaningfully. This addresses both the cost-booking timing issues observed in De Groene Boog, where administrative and site reality could diverge, and the progress-interpretation challenges in Tiel-Waardenburg, where forecasting only became reliable when actual production, remaining work, and planning updates were integrated into a coherent picture.

Criterion 3 — Double-Loop Learning: Strong

The package hierarchy provides a practical pathway for tracing deviations to specific scopes, interfaces, or readiness conditions rather than leaving them visible only at aggregated reporting levels. This creates conditions for intra-project learning, causal identification during execution, and inter-project learning, preserved package-level performance data for future estimation. When deviations at IWP or CWP level are recorded and their causes attributed to specific engineering readiness conditions, procurement status, or work front constraints, this provides a basis for improving future estimating assumptions and package definitions. AWP's reported contribution to project predictability (Halala & Fayek, 2019) is partly explained by this learning mechanism.

Criterion 4 — Indirect Cost Traceability: Moderate

Indirect activities can in principle be assigned to packages rather than treated as undifferentiated overhead. Engineering hours can be linked to specific EWPs, coordination effort to specific CWPs, and supervision to specific IWPs or construction areas. This is more traceable than the broad overhead categories observed across the empirical cases. However, this requires deliberate structuring decisions at project outset and does not occur automatically through AWP implementation. Without an explicit decision to include indirect activities in the package structure, AWP may improve direct cost traceability while leaving indirect costs in the same structurally difficult position as in traditional approaches.

Criterion 5 — Change Mechanism Support: Moderate

By aligning engineering deliverables with construction needs upfront, AWP reduces the frequency of execution disruptions that give rise to unplanned changes. When scope deviations do occur, the package structure provides a clearer basis for substantiating RFCs and linking them to specific work scopes, engineering deliverables, or procurement readiness conditions. As the Vierverlaten case suggests, the ability to connect a deviation to a specific contractual and technical cause, rather than leaving it embedded in a general production line, is critical to recovering costs through formal change mechanisms. AWP does not eliminate the need for formal change processes but improves their integration with the cost structure.

Appendix E: Question sheet validation interviews SQ4

Introductie

1. Wat is jouw huidige rol bij Dura Vermeer?
2. Bij welke projectfasen ben je betrokken?
3. Zit je op een of meerdere projecten?

Probleemuitleg

4. Herken jij dit beeld?

Het kernidee: de CWP als stabiele koppeleenheid

Uitleg:

In plaats van de kostenstructuur bij elke fase opnieuw op te bouwen, kies je één uitvoeringsgerichte eenheid — het Construction Work Package (CWP) — en hou je die vast door het hele project, van aanbesteding tot evaluatie. Alle informatie hangt aan diezelfde CWP-code, zodat de verbinding tussen oorspronkelijke aanname en eindresultaat intact blijft.

Validatievragen

5. Is één eenheid vasthouden door álle fasen heen realistisch bij een project? Waar zou het breken?
6. Wat zou er nodig zijn om dit niet bij elke fase-overgang los te laten?
7. Wanneer wordt het te grof om nog traceerbaar te zijn, en wanneer wordt het te gedetailleerd om beheersbaar te blijven?
8. Wie zou of zouden eigenaar moeten zijn van de CWP's?

Stap 2: De zeven informatielagen rond de CWP

Uitleg, aan elke CWP hangt:

- Scope (object, locatie, discipline, grens, raakvlakken, eigenaar)
- Tenderaannames (hoeveelheden, productiviteit, eenheidsprijzen, werkmethode, risico-opslag, indirecte aannames)
- Kostenbaseline (direct/indirect budget, post onvoorzien, budgethouder, koppeling kostencode)
- Readiness (randvoorwaarden vóór vrijgave)
- Planning & voortgang (start/eind, fysieke voortgang, PV, EV, restraming)
- Afwijking & wijziging (prognosemutaties, RFC's, scopewijzigingen, risico's, oorzaakcategorie)
- Leren (gerealiseerd vs. tender, hoofdoorzaak, lessen, aanpassingen voor toekomstige calculatie)

Validatievragen

9. Welke van deze lagen wordt nu al goed bijgehouden, en welke verwatert of ontbreekt?
10. Mist er een laag, of is er een laag die in de praktijk onhoudbaar zou zijn?

Stap 3: Drie benaderingen als complementaire lagen

Uitleg, het framework combineert drie methodes, niet als losse systemen maar als lagen van één logica:

- AWP (structurele laag): definieert de pakkethiërarchie en de koppeling engineering (EWP) → bouwscope (CWP) → uitvoeringstaak (IWP), en houdt de pakketstructuur intact over de fasen heen.
- LPS (operationele laag): beheert readiness en het wegnemen van constraints, en voorkomt het gat tussen financiële boeking en fysieke voortgang.
- EVM (meetlaag): herpositioneerd als kosten–voortgangsmeting op CWP-niveau (PV, EV, AC), zodat een afwijking laat zien wáár en waaróm er iets ontstaat.

Validatievragen

11. Drie methodes tegelijk introduceren: is dat haalbaar, of organisatorisch te zwaar?
12. Welke van de drie zou het meeste opleveren, en welke is het lastigst in te voeren?

Stap 4: Readiness als voorwaarde voor vrijgave

Uitleg:

Werk wordt pas vrijgegeven als kritieke randvoorwaarden expliciet zijn geverifieerd: ontwerpinformatie, materiaal, vergunningen, werkfront, capaciteit, stakeholdercondities. Dit verschuift de focus van terugkijken (wat is uitgegeven) naar vooruitkijken (welke condities veroorzaken straks een afwijking).

Validatievragen

13. Gebeurt vrijgave nu op basis van geverifieerde randvoorwaarden, of vaak toch onder planningsdruk?
14. Zou dit in de praktijk worden omarmd of als vertraging worden ervaren?

Stap 5: Causale toewijzing op pakketniveau

Uitleg:

Afwijkingen worden niet alleen als prognosemutatie geboekt, maar toegewezen aan een oorzaak op CWP-niveau: scopewijziging, calculatiefout, productiviteitsverlies, planningsverstoring, inkoopvertraging, coördinatie/indirecte inspanning, of contractuele/klantgedreven wijziging.

Validatievragen

15. Worden afwijkingen nu aan oorzaken gekoppeld, of vooral als bedrag geregistreerd?
16. Zijn dit de juiste oorzaakcategorieën? Mist er een, of zijn er te veel?

Stap 6: Twee feedbackloops + indirecte kosten

Uitleg:

- Binnen-project: afwijking → hoofdoorzaak → corrigerende actie → bijgestelde prognose (sturen tijdens uitvoering).
- Cross-project: CWP-evaluatie bij oplevering → terug naar toekomstige tenderaannames, normcijfers en pakketdefinities (organisatieleren).
- Indirecte kosten worden ingedeeld naar herleidbaarheid: pakketspecifiek, fasegebonden, projectbreed of wijzigingsgedreven.

Validatievragen

17. Wie zou eigenaar moeten zijn van dat leren, wil het niet bij individuen blijven hangen?

18. Gaat het indelen van de indirecte/tijdgebonden kosten op deze manier denk je werken?

Stap 7: Gefaseerde invoering (volwassenheidsniveaus)

Uitleg:

Het framework wordt niet in één keer volledig ingevoerd. Je start met minimale eisen (CWP + aannames vastleggen) en bouwt lagen op naarmate het team en de systemen meegroeien.

Validatievragen

19. Als je dit gefaseerd zou invoeren: waar zou jey beginnen, en wat zou de eerste stap moeten zijn?
20. Wat is het minimum dat al waarde oplevert zonder dat het te zwaar wordt?

Kritische & reflexieve vragen

21. Het risico: een strakkere, gestandaardiseerde structuur kan de informele sterktes ondermijnen; ervaren mensen, onderling vertrouwen, het vakmanschap van calculatoren en kostenbewakers. Vind jij dat dit professionals helpt bij hun oordeel, of dat het hun eigen oordeel juist in de weg zit?
22. Welke organisatorische condities of capaciteiten moeten er zijn voordat dit werkt (mensen, systemen, eigenaarschap, cultuur)?
23. Welk onderdeel van het framework is het meest overtuigend, en welk het minst?
24. Welk onderdeel zou je aanpassen voordat dit framework in een echt project getest wordt? Welk onderdeel zou je schrappen? Welk onderdeel moet juist scherper worden uitgewerkt?

Appendix F: Pre-Validation Version of the Implementation Framework

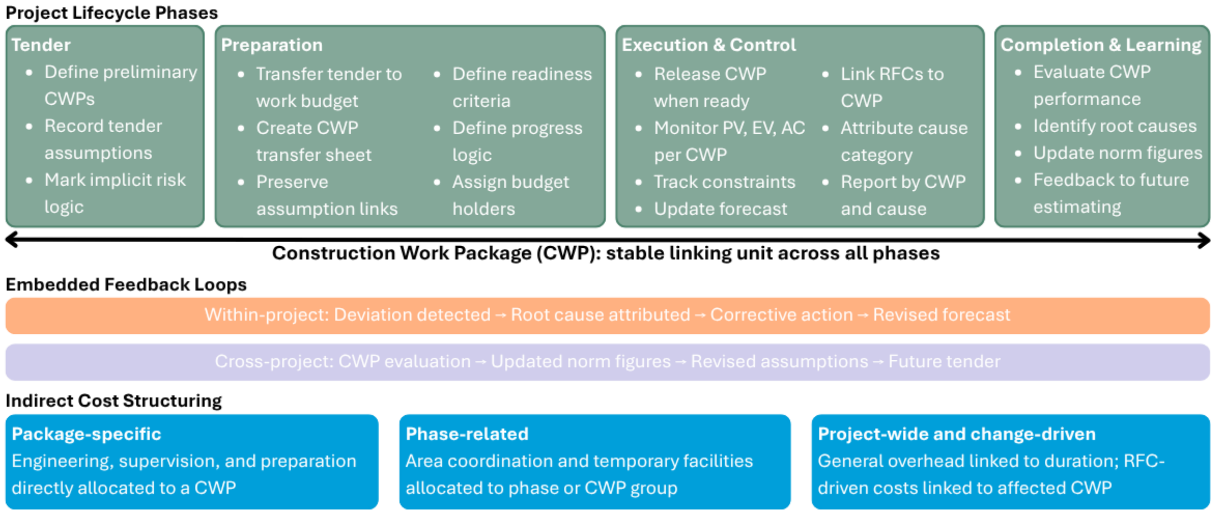
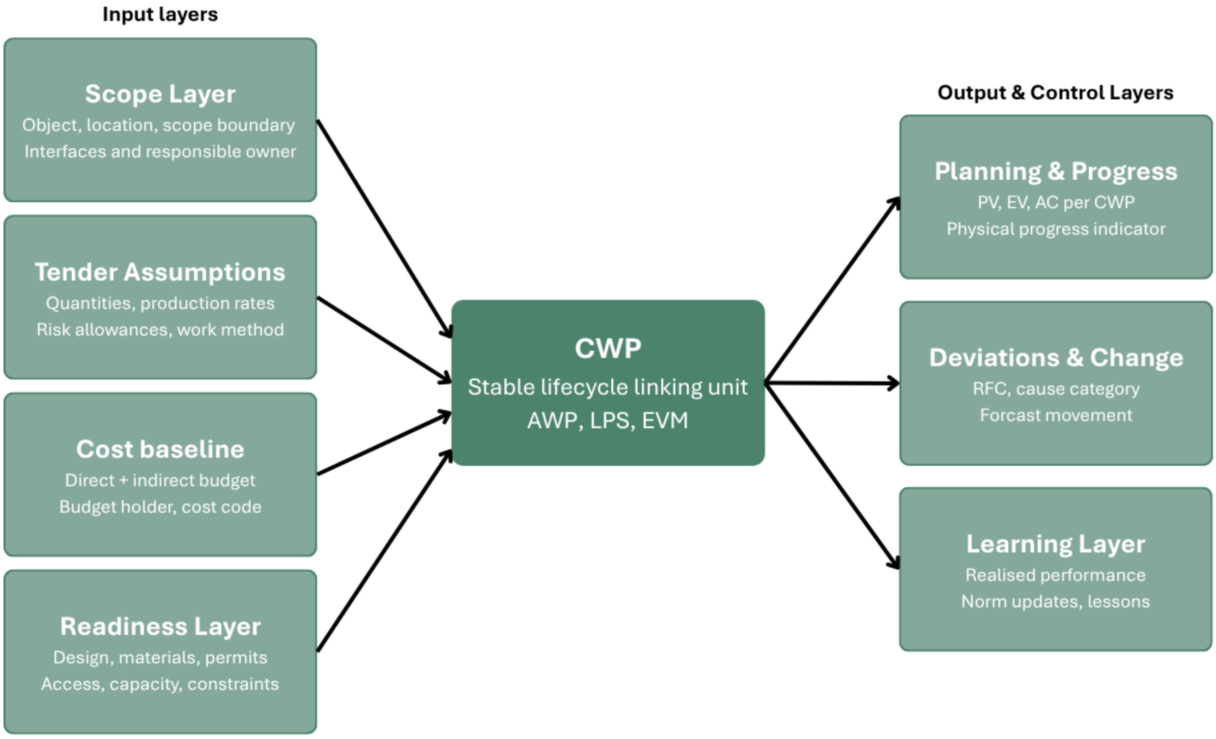


Figure F.1: Pre-Validation Version of The Construction Project Cost Traceability Framework (own figure)



Seven information zones preserve causal links from tender organisation to organisational learning

Figure F.2: Pre-Validation Version of CWP Information Layer Model (own figure)

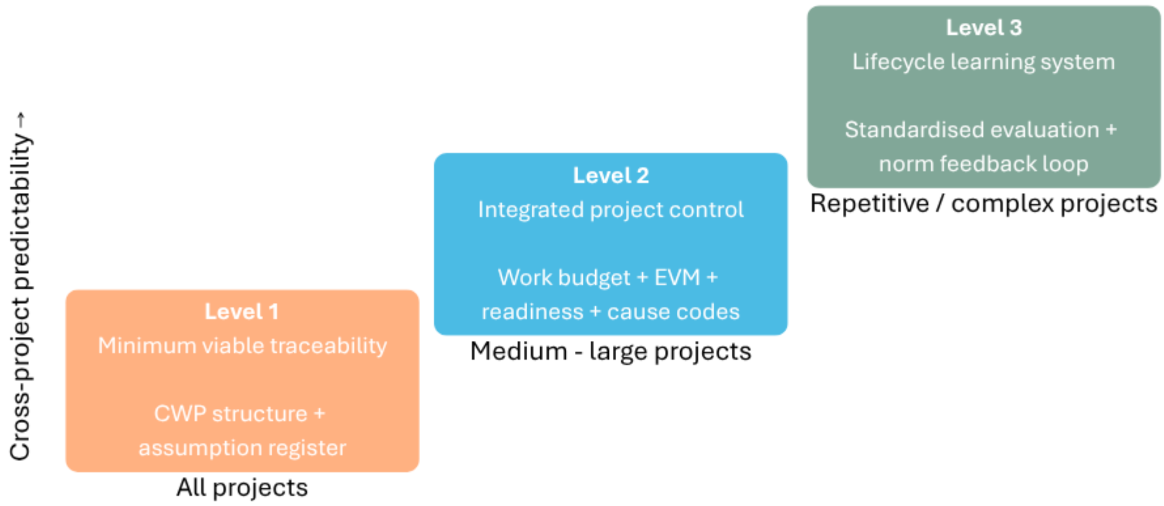


Figure F.3: Pre-Validation Version of CPCTF Staged Implementation Pathway (own figure)