Stimulating Innovation in the Explorative Phase: Contractor Influence Toward IFD Construction Adoption in Public Bridge Replacement

Master thesis

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TU Delft

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Master thesis

By

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Preface

Writing this thesis has been a demanding and eye-opening journey. I cannot say whether the academic process itself or the subject, together with insights from the research and many interviews, was more formative; both were. What is certain is that this work has given me lessons, skills, and knowledge that will endure.

I warmly thank my supervisor, Ir. J.P.G. Ramler (TU Delft), whose ongoing industry work grounded the study in real market dynamics and whose calm guidance gave me peace of mind. I am equally grateful to Prof. dr. P.W. Chan (TU Delft) for steering me through the academic process, providing the tools and structure to figure things out independently in a way that will stay with me. I thank Ir. T. Nillesen (Heijmans) for sharp technical feedback and generous guidance throughout, and Ir. N. Vervoort (Heijmans) for a complementary technical lens and, above all, a commercial perspective beyond the purely engineering view. Ir. Vervoort and Ir. Nillesen were remarkably open, granting access to meetings and contacts that proved essential; without that access, this research would not have been possible.

This work benefitted from collaboration with Heijmans, and I am deeply grateful to all interviewees and workshop participants across public authorities, engineering consultancies, and sector bodies for their time and candour. Any remaining errors are my own, and the views expressed do not necessarily reflect those of TU Delft, Heijmans, or the organisations represented by participants.

I also thank my peers, friends, and family for steady encouragement and patience during long writing days.

This thesis has been a period of both professional and personal growth that prepares me for the next steps in my career. I hope the insights help align contractor influence with procurement-market structures to accelerate responsible uptake of Industrial, Flexible and Demountable (IFD) bridge solutions.

P.A.E.M. van Casteren
Rotterdam, 22-08-2025

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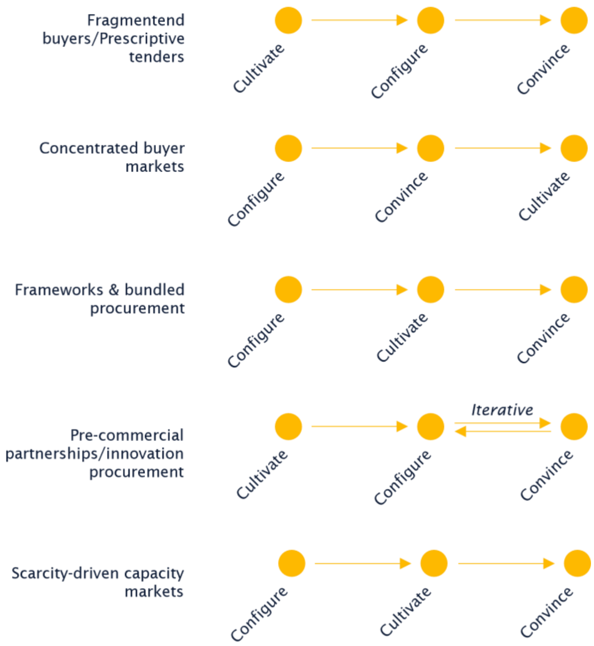
Management Summary

Industrialised countries, the Netherlands foremost among them, are staring down a wave of bridge renewals that dwarfs historic maintenance cycles: assets erected in the post-war boom are expiring together, yet public budgets, labour supply and procurement routines remain locked in business-as-usual mode. Heijmans, a tier-one Dutch contractor committed to modular and circular building methods, asked how it might steer the early, “explorative” phase of public bridge projects so that Industrial, Flexible & Demountable (IFD) solutions become the default choice rather than an after-thought. Three questions framed the study: how is that front-end decision spiral organised, which forces help or hinder IFD inside it, and what concrete levers can a contractor pull to tilt outcomes towards modular adoption?

To answer these questions the research combined a literature synthesis on demand-side innovation and modular construction with twelve semi-structured interviews spanning national, provincial and municipal clients, engineering consultancies and sector experts. The analysis followed a three-cycle coding protocol into ten recurring themes and, ultimately, three influence modes: Cultivate, Configure and Convince mapped onto the Desirability-Viability-Feasibility (DVF) framework.

Theoretical insights

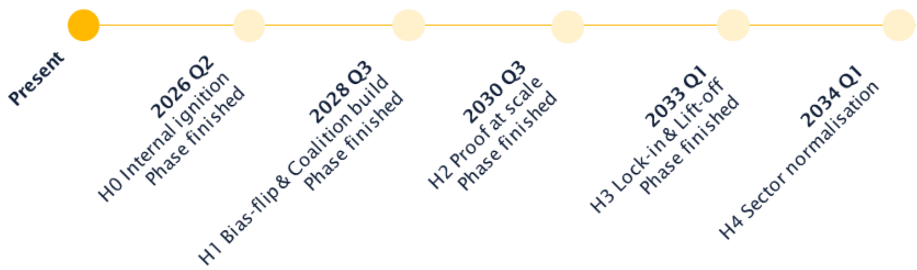
This thesis introduces the Cultivate–Configure–Convince (CCC) model and shows that its effective ordering is market-contingent rather than fixed. Derived from coded analysis of thirteen interviews (§5.3), CCC distinguishes three influence modes for suppliers: Cultivate (build awareness, legitimacy, trust), Configure (align technical, organisational, and contractual conditions), and Convince (evidence of viability and risk mitigation). The core contribution is that five procurement-market archetypes exhibit different CCC sequences, meaning CCC should be treated as a repertoire that adapts to procurement structure rather than a universal ladder. This market-sensitive interpretation is consistent with research on demand-side innovation in regulated, high-capital sectors, where public procurement shapes uptake and diffusion (Edler & Georghiou, 2007; Uyarra et al., 2014). Accordingly the figure to the right summarises how sequencing varies across archetypes; detailed rationale is provided in §6.3. Managerially, CCC functions as a market-sensitive sequencing framework: first diagnose the procurement archetype, then time Cultivate/Configure/Convince to focus resources, reduce transaction and political risk, and accelerate innovation adoption. In sum, the thesis reframes influence not as a fixed sequence but as a market-aligned playbook for suppliers and system integrators, with relevance beyond construction wherever procurement mediates innovation.



Practical insights

The evidence indicates that, although technical uncertainties are tolerated and cultural resistance is easing, public clients ultimately prioritise demonstrable life-cycle value. Viability therefore trumps feasibility and desirability. Contractors can break this stalemate only by supplying audited 'cost-and-carbon' dashboards, involving engineering consultancies, certified pilots and then hard-wiring IFD metrics into procurement templates. A five-horizon pathway emerges: ignite internally with a small certified span and open data passport, flip external bias by forming a multi-contractor coalition and harvesting tool, prove at scale via ordinary-span interface tests and shared cost benchmarks, lock-in with 3-to-5-span bundles and framework contracts, and, finally, normalise IFD through open data portals and multi-owner agreements. Each horizon is gated by an explicit go/no-go check to limit sunk costs and keep investment tied to verifiable savings.

The recommended course of action is both new and pragmatic. It asks contractors to invert the usual waiting game and become demand shapers: generate the viability evidence that clients lack, convene coalitions that can show sector wide development, and translate modular aspirations into off-the-shelf award criteria. First steps include completing the already-started pilot span with third-party certification, launching a public cost-carbon dashboard built on open formulas, and inviting peer contractors and advisory engineers into a neutral "family harvesting" working group. Provincial client clusters and certifying bodies should be recruited early, because they transform proof into policy and help navigate procurement-law constraints. Key limitations: free-rider risk, policy volatility, accounting rules that hide residual value, will be reduced, however stay present.



If Heijmans act now, as can be seen in the timeline underneath, they will enter the coming renewal peak with proven value, visible proof and policy alignment, positioning themselves not merely as bridge builders on demand but as makers of the Dutch living environment. Delay will leave late movers scrambling for scarce labour and outdated techniques, while early adopters set the rules of the game. The sector therefore has a clear call to action: publish the numbers, build the pilot, form the coalition and let procurement follow the evidence.

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List of Abbreviations

Abbreviation	Full Term
BIM	Building Information Modeling
CAPEX	Capital Expenditure
CME	Construction Management and Engineering
CO_2	Carbon Dioxide
CPI	Consumer Price Index
DfD	Design for Disassembly
DVF	Desirability–Viability–Feasibility
ECI	Early Contractor Involvement
EMVI	Economically Most Advantageous Tender (Economisch Meest Voordelige Inschrijving)
EU	European Union
IBR	Integrated Bridge Replacement
IFD	Industrial, Flexible & Demountable
IenW	Ministry of Infrastructure and Water Management (Ministerie van Infrastructuur en Waterstaat)
IPD	Integrated Project Delivery
KPI	Key Performance Indicator
LCC	Life-Cycle Costing
MCDA	Multi-Criteria Decision Analysis
MKI	Milieu Kosten Indicator (Environmental Cost Indicator)
MIRT	Multi-year Programme for Infrastructure, Spatial Planning and Transport (Meerjarenprogramma Infrastructuur, Ruimte en Transport)
NEN	Netherlands Standardization Institute
NTA	Netherlands Technical Agreement
O&M	Operations & Maintenance
OPEX	Operating Expenditure
PC	Public Client
PMP	Project Management Plan
R&D	Research & Development
RWS	Rijkswaterstaat (Directorate-General for Public Works and Water Management)
TNO	Nederlandse Organisatie voor toegepast-natuurwetenschappelijk onderzoek (Netherlands Organisation for Applied Scientific Research)
UAV-GC	General Conditions for Design & Construct Contracts
V&R	Vervanging & Renovatie (Replacement & Renovation)

1 Introduction

Industrialised nations are entering a decisive renewal cycle: bridges built during the post-war boom are now surpassing their design lives, and deferred maintenance has accelerated their deterioration (Reitsema et al., 2020). TNO's 2023 (second) national prognosis underlines the gravity of the task: annual spending on bridge- and civil-asset renewals must rise from €1.1 billion in 2021 to about €3.7 billion by 2100, pushing the cumulative bill to roughly €260 billion and dwarfing historic maintenance budgets (TNO,2023). Studies show that limited, unstable funding, short planning horizons and political preference for new projects push upkeep down the agenda, leaving owners to "sweat the asset" until replacement becomes unavoidable (Smith, 2017; Reitsema et al., 2020). At the same time, rising traffic loads are stressing ageing components, prompting experts to warn of an impending wave of structural failures if large-scale replacement programmes are not advanced (Proske, 2022).

The construction industry, however, faces a concurrent labour shortfall that lengthens schedules and inflates costs, pressures felt most acutely on labour-intensive civil works (Chavan et al., 2024; Juricic et al., 2021). These twin constraints, ageing stock and shrinking workforce, have sharpened interest in Industrial, Flexible & Demountable (IFD) bridge systems, which promise factory-based efficiency, shorter road closures and future re-use of components.

Yet technology alone will not solve the problem. Research on public procurement reveals a persistent "ambition-specification gap": clients espouse innovation and sustainability at the strategic level but translate those ambitions into highly prescriptive tenders that limit contractors' room to propose novel solutions (Loosemore & Richard, 2015; Vestola et al., 2024). Over-detailed specifications, coupled with tight budget ceilings, discourage suppliers from investing in new methods and perpetuate incremental, bespoke designs (Vestola et al., 2024).

This thesis therefore shifts the analytical lens. Instead of asking only what public clients should demand, it asks how contractors can strategically influence the explorative phase, where ambitions, variant matrices and reference designs are set, to normalise IFD bridges despite fragmented governance and procurement inertia. Concretely, the study pursues three objectives:

1. Describe how the explorative phase of Dutch bridge-replacement projects is structured and which systemic factors decide whether alternative solutions reach tender.
2. Diagnose the specific barriers and levers that affect IFD adoption within that phase.
3. Design a practicable contractor pathway that aligns verifiable value, demonstrable feasibility and procurement reform, thereby reconciling client ambitions with supplier offerings.

The central research question becomes:

"How can contractors strategically influence the explorative phase of public bridge-replacement projects to stimulate the adoption of Industrial, Flexible and Demountable construction?"

By positioning contractors as proactive change agents this report aims to enrich academic discourse on demand-side innovation and to equip industry actors with a roadmap for delivering the Netherlands' next generation of bridges.

This report progresses from context to actionable insight, beginning with the problem framing and research design, advancing through theoretical groundwork and empirical findings, and concluding with a critical discussion and integrated conclusion. Each chapter therefore adds a distinct layer, introducing the challenge, explaining the methods, analysing the evidence, interpreting the results, and synthesising the practical pathway, so readers can trace the full logic from research question to final recommendations.

2 Research approach

This chapter outlines the research approach and methodology used to investigate how contractors can strategically influence the explorative phase of public bridge replacement projects to stimulate the adoption of Industrial, Flexible, and Demountable (IFD) construction. It begins by presenting the problem definition, followed by the research goal, research questions, and the overarching research strategy.
The research is conducted in collaboration with Heijmans, one of the Netherlands' leading construction companies. Heijmans actively promotes innovation in the sector and is committed to sustainability by implementing industrialized and modular construction techniques that enable customized, low-waste infrastructure solutions (Heijmans, n.d.). Their strategic aim is to contribute to a healthier living environment, and their experience in infrastructure and strong network in the public sector make them a valuable partner in shaping IFD-related innovation. However, the successful implementation of IFD construction depends not only on technical solutions but also on navigating demand-side complexities, including how public clients plan, procure, and manage infrastructure replacements. This research provides actionable insights into how Heijmans and similar contractors can align with or influence these dynamics to accelerate the transition toward modular and sustainable construction in the Dutch infrastructure sector.

2.1 Problem definition

Globally, industrialized countries face a significant challenge in replacing aging bridge infrastructure (Reitsema et al., 2020). Many bridges constructed during the mid-20th century are now exceeding their designed service lives, leading to increasing risks of structural failures and necessitating large-scale replacement programs (Reitsema et al., 2020). Deferred maintenance further exacerbates this challenge. Several key factors contribute to deferred maintenance, including insufficient and unstable funding allocations, limited long-term strategic planning, and political prioritization of new projects over maintaining existing infrastructure (Smith, 2017; Reitsema et al., 2020). Additionally, decision-making barriers, such as a lack of technical expertise and the tendency to prioritize short-term cost savings over long-term asset management, further delay necessary maintenance activities (Smith, 2017; Reitsema et al., 2020). Neglected upkeep accelerates structural deterioration, contributing to an impending wave of bridge replacements (Smith, 2017; Reitsema et al., 2020). Moreover, increasing traffic loads and the deterioration of structural components have made replacement and rehabilitation unavoidable (Proske, 2022).

Simultaneously, the construction industry is confronted with significant labour shortages. This issue negatively affects project timelines, escalates costs, and reduces overall productivity, especially within infrastructure sectors that are heavily labour-dependent (Chavan et al., 2024; Juricic et al., 2021). The growing mismatch between labour supply and demand complicates the ability of contractors to efficiently deliver infrastructure projects (Juricic et al., 2021).

Given these interconnected issues, aligning procurement practices closely with client ambitions is crucial to stimulate suppliers and contractors to propose innovative and sustainable solutions (Vestola et al., 2024). However, current client demands are often not sufficiently stimulating to encourage the development of innovative and sustainable solutions (Loosemore & Richard, 2015). Public clients frequently exhibit mismatches between their stated ambitions for innovation and sustainability at the strategic (macro) level and the detailed specifications they include in tender documents (micro-level) (Loosemore & Richard, 2015; Vestola et al., 2024). These overly detailed specifications, combined with stringent budgetary constraints, often restrict contractors' ability to propose and realize innovative solutions, thereby hampering long-term infrastructure improvements (Vestola et al., 2024). This mismatch between client ambitions and supplier offerings can result in suboptimal outcomes, limiting the potential for efficient and future-proof bridge replacements.

2.2 Conceptual Framing of Research

The relationship between the central research concepts is shown in Figure 0. This simplified conceptual framing illustrates how the study investigates the two concepts: 1) Strategic Contractor Influence and 2) Adoption of IFD Construction. This results in the mechanisms through which *strategic contractor influence* can stimulate the *adoption of IFD construction* within the context of the *explorative phase* of public bridge replacement projects.

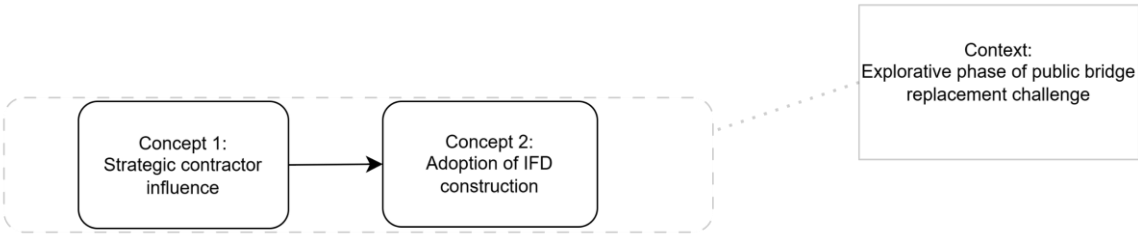

Figure 0 Basic conceptual framing of the research concepts

The complete conceptual model is in appendix C, but I'm struggling to move everything that is under the enabling conditions to concept 1 because those are in fact the mechanisms that are contractor influence. And the other struggle is then how to align that with the 'strategicness' with the levers social, technical and political, as explained in 4.3

2.3 Research Questions

2.3.1 Main research question

How can contractors strategically influence the explorative phase of public bridge replacement projects to stimulate the adoption of Industrial, Flexible, and Demountable (IFD) construction?

2.3.2 Sub questions

Answering the main research question requires addressing the following sub-questions:

1. How is the explorative phase structured in public bridge replacement projects, and what key factors influence the evaluation of potential construction solutions?
2. What specific challenges and opportunities arise in integrating IFD construction within the explorative phase?
3. How can contractors strategically engage and influence the explorative phase to enhance the consideration of IFD construction solutions?

2.4 Research Goal

The goal of this research is to identify and categorize methods through which contractors can exert strategic influence during the explorative phase of public bridge replacement projects to stimulate the adoption of IFD construction. The study aims to provide a structured overview of possible influence mechanisms and to develop a strategic pathway that contractors can follow to actively contribute to the adoption of IFD.

3 Research methodology

This chapter outlines the methodological approach adopted to investigate how contractors can strategically influence the explorative phase of public bridge replacement projects to stimulate the adoption of Industrial, Flexible, and Demountable (IFD) construction. Given the complex and context-specific nature of innovation uptake in public infrastructure, a qualitative, exploratory design was chosen to uncover mechanisms of contractor influence as perceived by actors across the Dutch infrastructure sector.

The chapter begins by detailing the overall research design and theoretical foundation, followed by an explanation of the participant selection strategy and data collection methods. Subsequent sections describe the analytical approach applied to the interview data, followed by reflections on research validity, ethical considerations, and methodological limitations.

3.1 Research design

This study adopts a qualitative and exploratory research design, aimed at uncovering underexamined mechanisms through which contractors can influence the explorative phase of public bridge replacement projects to support the adoption of Industrial, Flexible, and Demountable (IFD) construction. The research responds to the complex, emergent nature of modular and demountable construction in the Dutch infrastructure sector, where contractor' pushed innovation uptake is shaped by sectoral, institutional, organizational, and project-level dynamics that are not well captured in existing literature.

The research design combines a theory-informed foundation with field-based inquiry. A comprehensive literature review was conducted to define the characteristics and decision dynamics of the explorative phase, identify enabling conditions for IFD adoption, and map possible strategic levels of contractor influence. This review also produced a structured overview of mechanisms that may support the uptake of IFD construction, categorized across six key domains: social acceptance and cultural perceptions, procurement, supply-chain integration, institutional readiness, finance and risk, and technology and data. These theoretical insights informed both the conceptual framing of the study and the thematic design of the subsequent interviews.

To capture the nuanced and often informal character of contractor influence in practice, the study proceeded in two empirical stages. The first involved explorative fieldwork, including informal and formal interviews with practitioners at Heijmans engaged in innovative infrastructure projects (the TenneT Bay Replacement Program and a circular modular approach to guiderail replacement), participation in sectoral events such as the Bruggen Festival, and attendance at innovation workshops organized by Heijmans for public clients. This phase helped validate the relevance of initial themes and identify key actors and strategic entry points.

The second stage consisted of semi-structured interviews with strategically positioned experts from public clients, engineering firms, knowledge institutions, and Heijmans itself. These interviews aimed to identify stakeholder perceptions of IFD, assess enabling or constraining conditions within the institutional environment, and uncover concrete methods through which contractors can influence innovation-related decisions in the explorative phase. Rather than testing predefined hypotheses, the research tries to deliver strategies grounded in empirical insights from practice and experts, structured across system levels and categorized according to the nature of their initiation (formal/informal, client-/contractor-driven), strategic lever (technological, social, political), strategic level (project, organisational, institutional and sectoral) and their contribution to desirability, viability, and feasibility (DVF) dimensions for implementing IFD adoption.

3.2 Participant selection

The selection of interview participants was guided by the research objective of understanding how contractors can strategically influence the explorative phase of public bridge replacement projects to promote the adoption of Industrial, Flexible, and Demountable (IFD) construction. Since this influence is exercised through interactions with clients, consultants, and institutional actors, the research focused on gathering insights from strategically positioned stakeholders who operate at different levels of the Dutch infrastructure ecosystem.

Participants were drawn from four key actor categories: (1) Heijmans, as the collaborating contractor and initiator of several innovation-oriented initiatives; (2) public clients, who shape project demands and procurement environments; (3) engineering firms, who often act as intermediaries and advisors during the explorative phase; and (4) knowledge institutes or policy-aligned entities involved in setting standards or facilitating innovation dialogues. Within the public clients a distribution was made to cover the diversity of clients and create some, even though no statistically relevant, robustness for possible relations between clients.

Participants were selected using purposive sampling, based on three core criteria:

- A demonstrated mandate for innovation or close area's within their organization (e.g., innovation lead, V&R lead, asset manager etc),
- A strategic position with influence or oversight on decision-making in early project phases,
- A comprehensive overview of sectoral developments, including familiarity with innovation trajectories such as IFD.

The pool of interviewees was assembled through multiple channels. Several participants were identified through informal contacts made during the Bruggen Festival, a networking event for the Dutch bridge sector. The majority were introduced via the researcher's Heijmans supervisors, who leveraged their professional networks to connect the study with actors experienced in (IFD-related) innovation. Additional participants were found through the online knowledge-sharing platform Bruggen. This combination of sectoral engagement and referral-based recruitment enabled access to a diverse and strategically relevant group of experts.

The interviewees included individuals involved in developing or evaluating innovative approaches to modularity, flexibility, or demountability in infrastructure delivery, including those with experience in policy implementation, procurement design, or technical innovation.

All interviews were anonymized in the analysis and reporting stages to protect the confidentiality of individual responses. However, in the case of public-sector participants, responses are contextualized based on organizational characteristics to enable analytical comparison across client types while still ensuring that individual interviewees cannot be identified. Given the uniqueness of some organisations its possible that these can be identified, this was discussed with given participants.

This careful selection and anonymization approach allowed the research to generate nuanced, empirically grounded insights into the strategic dynamics of IFD adoption, while safeguarding ethical and professional standards. To ensure the completeness and legal grounds, an informed consent form was produced and distributed. This form is available in appendix B.

3.3 Data collection methods

The empirical basis of this study consists of a series of semi-structured interviews with strategically selected actors involved in public bridge replacement projects in the Netherlands. These interviews were designed to elicit expert insights into how contractors can influence the explorative phase of such projects to promote the adoption of Industrial, Flexible, and Demountable (IFD) construction. The data collection process was informed by the conceptual model developed through the literature review, which identified six key domains relevant to IFD adoption: social acceptance, procurement, industry ecosystem, institutional readiness, finance and risk, and technology and data.

Interviews followed a semi-structured format, allowing for a consistent thematic focus while retaining flexibility to explore case-specific experiences, organizational roles, and strategic reflections. Questions were designed to allow for embedded variation, enabling the interviewer to adapt follow-up questions to each respondent's expertise and organizational context. This approach aligns with Adeoye-Olatunde and Olenik's (2021) recommendation that semi-structured interviews be shaped by a conceptual framework, while still allowing researchers to explore unanticipated but relevant themes as they arise. The interviews therefore progressed from descriptive process mapping to normative reflection, and from actor-specific experiences to system-level analysis, ensuring both depth and theoretical coherence.

Interviews were conducted in person or via video conferencing, depending on participant availability and preference. All interviews were conducted in Dutch, recorded if consent was given, and transcribed verbatim (if possible) to preserve the integrity of the data. The interviews typically lasted between 45 and 75 minutes. Anonymity was guaranteed to all participants, with the exception that responses could be contextualized by organizational type (e.g., national agency, municipality) to support analytical comparisons across governance structures, unless stated otherwise.

In total, 13 semi-structured interviews were conducted with the following distribution of representatives: 1x Heijmans, 10x public clients, 1x engineering firms, and 2x experts within the sector. This data collection phase was concluded once thematic saturation within the frames of a master thesis was reached, meaning that all categories actors that possibly would have new perspectives were heard.

While some scholars argue that sharing interview questions in advance can enhance reflexivity and reduce anxiety (Haukås & Tishakov, 2024), this study opted to withhold the full question list to preserve the spontaneity and authenticity of participants' responses. As Haukås et al. (2024) note, pre-disclosure may lead to participant bias, overly curated narratives, and reduced emotional immediacy, particularly when participants feel compelled to tailor their responses to perceived expectations. Given the study's focus on uncovering how influence strategies operate in practice, the current state of the sector in their opinion and their experiences, maintaining openness in the interview encounter was considered essential for capturing unfiltered, practice-based insights.

In sum, purposive sampling, flexible yet theory-guided interviewing, a panel fit for saturation and pre interview strategies have yielded a corpus of thirteen rich transcripts; the logical next step is to make transparent how the interview structure itself was operationalised academically, this will be done in the next subsection.

3.4 Interview structure

The following subsection unpacks the internal architecture of that structure, tracing how each question and probe was crafted, sequenced, and refined to translate the conceptual model into practice. The structure of the questions can be found in appendix A.

Following the five-phase framework for developing a rigorous semi-structured interview guide, identifying prerequisites, retrieving prior knowledge, formulating the preliminary guide, testing and presenting the final guide (Kallio et al., 2016), the present study arranged its question schedule in a progressive order that moves from rapport-building to in-depth exploration.

A introduction about the research was done via a visual information sheet that quickly generated a complete overview of the research direction. This was followed by an initial warm-up question, grounded in participants' everyday context that 'breaks the ice' and helps interviewees relax before core items (Naz et al., 2022). Each thematic block of questions consisted of a main open question followed by pre-scripted and improvised probes; these 'gentle nudges' include verbal repetition and strategic silence to encourage elaboration without leading responses (Kallio et al., 2016).

The preliminary guide was refined through internal checks, allowing ambiguous wording to be removed and questions to be realigned with the study aims, thereby enhancing credibility and dependability (Kallio et al., 2016).

Throughout data collection informational saturation was monitored, understood as a check for reaching the point at which additional interviews no longer yielded substantively novel insights. By comparing analytic memo's after each session; once successive conversations became redundant the interview phase seemed successful based on saturation. This practice is consistent with qualitative recommendations for saturation-based sampling (Guest et al., 2020; Hennink et al., 2017). Minimizing cognitive load was done as the interview process progressed, a procedural adjustment not documented in the interview structure in appendix A.

Collectively, this structure aligns the interview protocol with established methodological guidance while demonstrating reflective adaptations that strengthen the trustworthiness of the resulting data. This resulting data will be processed and analysed by the steps in the next subsection.

3.5 Data analysis

This subsection describes how the interview material was transformed into a set of analytically categories. It outlines the mechanics of the analysis only; the substantive results follow in chapter . This method was based on the data analysis technique used by Pas et al. (2019).

Step	Purpose	Main actions	Output
1. Preparation	Create a transparent data trail	· Transcribed 12 interviews verbatim. · Assigned line numbers and speaker tags (e.g., *ENG3*, *PC10P*).	Clean, traceable corpus.
2. First-order (open) coding	Stay close to participants' language	· Line-by-line transcript analysis. · Highlighted fragments that expressed a single idea. · Attached *in-vivo* labels taken directly from the quotation (e.g., "*site-visits & kennissessies*").	≈ 150 first-order codes anchored in transcripted data.
3. Second-order (theoretical) coding	Abstract recurring incidents into concepts	· Compared first-order codes across transcripts. · Merged synonyms and clarified overlaps. · Re-named labels in more general terms (e.g., Experiential marketing, Knowledge seeding).	c. 60 second-order concepts refined to 10 stable thematic categories after iterative saturation checks
4. Aggregate dimension building	Link concepts to the research question	· Clustered related second-order concepts into broader themes that address the thesis question and capture the overarching . · Three aggregates (*Cultivate, Configure, Convince*) were retained when no new themes emerged.	3 aggregate dimensions.

Table 1 Structure data analysis

3.5.1 Preparatory work

All twelve semi-structured interviews were audio-recorded and transcribed verbatim in Dutch. Each line of the transcript was assigned a speaker number, a public client (PC) or engineering firm code code that reflects both the actor group and the organisational tier (e.g., ENG3 = engineering consultancy; PC10P = provincial public client). These identifiers allow every later code to be traced straight back to its original utterance, creating an auditable data trail. All files were stored in a version-controlled folder structure (date-stamped sub-folders for raw audio, clean transcript and coded transcript), so earlier stages can be reconstructed if needed.

3.5.2 Cycle 1 – first-order (open) coding

The first analytic sweep was intentionally descriptive. Reading line-by-line, highlighted each fragment that expressed a single idea about the explorative phase or about IFD more broadly. I then attached an in-vivo label: usually a direct phrase used by the interviewee (e.g., “site-visits en kennissessies,” “USB-stekker-metafoor”). When a fragment did not contain a clear label of its own, I coined a short literal description.

This cycle generated circa 150 distinct first-order codes. The total is smaller than the theoretical maximum (12 interviews × 20 excerpts) because many incidents repeated across interviews and were deliberately given the same label to avoid inflation.

3.5.3 Cycle 2 - second-order theoretical coding

In the second pass I compared first-order labels across all transcripts, merging overlapping codes and renaming them in more abstract, theory-oriented terms (e.g., “site-visits en kennissessies” → Experiential marketing). This produced a preliminary set of ≈ 60 distinct second-order concepts. To avoid fragmenting the analysis and to demonstrate theoretical saturation, I then collapsed conceptually related items and retained only those themes that recurred across at least two interviews and added distinct analytical value. This process yielded ten stable second-order themes, each grounded in multiple excerpts and aligned with the study’s conceptual framework (Guest et al., 2020).

3.5.4 Cycle 3 - aggregate-dimension building

The third cycle linked these ten second-order themes back to the central research question: “How can contractors strategically influence the explorative phase…?” Related themes were grouped under three strategic logics, Cultivate, Configure, and Convince, each of which remained stable after two full iterations with no new themes emerging.

At this stage it was verified that every first-order code could be traced upward to a second-order concept and, in turn, to one of the three labels. No codes remained without aggregates, indicating structural completeness.

3.6 Validity and Reliability

To ensure that the findings rest on trustworthy evidence, the study was designed around three widely used qualitative quality criteria: credibility, dependability and transferability. Each adapted to the scale of a single-researcher master's project.

Credibility was strengthened through line-by-line coding and saturation checks (Guest et al., 2020) and through systematic theme reduction: second-order labels were only retained if they recurred in multiple interviews and contributed unique insight, yielding ten robust themes.

Dependability was addressed with a stable, three-step coding protocol applied uniformly to every transcript: (1) open coding, (2) theoretical coding, and (3) aggregation into higher-order dimensions.

Transferability was enhanced through maximum-variation sampling. The interview set intentionally spans an engineering firm, two independent experts, and public clients at national, provincial, and municipal levels. This breadth increases the likelihood that the resulting themes resonate beyond a single organisation or governance tier.

Together, these modest but explicit procedures provide a clear chain of evidence from raw interview text to the final coding structure, underpinning the validity and reliability of the study's conclusions.

3.7 Ethical considerations

The project involved professionals discussing their organisations' procurement strategies, a topic that can carry reputational and commercial sensitivities. The following measures were therefore taken to safeguard the rights and interests of all participants.

- Informed consent

  Each interviewee received an information sheet describing the study aim, the voluntary nature of participation, the use of audio-recording, and the right to withdraw at any time without consequences. Consent was confirmed in writing (e-mail reply) before the interview and reconfirmed verbally when recording started.

- Confidentiality and anonymity

  Personal names were never recorded. Organisations are referred to only at the level necessary for analytical sense (engineering firm, national agency, provincial client, municipal client, or expert). Interview codes (e.g., PC10P) prevent direct traceability while still indicating the actor group and governance tier relevant for interpretation. Direct quotations used in the thesis were edited to remove project identifiers or commercial details.

- Data protection

  Audio files and transcripts are stored on the university's secure cloud environment, accessible only to the researcher and the academic supervisor. Files are encrypted at rest and will be deleted five years after thesis submission, in line with the university's research-data policy.

- Risk assessment

  Because the interviews focused on professional rather than personal matters, the study poses minimal risk. The main ethical concern is inadvertent disclosure of organisational strategy. This risk is mitigated by the anonymity protocol and by allowing participants to review any quotation selected for publication.

- Ethical approval

  The study protocol, consent form and information sheet were reviewed and approved by the Faculty Ethics Committee before data collection commenced.

These measures ensure that the study meets the ethical expectations for a master's-level thesis while protecting the confidentiality and autonomy of all participants.

4 Theoretical background

This chapter reviews the key bodies of theory and evidence that underpin our exploration of IFD adoption in bridge replacement projects. We begin by dissecting the “front-end” or explorative phase (§ 4.1), where early choices set the trajectory for technical, economic, and institutional outcomes. We then introduce the concept of Industrial, Flexible & Demountable (IFD) construction (§ 4.2), identifying its core principles and the six interdependent domains that enable its uptake. Next, we examine how contractors can strategically influence IFD adoption across multiple levels of the infrastructure system (§ 4.3), before presenting the Desirability-Viability-Feasibility (DVF) framework as a tool to prioritize and sequence interventions (§ 4.5). Throughout, we draw on both established literature and recent Dutch practice to build a comprehensive lens for the practical recommendations that follow in Chapter 5.

4.1 The Explorative Phase in Bridge Replacement Projects

The explorative phase, often termed the “front-end”, spans from the first spark of an idea through to the formal go-ahead for detailed design. It is in this window that project purpose is clarified, alternative solutions are framed, and critical path-dependencies begin to form. Decisions made here under conditions of uncertainty not only shape immediate feasibility and cost but lock in long-term adaptability, lifecycle performance, and stakeholder alignment. In what follows we define the contours of this phase (§ 4.1.1), examine how uncertainty and lifecycle thinking interact to challenge linear planning (§ 4.1.2), and analyze how governance structures and risk aversion, both procedural and cultural, can either enable or stifle innovation (§ 4.1.3). We then map the principal actors whose resources and incentives determine whether flexible, demountable options remain alive or are quietly closed off (§ 4.1.4). Together, these perspectives establish why the front-end deserves both strategic attention and tactical leverage in any push toward Industrial, Flexible & Demountable bridge solutions.

4.1.1 Definition and Strategic Importance of the Explorative Phase

The explorative phase, commonly referred to as the “front-end” in project literature, is defined as the period between the initial emergence of a project idea and the formal decision to proceed with implementation. During this phase, the project’s purpose is clarified, feasibility is assessed, and the strategic foundation for success is laid. Williams et al. (2019) emphasize that this phase involves crucial decisions under uncertainty and incomplete information, often determining a project’s long-term performance and adaptability.

A key feature of the front-end is its dual nature: it offers significant flexibility for shaping alternatives, yet early decisions tend to create path dependencies that restrict future options. Williams et al. (2019) stress that early lock-in effects can arise from framing decisions or pre-emptive commitments, making it difficult to reorient the project later without major cost or delay.

Molaei et al. (2021) further argue that the explorative phase is not linear or merely procedural, but dynamic and sense-making in nature. It involves cycles of reframing and institutional alignment, in which legal, societal, and governance considerations play an integral role. Their findings suggest that the value potential of this phase lies not only in problem analysis, but also in facilitating cross-actor learning and agenda alignment.

This perspective is institutionalized in the Dutch infrastructure context. The Ministry of Infrastructure and Water Management (IenW, 2022) formally defines the verkenningsfase as a mandatory step in the MIRT planning procedure. Its purpose is to generate a sustainable and broadly supported preferred decision by assessing long-term societal goals, legal constraints, and strategic alternatives in a participatory manner.

Despite this recognition, the explorative phase often falls short of its potential in practice. Shi et al. (2020) identify how institutional fragmentation, rigid governance routines, and short-term performance pressures can hinder early-stage exploration. Their case analysis shows that even when formal procedures are followed, strategic flexibility and long-term public value are frequently undermined by path-dependent behavior.

Vuorinen et al. (2019) provide a further critique by emphasizing that early-stage decisions are often shaped by conflicting value orientations. Their work reveals tensions between efficiency goals and broader public value agendas, which are rarely resolved during the front-end. They argue that unless such tensions are explicitly addressed, early choices risk institutionalizing misalignment between project outcomes and societal expectations.

In a similar vein, Vosman et al. (2023) point out that early project phases increasingly take place within complex ecosystems of actors, each with partial control and differing temporal logics. They argue that fostering a “collaborative infrastructure” during the front-end is essential to avoid fragmentation and support durable alignment across public and private stakeholders.

In sum, the explorative phase is a formative and politically sensitive stage of infrastructure development. It offers high leverage for shaping adaptive and sustainable project trajectories, but also carries the risk of premature lock-in. The strategic relevance of this phase depends not only on procedural thoroughness, but on the capacity to confront institutional complexity, align divergent values, and embed decisions within broader societal goals. This logic is also reflected in the typical structure of Dutch infrastructure projects, where the explorative phase precedes formal design preparation and includes key activities such as market exploration, evaluation of solution directions, multi-criteria decision analysis (MCDA), and the selection of a preferred alternative (IenW, 2022; see Figure 1).

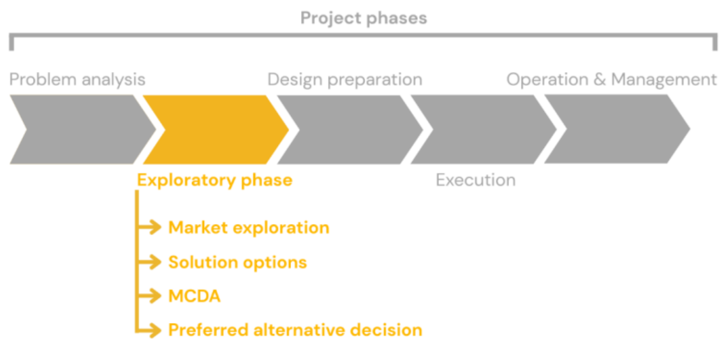

Figure 1 Exploratory phase in project phases

4.1.2 Decision-Making Under Uncertainty and Lifecycle Thinking

Decision-making in the explorative phase of infrastructure projects is deeply shaped by uncertainty, particularly in bridge replacement projects where the long operational lifespan of assets magnifies the consequences of early decisions. These early choices determine not only initial performance but also long-term adaptability, maintenance demands, and structural resilience (Biondini & Frangopol, 2016). To address these complexities, lifecycle-oriented approaches are increasingly promoted to integrate long-term risks and opportunities into early project planning. Qazi et al. (2019) argue that uncertainty should be understood not merely as a threat but as a dual-natured condition encompassing both risks and opportunities. They emphasize the importance of recognizing the interdependencies between technical, economic, institutional, and social uncertainties, as these interactions significantly influence project outcomes. Viewing uncertainty as a dynamic and interconnected feature of infrastructure systems is therefore essential to enable resilient and future-proof design strategies from the outset.

Institutional uncertainty is particularly salient in innovation-oriented contexts. Wuni et al. (2019) observe that evolving or ambiguous legal frameworks often hinder the adoption of novel solutions. In early-stage decision-making, this can lead to reluctance toward modular or demountable methods, given perceived approval risks and misalignment with existing standards. Such ambiguity may delay or prevent the uptake of otherwise viable alternatives.

Social and stakeholder-related uncertainty also plays a crucial role in shaping early project trajectories. Pervez et al. (2022) highlight that innovative construction methods often challenge established stakeholder expectations and routines. If unaddressed, this may provoke resistance and erode legitimacy. As Riemann et al. (2014) argue, such uncertainty is not merely procedural but also value-based. Early engagement must therefore address deeper tensions between competing stakeholder interests, rather than settling for superficial consensus.

Economic uncertainty further complicates the evaluation of early design alternatives. Shahpari et al. (2020) stress that lifecycle costing and scenario-based modeling are essential for managing financial unpredictability, especially for prefabricated or modular systems. These tools enable decision-makers to move beyond short-term budget constraints and to assess long-term performance, adaptability, and maintenance requirements. Lifecycle planning involves anticipating performance degradation, risk evolution, and changing environmental conditions, often over several decades (Ilg et al., 2017; Biondini & Frangopol, 2016). However, Van Wijck et al. (2018) caution that such models are frequently overlooked in practice, especially when responsibilities are fragmented or long-term incentives are not institutionally embedded.

Residual service life assessments represent a particularly relevant tool in this context. Bajaj et al. (2021) argue that rather than focusing solely on whole-asset replacement, component-level evaluations allow project teams to assess the remaining functional value of specific elements such as girders, decks, or supports. This approach aligns with IFD principles of modularity, circularity, and adaptability by supporting selective reuse or replacement of components.

Yet, the capacity to implement robust long-term planning varies considerably across public authorities. Amador-Jimenez et al. (2021) show that local and municipal clients often face institutional and financial limitations that restrict their ability to apply lifecycle-based strategies. In contrast, national agencies typically benefit from more stable governance, technical expertise, and access to long-term funding (Liu et al., 2019). Governmental capacity is thus a critical enabler of lifecycle-oriented planning, encompassing not only analytical tools and data availability but also the skills required to interpret and operationalize such insights.

Lifecycle thinking is also essential to mitigate the risk of premature lock-in. Williams et al. (2019) note that early decisions tend to create irreversible trajectories. Moreover, Love et al. (2014) demonstrate that this phase is marked by optimism bias and underestimated rework risks, with front-end decisions often based on narrow cost and time projections that obscure the full extent of future uncertainty. In this context, the limited consideration of genuinely different alternatives becomes especially problematic. Empirical findings from Norwegian infrastructure projects show that in two-thirds of the cases, only variants of a single solution direction were explored, rather than fundamentally different alternatives (Wondimu et al., 2019). This narrow framing severely restricts the space for modular or demountable concepts like IFD to emerge, reinforcing conventional choices even in situations where long-term adaptability would be advantageous.

Finally, Ishtiaque et al. (2024) critique early-phase evaluation models for being overly static and deterministic. These models, they argue, often fail to reflect the dynamic nature of uncertainty and limit adaptive capacity in later stages. In line with Qazi et al. (2019), they advocate for framing uncertainty not solely as a threat but as a dynamic opportunity space capable of generating innovative outcomes.

In summary, effective decision-making in the explorative phase demands the integration of systemic uncertainty assessment with lifecycle-oriented evaluation frameworks. This includes the early identification of long-term risks and opportunities, the use of component-level tools such as residual service life assessments, and the institutional capacity to embed such practices into public sector governance. Without these conditions, uncertainty will continue to be simplified, sidelined, or mismanaged, undermining long-term value creation.

4.1.3 Governance and Risk Aversion

Governance frameworks play a crucial role in shaping how uncertainty and innovation are managed during the explorative phase of infrastructure projects. Particularly in public sector environments, governance arrangements are both a structural enabler and a constraint. Vosman et al. (2023) describe the Dutch infrastructure sector as institutionally fragmented and dominated by project-based logic, which undermines the continuity required for project-transcending innovation. The tendency to isolate projects within strict procurement procedures limits possibilities for collaborative learning and constrains innovation to the boundaries of individual tenders.

Risk aversion further reinforces these structural constraints. Boersma (2018) observes that Dutch public authorities often exhibit a culture of procedural caution, where managing accountability and minimizing legal exposure take precedence over fostering innovation. This risk-averse orientation is particularly problematic in early project phases, where uncertainty is unavoidable and innovation depends on flexibility. As a result, public actors tend to fall back on standardized proven solutions, even when alternatives such as modular or demountable construction may offer superior lifecycle performance.

This tension between control and exploration is a recurring theme in infrastructure governance. Sergeeva et al. (2019) emphasize that overly rigid governance arrangements suppress adaptive learning and experimentation, particularly in technically complex projects. In such environments, project actors often prioritize compliance with predefined procedures over iterative problem solving, thus impeding the incorporation of innovative or unfamiliar approaches during the explorative phase.

Institutional capacity also limits what can be achieved in the front end. Gullmark (2021) distinguishes between routinized and entrepreneurial innovation capabilities within public sector organizations. While routinized capabilities ensure procedural stability, entrepreneurial capacity is essential for cross-boundary collaboration, iterative learning, and adaptive planning. In the Dutch context, such capacities vary across governance levels. Rijkswaterstaat (RWS), as a national infrastructure agency, typically has greater organizational continuity, technical expertise, and access to discretionary resources than most municipalities, which often face fragmented responsibilities and limited in-house expertise (Boersma, 2018; Van Wijck et al., 2018). However, this institutional capacity does not necessarily translate into structural innovation leadership. As Boersma (2018) and Van Wijck et al. (2018) observe, even RWS remains embedded in procedural and risk-averse governance routines that restrict the potential for experimentation and adaptive design. As a result, both national and local public clients face constraints in supporting innovation during the explorative phase, albeit for different institutional reasons.

Leadership can play a pivotal role in navigating these constraints. Lewis et al. (2017) show that strong leadership practices, focused on enabling cross-sector collaboration, fostering strategic learning, and creating protected spaces for experimentation, are more influential than formal governance reforms alone. Yet in many Dutch public organizations, such leadership is constrained by institutional norms and accountability frameworks that limit discretionary action, making it difficult to deviate from procedural routines or create room for innovation (Boersma, 2018).

Procurement design is another mechanism through which governance limits innovation. Eriksson et al. (2022) and Wondimu et al. (2016, 2019) argue that traditional performance-based procurement models often prioritize short-term cost efficiency and risk transfer, thereby discouraging early-stage exploration and contractor involvement. Wondimu et al. (2018) emphasize that, in general, rigid separations between design and execution phases and a lack of incentives for early contractor input can hinder the adoption of innovative practices such as IFD construction. While their study is not specific to the Dutch context, similar patterns have been observed in Dutch infrastructure governance. Boersma (2018) notes that public clients in the Netherlands often rely on tendering procedures that leave limited room for co-development or early market dialogue. Similarly, Van Wijck et al. (2018) point out that procurement frameworks in the Dutch infrastructure domain frequently fail to operationalize lifecycle ambitions, resulting in a disconnect between early decisions and long-term performance goals.

In summary, governance in the explorative phase of infrastructure projects is marked by structural fragmentation, institutional risk aversion, and procedural rigidity In the Dutch context specifically, these constraints are reinforced by procurement routines and accountability structures that prioritize procedural compliance over exploratory or outcome-oriented approaches, thereby limiting the space for innovation (Boersma, 2018; Lewis et al., 2017). Overcoming these challenges requires strengthening institutional learning, leadership, and inter-project continuity, and rethinking procurement logic to enable adaptive and collaborative exploration of sustainable infrastructure solutions.

4.1.4 Actors in the arena

The explorative phase is neither a tabula rasa nor a purely technical exercise; it is shaped by a finite set of organisations that possess the authority, resources and motivation to keep, or choke, Industrialised, Flexible & Demountable (IFD) options alive. This sub-section therefore distils who those actors are, what they control, and why they matter. The resulting clusters offer a conceptual baseline against which the interview-based insights will be contrasted.

#	Actor cluster	Typical resources	Dominant incentive during explorative phase	Core evidence
1a	**Client Asset-management units (OPEX)**	Condition data; O&M budgets	Minimise life-cycle cost and network downtime	Boersma (2018); Krane et al. (2014)
1b	**Client Project / CAPEX delivery teams**	Capital budgets; political visibility	Deliver visible projects on time and budget, favouring scope certainty	Lenferink et al. (2014); Boersma (2018)
2	**Contractor**	Serial-production capacity; supply-chain control	Capture margin through repeatable modular solutions	Azhar et al. (2013); Lam & Gale (2024)
3	**Engineering consultancies**	Variant studies; conformity assessment	Shape design space through advice; police compliance ex-post	Boersma (2018); Hofman et al. (2009)
4	**Component suppliers / manufacturers**	Proprietary modular elements; logistics networks	Secure demand for standard sections; push dimensional harmonisation	Feldmann et al. (2022); Gosling et al. (2016)
5	**Knowledge & standardisation brokers**	Convening power; norm-setting authority	Translate niche experiments into regime-compatible templates	Goulding et al. (2014); Lember et al. (2019)
6	**Regulatory & political actors**	Budget veto; permitting power	Balance fiscal prudence with societal targets	Feldmann et al. (2022)
7	**Community / traditional authorities**	Local legitimacy; cultural capital	Safeguard heritage; seek socio-economic benefits	Dansoh et al. (2020)

Table 2 Actors in the arena

- Cluster 1 Public asset-management and project-delivery units

Empirical studies of infrastructure governance show that public owners often separate OPEX-oriented asset-management departments from CAPEX-driven project-delivery teams, each operating under distinct KPIs and budget logics (Johansen et al., 2016; Hueskes et al., 2017). Although both are embedded in the same public organisation, the routines and key performance indicators differ markedly. Asset-management units steward long-term network performance, drawing on condition-monitoring data and lifecycle-cost thinking (Krane et al., 2014). Project teams, by contrast, operate in a politically exposed environment: their success is measured in timely delivery of visible actions, which can incentivise early scope-freeze and path-dependence (Lenferink et al., 2014).

- Cluster 2 System integrators / contractors

Contemporary studies suggest that vertical fragmentation in the Dutch construction sector often curtails contractors' early-stage involvement, limiting opportunities to shape production-oriented modular concepts (Azhar et al., 2013). In addition, prevailing procurement norms generally remunerate contractors only for delivering work packages explicitly priced in the tender, offering little compensation for development activities outside the tender scope (Laryea & Watermeyer, 2016).

Tier-one Dutch contractors, such as Heijmans, possess integrated design–build capacity and, on paper, could potentially realise IFD economies of scale. In practice, however, several structural conditions appear to limit this potential:

- Fragmented project pipeline: Many bridge-replacement contracts are still let as single assets. Learning-curve benefits typically emerge only after at least three comparable units, a threshold that current tender calendars seldom reach, echoing the scale-economy barrier highlighted by Azhar et al. (2013).
- Strict contractual rulebook: Mandatory compliance with rules like UAV-GC 2005, the Aanbestedingswet 2012 and Eurocode load models tends to narrow the design envelope for proprietary modules and can shift a relatively high share of risk to contractors (Masmeijer, 2021).
- Limited cross-project learning: Competitive isolation and short Early Contractor Involvement (ECI) windows may restrict knowledge carry-over; sector-wide assessments continue to flag limited learning across sequential projects (Lam & Gale, 2024).
- Deliverables-based remuneration: Under UAV-GC clients generally pay contractors only for the scope priced in the Basic Agreement; with few earmarked funds for exploratory iterations, contractors tend to refrain from investing beyond what the tender explicitly demands (Masmeijer, 2021; Laryea & Watermeyer, 2016).
- Project-specific wish lists: Demand specifications frequently bundle an eclectic mix of project-unique wishes, ranging from CO_2 caps and noise abatement targets to site-specific aesthetics, heritage integration, digital-twin readiness, or social-return quotas. Empirical analyses of Dutch integrated contracts find that such wish lists are drafted anew for almost every tender and often contain internal contradictions that contractors must price but cannot harmonise (Masmeijer, 2021). Interview-based work on tendering practice shows that selection and award criteria fluctuate markedly between projects, with clients inserting bespoke deliverables and data requests that are "unnecessary for a proper procurement" (De Jong, 2016). Surveyed contractors therefore perceive each tender as a one-off 'special', hampering the reuse of modular bridge designs and supply-chain routines. Optional sustainability and innovation check-lists in modular-construction guidance further magnify this variance by leaving many requirements discretionary (Azhar et al., 2013). Taken together, these factors help to explain why contractors appear to be evolving from potential IFD frontrunners towards risk-managed integrators: willing to adopt catalogue-level modularity where the business case is unequivocal, yet hesitant to bankroll fully demountable solutions without a clearer pipeline or regulatory slack.

- Cluster 3 Engineering consultancies

The consultancy ecosystem splits into third-party certifiers (e.g., KIWA, TÜV, Vinçotte) and design advisers (e.g., Witteveen + Bos, Royal HaskoningDHV). Certifiers exercise a statutory conformity-assessment mandate, drawing upon accredited testing procedures to safeguard structural reliability. Design advisers occupy an earlier position in the value chain; through variant and risk analyses they heavily influence whether public clients retain or discard IFD options (Hofman et al., 2009). In practice, both sub-roles frequently interact, yet their incentive structures diverge: certifiers are rewarded for compliance assurance, advisers for conceptual creativity.

- Cluster 4 Component suppliers

Precast-concrete and steel-fabrication firms control proprietary catalogues of standard girders, bearings and connection details. Because each catalogue embeds dimensional 'lock-ins', suppliers lobby asset owners to adopt their envelope as the reference standard, a dynamic well-documented in industrialised-housing literature and increasingly visible in bridge manufacture (Gosling et al., 2016).

- Cluster 5 Knowledge & standardisation brokers

Bodies such as NEN and Bouwcampus act as neutral arenas where niche experimentation is codified into broadly accepted norms. By embedding IFD design rules into pre-normative documents (e.g., NTA 8710), they lower transaction costs during project-level discussions (Lember et al., 2019). Their influence is therefore systemic rather than project-specific.

- Cluster 6 Regulatory & political actors

Provincial executives and municipal councils allocate budgets, issue permits and anchor long-term climate targets. Policy volatility at this level can abruptly reopen or close the design space, underscoring the need for robust but flexible solution sets (Hertogh & Westerveld, 2010).

These literature-grounded portraits set the empirical stage, but the extant literature also exhibits blind spots and contradictions. The next subsection therefore interrogates power–interest configurations more critically, asking whether the same actors who could champion IFD actually possess the clout and motivation to do so.

Assessment of power-interest configurations

The bridge-replacement arena differs from generic infrastructure settings because long-life civil assets amplify asymmetric bargaining positions among public, private and hybrid actors (Li et al., 2021). A synthesis of studies reveals four recurring tension lines:

1. High-power/low-innovation interest among CAPEX teams. Project units command the investment budget yet remain judged on schedule fidelity, fostering "least-regret" design choices (Lueger et al., 2005). Several case-reviews show that even when lifecycle models favour modularity, CAPEX managers default to conventional materials to protect political reputation (Love et al., 2014).
2. Moderate-power/high-interest among system integrators. Contractors stand to capture economies of scale, but their leverage is curbed by single-asset tenders and late market involvement (Lahdenperä, 2012). Risk-transfer clauses in DBFM contracts often neutralise any first-mover advantage, explaining why modular pilot bridges remain sporadic despite strong contractor advocacy (Kakar et al., 2023).

3. Diffuse power among engineering consultancies. Advisory firms wield agenda-setting influence through variant matrices, yet empirical work by Krishnan et al. (2023) shows their risk assessments systematically over-penalise prefabrication unknowns, effectively acting as status-quo guardians. Certification bodies reinforce this conservatism because liability regimes incentivise zero-defect compliance over incremental experimentation.
4. Latent veto power in regulatory and community actors. Political boards rarely initiate IFD but can halt it via permit stipulations or budget resets (Hueskes et al., 2017). Traditional authorities exert moral legitimacy rather than financial power, yet case evidence from Ghana and Norway indicates that failure to address their concerns leads to prolonged standstills, offsetting any schedule gains promised by modular methods (Haugbolle et al., 2015).

Putting these strands together, the literature implies a misaligned power-interest grid: those most enthusiastic about IFD (contractors, some asset managers) lack unilateral authority, while high-power actors (CAPEX teams, regulators) remain structurally cautious.

4.2 Industrial, Flexible and Demountable (IFD) construction

4.2.1 Principles of IFD construction

Industrial, Flexible, and Demountable (IFD) construction is increasingly recognized in the infrastructure sector as a promising strategy to address the challenges of efficiency, adaptability, and sustainability in project delivery. The concept of IFD is grounded in the integration of three interrelated principles, industrialization, flexibility, and demountability, each of which contributes to enhancing the lifecycle performance and resource efficiency of infrastructure assets (Chavan et al., 2024).

Industrialization refers to the systematic optimization of construction processes through off-site production, standardization of components, and the application of advanced manufacturing technologies. Bletsis (2025) outlines five key principles of industrialized infrastructure delivery: repeatability, specialization, knowledge codification, pre-engineering, and socio-technical alignment. These principles collectively enable process optimization, cost control, improved quality assurance, and reduced dependency on on-site labour. Particularly in the context of bridge replacement projects, industrialization supports shorter construction times, reduced disruption, and increased predictability of outcomes (BRON).

Flexibility, as the second pillar of IFD, addresses the need for infrastructure solutions that can adapt to changing functional requirements, environmental conditions, or technological developments over time. However, achieving flexibility requires a careful balance between standardization and context-specific adaptability. Antoniou et al. (2020) and Zhang et al. (2021) highlight parametric design approaches as a key enabler of flexibility within modular systems. In this approach, standardized components are embedded within adaptable frameworks, allowing for site-specific customization without undermining process efficiency.

Demountability, or design for disassembly (DfD), is the third principle of IFD and is closely linked to circular economy strategies within the built environment. Demountable infrastructure designs facilitate the selective replacement, reuse, or recycling of components, thereby reducing material waste and minimizing lifecycle environmental impacts (Visser, 2022; Anastasiades et al., 2023). Although the concept of demountability has traditionally been applied in the building sector, its transferability to infrastructure projects, including bridges, is increasingly explored in the literature (Vandervaeren et al., 2022). Demountable designs not only support component reuse but also reduce maintenance-related disruptions by enabling targeted interventions during the operational phase (Trubina et al., 2024).

4.2.2 Enabling Conditions for IFD in the Explorative Phase

Despite well-documented advantages; such as accelerated delivery, reduced material waste, improved safety, and enhanced adaptability, the adoption of Industrial, Flexible, and Demountable (IFD) construction in public infrastructure remains limited (Rahman et al., 2013; Wuni & Shen, 2020; Feldmann et al., 2022). As Rahman et al. (2013) observe, “their uptake is low. Their contribution to the construction industry is also low” (p. 202). This persistent implementation gap suggests that technical feasibility alone is insufficient to drive systemic innovation. Instead, adoption is shaped by a complex constellation of conditions that interact across organizational, regulatory, financial, and cultural levels (Feldmann et al., 2022; Wuni et al., 2020; Kolugala et al., 2022).

The literature increasingly emphasizes that successful IFD adoption requires more than project-level optimization. It depends on coordinated change across institutions, procurement regimes, value chains, and professional cultures. As Feldmann et al. (2022) observe, “the holistic interaction of barriers has been largely overlooked,” despite the fact that many challenges to modular construction are “interacting and mutually reinforcing” (p. 8). Similarly, Kolugala et al. (2022) argue that enabling conditions must be understood as “inter-related system components,” including technology uptake, regulatory flexibility, stakeholder collaboration, and financial incentives. Wuni et al. (2020) support this perspective by clustering 120 modular construction barriers into eight interdependent categories, underscoring that adoption depends on alignment across multiple strategic dimensions.

Building on this systemic perspective, the literature substantiates a prioritization of enabling conditions that are most critical to IFD diffusion; accordingly, the barrier clusters identified by Wuni and Shen (2020) are first inverted into their positive counterparts, conceptually overlapping clusters are combined to avoid redundancy (Feldmann et al., 2022), and drawing on the additional insights reviewed later in this chapter, these refinements end up into six coherent domains of enabling conditions. Foremost among these is social acceptance and cultural perception, as multiple studies underscore that attitudinal resistance, path dependency, and industry conservatism often outweigh technical or financial constraints (Martin et al., 2024; Ozorhon et al., 2014; Ling, 2003). These people- and culture-centered factors shape the perceived legitimacy and trustworthiness of modular methods. Closely following are issues of procurement design and flexibility, which determine whether early contractor involvement, design integration, and value-based criteria can enable the collaborative arrangements needed for innovation (Wuni et al., 2020; O’Connor et al., 2014; Slaughter, 1998). The third critical domain is supply-chain and ecosystem integration, as modular adoption hinges on logistical coordination, manufacturing-readiness, and vendor involvement, factors often overlooked in conventional project planning (Krishnan et al., 2023; O’Connor et al., 2014). The fourth domain is

These operational domains are underpinned by broader structural enablers. Institutional readiness, while necessary, typically functions as a background condition, setting the regulatory space for modular uptake but insufficient to compel change on its own (Slaughter, 1998; Ling, 2003). Similarly, finance and risk considerations are often shaped by the credibility of IFD business models and risk perceptions among clients and insurers, making financial readiness more of a reinforcing factor than a trigger (Feldmann et al., 2022; Ozorhon et al., 2014). Finally, while technology and data, including BIM, automation, and digital fabrication, are often cited as enablers, they are rarely the decisive constraint in practice. Instead, they become effective only when supported by the preceding socio-organizational conditions (Slaughter, 1998; O’Connor et al., 2014).

Figure 2 introduces these six interdependent domains that together constitute the enabling environment for IFD adoption: (1) social acceptance and cultural perceptions, (2) procurement design and flexibility, (3) industry ecosystem & supply-chain integration, (4) institutional readiness/capacity, (5) finance and risk, and (6) technology and data. These domains do not operate in isolation; their

influence is cumulative and often contingent on alignment across levels of the infrastructure system. Crucially, their interaction determines whether IFD solutions are considered viable, desirable, and legitimate during the early, explorative phase of public project planning.
The remainder of this chapter unpacks each domain individually, not to propose prescriptive measures, but to expose the systemic prerequisites for credible and sustainable IFD adoption. The emphasis lies on enabling conditions that make innovation both possible and plausible within the complex reality of public infrastructure delivery.

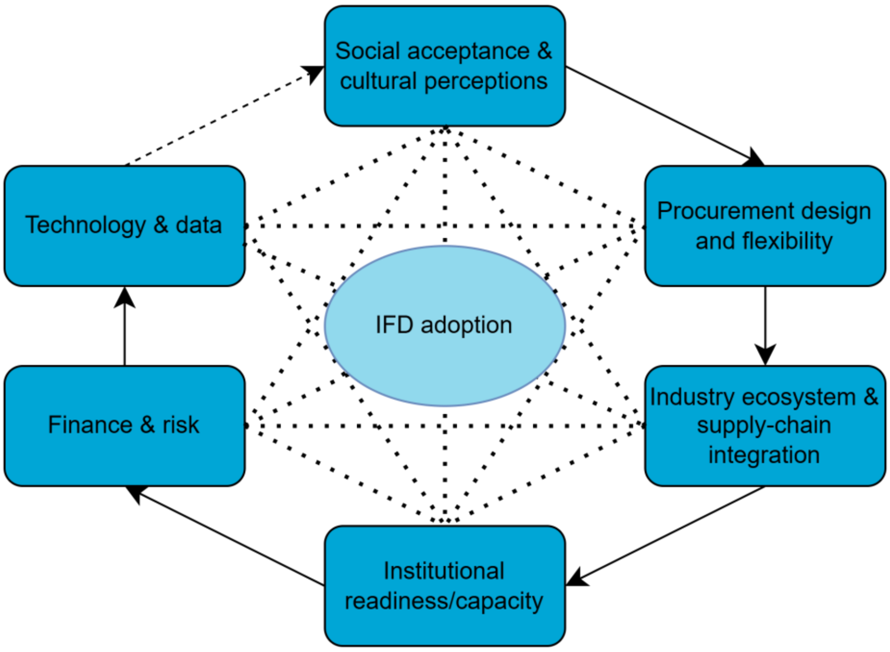

Figure 2 Enabling conditions for IFD adoption

4.2.3 Social acceptance and cultural perceptions

A critical dimension influencing the adoption of Industrial, Flexible, and Demountable (IFD) construction is the degree to which new practices align with prevailing cultural perceptions, values, and norms within the construction industry. While technical and economic feasibility are necessary conditions for innovation adoption, recent research underscores the decisive role of social acceptance and stakeholder attitudes in shaping the diffusion of modular and offsite methods that underpin the IFD paradigm.

Historically, offsite and modular approaches have suffered from limited social legitimacy due to negative associations with post-war prefabricated housing and perceptions of reduced aesthetic and architectural quality (Blismas et al., 2009). These views persist across sectors and geographies, despite the demonstrable technical and environmental benefits of offsite manufacture. For example, Blismas et al. (2009) report that while skill shortages and site productivity pressures were seen as primary drivers for offsite uptake in Australia, deeply rooted cultural conservatism, resistance to change, and the dominance of traditional contracting methods were simultaneously the most frequently cited constraints. Their study found that the success of offsite construction was significantly impeded by a general lack of industry knowledge, negative past sentiments, and regulatory fragmentation, particularly in regions where offsite methods were not culturally embedded. These findings suggest that social acceptance depends not only on the technical characteristics of IFD components but also on the extent to which such systems are perceived as legitimate within existing professional, regulatory, and procurement cultures.

This conclusion is echoed and further quantified in the work of Martin et al. (2024), who apply Rogers' diffusion of innovation theory to examine the persistent non-adoption of modular construction in the UK despite its well-documented advantages. Their survey-based analysis, using a validated instrument aligned with the five dimensions of technology diffusion (relative advantage, compatibility, complexity, trialability, and observability), reveals that social and attitudinal barriers decisively outweigh technical ones. Specifically, the study identifies compatibility-related constraints, such as conventional mindsets, dominance of traditional construction practices, resistance to change, and past negative experiences, as the most significant barriers to modular adoption. These factors ranked consistently higher than complexity, risk, or cost-based concerns, suggesting that misalignment with professional norms and legacy practices poses the greatest threat to innovation diffusion in modular construction contexts.

Importantly, the study further finds that professional role and modular experience moderate perceptions of feasibility. For instance, construction managers expressed significantly greater concern over aesthetic limitations and standardization effects compared to design professionals, indicating that perceived threats to creativity or craftsmanship may vary by stakeholder group (Martin et al., 2024). This highlights the importance of audience-specific strategies to foster acceptance, including targeted education, demonstration projects, and communication of long-term value propositions. Moreover, Martin et al. (2024) emphasize that observability, the visibility of successful modular applications in real projects, is essential for building confidence. Without tangible, credible reference cases, clients and practitioners are likely to revert to familiar practices, thereby reinforcing the inertia of the status quo.

This need for demonstrated legitimacy is reinforced by Ozorhon et al. (2014), whose case study of innovation adoption in an urban regeneration project found that overcoming cultural resistance and unfamiliarity required deliberate efforts to integrate teams and foster leadership across organizational boundaries. Their findings highlight that innovation in construction is fundamentally a social process, dependent on building mutual trust, shared learning, and a supportive culture across actors. In particular, they show how resistance to modern construction methods like modular and lean production was mitigated through collaborative relationships and visible project success, demonstrating that cultural alignment must be cultivated within the project environment itself.

Slaughter (1998) adds further theoretical weight to these insights by arguing that construction innovation is inherently embedded in complex social and organizational systems. Because construction projects are temporary alliances rather than stable firms, and because they are delivered within strict regulatory and public accountability frameworks, innovations must be accepted not just technically but culturally and institutionally. Slaughter emphasizes that innovations requiring cross-boundary coordination or shifts in standard routines are especially vulnerable to rejection unless their benefits are made tangible within the social context of the project system. In other words, construction innovations such as IFD must be perceived not merely as feasible, but as coherent with the prevailing professional identities and institutional expectations of the sector.

Complementing these academic perspectives, sector-specific policy analysis further illuminates the trust dimension of cultural compatibility. An evaluation of the Dutch national programme for serial bridge replacement shows that smaller public asset owners often hesitate to transfer, even temporarily, the ownership and associated risks of their structures to external partners, thereby impeding the bundling of demand that modular, serial approaches require (Platform Bruggen, 2022). The report contends that this trust gap can be bridged through deliberate governance mechanisms such as long-term framework contracts, harmonised technical and contractual requirement sets, and clear performance metrics that make quality more observable. In addition, executive-level leadership within client organisations is deemed crucial to legitimise the temporary transfer of responsibilities to integrated project coalitions. By treating serial procurement as a trust-building catalyst rather than a purely contractual device, Platform Bruggen (2022) demonstrates that cultural acceptance in public-sector contexts is as much about relational governance as about technical performance.

Both Blismas et al. (2009) and Martin et al. (2024) also stress that perceptual barriers are reinforced by the absence of supportive institutional frameworks. When government investment, subsidies, or standardized codes are lacking, cultural legitimacy remains fragile and innovation becomes isolated. In this context, Goulding et al. (2014) argue that “socio-cultural interoperability” must be treated as an integral condition for successful technical innovation. They highlight that acceptance of IFD construction depends on embedding innovation within the social structures, routines, and expectations of the construction environment, repositioning modular practices not as externally imposed disruptions, but as culturally coherent solutions.

In summary, enabling conditions for social acceptance and cultural perceptions of IFD construction include the reframing of modular methods as integral to future-proof, sustainable, and high-quality infrastructure. Such acceptance is fostered when IFD aligns with the core values, routines, and identity of the construction sector, rather than being seen as a disruptive or inferior alternative. Blismas et al. (2009) emphasize that industry-wide familiarity with offsite methods remains low, and that resistance is often rooted in cultural conservatism and negative historical associations. Similarly, Martin et al. (2024) demonstrate that stakeholder perceptions, particularly around compatibility with existing norms, form the most significant barrier to adoption, outweighing technical or financial concerns. Goulding et al. (2014) further argue that successful implementation of offsite innovation depends on “socio-cultural interoperability,” meaning that innovation must resonate with existing professional cultures and expectations. This perspective is also supported in the Dutch context. Van Wijck et al. (2018) observe that although Dutch contractors are generally open to innovation, modular and standardized approaches often struggle with perceived misalignment with sectoral identity and craftsmanship ideals. Similarly, Boersma (2018) highlights that despite political support for industrialized construction in the Netherlands, ingrained perceptions of modular methods as inflexible or low-quality remain a key barrier. These findings confirm that social acceptance of IFD construction is not merely a function of technical awareness, but is shaped by the sector’s broader cultural ecosystem. Overcoming cultural inertia therefore requires long-term investment in shaping perceptions that collectively redefine what is considered legitimate and desirable in contemporary infrastructure delivery (Blismas et al., 2009; Goulding et al., 2014; Martin et al., 2024; Ozorhon et al., 2014; Slaughter, 1998; Van Wijck et al., 2018; Boersma, 2018).

4.2.4 Procurement design and flexibility

Procurement plays a decisive role in enabling innovation in public-infrastructure projects, particularly when it comes to the adoption of Industrial, Flexible, and Demountable (IFD) construction methods. As the interface between public clients and market actors, procurement mechanisms structure the incentives, freedoms, and obligations that determine how innovation can emerge and be integrated into early project phases. Rather than functioning solely as a contractual process for allocating work, procurement can act as a systemic enabler of innovation when it is strategically designed to facilitate collaboration, early engagement, and value-based evaluation.

From a theoretical perspective, public procurement has increasingly been recognised as a demand-side innovation-policy instrument (Edler et al., 2007; Uyarra et al., 2014). This reframes the public client from a passive consumer into an active stimulator of innovation. Through targeted specification, functional requirements, and the early engagement of suppliers, procurement can be configured to shape market responses and mobilise innovation capabilities. In the context of IFD, where modularity and adaptability often demand early design freedom and systemic integration, this policy orientation is particularly salient.

Lenderink et al. (2020) emphasise that innovation in infrastructure demands not only technical and organisational readiness but also procedural space, which procurement can either enable or constrain. Their findings show that traditional strategies, characterised by rigid specifications, risk-averse contracting, and lowest-price selection, tend to marginalise opportunities for non-standardised, modular, or flexible solutions. In contrast, procurement that emphasises functionality, process flexibility, and qualitative award criteria can create institutional environments in which IFD becomes both imaginable and feasible.

Procurement also shapes the timing and nature of contractor involvement, which is critical for the emergence of IFD-compatible solutions. Wondimu et al. (2019) demonstrate that early-contractor-involvement (ECI) mechanisms facilitate knowledge integration and joint problem-solving in the pre-contractual phase, thereby increasing the feasibility of modular approaches. This finding echoes the broader argument in Section 4.2.1 that cultural and social acceptance of innovation requires a supportive regulatory basis.

The Dutch context provides further empirical substantiation. Boersma (2018) highlights that, although EU procurement law formally permits innovation-enabling procedures such as Competitive Dialogue or Design & Construct, these are rarely deployed to their full strategic potential. In practice, public clients often adhere to conservative routines, prescriptive tendering, and narrow interpretations of functionality, thereby constraining the adaptive potential of procurement. This confirms that legal flexibility alone is insufficient; institutional readiness, social acceptance, and cultural perception are equally critical. Similarly, Van Wijck et al. (2018) observe that, despite growing awareness of collaborative models such as Bouwteam, the actual uptake of such arrangements remains limited in Dutch practice because of ingrained risk aversion and the absence of shared routines that support co-creation.

Practice-based insights from the Platform Bruggen working-group report indicate that the decisive enabling condition for IFD adoption is not any single tender procedure but the broader procurement domain, that is, the extent to which frameworks combine legal proportionality, predictable demand, and outcome-oriented specifications to create design space (Platform Bruggen, 2022). When similar assets are clustered under harmonised performance requirements and multi-year commitments, procurement signals that iterative learning and modular solutions will be valued; early, collaborative market dialogues then distribute risks according to capabilities, allowing even small authorities to engage without forfeiting strategic control. In this way, procurement design and flexibility function as a systemic domain condition that shapes incentives, information flows, and trust relationships, ultimately determining whether IFD concepts can move from isolated pilots to mainstream practice.

Beyond technical and contractual levers, procurement flexibility is conditioned by the political–administrative cycle. Election timetables and leadership turnover compress decision horizons, creating what Williams et al. (2022) describe as a perverse-incentives paradox: ministers seek visible results within a single term, even when long-run value is uncertain. Dutch experience with the Betuweroute freight line shows how early political commitments, made before a mature appraisal of alternatives, locked in an expensive solution and crowded out more incremental options

(Williams et al., 2022). Contractors likewise perceive four-year windows as periods of heightened political risk; without assurance that a new cabinet will honour exploratory agreements, they hesitate to invest in front-end (IFD) design work, limiting the effectiveness of ECI instruments (Lenferink et al., 2014). While these election-driven timing constraints affect the window for letting flexible contracts, their deeper organisational implications, such as knowledge continuity and leadership turnover, are analysed in Section 4.2.7 (Institutional Readiness).

The strategic signalling function of procurement is further highlighted by Eriksson et al. (2022), who argue that procurement practices communicate which types of innovation are encouraged or discouraged. If modularity or flexibility is not explicitly rewarded, actors are unlikely to propose IFD-aligned solutions. Similarly, Pan et al. (2011) and Chen et al. (2018) demonstrate that procurement fragmentation and a predominant cost focus act as systemic disincentives for modular construction, even when technical viability is established.

Finally, procurement's role in institutional learning is essential. Haugbølle et al. (2015) suggest that procurement innovation must be understood as a dynamic and iterative process. Especially in contexts involving IFD, where traditional roles and sequencing are challenged, procurement must evolve to accommodate new forms of value creation and shared risk. Without this evolution, even well-intended innovation initiatives risk dilution during implementation.

In conclusion, procurement constitutes a foundational enabling condition for IFD adoption. It mediates how, when, and under what terms innovation can occur within public projects. Through strategic design, careful timing, and sustained implementation, procurement can align institutional structures, sectoral values, and technical opportunities to support industrialised, flexible, and demountable construction, provided that procurement flexibility is matched by political continuity and the life-cycle funding conditions discussed in Section 4.2.8 (Finance & Risk).

4.2.5 Industry ecosystem & supply-chain integration

The adoption of Industrial, Flexible, and Demountable (IFD) construction methods depends not only on decisions made within individual projects but also on the broader capacity of the construction sector to support coordinated, modular innovation. As emphasized by Zhang et al. (2023), modular construction systems require alignment across supply chains and organizational interfaces to function effectively, and this coordination is not yet widely present in current industry structures. Crucially, adoption is shaped by how well the ecosystem can integrate design, production, and delivery processes in ways that reduce fragmentation and build confidence among stakeholders (Feldmann et al., 2022; Vosman et al., 2023). Although full-scale industrialization remains a long-term ambition, current enabling conditions must focus on overcoming systemic disconnections in the supply chain that inhibit early adoption (Liu et al., 2023; Zhang et al., 2023).

A key obstacle lies in the sector's dominant project-based logic, which typically emphasizes short-term, transactional relationships over long-term collaboration. Vosman et al. (2023) argue that such a structure undermines the formation of trust and learning routines essential for innovation. For IFD adoption to take root, actors must be embedded in ecosystems that support continuity across projects and foster shared exploration of new approaches. This shift from isolated project thinking toward more integrated value network logic is central to creating an enabling environment for modular innovation.

Social and behavioural coordination is another critical dimension, closely connected to the enabling conditions discussed in Section 4.2.1 on social acceptance and cultural perceptions. Martin et al. (2024) demonstrate that reluctance to adopt modular methods often stems not primarily from technical limitations, but from uncertainty regarding the capabilities of supply chain partners, the reliability of delivery timelines, and coordination risks. These concerns are particularly pronounced in fragmented industry contexts, where design, engineering, and construction processes are insufficiently integrated. As such, enabling conditions for IFD adoption must aim to reduce perceived relational and operational risks by fostering stronger behavioural alignment and mutual trust across the supply chain.

Zhang et al. (2023) add that the sector's current industrial structure must evolve in parallel with the diffusion of modular solutions. They caution against assuming that automated offsite capacity already exists, instead stressing the importance of transitional supply-chain readiness. For adoption to be feasible, the ecosystem must support more synchronized planning and stable interactions across firm boundaries, even in the absence of fully mature industrial systems.

The challenge, as Feldmann et al. (2022) articulate, is that construction's inherent variability contrasts sharply with the predictability modular approaches typically require. This tension means that early adoption hinges on the ability to accommodate variation while gradually moving toward greater standardization. In this context, ecosystem readiness does not imply full integration but rather the presence of conditions that allow modular principles to be adapted and tested within real-world constraints.

From a risk perspective, Wuni et al. (2019) emphasize that fragmented modular supply chains increase the likelihood of schedule delays, coordination failures, and unanticipated disruptions. Their findings suggest that the successful application of modular construction is contingent upon effective integration across multiple actors and phases. Without this systemic coherence, even technically feasible IFD solutions may struggle to gain traction.

In the Dutch context, Vosman et al. (2023) highlight that progress toward modular infrastructure delivery is emerging through informal networks and collaborative learning environments. Rather than relying on fully developed industrial infrastructures, early IFD initiatives are grounded in iterative experiences that build sectoral trust and shared understanding. This aligns with Van 't Hoen (2024), who stresses that ecosystem innovation in Dutch infrastructure depends on a mix of institutional stability and adaptive project-level coordination.

In conclusion, ecosystem and supply-chain integration function as essential enabling conditions for the adoption of IFD construction. While long-term transformation may require structural industrial change, current adoption efforts depend on fostering alignment, reducing fragmentation, and cultivating the relational infrastructure needed to support modular practices. Only when these conditions are met can IFD begin to move from theoretical potential to practical reality in public infrastructure delivery.

4.2.6 Institutional readiness/capacity

Institutional readiness is a key enabling condition for the adoption of Industrial, Flexible, and Demountable (IFD) construction. It denotes the capacity of public-sector organisations to support innovation through adaptive governance, coordinated procedures, credible long-term funding, and continual learning. Whereas regulations and procurement frameworks establish formal boundaries, it is the institutional ability to manage complexity, uncertainty, and inter-departmental collaboration that ultimately determines whether new methods such as IFD can be adopted at scale (Williams et al., 2022; Gullmark, 2021).

A first facet of readiness is procedural flexibility in the front end of projects. Public clients that align long-term objectives with adaptive planning routines create space for modular and life-cycle-based approaches. Lenferink et al. (2014) emphasise that avoiding rigid, stepwise processes prevents “implementation gaps” and allows insights from later stages: constructability, modularity and maintenance to inform earlier design and procurement decisions. Strategic alignment during these earliest phases is equally crucial; Williams et al. (2022) show that value creation hinges on institutions clarifying roles, evaluation criteria, and accountabilities before key choices become locked in, enabling exploration of integrated, flexible concepts such as IFD well before design freeze.

Readiness also depends on the ability to deal constructively with ambiguity. Levander et al. (2011) find that clients able to build shared understanding across internal departments and external suppliers manage uncertainty in early design more effectively, legitimising innovation rather than reverting to routine. To sustain this beyond one-off pilots, routinised innovation capability is required. Gullmark (2021) demonstrates how evaluation frameworks, capability-building programmes, and continuous-learning mechanisms enable public agencies to scale modular and flexible approaches instead of treating them as isolated experiments. This routinisation is further strengthened by the publication of technical agreements, NTA 8085 for fixed bridges (NEN, 2021) and NTA 8086 for movable bridges (NEN, 2020), which codify IFD design rules and interface dimensions. By giving even small municipalities a ready-made, risk-mitigating specification framework, the NTAs lower transaction costs and provide a common technical language, thereby reinforcing institutional capacity to adopt IFD.

Complementing these insights, Andersen et al. (2014) show that expanding an organisation’s “option space” by delaying irreversible decisions keeps alternative solutions viable, ensuring that IFD is assessed as a legitimate option rather than a disruptive outlier. Governance flexibility reinforces such capability: Sergeeva et al. (2019) note that institutions combining strong leadership with non-contractual coordination, trust-based collaboration and iterative feedback loops are more successful in embedding innovation. Yet the Platform Bruggen report reveals that modern asset-management tasks such as risk-based budgeting, AI-enabled monitoring and cybersecurity, now outpace the resources of most Dutch municipalities, 312 of the 344 councils having fewer than 100 000 residents. Faced with stringent national safety directives written for mega-structures, smaller owners increasingly outsource expertise, eroding in-house capability and slowing consistent IFD uptake (Platform Bruggen, 2022).

A structural financial constraint further undermines the flexibility these mechanisms seek to create (Verlaan, 2017). Until a reform occurs, procurement instruments may preach life-cycle value, but the absence of depreciation signals and capital envelopes will continue to undercut the long-term collaboration and supplier investment that IFD requires (see Section 4.2.8 on Finance & Risk).

Institutional readiness is further strengthened when procurement practices and innovation goals are aligned. Edler et al. (2007) show that public procurement can serve as a proactive innovation-policy tool, provided institutional actors design tenders that reward experimentation, life-cycle benefits, and performance outcomes. When tenders explicitly value these attributes, IFD becomes more attractive for both clients and contractors.

In sum, enabling institutional conditions for IFD adoption include adaptive governance, feedback-rich decision-making, cross-organisational coordination, routinised innovation capability, sector-wide technical standards, credible life-cycle funding signals, and procurement strategies aimed at long-term value. As demonstrated by Lenferink et al. (2014), Williams et al. (2022), Levander et al. (2011), Gullmark (2021), Sergeeva et al. (2019), Andersen et al. (2014), Edler et al. (2007), Verlaan (2017), NEN (2020, 2021), and Platform Bruggen (2022), institutional readiness is not fixed; it can be built through deliberate governance choices, technical-standard development, financial-system reform, and sustained inter-departmental learning.

4.2.7 Finance & risk

The financial and risk landscape of public-infrastructure projects fundamentally shapes the uptake of Industrial, Flexible, and Demountable (IFD) construction. Although life-cycle savings and performance gains are well documented for modular solutions (Shahpari et al., 2020; Wuni et al., 2020), implementation is constrained by high up-front capital outlays, financing complexity, and entrenched risk aversion (Wuni et al., 2019; Rahman, 2013). Comparative reviews show that prevailing budget rules and insurance norms still favour conventional delivery with familiar risk profiles and short-term cost visibility (CMS & Arcadis, 2019; Zhang et al., 2023). Finance and risk therefore operate not merely as contextual barriers but as core structural determinants of IFD adoption, shaping both economic feasibility and the willingness of public and private actors to pursue off-site methods (Wuni et al., 2020; Eriksson et al., 2022).

A persistent obstacle is the capital intensity of modular production. Establishing factories, specialist assembly lines, and heavy-lift logistics imposes large fixed costs; without reliable demand, modular bids struggle to compete on lowest price (Wuni et al., 2020). Where such demand is absent, “financial institutions expressed reluctance to finance modular projects due to limited actuarial data and concerns over the rapid evolution, and possible obsolescence, of off-site manufacturing technologies” (Wuni et al., 2020, p. 6).

Modular delivery also introduces distinct operational vulnerabilities, dimensional mis-coordination, transport disruptions, and limited on-site adaptability, that impose higher penalties for design errors and magnify cascade effects along tightly coupled supply chains (Wuni et al., 2019; Zhang et al., 2023). Without clear contractual provisions for sharing these liabilities, such as rolling contingency funds, public clients and contractors tend to retreat to familiar stick-built methods.

A deeper systemic constraint lies in the Dutch budgetary framework. Central government records infrastructure on a cash basis; once a bridge is paid for, “na 2011 niets meer van een brug terug is te vinden in de financiële administratie van de overheid” (Verlaan, 2017, p. 173). Because depreciation and capital interest remain invisible, life-cycle liabilities are off-balance-sheet and the system “geneigt … investeringen uit te stellen bij budgettaire krapte, waardoor achterstallig onderhoud ontstaat” (Verlaan, 2017, p. 196). Verlaan concludes that adopting a full baten-lasten (accrual) regime is “een noodzakelijke voorwaarde om bij de Rijksoverheid bedrijfsmatig te kunnen werken,” as only accrual accounting spreads annual charges over an asset’s useful life and enables multi-year capital envelopes (Verlaan, 2017, pp. 242–243). Until this reform occurs, tenders that claim life-cycle value lack matching budget signals, limiting the credibility of serial IFD programmes.

Aligning finance with risk therefore requires active public-sector intervention. Bundling demand through long-duration frameworks, sharing contingency funds, offering credit guarantees, and timing commitments mid-term to bypass election-year freezes all lower capital barriers and risk premia (Platform Bruggen, 2022, § 3.3). Embedding total-cost-of-ownership in bid evaluation will gain traction only when accrual budgeting makes depreciation charges transparent (Verlaan, 2017). When procurement criteria explicitly reward life-cycle value and calibrated risk-taking (Eriksson et al., 2022) and budget systems supply the requisite capital commitments, suppliers have clear incentives to invest in off-site capacity and present IFD solutions. Conversely, where project pipelines remain too small to amortise fixed costs or life-cycle benefits stay off-balance-sheet, IFD adoption stalls despite its technical appeal.

Enabling conditions for finance and risk in IFD adoption thus include bundled demand, shared-risk funds and guarantees, accrual-based budgeting that reveals true life-cycle costs, and tender models that monetise long-term performance. Without these structural levers, the economic case for IFD remains obscured and conventional, short-horizon delivery continues to dominate public-infrastructure practice.

4.2.8 Technology & data

The adoption of Industrial, Flexible, and Demountable (IFD) construction methods is critically shaped by the presence of enabling conditions related to digital infrastructure and data ecosystems. While physical modularization is central to IFD, its realization in practice is contingent on integrated technological environments that allow for synchronized design, production, and delivery processes. These digital and data-related conditions are not ancillary but form part of the structural foundation upon which modular feasibility rests.

One of the key enabling conditions is the existence of interoperable digital environments that support reliable and traceable information flows across stakeholders and project stages. Modular construction relies on early design finalization and precise coordination, which are often at odds with conventional practices marked by fragmented tools and reactive planning. Feldmann et al. (2022) emphasize that such misalignment, where late-stage design changes conflict with prefabrication requirements, creates systemic obstacles to modular implementation. This incompatibility is exacerbated when shared digital standards and data protocols are lacking. Vosman et al. (2023) further note that overcoming these challenges requires a sector-wide cultural and processual shift, particularly in settings where sequential workflows dominate. These coordination dependencies echo the supply-chain integration issues discussed in Section 4.3.3.

Another foundational condition concerns the availability and structuring of data across the component lifecycle. The reuse and adaptability of IFD components depend on detailed, accessible information regarding material properties, connection logic, and disassembly strategies. Mackenbach et al. (2020) identify fragmented data environments as a significant barrier to circular construction practices, while Wuni et al. (2020) emphasize the need for standardized documentation to enable lifecycle planning and residual value assessment. As argued in Section 4.3.5, without such data structures, the economic logic underpinning IFD becomes difficult to substantiate.

Digital planning capacity is also essential. The feasibility of modular delivery is often contingent on advance simulation of logistics, site constraints, and regulatory conditions. Yi et al. (2023) show that modular workflows are sensitive to uncertainties in transportation and storage, which require anticipatory modelling and dynamic reconfiguration. These capacities must be available early in the design process, linking this condition to the institutional feedback mechanisms described in Section 4.3.4.

Finally, technological infrastructure alone is insufficient without organizational routines that embed digital tools into everyday project governance. Williams et al. (2022) highlight that collaborative digital environments allow for simultaneous, evolving project representations, but their value depends on active coordination across actors. Similarly, Saad et al. (2023) warn that digital fragmentation within public clients can undermine innovation, even when technical tools are present. These insights reinforce the broader point that digital maturity is not a technical state but an institutional capability.

In summary, enabling conditions for technology and data in IFD adoption include interoperable digital environments, lifecycle-relevant data structures, anticipatory planning capacity, and embedded organizational routines for digital integration. These conditions determine whether IFD solutions can be translated from conceptual promise to scalable implementation in complex public infrastructure contexts.

4.3 Strategic Contractor influence

Influence never happens in a vacuum. It takes shape inside what Lueger et al. (2005) call "social arenas", settings where people decide together what each move means. Using that idea, plus clear examples from supply-chain contracts (Chu et al., 2012), a UK rail megaproject (Badi et al., 2020) and a network study of many project actors (Fares, 2024), this study defines strategic contractor influence as *the planned use of technical, social and political influence to guide the choices of clients, partners and regulators at every layer of the construction industry.*

4.3.1 Rationale for Mapping Levers

Because levers rarely act in isolation, a structured map is needed to show how contractors combine them, where they intervene and which lever dominates in a given setting. Without such a map, research risks treating individual tactics as transferable "best practices" when, in fact, their success is contingent on context (Hartley et al., 2013).

4.3.2 Need for Scenario Validation

Influence activities "derive their meaning from the context they are embedded in" (Lueger et al., 2005). Managers on the rail megaproject, for instance, intervened only after charting the specific zones of uncertainty they faced (Badi et al., 2020), while network research shows that macro-factors such as labour-market tightness reshape what counts as a powerful move (Fares, 2024). For public clients, innovation tools are "contingent rather than absolute" (Hartley et al., 2013). Accordingly, this study first validates the sector scenario, replacement urgency, skilled-labour shortages, procurement norms, before classifying any tactic as technical, social or political.

4.3.3 Mapping the Levers

The three levers are attributed to mechanisms according to their relation in comparison with the following descriptions:

- Technical influence formalises rules in contracts, performance targets or design standards; on the rail project new methods gained traction only after being tied to explicit time- and cost-savings (Badi et al., 2020).
- Social influence relies on trust, narratives and boundary-spanning positions; a project manager won support by combining senior endorsement with one-to-one conversations (Badi et al., 2020), while network "bridges" steer debates by filtering information (Fares, 2024).
- Political influence exploits asymmetries in resources and authority; gate-keeping and even threat of delay accompanied softer persuasion on the same rail job (Badi et al., 2020), and contractors routinely shape budgets and rules through both formal mandates and quiet coalitions (Hartley et al., 2013).

All three levers are present at every level, their mix shifting with project scale, governance mode and market pressure.

Taken together, technical rules, social ties and political power form a single toolkit that contractors recombine for each scenario. The following section (4.4) therefore projects these blended tactics onto four widening lenses, project, organisational, institutional and sectoral, and, using the initiator/formality typology, maps the concrete mechanisms that emerge at each level.

4.4 Contractor Influence Across Strategic Levels

The ability of contractors to influence the explorative phase of infrastructure projects is not limited to individual project settings. While much of the literature on Early Contractor Involvement (ECI) focuses on project-specific mechanisms, studies such as Wondimu et al. (2019) and Walker and Lloyd-Walker (2015) demonstrate that contractor engagement can also be institutionalized through long-term procurement frameworks, collaborative delivery models, and alliance arrangements. These approaches suggest that influence may also operate at broader organizational and institutional levels. Building on these insights, this study further interprets contractor influence as extending to the sectoral level, where shared norms, standards, and collaborative platforms shape innovation trajectories across multiple projects.

4.4.1 Rationale for Assessing Strategic Levels

To systematically capture this wide spectrum of influence, this chapter introduces a typology of contractor influence mechanisms along two analytical dimensions: (1) the initiating actor, either the client or the contractor and (2) the nature of the mechanism, either formal or informal. This distinction builds on classifications found in the procurement and innovation policy literature, including Wondimu et al. (2019), Edler and Georghiou (2007), and Uyarra et al. (2014). While these authors do not provide a unified framework, they describe a range of mechanisms that differ in terms of procedural rigidity and the source of initiative.

This typology enables a more nuanced analysis of contractor influence in the explorative phase, extending beyond procurement procedures alone to include domains such as financing, data infrastructure, and policy development. It also serves as a conceptual foundation for the development of targeted contractor strategies later in this study. The following sub-sections apply the typology across four strategic levels: project-system, organizational, institutional, and sectoral to identify where and how contractors can exert influence that supports the adoption of Industrial, Flexible, and Demountable (IFD) construction practices.

4.4.2 Mapping Initiator and Formality Levels

To analytically structure this broad spectrum of influence, this study introduces a typology of contractor influence mechanisms based on two dimensions: the initiating actor (client or contractor) and the nature of the mechanism (formal or informal). While this distinction originates in the literature on procurement and ECI (Wondimu et al., 2019), it applies more broadly to other domains of influence such as finance, data infrastructure, and policy development. Formal mechanisms are defined here as those embedded in legally regulated or contractually defined frameworks, whereas informal mechanisms involve non-binding, discretionary interactions often grounded in trust, voluntary consultation, or exploratory dialogue (Edler & Georghiou, 2007; Uyarra et al., 2014).

Importantly, the classification by initiating actor does not imply exclusivity of control. Even in cases where mechanisms are formally initiated by public clients, such as competitive procurement procedures or framework agreements, contractors may still exert influence by advocating for their adoption, shaping their design, or strategically positioning themselves to benefit from them. This highlights that contractor influence is not confined to mechanisms they directly initiate, but also includes proactive engagement with client-led processes. This results in four categories of influence mechanisms:

- Client-initiated formal mechanisms – Procedures embedded within legal or contractual frameworks requiring active client initiation (e.g., Competitive Dialogue, Innovation Partnerships, MEAT criteria design).
- Client-initiated informal mechanisms – Non-regulated mechanisms initiated by clients to gather input without legal obligation (e.g., early market consultations, idea competitions).
- Contractor-initiated formal mechanisms – Strategic use of opportunities created within the formal framework (e.g., submitting variant proposals under permitted procedures).
- Contractor-initiated informal mechanisms – Influence initiated independently by contractors, such as unsolicited proposals, lobbying efforts, or contributions to policy frameworks.

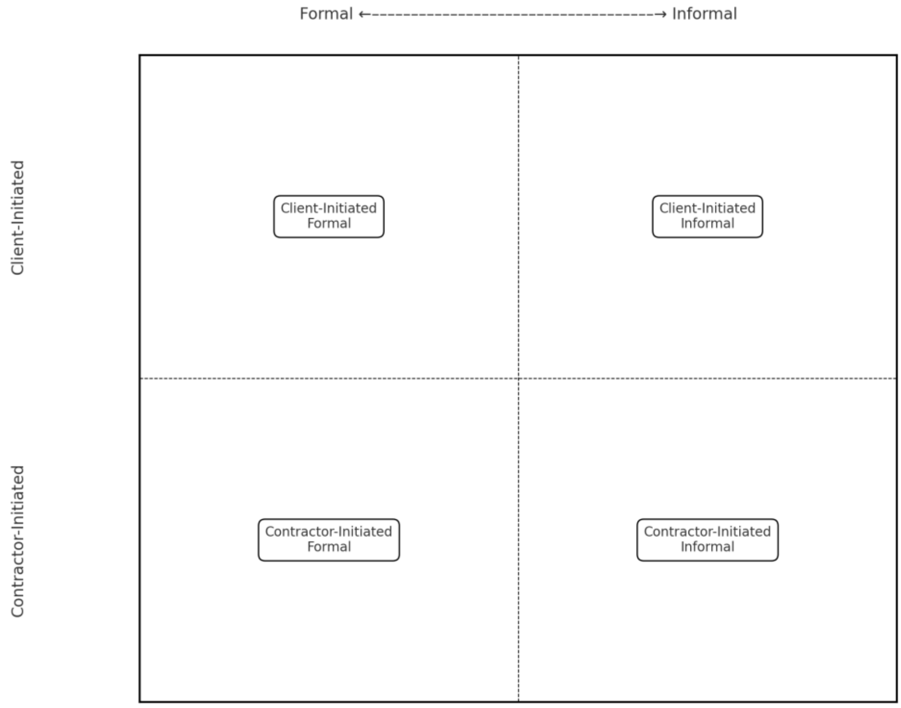

Figure 3 Client/Contractor initiated (in)formal level quadrant (AI generated, ChatGPT)

This typology offers a unified lens to classify influence mechanisms across strategic levels and thematic domains. The following sub-sections elaborate on how these mechanisms manifest at the project-system, organizational, institutional, and sectoral levels.

4.4.3 Mapping Strategic Levels

To demonstrate how the client, contractor, formal-informal typology plays out across increasingly broad scopes of action, Table X maps each of the four mechanism categories (client-initiated formal, client-initiated informal, contractor-initiated formal, contractor-initiated informal) against four strategic levels: project-system, organizational, institutional, and sectoral. This mapping highlights both the most typical expressions of influence at each level and the ways in which contractors may leverage multiple mechanism types in parallel. By situating specific examples, ranging from tender-phase constructability reviews at the project level to participation in national standardization committees at the sectoral level, this section illustrates the multi-scalar nature of contractor agency in the explorative phase.

Project Level

At the project level, contractor influence mechanisms are most direct and operationalized within specific projects. These mechanisms include early design participation, constructability reviews, technical advice on modular solutions, and the negotiation of project-specific procurement conditions (Molavi et al., 2016). Procurement strategies that combine flexible contract forms such as Design-Build or collaborative delivery models like Integrated Project Delivery (IPD), with enabling procurement procedures such as Competitive Dialogue or Innovation Partnership, are specifically designed to facilitate this type of early contractor input (Wondimu et al., 2020).

Contractors can leverage both formal and informal mechanisms at this level to shape problem definition, propose demountable design alternatives, and align technical solutions with lifecycle goals (Salem et al., 2017). Influence typically occurs through structured design sessions, tender dialogue phases, or informal preparatory meetings (Lenferink et al., 2012).

Organizational Level

Contractor influence also operates within the organizational level, where long-term relationships between public clients and market actors are managed. Mechanisms here include framework agreements, preferred supplier models, strategic partnerships, and early market consultations (Walker et al., 2015). These allow contractors to position themselves as innovation partners and shape procurement and design norms across projects.

Organizational-level influence may combine client-initiated formal structures (e.g., long-term innovation partnerships) with contractor-initiated informal actions (e.g., proactively proposing modular standards). Product platform development is another example where internal innovation aligns with public clients' strategic ambitions, reinforcing IFD-compatible practices (Lahdenperä, 2012).

Institutional Level

At the institutional level, contractors influence the regulatory and policy environment. They may engage in lobbying, participate in industry forums, or co-develop standards that support modular construction (Wondimu et al., 2020). This is often achieved through contractor-initiated informal means such as white papers or advisory roles, although formal contributions (e.g., via public consultations) are also possible.

Institutional influence is particularly important where regulatory barriers hinder IFD uptake, such as reuse restrictions or outdated performance criteria (Visser, 2022). Contractors may promote regulatory innovation by sharing best practices or engaging in policy experimentation (Gullmark, 2021).

Sectoral Level

At the sectoral level, contractor influence is exercised collectively across the construction industry. Typical mechanisms include co-authoring national handbooks and technical standards, contributing to formal standardisation committees, joining sector-wide learning platforms, and forming programme or service alliances that bundle multiple infrastructure projects under one long-term framework (Walker et al., 2016). Public clients also engage contractors indirectly, for example: as expert consultants during the preparation of sector handbooks or guidelines, so that practitioners' tacit knowledge is embedded in documents used by many organisations (Wondimu et al., 2020).

Such collective arrangements align dispersed supply chains, diffuse innovation, and normalise the use of modular and demountable systems. They codify best practice, facilitate lessons-learned transfer, and nurture a sector-wide culture of continuous improvement, pre-conditions that large-scale IFD adoption requires (Walker et al., 2015). Consequently, sectoral alignment reduces transaction costs for both public and private actors, while providing the institutional backbone needed to scale innovative construction solutions.

In conclusion, contractor influence in the explorative phase extends across multiple strategic levels and manifests through a combination of client- or contractor-initiated, formal or informal mechanisms. Understanding this typology is key to identifying leverage points for IFD adoption, not only within procurement but across broader domains of innovation such as financing models, data infrastructure, and regulatory frameworks.

4.5 DVF-Framework

To assess how different enabling conditions and influence strategies can accelerate the uptake of Industrial, Flexible and Demountable (IFD) bridge construction, this section introduces the Desirability-Viability-Feasibility (DVF) framework as an organising lens. Building on foundational work in design thinking (Brown, 2008; Liedtka, 2014) and strategic innovation management (Nagji et al., 2012; Hunsaker et al., 2017), the framework distinguishes between what stakeholders want (desirability), what is economically justifiable (viability), and what is technically and organisationally executable (feasibility). This chapter applies that structure in two ways.

First, it introduces the rationale for using the DVF-Framework. Second it gives the definitions and mapping sequence of the three pillars for the mechanisms, whether derived from literature (chapter 4) or developed through empirical fieldwork (chapter 5). Third, this chapter provides a baseline DVF assessment of the Dutch infrastructure sector's current state with respect to IFD implementation. Drawing on published sources, it maps where desirability, viability and feasibility are relatively well-developed, and where they remain under strain. This provisional assessment will then be tested and refined through the empirical chapters that follow.

4.5.1 Rationale for using DVF-Framework

Applying DVF therefore serves three literature-derived purposes:

1. Comprehensiveness, it forces simultaneous consideration of social acceptance, business logic and technical readiness. As Brown (2008) explains, design thinking involves "…it is a discipline that uses the designer's sensibility and methods to match people's needs with what is technologically feasible and what a viable business strategy can convert into customer value and market opportunity." highlighting the triadic balance between desirability, feasibility, and viability.
2. Comparability, subsequent authors treat DVF as a single balancing framework that lets heterogeneous practices be judged on common ground; for instance, Baldassarre et al. (2020) describe strategic design as the effort "to balance desirability… feasibility… and viability". Mapping mechanisms to these three axes therefore supplies shared grounds for otherwise dissimilar interventions.
3. Strategic prioritisation, in contexts where resources are limited and multiple barriers coexist, DVF helps identify the dominant constraint that must be addressed first. Hunsaker and Thomas (2017) emphasise that high-impact innovation occurs where desirability, viability, and feasibility intersect, making DVF not just a diagnostic lens but also a strategic filter to guide action sequencing.

4.5.2 Mapping DVF-Framework

Every enabling move collected in this study, whether extracted from the literature synthesis in Chapter 4 or generated by the empirical fieldwork in Chapter 5, is allocated to the Desirability-Viability-Feasibility (DVF) framework through a two-step interpretive procedure. First, the three dimensions are operationalised. Desirability is taken to mean the degree to which stakeholders regard an IFD solution as legitimate, attractive and low-risk, echoing Brown's (2008) description of design thinking as starting from human needs. Viability refers to the strength of the economic argument over the bridge life-cycle, including capital expenditure, residual value of demountable modules and risk allocation, the "business strategy" component in Brown's (2008) triad. Feasibility denotes technical and organisational readiness: proven technology, supply-chain capacity and available competences, echoing the way Baldassarre et al. (2020) position feasibility in sustainable-business-model tooling.

Second, each mechanism is given a primary DVF tag on the basis of the dominant problem it is designed to solve. For example, a peer-province testimonial aims chiefly to boost legitimacy and trust, so it is classified under Desirability, whereas a digital passport primarily unlocks residual value and therefore falls under Viability. Where a mechanism demonstrably addresses a second dimension, digital passports also strengthen Feasibility by creating traceability infrastructure, this secondary influence is noted parenthetically but does not override the primary assignment. The rationale for every tag is recorded in an audit log so that subsequent readers can trace each decision.

4.5.3 Baseline DVF profile

The literature offers a provisional picture of how well each DVF pillar is currently supported regarding IFD uptake; Table 3 distils the key indicators.

DVF dimension	Key indicator(s) from literature	Status
Desirability	• Cultural conservatism and aesthetic scepticism persist among public-sector clients (Blismas et al., 2009) •Compatibility with existing operations routines scores higher than cost in recent stakeholder surveys (Martin et al., 2024)	Interest is rising but trust remains fragile.
Viability	• Scenario LCC shows prefab bridges become 8–12 % cheaper than cast-in-situ once batches ≥ 5 spans are procured (Shahpari et al., 2020) • Cash-basis budgeting and annual political cycles mute life-cycle signals (Verlaan, 2017) • Limited empirical cost evidence**:** modular-construction studies acknowledge “poor understanding of the cost performance of MiC” because of inconsistent metrics (Wuni et al., 2020) and report “a lack of awareness of the possible cost savings over the whole-life of OSM products” (Blismas et al., 2009)	Cost upside proven in models, yet budgeting data and practice obscures it.
Feasibility	• Laboratory and pilot data confirm structural adequacy of modular girder systems (Feldmann et al. 2022) • Supply-chain fragmentation and interface-management remain top barriers (Zhang et al. 2023; Wuni et a., 2020) • *Standardisation*: NTA 8085/8086 (2020-2021) provides pre-normative interface rules (for detachable connections), but adoption is still voluntary and often omitted from tender annexes (Feldmann et al. 2022)	Technology partially proven; a formal standard now exists, yet systemic readiness, and actual application of the NTA, remains uneven.

Table 3 Baseline DVF profile

Together, the mapping protocol and baseline scan reveal an uneven playing field but don’t surface a distinct order or pillars in terms of importance. Chapter 4 will attribute the pillars to the by literature identified mechanisms. Chapter 5 moves beyond the literature to test and update, where necessary, the desirability, viability and feasibility baseline and mechanisms with fresh interview data. Laying a fully evidenced foundation for the strategic recommendations presented in the same chapter.

4.6 Overview Of Gathered Mechanisms For Enabling IFD Construction

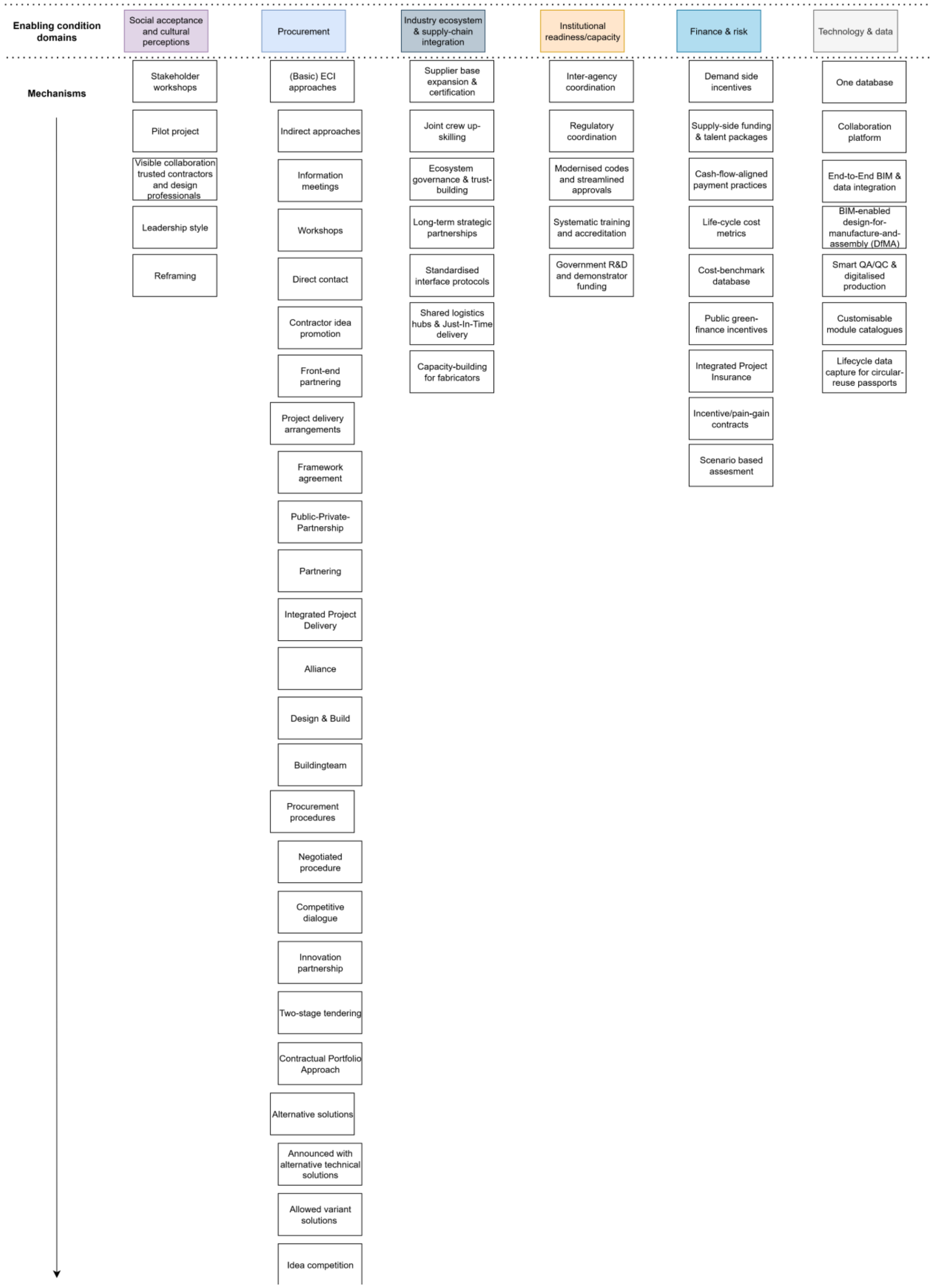

Figure 4 Gathered Mechanisms for Enabling IFD Construction

Figure 4 consolidates all fifty-odd enabling mechanisms into six system-level categories: Social Acceptance & Cultural Perceptions; Procurement; Industry Ecosystem & Supply-Chain Integration; Institutional Readiness/Capacity; Finance & Risk; and Technology & Data, and assigns each mechanism to the category where its primary influence on desirability, viability or feasibility is strongest. To minimise repetition, every tool appears only once, even though many recur across contexts and exert secondary effects on other DVF dimensions. Subsections 4.6.1 through 4.6.6 then unpack each category in turn, describing the specific mechanisms, their usual initiators and level of formality, and how they work together to accelerate IFD uptake.

4.6.1 Social Acceptance & Cultural Perceptions

Stakeholder-centred mechanisms cultivate a shared mental model for innovation before contractual commitments emerge. Stakeholder workshops, pilot projects and visible collaboration create low-stakes arenas in which clients, designers and contractors discuss expectations, observe tangible outcomes and reframe entrenched beliefs (Boersma, 2018; Goulding et al., 2014; Blismas & Wakefield, 2009). Complementary 'soft'-power levers such as transformational leadership and deliberate reframing further legitimise unfamiliar practices by signalling top-management commitment and narrating benefits in user-centred language (Lewis et al., 2017; Ozorhon et al., 2014). Collectively, these informal, socially oriented interventions raise *desirability* and lower cultural resistance, thereby smoothing the pathway for Industrial, Flexible & Demountable (IFD) solutions to progress into formal project routines.

Mechanism	Literature ref.	Initiator	Lever	System level	Formality	DVF target
Stakeholder workshops	(Boersma, 2018; Goulding et al., 2014)	Mixed	S	O	Informal	D
Pilot project	(Blismas & Wakefield, 2009; Goulding et al., 2014)	Client	T/S	P	Formal	D&F
Visible collaboration by trusted actors	(Blismas & Wakefield, 2009; Martin et al., 2024)	Contractor/Designer	S	P/O	Informal	D
Leadership style	(Lewis et al., 2017; Ozorhon et al., 2014)	Client/Contractor	S/P	O/P	Informal	D
Reframing	(Goulding et al., 2014)	Client/Contractor	S	P/O	Informal	D

Table 4 Social Acceptance & Cultural Perceptions literature mechanisms

4.6.2 Procurement

Basic Early Contractor Involvement (ECI) approaches refer to low-threshold mechanisms that allow contractor knowledge to inform public infrastructure planning before the start of formal procurement. These mechanisms are typically informal, non-binding, and initiated either by the client or the contractor. Their strength lies in procedural flexibility and broad applicability across project types, making them particularly useful in the explorative phase, when early scoping and system-level decisions significantly affect long-term performance and lifecycle outcomes (Wondimu et al., 2019; Williams et al., 2022). Depending on the specific method, these approaches operate at varying strategic levels. Some, such as indirect approaches, function outside of project-specific contexts and aim to embed constructability or modularity thinking at the organizational or sectoral level (Wondimu et al., 2019; Rahmani et al., 2022). Others, like workshops or information meetings, are typically project-bound but can generate wider institutional learning when applied consistently (Boersma, 2018; Uyarra et al., 2014; Papenhuijzen et al., 2020). Across this spectrum, basic ECI approaches provide clients with a legally robust and procedurally light-weight toolset for engaging with market knowledge in support of Industrial, Flexible, and Demountable (IFD) construction, provided timing, transparency, and follow-through are ensured.

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Relational and integrated delivery models move decision rights upstream and realign risk–reward structures to favour long-term value. Partnering, Integrated Project Delivery and full Alliances place owners, designers and contractors under shared-governance, open-book frameworks, thus embedding constructability knowledge during conceptual design and safeguarding joint gains through pain-/gain-share clauses (Bygballe et al., 2019; Lahdenperä, 2012; Engebø et al., 2019). Framework agreements and Design-&-Build contracts extend this logic across multiple assets, offering repetition and standardisation benefits that reinforce modular thinking (Laryea et al., 2016; Sullivan et al., 2017). Formal but collaborative by design, these arrangements enhance *feasibility* and *viability* for IFD by synchronising technical, commercial and lifecycle incentives at precisely the stage where modular and demountable options are most malleable.

Formal multi-stage procedures such as Negotiated Procedure, Competitive Dialogue and Two-Stage Tendering introduce structured interaction windows inside regulated procurement (Hoezen et al., 2012; Wondimu et al., 2025; Røfstado et al., 2025). By allowing iterative clarification of functional requirements, risk allocation and target cost, these mechanisms reduce information asymmetry and permit early stress-testing of modular concepts under legally robust conditions. Innovation Partnerships and the Contractual Portfolio Approach go further by bundling R&D and rollout or by aggregating serial works, respectively, thereby shifting both technical and financial risk into manageable, contract-protected envelopes (Koopmans, 2021; Hoekstra, 2023). The net effect is a measured expansion of the *feasible* and *viable* design space for IFD while preserving procurement probity.

Mechanism	Literature ref.	Initiator	Lever	System level	Formality	DVF target
Basic ECI approaches	-	-	-	-	-	-
Indirect approaches	(Wondimu et al., 2019; Rahmani et al., 2022)	Client	T	O/S	Informal	F&V
Information meetings	(Wondimu et al., 2020; Boersma, 2018; Papenhuijzen et al., 2020)	Client	T/S	P	Informal	F&V&D
Workshops (pre-tender)	(Wondimu et al., 2020; Papenhuijzen et al., 2013; Uyarra et al., 2014)	Client	S	P/O/S	Informal	F
Direct contact with specialists	(Wondimu et al., 2020; PIANOo, 2016; Boersma, 2018)	Client	T	P	Informal	F&V
Contractor idea promotion	(Boersma, 2018)	Contractor	T/P	P	Informal	D
Front-end partnering	(Wondimu et al., 2019)	Client	S/P	P	Formal	V
Project-delivery arrangements	-	-	-	-	-	-
Framework agreement	(Laryea et al., 2016; Wondimu et al., 2016; Hoekstra, 2023)	Client	T	P/O/S	Formal	—
Public-private partnership	(Wondimu et al., 2019; Liu et al., 2023; Hueskes et al., 2017; Arata et al., 2016; Lember et al., 2019)	Client	P	P/O	Formal	—
Partnering	(Bygballe et al., 2019; Lahdenperä, 2012; Engebø et al., 2019)	Client	T	P	Formal	F&V&D
Integrated Project Delivery	(Lahdenperä, 2012; Wondimu et al., 2020)	Client	T	P	Formal	F&V
Alliance	(Lahdenperä, 2012; Engebø et al., 2019)	Client	P/T	P	Formal	V
Design & Build	(Sullivan et al., 2017; Hoekstra, 2010)	Client	T	P	Formal	F&V
Building Team	(Sewalt, 2019)	Client	S	P	Semi-formal	F
Procurement procedures	-	-	-	-	-	-
Negotiated procedure	(Wondimu et al., 2025)	Client	T	P	Formal	F&V

Competitive dialogue	(Hoezen et al., 2012; Uttam et al., 2015)	Client	S/T	P	Formal	F&D
Innovation partnership	(Koopmans, 2021; Brinkerink, 2019)	Client	T	P	Formal	F&V
Two-stage tendering	(Røfstado et al., 2025; Lahdenperä, 2010)	Client	T	P	Formal	F&D
Contractual Portfolio Approach	(Hoekstra, 2023)	Client	P	O	Formal	V&F
Alternative-solution tools	-	-	-	-	-	-
Announced alt. technical solutions	(Wondimu et al., 2019)	Client	T	P	Formal	F&D
Allowed variant solutions	(Wondimu et al., 2019)	Client	T	P	Formal	F
Idea competition	(Havenvid, 2015; Wondimu et al., 2019)	Client	S	P	Informal	F

Table 5 Procurement literature mechanisms

4.6.3 Industry Ecosystem & Supply-Chain Integration

A resilient ecosystem lowers systemic adoption barriers by expanding capacity and trust. Supplier-base enlargement programmes, capacity-building subsidies and standardised interface protocols tackle production bottlenecks and interoperability risks at sector scale (Zhang et al., 2023; Feldmann et al., 2022). Parallel social-political mechanisms, joint up-skilling, long-term strategic partnerships and ecosystem governance platforms, build mutual confidence and knowledge continuity beyond single projects (Dang et al., 2023; Vosman et al., 2023). Together, these measures lift both *feasibility* and *viability* by ensuring that demountable modules can be produced, exchanged and iterated across a competitive, well-coordinated supply network.

Mechanism	Literature ref.	Initiator	Lever	System level	Formality	DVF target
Supplier base expansion & certification	(Zhang et al., 2023)	Mixed	P	S/I	Formal	V&F
Joint crew up-skilling	(Dang et al., 2023)	Consultant (on behalf of client)	S	P/O	Formal	F
Ecosystem governance & trust-building	(Vosman et al., 2023)	Public/hybrid platform	S/P	S/I	Formal	V
Long-term strategic partnerships	(Vosman et al., 2023)	Mixed	S/P	O/I/S	Formal	V
Standardised interface protocols	(Feldmann et al., 2022)	Sector working group	T	I/S	Formal	F&V
Shared logistics hubs & JIT	(Yang et al., 2020)	Logistics coalition	T	P/O	Formal	F&V
Capacity-building for fabricators	(Zhang et al., 2024)	Government	T	O	Formal	F&V

Table 6 Industry Ecosystem & Supply-Chain Integration literature mechanisms

4.6.4 Institutional Readiness / Capacity

Macro-level alignment of rules and resources dismantles regulatory friction that otherwise freezes innovation. Inter-agency and regulatory coordination bodies harmonise codes, permits and inspections, shortening approval cycles and clarifying compliance expectations (Zhang et al., 2023; 2024). Modernised, performance-based modular codes institutionalise digital deliverables and one-time product pre-acceptance, while public R&D + demonstrator funding supplies the empirical evidence regulators demand (Wuni et al., 2020). These political levers enlarge the *feasible* and *viable* envelope for IFD by de-risking conformity and signalling long-term policy support.

Mechanism	Literature ref.	Initiator	Lever	System level	Formality	DVF target
Inter-agency coordination	(Zhang et al., 2024)	Government	P	I	Formal	F&V
Regulatory coordination	(Zhang et al., 2023)	Government	P	I	Formal	F&V
Modernised codes & streamlined approvals	(Zhang et al., 2024; Wuni et al., 2020; Martin et al., 2025)	Government	P	I	Formal	F&V
Government R&D & demonstrators	(Zhang et al., 2024; Wuni et al., 2020)	Government	P	I/S	Formal	F

Table 7 Institutional Readiness / Capacity literature mechanisms

4.6.5 Finance and Risk

Financial-engineering mechanisms translate technological promise into bankable propositions. Demand-side incentives and green-finance facilities guarantee market volume and reward carbon savings, whereas supply-side capital grants and talent packages lower entry costs for modular factories (Zhang et al., 2024; Xin, 2022). Project-level tools, cash-flow-aligned payments, life-cycle-cost analytics, benchmark databases and integrated project insurance, mitigate liquidity strain, uncertainty and blame culture (CMS et al., 2019; Shahpari et al., 2020). By synchronising cost, risk and reward profiles with modular business models, these interventions fortify viability and normalise IFD in investment decision-making.

Mechanism	Literature ref.	Initiator	Lever	System level	Formality	DVF target
Demand-side incentives	(Zhang et al., 2024)	Government	P	I/S	Formal	V
Supply-side funding & talent	(Zhang et al., 2024)	Government	P	I/S	Formal	V
Cash-flow-aligned payments	(Zhang et al., 2024)	Client	S	P/O	Formal	V
Life-cycle cost metrics	(Wuni & Shen, 2020; Shahpari et al., 2020)	Mixed	T	P/O	Formal	V
Cost-benchmark database	(Pan et al., 2011; Rahman, 2014)	Mixed	T	I/S	Formal	V
Public green-finance incentives	(Xin, 2022)	Government	P	I/S	Formal	V
Integrated Project Insurance	(CMS et al., 2019)	Government/Alliance	P	O/I	Formal	V
Incentive / pain-gain contracts	(Eriksson et al., 2022)	Client	P	P	Formal	V
Scenario-based assessment	(Shahpari et al., 2020)	Public client	T	P/O	Formal	F

Table 8 Finance and Risk literature mechanisms

4.6.6 Technology & Data

Digital backbone mechanisms convert modular intent into operational certainty. Shared data repositories, end-to-end BIM integration and BIM-enabled DfMA embed manufacturability and traceability rules into the design-to-assembly continuum, reducing clashes and rework (Li et al., 2021; Zhang et al., 2023). Smart QA/QC, parametric module catalogues and lifecycle data passports extend this transparency into production, installation and eventual reuse, ensuring each component retains a verified digital identity (Zhang et al., 2024; Bakhshi et al., 2022). These technical levers decisively enhance feasibility, and, by cutting coordination costs, viability, for the circular workflows intrinsic to IFD construction.

Mechanism	Literature ref.	Initiator	Lever	System level	Formality	DVF target
One shared database	(Zhang et al., 2024)	Mixed	T	I/S	Formal	F&V
End-to-end BIM & data integration	(Zhang et al., 2023)	Client/Government	T	P/O	Formal	F
BIM-enabled DfMA	(Li et al., 2021; Kolugala et al., 2022)	Government	T	P/O	Formal	F
Smart QA/QC & digital production	(Zhang et al., 2024)	Regulator	T	I/S	Formal	F
Customisable module catalogues	(Bakhshi et al., 2022; Wuni & Shen, 2020)	Contractor/Supplier	T	P/O	Formal	F
Lifecycle-data capture for reuse passports	Feldmann et al. (2022)	Mixed	T	P/O	Formal	F

Table 9 Technology and Data literature mechanisms

5 Findings

This chapter serves a dual purpose. First, it validates key enabling conditions and theoretical propositions reported in the IFD literature by confronting them with empirical insights from 11 stakeholder interviews. Second, it synthesises the corroborated (and contested) findings from both evidence streams to formulate actionable recommendations for contractors. The argument therefore progresses from the explorative phase (§1) through the market and scenario validation (§2) to the strategic levers within system contexts (§3) and, finally, practical guidance (§4).

5.1 Explorative phase of IFD implementation

The explorative phase starts well before any tender dossier is drafted and functions as the real “make-or-break” window for Industrialised Flexible & Demountable (IFD) thinking. Far from being a neat Gantt chain, interviewees liken it to a spiral: “het wordt nogal als een lineair proces benaderd, maar in werkelijkheid kom je telkens terug zodra er nieuwe feiten opduiken” (EXP9). Enforcing the already mentioned (in 4.1.1) non-linearity that Molaei et al. (2021) theorise. The scope is frozen and budgets are signed off only to be reopened when new data demand a back-loop, making the phase inherently iterative (PC3P, ENG3, EXP9). This empirical pattern slightly qualifies the lock-in argument advanced by Williams et al. (2019) (in 4.1.1 & 4.1.3): decision knots portrayed as irreversible in theory do, in practice, get reopened when fresh data or political pressure mounts, showing that lock-in is less absolute than the literature suggests. However, interviewees stress that such triggers are rare: an consultant mentioned, “Je krijgt zelden nieuwe harde data die alles op z’n kop zet; meestal rommelen we door met wat er is” (EXP9). A municipal asset-manager adds, “Ons college komt pas in beweging als er echt bruggen uitvallen; tot die tijd is er weinig politieke druk” (PC7M). With no big shock to force change, teams default to their annual update cycle.

Asset-management teams refresh their project ‘to-do’ lists every year on the basis of condition scores, safety risk and remaining service life. Life extending, reactive, maintenance throughout the projects is the norm. A provincial manager explains that the resulting ten-year programme “blijft open voor schuivende prioriteiten; wat vandaag in jaar 5 staat, kan volgend jaar weer omhoog of omlaag” (PC3P). Although some public clients claim to plan their assetlife 70 to 80 years ahead, they admit that binding investment decisions rarely look further than eight to ten years. What looks like a long-term horizon, PC3P said, is in practice “meer een papieren werkelijkheid” than an enforceable strategy. EXP9 agreed, noting that budget resets and shifting ambitions continuously unsettle long-range commitments. These observations were seen throughout almost all types of clients. This connects with Verlaan’s (2017) findings that short political horizons, shifting budgets, and cash-flow accounting lock the sector into a reactive posture that blocks genuine life-cycle thinking. A tangible example of the short political horizons and shifting budget was made during a workshop hosted by Heijmans, a provincial representative mentioned that a recent change in the governing coalition had abruptly shelved existing and planned CO_2-reduction measures and rewards. These short term dynamics are confirmed and felt strongly over the full scale of the project acquisition department of Heijmans.

However, a handful of larger, innovation-oriented public clients are claiming to turn the tide by hard-wiring lifecycle metrics into their decision frameworks. Consequently, assumptions now range widely across the sector: one progressive province is piloting 100- to 200-year LCC calculations for individual bridge elements (PC5P), whereas the national agency still treats 75 years as the minimum baseline component life (PC2N). At the other end of the spectrum smaller municipal owners or other provinces still and react only when inspections flag urgent defects (PC11M & PC12M). Interviewees expect this gap to narrow rapidly as frontrunners push the sector toward longer horizons (PC7M).

Once regular inspections or recalculations flag serious structural decline, public owners still follow a clear preference order: “eerst kijken we of we kunnen versterken of de levensduur verlengen … vervanging is pas de allerlaatste stap” (PC3P); the national agency echoes the same logic, adding that every reinforcement scenario is costed before a replacement brief is drafted (PC2N).
If replacement becomes inevitable, they launch ambition sessions in which ambitions are weighed in a single multidisciplinary debate (PC1P; PC13P). The process outlined below reflects the structure reported for most projects, yet less typical projects could follow a (slightly) different route. Engineering firms sit at that table by default, often having produced the inspections that triggered the session in the first place (ENG3) and being seen by clients as a “safer” early sounding board than contractors (ENG3). Their influence cuts both ways: some advisors still file long memos arguing against IFD (“het eerste wat ik krijg is een epistel waarom we géén IFD moeten doen,” PC8P), while others claim to actively promote NTAs and modular catalogues through internal training sessions (ENG3). Engineers first compile a variant matrix; on a certain scale and in combination with project delivery arrangements a non-binding market consultation and/or price check is done with (a few) contractor(s) (PC3P). As a project-delivery arrangement, some owners now pilot a two-phase Bouwteam: in Phase 1 the contractor co-designs and prices the variant matrix with the engineer, and only in Phase 2, with a possible contractor switch, does the contract becomes (often) fixed-price (PC1P). If the price check flags major issues, the engineers run a brief back-loop to meet the budget (ENG3; PC2N). Once the preferred variant, chosen by the client by screening them with a multi-criteria check, is confirmed, the engineering bureau turns it into the reference design, which locks the essential geometry and performance envelope while still leaving contractors “how” freedom at tender (ENG3; PC11M/PC12M). As a procurement strategy, several clients also test bundled or series contracts to foster industrial learning; however, ENG3 warns that entry thresholds such as “six prior IFD bridges” could exclude most smaller firms (PC3P; ENG3).

The degree of design freedom left to bidders ultimately hinges on delivery form, risk allocation, performance specs and permit constraints. Interviewees repeatedly stress that if the client “crystallises” too many technical parameters at this reference-design stage, every later modular or demountable option is choked off, “zet je te veel techniek vast, dan is modulair bouwen later kansloos” (PC13P). Several recalled projects where catalogue thinking survived the ambition session, only to be frozen out once deck depths or connection details were hard-coded into the tender package (ENG3; PC8P).

After the reference design is locked, the project team moves into permit acquisition and tender documentation; once the dossier is uploaded, the explorative phase is officially closed. Interview evidence places the elapsed time from first portfolio scan to tender publication at approximately four to eight years for a single bridge, and up to a decade for multi-asset urban corridors (PC3P; EXP9).

Because the latitude to keep IFD alive, or to freeze it out, depends on the incentives, motives and bargaining power of the actors at each gate too, the next section maps the market and validates the assumptions about the scenario the market is in.

5.2 Market & scenario validation

Having explored front-end dynamics in § 5.1, we now test the broader portrayal of IFD adoption against real-world evidence. Drawing on in-depth interviews with public clients, experts, and engineering firms, supplemented by exploratory discussions and a client-market workshop, this section evaluates five critical dimensions: the validity of our actor map, the gap between theoretical and actual enabling conditions, the market urgencies driving behaviour, the disconnect between policy ambitions and organisational realities, and the empirical standing of the DVF dimensions. By contrasting literature-based assumptions with practitioner insights, we identify where theory holds, where it falls short, and how market pressures reshape the pathway to scaled IFD deployment.

5.2.1 Validation of the actor map

Empirical findings in the literature review challenge simplified theoretical portrayals of actors, revealing significant complexities and organisational fragmentation.

Public Clients

- Contrary to the theoretically coherent split between OPEX-driven asset management units and CAPEX-driven project teams, interviews reveal significant internal complexity among public clients. One municipal client explicitly described their organisation as "a multi-headed beast," referring to competing internal interests (PC7M, Workshop). This organisational fragmentation undermines coherent strategic decisions, causing substantial variations in tender demands between different projects, a direct outcome of conflicting internal priorities.

Engineering Consultancies

- Consultancies operate with conflicting incentives. On one hand, they actively promote modular construction through workshops (ENG3). On the other hand, as explicitly stated by an engineering consultant (ENG3), their revenues largely depend on bespoke design work, creating structural disincentives against widespread modular standardisation. Additionally, explicit (liability) concerns regarding technical risks and safety further hinder their proactive support for modular adoption (EXP9). These disincentives in combination with the advisory role in the early orientation phases of projects, showcases possible inhibitory effect on IFD uptake caused by engineering consultancies' advice.

Contractors

- Interviewees repeatedly emphasised the understood practical barriers faced by contractors. Modular investments explicitly need some certainty regarding the volume of projects to become economically viable. Clients often mention portfolio and framework agreements, but do not state what defines the composition of objects in those. Moreover, contractors emphasised that public procurement remunerates strictly tender-defined deliverables, providing no incentives for voluntary early-phase innovation (PC1P). Furthermore, the earlier mention of inconsistency in tender requirements, stemming directly from political and internal client fragmentation, reinforces these financial disincentives. Contractors face constant changes in expectations, further diminishing their financial and intrinsic motivation to proactively innovate and ability to pre-sort on futureproof solutions.

Regulatory Bodies

- Although the National Technical Agreement (NTA) for modular bridges is publicly available, designers default to familiar ROK guidelines unless the tender explicitly calls for NTA compliance (ENG3). In other words, the standardisation document remains on the shelf unless the contracting authority writes “NTA van toepassing” into the annex; when that mandate is absent, project teams (and the contractors) revert to bespoke ROK checks and project-specific details.
  A more technical obstacle is that several legacy clauses in Dutch bridge rules actively collide with modular practice. Provincial specialists point to minimum deck depths, fatigue-verification formats and the long-standing requirement for bonded post-tensioning, clauses that complicate girder re-use or detachable connections (PC13P). These regulatory frictions add paperwork and perceived risk, so public owners retreat to conventional cast-in-place solutions. Together, under-use of the NTA and conflicting legacy norms turn what should be an enabling standards landscape into a practical brake on IFD adoption.

This fragmented and misaligned actor landscape not only constrains strategic coherence but also undermines the systemic conditions required for modular construction to gain broader traction. The next section therefore examines how these actor-level dynamics translate into the concrete enabling conditions, and highlights where critical discrepancies persist between literature and operational reality.

5.2.2 Critical discrepancies in enabling conditions

Empirical validation across the six theoretically established enabling domains: social acceptance, procurement flexibility, ecosystem integration, institutional readiness, finance & risk and technology & data reveal practical gaps.

Social Acceptance and Cultural Perceptions:

- Interviewees explicitly confirmed that persistent cultural conservatism remains a significant barrier. A frontrunner province explicitly acknowledged internal resistance to modular approaches as a major obstacle, despite policy-level support (PC10P). Workshop attendee’s also described this misplaced negative attitude as mainly based on “gut-feelings” and just the repeating of the same arguments.
- Given the large number of public clients and the relatively low frequency of bridge replacements, opportunities for learning and knowledge diffusion remain limited. One workshop participant contrasted this with road surface management, noting that knowledge around pavements is far more developed and routinely applied, simply because it forms a more frequent and familiar part of their responsibilities.

Procurement Design and Flexibility:

- Empirical findings clarify that despite theoretical discussions around innovative procurement approaches, current practice predominantly utilises traditional procurement methods. Interviews explicitly revealed a strong preference by clients for proven solutions (high TRL-level), creating a "proof paradox" where modular innovation is severely restricted (PC2N, PC11M).

Industry Ecosystem & Supply Chain Integration:

- ENG3 observed that even well-intentioned reuse pilots often *"get lost in the paperwork"* when no single digital platform ties suppliers, designers and clients together (ENG3), highlighting the fragmented supply chains and immature infrastructure that currently impede seamless modular integration.

Institutional Readiness and Capacity:

- While even leading province acknowledged that lifecycle-cost analyses are still outsourced to specialist consultancies ("Wij hebben lifecycle-berekeningen nog volledig uitbesteed aan adviseurs," PC10P), this reflects both a temporary capacity gap and a strategic choice to leverage external expertise. However, it does underscore that most authorities have not (yet) built in-house teams capable of independently managing complex IFD appraisals, leaving engineering firms with significant agenda-setting influence.
- The fact that, except for the leading province, no interviewee mentioned a dedicated IFD team, budget or training programme could suggest there isn't enough push from senior management to make IFD a real priority.

Finance and Risk:

- Heijmans indicated that without (sight on possible) procurement volumes and remuneration for early-phase modular innovations, financial justifications seem impossible. A client confirmed this by saying that remuneration strictly follows explicitly tendered deliverables, explicitly preventing financially viable early-stage innovation (PC1P).

Technology and Data:

- Interviews confirmed the absence of operational digital platforms such as lifecycle management tools (TCO dashboards, digital twins), describing these explicitly as aspirational rather than practically available (ENG3, PC3P).

In sum, despite broad recognition of IFD's potential, key enabling conditions remain underdeveloped in practice. The next section turns to external pressures that may compel change, even where internal readiness still lags.

5.2.3 Market pressures

Interviews explicitly highlighted two critical market pressures that shape real-world actor behaviours:

Volume and Timing Urgency:

- Multiple municipal, provincial national agencies explicitly acknowledged a significant upcoming peak in bridge replacements, expected between approximately 2035 and 2050. Current replacement capacity is explicitly recognised as inadequate, necessitating an increase in volume and with that efficiency (PC2N, PC11M, Workshop). This urgency was explicitly confirmed broadly, with provinces and the national agency highlighting the scale of the replacement wave as a substantial interconnected logistical and organisational challenge demanding higher efficiency through modular solutions.

Budget and Political-Cycle Volatility:

- Interview data indicate that public buyers operate under volatile budget cycles that reset priorities annually and after each coalition change, undermining long-term modular commitments. A municipal asset manager noted that the bridge programme is revisited every budget year and “moves up or down depending on which projects scream loudest” (PC7M). The same interviewee added that political turnover can abruptly shelve policy. These comments were reinforced by an external expert, who observed that project teams “muddle through with whatever funds survive the next coalition reshuffle” (EXP9). Such instability prevents authorities from locking in multi-year volume guarantees, which modular suppliers require to justify upfront investment in standardised components and off-site production lines. Because the sustainability bonuses in EMVI award criteria can likewise be toned down or removed when councils change, interviewees conclude that IFD must beat conventional solutions on upfront cost not merely on, by example CO_2 scores, if it is to survive each annual reprioritisation. Consequently, even when officials acknowledge the looming replacement wave, the stop-start nature of appropriations and shifting agendas acts as a structural brake on large-scale IFD uptake unless the modular option is demonstrably cheaper from day one.

Furthermore, stakeholders explicitly identified a consistent mismatch between stated innovation ambitions and actual tender practices. Every project tender features substantially different requirements, a direct result of internal organisational fragmentation, described explicitly by one client representative as the manifestation of their internal "multi-headed beast" (PC7M, Workshop).

5.2.4 Ambitions versus organisational realities

Workshop discussions explicitly revealed significant gaps between formally declared ambitions and practical realities.

Policy Ambitions without Procurement Translation

- Follower provinces acknowledged that, while modular ambitions are included in early-stage policy documents ("startnotities"), these intentions often fail to reach the execution phase. This disconnect was attributed to constrained resources, limited time, and a lack of specialised knowledge among project leads. Such implementation gaps are especially problematic in light of the recognised role of public procurement as a demand-side innovation policy instrument (Edler et al., 2007; Uyarra et al., 2014). Without translating strategic ambitions into concrete tender frameworks, public clients forfeit their leverage to stimulate modular adoption.

Stalled by Risk and Cost Conditions

- Innovation-oriented regions acknowledged that unresolved issues around liability and supplier roles continue to stall IFD implementation; *"who actually carries the risk is still unclear"* was heard during the workshop. Participants clarified that structural safety is not just a weighted criterion, it is a strict go/no-go condition. Clients are even exploring how they can fit modular safely principles into the existing quality level of structural safety, highlighting how sensitive any change to structural assumptions remains. Alongside safety, initial CAPEX remains a dominant award factor, reinforcing pressure toward conventional solutions over modular alternatives that may have higher upfront costs. As long as these foundational conditions remain unsettled, frontrunners are limited in their ability to move beyond controlled pilots; making cost and risk clarity prerequisites for any wider shift toward modular delivery.

Absent data amplifies gut-feel governance

- Decision-makers acknowledged that, in the absence of reliable performance data, decisions are still largely driven by gut feeling. Many professionals are trained to optimise bespoke solutions, reinforcing a cultural preference for conventional approaches. During the workshop, even basic questions about CO_2 savings or cost differences related to reused girders remained unanswered, fueling scepticism rather than confidence. Without a shared, credible evidence base, intuitive judgments will continue to outweigh formal ambitions for IFD adoption.

Together, these findings reveal a persistent gap between strategic ambitions and operational realities. While IFD is increasingly present in policy rhetoric, its translation into procurement practice, technical design, and organisational routines remains inconsistent and fragile. Bridging this gap requires more than general support, it demands a closer understanding of how different actors attempt to steer modular adoption within the constraints they face. The next section therefore distils the strategic levers implicit in the interviews, categorising them into recurring forms of influence that actors, especially contractors, can activate within their broader system context.

5.2.5 Validation of DVF dimensions

The preceding section (§ 5.2.4) showed how ambitions collide with day-to-day constraints across the Dutch bridge-replacement arena. To understand where contractors should intervene first, the interview evidence was re-mapped onto the DVF framework introduced in Chapter 4. All three pillars remain important, yet a clear hierarchy now emerges.

Viability, the decisive hurdle
Public clients insist on a quantified indication of CAPEX, OPEX, life-cycle CO_2 (MKI) and residual value: “another inspirational deck will fail if it has no figures” (PC10P). Tender scoring therefore continues to privilege initial outlay. One province is piloting a 200-year element-level LCC method that could translate future re-use gains directly into the CAPEX column (PC1P), while Rijkswaterstaat’s new standardisation guideline for aerial structures further lowers perceived technical risk (PC2N). Because Rijkswaterstaat owns a large, cohesive asset base, these advances are not yet comparable with the fragmented municipal market.

The onus thus shifts to the innovating agent, Heijmans, to supply bankable numbers. PC2N notes that a (non-IFD) pilot succeeded only because Rijkswaterstaat earmarked funds for feasibility work and trials; “the market only moves when the client specifies what it wants, otherwise contractors won’t invest a euro of their own”. Heijmans therefore needs to deliver an indication of “cost + carbon pack”: expected CAPEX, OPEX, MKI savings and residual value. Changing the game by supplying these numbers comes with the cost of investment and the uncertainty in uptake and future tenders. However only with that dossier on the table can clients allocate matching budgets and convert IFD aspirations into binding tender clauses fitting Heijmans but presumably also other contractors.

Feasibility, proven in principle, not yet at programme scale
Modular girders have reached Technology Readiness Level 7–8 and the NTA defines interfaces, yet owners still require proof of repeatable delivery and a certifiable detachable connection. Conflicts between NTA clauses and legacy specifications, together with long-term liability concerns, prevent the joint from becoming the “plug-and-play” element clients expect (ENG3). Hence the call for catalogue certainty ,“bridge 20 × 25 m costs € 2 million” (PC8P), and for a pilot that demonstrates production, even at modest scale. Heijmans’ goal of completing such a pilot by the end of 2025 is viewed as the first credible step and defining Heijmans lead position according to workshop attending clients. However possible, this is also indicating possible free-ride behaviour of other contractors.

Desirability, culturally high, commercially soft
Aesthetic resistance has weakened according to the panel of, mostly pro-orientated IFD, interviewee’s: “If you sit down with architects, the concerns fall away” (PC8P); remaining doubts are “more gut feeling than hard argument” (EXP4). A heritage-heavy municipality shows that, with codified welfare catalogues, almost all historic bridges can accept an IFD chassis (PC7M). One province already enforces an hard IFD obliging policy, another client told this policy is only successful when it is: “IFD unless a director signs an exemption” (PC7M), and others are drafting similar policies. Formal adoption, however, is still limited, leaving contractors reluctant to invest heavily until desirability is embedded in binding procurement rules. However, due to the indicated willingness of provinces, therewithal the most leading type of client, to organise and bundle their underlying municipalities, this could mean a gigantic anticipated leap in the coming years in terms of volume.

Strategic ordering

Innovation-management literature argues that the pillar exerting the greatest constraint must be addressed first if diffusion is to accelerate (Hunsaker & Thomas, 2017). Applying that logic to the interview evidence yields the following sequence:

1. Close the business case (Viability).

Adopt a sector-wide LCC + MKI template, earmark innovation budgets and give the resulting sheet real weight in award criteria.

2. Demonstrate feasibility.

Certify subsystems, lower perceived risk and make it tangible through (small) pilots and cooperation within the sector.

3. Consolidate desirability.

Culturally, IFD is more widely tolerated, design objections are “old stories” or “gut feeling” (PC8P; EXP4). What is missing is formal market pull: only one province obliges IFD in every tender, and others are still drafting similar rules. Once viability and feasibility are secured, those policy templates can be rolled out rapidly.

In sum, taste is largely managed and the core engineering is adequate; what still blocks scale is a defensible business case, clear financial targets and practical proof that the subsystems perform. The next section distils what modes contractors can use to consolidate these findings into concrete expectations for clients through a three-fold approach, Cultivate, Configure and Convince, and identifies the mechanisms Heijmans must deploy to meet them. Followed by a validation of these mechanisms (§ 5.5) and finally a practical strategy pathway (§ 5.6).

5.3 Contractor Influence Modes

The previous chapter translated interview insights into an updated ranking of the DVF pillars; the present chapter drills down one level further and shows how contractors can act according to the empirical research. Section § 3.5 detailed the coding protocol applied to all thirteen interviews. Using that protocol, each raw quotation was assigned a 1st-order code (direct meaning), clustered into a 2nd-order category (underlying theme), and finally distilled into an intent for contractors, a short actionable statement that indicates where and when influence can be exercised.

When these intents were laid side-by-side, three recurring modes of contractor leverage became visible:

- Cultivate, shape awareness, trust, and framing of IFD before formal criteria are set;
- Configure, embed modular logic by providing pre-designed components, rule-ready interfaces and aligned supplier networks;
- Convince, co-author evidence-based success stories that lock in political and organisational commitment once pilots exist.

The remainder of § 5.3 is organised around these three modes. For each mode, a table presents the 2nd- and 1st-order codes, a representative quotation, and the derived contractor intent, followed by a short analytic commentary. Together, these tables turn the qualitative coding results into a practical playbook that will feed directly into the strategic mechanism map in § 5.6.

5.3.1 Cultivating

Cultivate refers to shaping awareness, trust, and framing of IFD in the pre-tender and pre-adoption phases by embedding modular thinking via trusted advisors, informal learning environments, and sectoral alignment, thereby influencing perceptions before formal criteria are set. It mobilises social and political levers at the organisational, institutional, and sectoral levels to increase desirability and feasibility through low-risk, familiar entry points that align with existing capacities and policy goals.

2d-order code	1t-order code	Quotation (ID)	Early-stage, contractor-manageable intent
Framing awareness	Courses & training	“Wij geven cursussen … zo probeer ik beheerders te kneden richting prefab/IFD.” (ENG3)	Exploit the engineer’s trusted advisor status or reduce the need for this status via certification, so contractor modular design logic migrates to the client.
	Means-not-goal messaging	“IFD is een **middel**, dus niet een doel.” (PC1P)	Defuse tech-label allergy; talk outcomes, not acronyms.
	No tailor-made thinking	“Denk in **families** van kunstwerken in plaats van alles uniek.” (EXP4)	Normalize standard design as default engineering common sense in all communication. Custom-made should be perceived as negative.
	Easier alternative framing	“Een **gemakkelijker alternatief** verhoogt adoptie.” (EXP9)	Portray IFD as the path of least effort, and in the end, costs (at the client-side).

Early access & dialogue	Informal contact	“Die **koffietjes** met aannemers gebeuren soms een jaar vóór het budget.” (PC10P) “We laten ons inspireren door **congressen, beurzen, vakbladen.**” (PC11-12M, Interview 2024)	Seed ideas and shape evaluation criteria before they harden.
	Scarcity driver	“Er is enorme **schaarste** … standaardisatie afdwingen is logisch.” (EXP4)	Labour/capacity shortages (automatically) turn into urgency for supplier owned offsite modules.
Multi-actor alignment	Inter-municipal workshop	“We zetten een **Platform Bruggen** workshop op zodat gemeenten samen risico’s in kaart brengen.” (EXP9, Interview 2024)	Surface shared obstacles between clustered (small) actors, then return with ready-made fixes.
	Peer-province testimonial	“Ik heb **Noord-Holland** laten vertellen; een collega-provincie overtuigt beter dan een aannemer.” (PC10P, Interview 2024)	Borrow peer legitimacy to neutralise vendor bias and boost trust.

Table 10 Cultivating pillar mechanisms

Framing & Awareness

Engineer Leverage & Certification

Contractors strategically rely on engineering consultants to act as conduits for introducing IFD thinking, due to their institutionalized role as neutral and trusted advisors. As one engineer explains, “Wij geven cursussen … zo probeer ik beheerders te kneden richting prefab/IFD” (ENG3). Because these consultants engage with clients well before the tender phase ,“een aannemer heeft pas contact ná aanbesteding … wij kunnen veel eerder praten”, they operate in a window where influence is both permitted and credible. In this stage, the engineer serves as a proxy for the contractor, embedding modular design logics into the client’s frame of reference under the guise of neutral knowledge transfer. This reflects a social lever of influence, rooted in trust and informal advisory relationships at the organizational level, targeting the desirability of IFD among client actors.

To operationalize this mechanism, contractors should form strategic partnerships with advisory engineering firms, ensuring these advisors are not only aligned with IFD principles but also kept up to date with technical developments and evolving standards. This alignment transforms the engineering firm into a credible carrier of modular logic toward the client. Moreover, in light of the growing scarcity of qualified engineers, firms that develop an IFD specialization early can position themselves as indispensable. Since engineering services for bridge projects are often procured through long-term frameworks rather than open competition, this positioning can create a near-monopoly effect: if clients want IFD, they must go to the firm that knows how to deliver it. Although this mechanism is heavily dependent on willingness of the engineering firm and possible stretching the limits of the independency of the engineer, as they would be inflicting with procurement law.

An alternative, complementary route is to certify contractor-developed IFD systems and actively publicize them. Certification reduces the perceived risk for public clients and formalizes the contractor’s design logic within existing institutional structures. This represents a political lever, as it shifts decision-making authority away from individual engineering advisors and embeds the contractor’s preferred solution directly into formal procurement and specification routines. It operates primarily at the institutional level and introduces a formal mechanism of influence. Crucially, it enables contractors to sidestep the “make-or-break” power of engineering firms by ensuring that modular systems are pre-approved and specification-ready. As such, certification supports the feasibility of IFD by codifying technical readiness and reducing adoption risk within public organizations.

However, the certification route involves considerable upfront investment; contractors must fund testing processes, develop demonstrator projects, or engage with standardization bodies to achieve recognition. These costs are only justifiable if the certified system is ultimately accepted and integrated into client-side routines. As with the advisor-based mechanism, the effect is conditional: both approaches can open doors to IFD adoption, but neither guarantees lasting institutional anchoring without wider sectoral alignment.

Benefit-First Framing

The label “IFD” can unintentionally trigger perceptions of risk or resistance among public clients, particularly when associated with abstract innovation or industrialised construction. To counteract this, contractors deploy a social influence mechanism by strategically reframing the conversation: rather than promoting “IFD” as a technological concept, they highlight tangible, low-risk benefits such as interchangeability, reduced closure times, and lower life-cycle costs. As one expert advises, “Vertel de voordelen: uitwisselbaar, sneller, goedkoper, níet het label IFD” (EXP4). The reframing proves effective: a provincial client independently echoes this message, noting that “IFD is een middel, dus niet een doel” (PC1P).

This mechanism operates informally at both the project and organizational levels, targeting client-side decision-makers during early planning conversations and steering committees. By downplaying the abstract label and instead tying modular design directly to policy goals, contractors shift the frame from technical novelty to pragmatic value. In doing so, they reduce the perceived risk of adopting IFD and help project leaders justify their choices internally without being framed as “experimenting.”

However, this informal reframing has limits. While it lowers entry barriers, it does not in itself institutionalise IFD or address technical objections later in the process. The mechanism remains context-sensitive and depends on the contractor’s ability to maintain credibility and alignment with broader client goals.

Family Thinking

Contractors promote Industrial, Flexible and Demountable (IFD) adoption by introducing “family thinking”: the idea that bridges belong to a repeatable asset family rather than being bespoke one-offs. As one expert puts it, “Denk in families van kunstwerken in plaats van alles uniek” (EXP4). This constitutes a social and technical lever at the organizational level, deployed informally through everyday communication and design framing. It targets feasibility and desirability by presenting standardisation as the natural engineering baseline, while subtly positioning custom-made solutions as inefficient.

Path of the Least Effort

Contractors frame Industrial, Flexible and Demountable (IFD) construction as the path of least effort and lowest internal cost for public clients. This mechanism combines a technical and political lever at the organizational level, using informal means such as ready-made templates, catalogues, and specification texts to reduce the perceived design burden. It primarily targets the viability of IFD by aligning it with internal workload reduction and fiscal efficiency.

As one expert notes, “Een gemakkelijker alternatief verhoogt adoptie … stel je voor dat die Heijmans-brug 30 % goedkoper is” (EXP9). Clients echo this logic: parametric tools eliminate repeat design work (PC1P), and standardisation offsets internal hours that are often politically invisible in budget calculations (PC13P). By arriving with pre-filled MEAT criteria, auto-configurators, and procurement-ready design logic, contractors transfer complexity from public engineering teams to off-site systems and predictable packages.

The effectiveness of this mechanism may increase under conditions of political pressure, such as scrutiny of staff time or expectations for visible savings, but also depends on IFD being sufficiently developed and recognised. If modular solutions are still seen as unfamiliar or under-defined, the promise of effort reduction may not be credible. The mechanism works best when IFD is no longer perceived as an innovation to assess, but as a ready-made option to adopt.

Early Access & Dialogue

Promoting the Idea

Contractors keep the IFD message alive in settings that procurement law treats as neutral learning environments. A municipal asset manager notes, “Er zijn natuurlijk een hele hoop congressen, beurzen … en vakbladen waar wij ons door laten inspireren” (PC11M). The same bridge reappearing in lunch lectures, “Die brug heb ik wel vijf keer in de lunchlezing terug zien komen” (PC11M), shows how familiarity builds, but also how repetition can backfire. Sector experts propose using platforms like the Bruggenfestival to let clients “laten zien en ervaren wat er mogelijk is, zodat ze het gaan willen” (EXP9).

This mechanism uses a social and political lever at the sectoral and organizational levels, working informally to build desirability for IFD. It is suited to the pre-adoption phase of sectoral uptake, when ideas are still fluid and criteria unset.

By repeating messages across open-access platforms, conferences, journals, public events, contractors shape early narratives without violating procurement law. But overuse of the same example or speaker risks message fatigue. The mechanism is most effective when varied, peer-led, and embedded in high-quality platforms that match the audience’s readiness.

Automatic urgency

Contractors may no longer need to actively promote standardisation; growing labour and capacity shortages do it for them. As one expert puts it: “Er is enorme schaarste … standaardisatie afdwingen is logisch” (EXP4). A provincial programme manager links this urgency to the scale of the replacement task: “We zitten in de aanloop naar die vervangingsopgave … dat kunnen we absoluut niet aan, hè, als bouwmarkt” (PC8P). With overlapping demands from housing, energy, and infrastructure, capacity is spread thin (PC8P).

This mechanism functions as a political and technical lever at the organizational and sectoral levels, working formally through default procurement choices and informally via urgency in internal planning. It primarily targets feasibility, by aligning IFD with real-world delivery capacity. Its timing is most efficient when sector-wide scarcity starts constraining traditional delivery models, but the exact moment is hard to determine.

Contractors can exploit this timing gap by maintaining a shelf-ready technique of offsite bridge modules. When the surge hits, clients constrained by staffing, time, and procurement inertia may turn to supplier-owned solutions by necessity. IFD is thus reframed not as innovation, but as the viable option.

However, this strategy presumes readiness and availability on the contractor side, coherence to legislation and thereby applicable by multiple contractors. If modular systems are not truly pre-engineered and deployable, the urgency may default to crisis response rather than standardisation. Additionally, relying on scarcity as a trigger risks undermining long-term client ownership and integration if adoption is rushed. The mechanism is powerful but reactive, it succeeds when anticipation and operational readiness align.

Multi-Actor Alignment

Clustered stakeholder approach

Contractors surface shared obstacles through informal, low-stakes engagement formats well before tenders are on the table. These include corridor chats at trade fairs, candid “koffietjes” a year before budgeting (PC10P), and co-hosted mini-workshops with clients and intermediaries (PC7M). In these early exchanges, municipal and provincial actors reveal real-world blockers: capacity shortages, downtime tolerances, CO_2 goals, that seldom make it into formal documents. Contractors collect these signals and return with ready-made contributions: IFD-aligned MEAT matrices, parametric design aids, and standard module libraries tailored to the revealed concerns. These are not vendor pitches, but pre-aligned solutions calibrated to the client’s own expressed priorities.

This mechanism combines social and technical levers, operating at the organizational and sectoral levels. It is primarily informal, outside contractual frameworks, but directly shapes future formal criteria. Its core target is desirability and feasibility by reducing search costs and translating IFD into concrete, low-friction options. Its timing fits the pre-adoption and early transition phase, when needs are still fluid and buying power can still be pooled.

Several interviewees suggest this approach scales best through provincial facilitation. PC10P explains how provinces already support around 15 municipalities to explore bundled solutions. These inter-municipal workshops, which welcome contractor interference (PC10P), deliver three compounding effects: they reduce administrative friction by staying legally low-risk, create peer pressure for standard adoption, and anchor modular ambitions in common circular policy goals and funding incentives. Contractors benefit by responding once to many, instead of chasing dozens of bespoke clients.

However, this mechanism hinges on the credibility of follow-through. If contractors surface needs but fail to return with realistic, costed fixes, or if standardisation is pushed without adjusting for (subjective) local constraints, it risks being dismissed as opportunistic rather than strategic. Likewise, scale effects only materialise when clients align not just in principle, but in timing, scope, and commitment. Without those alignments, even a well-prepared IFD “family” risks being shelved.

Peer Legitimacy

Contractors overcome scepticism by letting public-sector peers co-present, transforming IFD presentations from vendor pitches into sector-led endorsements. A provincial project director explains, “Ik heb [een bepaalde provincie] laten vertellen; een collega-provincie overtuigt beter dan een aannemer” (PC10P). This tactic taps into clients’ greater confidence in peer success stories, positioning IFD as a trustworthy and proven approach rather than a supplier-driven novelty. Crucially, peers must be matched, clients are most persuaded when a colleague from a similar governance tier or functional role presents the case, not the contractor.

Beyond individual endorsements, contractors sometimes organise joint briefings where two or more firms share a platform, an arrangement perceived as inherently more neutral because no single company is seen as pushing its own agenda. When modular benefits are framed and validated by both trusted peers and a balanced supplier group, client-side hesitation often diminishes. Several interviewees confirm that under such conditions, IFD criteria are received better.

This approach constitutes a social lever of influence, operating at the sectoral level through informal mechanisms, and primarily targets the desirability dimension of the DVF model. Its effectiveness is closely tied to the pre-adoption phase, when client norms and tender criteria are still flexible. However, the mechanism’s success depends on strategic matchmaking and credible storytelling. Overuse or insincere pairings risk backfiring, especially if the audience perceives the endorsement as orchestrated rather than authentic.

5.3.2 Configure

Configure refers to the contractor's preparatory efforts to embed modular thinking into the project environment before formal decisions are made, by standardising bridge typologies, aligning suppliers, pre-designing compliant components, and seeding systemic enablers like digital passports and scan tools. These actions combine technical and political levers at the project, organisational, institutional, and sectoral levels, and are most effective during the pre-adoption and early transition phases, when clients are open to ideas but lack clear structures for implementation.

2d-order strategy code	1t-order cluster	Tight quotation (+ ID)	Exploratory-stage, contractor-manageable intent
Navigating rule-setting	Mandate IFD as ambition	"Wij hebben besloten dat **alle bruggen** via het IFD-principe worden vervangen." (PC1P) "We waarderen het als de **systematiek** in het plan zit." (PC5P)	Institutionalise modular thinking via soft policy and bid practice.
	One market baseline	"We stellen randvoorwaarden; anders krijg je een **Heijmans-standaard, BAM-standaard** …" (PC2N)	Economic value creation for contractors has to be within the prescribed conditions. Innovate in there.
Standardising	Fix trusted universal interfaces	"Een **USB-stekker-metafoor** … uitwisselbaarheid." (EXP4)	Offer a test of the interface on an existing 'ordinary' bridge span.
	Define family & parametrics	"Het zijn maar **zeven brug-typen** … parametrisch ontwerp." (PC7M)	Provide a tool for harvesting possible bridge families data within the clients acreage
	Swap & traceability plan	"**QR-codes** op elk losmaakbaar deel." (PC7M)	Create digital passports to prove lifecycle & circular benefits.
Co-designing	Commit & de-risk early	"In de **pre-verkenningsfase** helder hebben …" (PC10P)	Offer an IFD-potential check during market consultation, make it very distinct from standard practice.
	Shift roles to integrator	"De aannemer wordt **systeem-integrator**." (PC8P)	Be the accountable interface for more key suppliers.
Bundling	Secure multi-asset frameworks	"We hebben **langetermijn-raamovereenkomsten** …" (PC7M)	Innovation lot steering, enough volume, limited risk.
	Batch projects into series	"Een **serie van 10–20 bruggen** …" (PC1P)	Start with 3–5 similar spans to prove scaling logic.

Table 11 Configure pillar mechanisms

Navigating rule-setting

Institutionalising modular thinking

Even as public clients voice formal IFD ambitions, “We have decided that every bridge will be replaced according to the IFD principle” (PC1P), they admit that contractors still deliver bespoke designs. To bridge this gap between policy and practice, contractors can propose “strive-for” clauses during non-binding market dialogues, combined with option-out conditions tied to budget or permit constraints. This approach functions as a political lever at the institutional level, using formal contract mechanisms to make IFD desirable without making it mandatory. It is particularly useful in the pre-adoption or early transition phase, where clients are open to innovation but wary of risk.

In parallel, contractors should proactively integrate modular (sub)systematics into every tender response, regardless of whether IFD is explicitly requested. Clients notice and reward this effort: “We waarderen het als de systematiek in het plan zit” (PC5P). This technical lever, operating at the organisational level, builds trust in the feasibility of IFD by embedding it into actual design practice and reducing perceived implementation barriers.

Together, these mechanisms keep modular thinking present both contractually and operationally. However, the critical risk is (symbolic) adoption: without coherence to policy or concrete follow-through, such as performance evidence or scaling strategies, the strive-for clause may remain an ambition on paper, and embedded systematics may be overlooked if not tied to measurable procurement benefits.

Innovation within IFD

Contractors can strategically innovate within the IFD framework by developing and validating technologies that fall inside its standardised specification envelope. By investing in subsystems for IFD technologies, contractors enhance their perceived technical reliability and tender readiness, improving future bid performance where modular solutions are valued. This represents a technical lever at the institutional level, targeting the feasibility of IFD and suited to the early transition phase, when formal standards are still evolving. Nevertheless, it requires upfront investment and alignment with certifying bodies, which may only be justified if demand for modular procurement continues to grow.

Standardising

Testing on ordinary spans

In parallel, contractors can use ordinary bridge projects as test beds for IFD interfaces, such as modular joints or demountable deck assemblies, without reclassifying the project as experimental. By embedding these elements in otherwise traditional designs, they familiarise clients with IFD principles in a low-risk setting. This leverages both technical and social levers at the organisational level, supporting feasibility while reducing resistance rooted in novelty. Yet this strategy depends on whether the clients view these integrations as credible precedents or isolated deviations. Without consistent follow-up or institutional recognition, such efforts risk being seen as one-offs rather than stepping stones toward system-wide change. Furthermore this ‘experimenting’ has to be accepted by the client of the ordinary project.

Coalition Built Family Harvesting Tool

Contractors can support IFD adoption by helping public clients identify which existing bridges fall into standardisable typologies. As a municipal programme manager observes, “Het zijn maar zeven brug-typen … parametrisch ontwerp” (PC7M), suggesting that a small number of span types, once façade and context-specific elements are abstracted, could cover the bulk of replacement needs. To unlock this potential, the sector needs a systematic approach to span classification across municipal and provincial portfolios.

Rather than developing competing tools in isolation, contractors should form a coalition to co-develop a shared, vendor-neutral mapping instrument, designed to categorise existing assets into parametric bridge families. This represents a technical and political lever at the sectoral level, targeting the feasibility of IFD by simplifying early scoping decisions. The timing is particularly suited to the pre-adoption and early transition phases, when public clients still lack internal tools to recognise modular opportunities in their own inventories.

Importantly, this direction aligns with an ongoing post-doctoral research project at TU Delft, which aims to develop an independent ecosystem for modular bridge classification, and explicitly seeks contractor involvement to ensure practical applicability. Anchoring the resulting typology in a neutral framework, such as the National Technical Agreement (NTA) process or a comparable standards body, would allow contractors to shape the modular envelope through formal consultation, while safeguarding client-side trust through transparent governance. Still, realising this ambition requires cross-sector coordination and a willingness among contractors to temporarily set aside proprietary formats in favour of a collective sectoral gain. Without that alignment, scattered individual efforts risk undermining the legitimacy and uptake of modular standards.

Digital Passports

Contractors can reinforce IFD’s circular-economy promise by embedding traceability directly into components. A municipal asset manager argues that “QR-codes op elk losmaakbaar deel” (PC7M) should become standard. Tagging prefabricated elements with unique identifiers adds negligible cost, especially for high-turnover or long-lifespan parts. Broad deployment, not just on flagship IFD components, signals that traceability is routine, not exceptional.

The mechanism acts as a technical lever at the institutional level, targeting feasibility by providing verifiable lifecycle data. Its timing is most appropriate during the early transition phase, once modular production has scaled but long-term reuse infrastructure is still forming. However, a sector-wide data platform is currently missing. Until such infrastructure exists, contractors must minimal prototype it themselves: logging fabrication data, maintenance events, and reuse actions to ensure that QR codes serve as functional passports, not symbolic add-ons.

A pragmatic path is to launch a pilot that tags both high-turnover items (e.g. joints, barriers) and a few structural elements like prefab girders, likely to be refurbished within the pilot window. This builds a example data foundation without large capital outlay. It also aligns with the ongoing TU Delft post-doctoral study on modular bridge ecosystems. Still, the credibility of such a system hinges on continuity: without shared standards and open data agreements, early pilots risk becoming siloed, limiting institutional uptake across the public sector. However passports could be part of portraying a mindset other than product development.

Co-designing

IFD Check

To prevent IFD from being ruled out by default, contractors must intervene before the scope is fixed. A provincial programme lead stresses that feasibility must be “in de pre-verkenningsfase helder hebben” (PC10P); once scope documents are set, design latitude shrinks and novel options rarely survive procurement filters. Heijmans could address this by offering a concise, fixed-fee IFD-potential check the moment acquisition staff hears of a likely bridge tender. This scan cross-checks characteristics against a modular library, returning a simple go/no-go verdict. Delivered well before formal design starts, it allows clients to adjust course while change is still feasible.

This mechanism acts as a technical lever at the project-system level, targeting the feasibility of IFD adoption. Its timing is well-suited to the pre-adoption phase, before project path-dependencies and evaluation criteria have locked in. Publishing the scan method in line with NTA guidelines ensures vendor neutrality while protecting proprietary advantages. However, the tool’s success hinges on careful positioning: if framed too aggressively, the offer may be perceived as self-serving or even arrogant. Yet in a context of rising contractor scarcity and pressure to align fragmented demand, larger clients and municipal clusters would increasingly be open to this kind of pre-configurational support.

A further benefit is strategic learning: by engaging early, contractors gather intelligence on clients’ sustainability ambitions and identify latent evaluation signals before they appear in MEAT criteria. Still, sustaining personal ties with 350+ public owners is unrealistic; the scan should be routinized for volume clients with room for innovation, while smaller clients access it on demand. If correctly framed (Chapter 5.6), this “IFD check” does not only ease decision-making, it positions Heijmans as the modular configurator of choice once the tender lands.

System Integrator

By arriving with a visible, coordinated supplier network already aligned on key interfaces and data protocols, Heijmans builds trust in the reliability of IFD delivery. Several interviewees stressed that confidence in modular construction depends less on standalone innovations and more on the perceived strength of the ecosystem behind them. Public clients are more willing to adopt IFD when they see that critical suppliers already collaborate smoothly and consistently.

This strategy directly responds to a gap raised in the workshops, where clients noted that suppliers are often excluded from innovation tracks. Demonstrating that this coordination is already in place reassures clients that IFD delivery will be efficient and low-risk.

The mechanism applies a technical lever, operates at the sectoral level, and targets feasibility by reducing integration risk. Its timing fits the mid-transition phase, when modular ambitions exist but delivery trust still lags. However, the effect depends on clear, transparent communication: if the system appears proprietary, clients may still hesitate. Framed correctly, it positions Heijmans as a credible integrator and accelerates sector-wide convergence on modular standards.

Bundling

Scaling

A municipal programme-manager observes that "we hebben langlopende raamovereenkomsten…" (PC7M), while a provincial strategist notes that real savings emerge once bridges are delivered "in series" (PC1P). These observations signal bundling as a route to scale, yet underline a crucial asymmetry: only public owners can decide to package projects into multi-asset lots or framework agreements. Contractors cannot impose such structures, but they can shape preconditions that make bundling more attractive. To do so, Heijmans should first lead with a pilot bundle of 3–5 bridges, ideally under one province or larger municipality, combining similar spans with controlled variation. The pilot should gather hard data on cycle time, CO_2 reduction and life-cycle maintenance gains, using transparent metrics. This generates a modest but credible evidence base for modular replication and allows procurement and engineering departments to experience the benefits of standardisation without major institutional risk.

Innovation lot

In parallel, Heijmans should proactively communicate the readiness of its supplier network, emphasising that multiple manufacturers can plug into a shared design envelope. This counters vendor lock-in concerns and strengthens the credibility of a sector-wide ecosystem. Past efforts like the TenneT Bay Replacement Programme illustrate the technical feasibility of modular frameworks but also reveal their context-dependence: TenneT operated as a single asset-owner under urgent capacity constraints, whereas public bridge owners face fragmented authority and slower decision cycles. Similarly, the SSRV (Samen Slimmer Renoveren & Vervangen) initiative shows that provinces are exploring multi-bridge bundling, yet scope, funding and governance remain unsettled. Therefore, contractors must position any framework proposal not as a demand, but as a client-led option, supported by demonstrable value and a viable supplier architecture.

While the formal initiation of bundling structures sits with public clients, contractors can exert indirect influence at the institutional and sectoral level, primarily through political and social levers. By delivering small-scale proof and visibly coordinating a modular supplier network, they reduce perceived risk and make bundling appear administratively safer and technically feasible. The mechanism targets viability, as it reframes IFD not as a one-off innovation but as a scalable delivery method within the sector's capacity constraints. However, this influence is conditional: it requires pre-existing client trust, visible ecosystem readiness, and dialogue formats that precede formal tendering. Contractors must take care to respect procurement boundaries and avoid any perception of strategic overreach. This mechanism is best suited to the mid-transition phase, where appetite for IFD exists but policy instruments and delivery models are not yet mature.

5.3.3 Convince

Convince refers to the strategic communication and framing of IFD as a credible, desirable innovation by co-authoring success narratives with clients, embedding measurable evidence in sector-wide stories, and aligning messaging with public agendas. It applies social levers at the institutional and sectoral levels, targeting the desirability and viability of IFD during the pre-adoption and mid-transition phases, when legitimacy, familiarity, and proof of concept are critical to unlock broader uptake.

2nd-order code	1t-order code	Tight quotation (+ ID)	Strategic intent
Co-narrating	Joint client-contractor storytelling	"*Het is heel sterk als je samen met de opdrachtgever een dúo-presentatie geeft … dan is het niet jullie verkoopverhaal maar óók het succesverhaal van de provincie.*" (PC8P)	Build a single, shared success narrative so the buyer "owns" the story too.
	Sector-forum advocacy	"*Er zijn genoeg bijeenkomsten … WOW-dagen … als een aannemer daar presenteert, zitten er veel opdrachtgevers bij.*" (PC13P)	Use open industry stages to influence many public clients at once.
	Knowledge-sharing sessions	"*Er zijn partijen die geregeld lezingen geven … een kennissessie waar opdrachtgevers wel voor open staan.*" (ENG3)	Offer low-threshold learning events that position the contractor as trusted expert.
	Balanced "sober-but-smart" narrative	"*Een heel evenwichtig verhaal vertellen, positief én kritisch, werkt het beste om ze mee te krijgen.*" (EXP4)	Win sceptics by being honest, IFD does have disadvantages
Lobbying relationally	Persistent relational lobbying	"*Heijmans komt … niet één keer, maar gewoon continu, totdat we móe worden van Heijmans.*" (PC10P)	Keep the topic alive through steady, long-horizon contact.
	Empathy-led discovery questioning	"*Ga ook eens vraag stellen … waar loopt de opdrachtgever nou tegenaan?*" (PC2N)	Start with the client's pain-points to pull, not push, the solution.
	Ambassador / collective-platform cultivation	"*Zo'n initiatief moet onder een collectief platform worden gebracht … dan stappen markt én opdrachtgevers in.*" (EXP9)	Create broader coalitions that can later champion the concept from within.
Demonstrating value	Benefit-first framing	"*Gestandaardiseerde elementen … zou de productie ook sneller en goedkoper of met minder mensen kunnen.*" (ENG3)	Sell concrete time-, cost- and staff-savings rather than the buzzword.
	Proof-of-concept demonstration	"*Eén of twee goede voorbeelden vanuit de praktijk … schept toch ook wel weer vertrouwen.*" (PC7M)	Use tangible reference projects to lower perceived risk.

	Quick-win pilot focus	"*Begin simpel … gewoon met een vaste brug met prefab liggers.*" (PC1P)	Start with a small, low-complexity pilot that proves value fast.
Reframing procurement	Alternative contracting route	"*Die aanbestedingsdrempel moeten we 'hacken' … bijvoorbeeld door langjarige overeenkomsten te sluiten.*" (PC5P)	Propose contract forms that bypass tender thresholds and reassure risk-averse buyers.
	Bold system positioning	"*Positioneer je agressiever: 'dit is het Heijmans-systeem' … het verstandige alternatief.*" (PC3P	Recast IFD as a ready-made, branded system rather than a one-off tweak.

Table 12 Convince pillar mechanisms

Co-narrating

Succes Narrative

Public clients consistently stress that innovations like IFD only gain traction when the story becomes theirs to tell. As one engineering consultant put it, "Het is natuurlijk heel sterk als je samen met de opdrachtgever een duo-presentatie geeft … dan is het niet jullie verkoopverhaal, maar ook het succesverhaal van de gemeente of van de provincie" (ENG3). By co-presenting results from pilot projects, whether at sector events, in newsletters, or internal debriefs, contractors help clients visibly align innovation with their own public agendas, turning technical success into political capital.

This is a social lever, situated at the institutional and sectoral levels, aimed at strengthening desirability, and particularly relevant in the mid-transition phase, when early reference projects exist. The goal extends beyond IFD itself: it supports clients in managing internal dynamics, justifying new directions to boards, finance departments, or elected officials. Importantly, it is often more effective to spotlight a lesser-known client rather than a high-profile frontrunner, doing so keeps the story fresh, relatable, and attainable for peers across the sector. Still, the tactic requires restraint, if the contractor dominates the message, it risks undermining the client's sense of authorship. Done well, co-narration reframes IFD as a jointly achieved, politically navigable outcome rather than a technical push from the market.

Low-threshold learning sessions

Contractors can scale their influence by leveraging existing industry fora and informal knowledge-sharing moments that attract multiple public clients simultaneously. An engineering consultant remarked, "Er zijn genoeg bijeenkomsten … WOW-dagen … als een aannemer daar presenteert, zitten er veel opdrachtgevers bij" (ENG3). Presenting early IFD insights on such neutral stages allows contractors to shape perceptions across a broad audience during the explorative phase, before scopes and budgets are fixed.

Alongside these conferences, short in-house lectures and themed sessions also serve as discreet entry points. "Er zijn best wel wat partijen die geregeld lezingen geven … het is een kennissessie waar opdrachtgevers wel voor open kunnen staan" (ENG3). These smaller settings allow for deeper dialogue while positioning the contractor as a trusted technical reference in organisations that often lack in-house IFD expertise.

This is a social lever at the sectoral and institutional levels, geared toward desirability in the pre-adoption phase. However, effectiveness depends on substance and variety: repetition without novelty may diminish credibility, and sales-driven messaging risks alienating the intended audience. Done well, this approach reinforces sector-wide familiarity with IFD while establishing the contractor as a legitimate, neutral guide.

Balanced narrative

Co-narrating succeeds when Heijmans (1) invites the buyer on stage, (2) leverages neutral sector platforms and offers low-threshold learning moments, and (3) tells a candid, evidence-backed story. However, several respondents caution that another inspirational deck will fail without hard numbers. One provincial strategist demanded "hardere feiten … wat kost het, wat voor technische specificaties hebben?" (PC13P), while a national expert remarked, "we hebben erg de neiging om elkaar allemaal na te praten … doe eens een bewijs" (EXP9). Municipal buyers echo that "Eén of twee goede voorbeelden vanuit de praktijk … schept toch ook wel weer vertrouwen" (PC11M).

Crucially, respondents stress that credibility hinges on a sober-but-smart tone. A provincial asset strategist warned: "Als je alleen maar een halleluja-verhaal vertelt worden mensen argwanend; een heel evenwichtig verhaal, met ook de kanttekeningen of beperkingen, werkt het beste" (PC10P). A balanced narrative openly acknowledges IFD's current limitations, such as unsuitability for certain soil types, lack of proven solutions for durable demountable joints, or the added complexity of interface management. This transparency increases legitimacy, tempers inflated expectations, and preempts resistance from sceptical buyers.

Still, co-narration is resource-intensive and public platforms risk revealing strategic insights. Until (stronger pilot) evidence is available, Heijmans should rely on leaner tools, such as a the IFD-potential checklist paired with a single illustrative case, to gradually build a shared, credible narrative without overspending or overpromising.

Lobbying relationally

Long Horizon Contact

Interviewees stress that influence grows only through "continuous" presence:
"Heijmans komt … niet één keer, maar blijft gewoon komen, tot we Heijmans zat zijn" (PC7M).
Such long-horizon nurturing keeps the modular option on the table during every planning cycle. However, officials warn that excessive visits risk "lobby fatigue" or perceptions of vendor capture. A more productive path links relational contact to concrete decision-milestones, such as pre-market consultations, where IFD scope-setting is still open. This mechanism operates as a social lever at the project-system and organisational levels, in an informal mode, targeting desirability and viability during the pre-adoption and early transition phases. To avoid wasted effort, contacts should be concentrated where a realistic opportunity exists and spaced to match each authority's project rhythm.

Understand the Pain Points

Rather than entering with a pre-packed answer, sector experts recommend a Socratic stance:
"Ga vragen stellen … waar worstelt de opdrachtgever nu echt mee?" (EXP9).
By starting from the client's stressors e.g. staffing shortages, CO_2 reduction targets, or maintenance backlogs, contractors reframe IFD not as a sales pitch but as a response to the authority's self-defined constraints. This empathy-based approach helps surface latent demand and positions the modular solution as client-led. This informal, social lever functions at the project-system level, primarily addressing desirability in the pre-adoption phase, when project ambitions are still open to

reframing. Still, open questioning may expose conflicting views within the client organisation. Contractors must be prepared to mediate between departments, rather than exploit internal fragmentation.

Broader Coalition Building

Officials repeatedly argue that innovations gain traction only when collectivised:
“Zo’n initiatief moet onder een collectief platform vallen … dan stappen markt en opdrachtgevers erin” (PC2N).
This suggests that contractors should not position IFD as a firm-specific offer, but embed it in neutral fora such as Platform Bruggen, the SRV consortium, or joint knowledge events. These environments make IFD vocabulary more familiar and shift risk discussions from bilateral friction to collective problem-solving. However, shared platforms dilute individual branding. Heijmans therefore needs a dual strategy: publicly support neutral knowledge exchange while quietly showcasing its own pilot metrics.

To institutionalise this coalition logic, the sector should form a contractor alliance to selectively co-invest in a small number of high-trust, high-impact initiatives. This helps avoid the risk of sunk innovation effort when clients eventually award the project to a competitor. Participation would be selective, aligning with only those initiatives that offer a credible route to specification uptake and sector-wide reuse.

As a concrete expression of this principle, the coalition could anchor itself in a joint public client–contractor investment programme, coordinated through a trusted knowledge institution in collaboration with a public authority. This programme would serve both as a funding mechanism and a governance framework, enabling contractors and clients to co-invest in modular innovation pilots, formalise shared data collection protocols, and collectively assess performance outcomes. Participation would be voluntary but conditional: only those contractors who commit to pre-agreed standards and transparent data governance would be included, thereby ensuring both neutrality and system-wide compatibility. This mechanism combines social and political levers at the sectoral and institutional levels, formalised through shared governance, targeting both viability and feasibility during the early transition phase of IFD uptake.

As one national-level interviewee noted, the market advantage from a fully self-developed solution is unlikely to hold: specifications will ultimately demand transparency, and once modular components are implemented through consortia, the construction method will no longer remain proprietary. This reality underlines that pre-competitive cooperation and shared evidence generation may offer more durable strategic advantage than protecting firm-specific solutions.

Demonstrating value

Data Does The Talking

Public clients across governance levels repeatedly emphasise that persuasive innovation must be anchored in operational gains, not abstract ambition. As one provincial project manager notes, “Gestandaardiseerde elementen … zou de productie ook sneller en goedkoper of met minder mensen kunnen” (PC3P), while a national-level expert adds, “we moeten drie keer zo veel kunstwerken met dezelfde mensen realiseren” (PC2N). These statements reveal that decision-makers prioritise pragmatic benefits, time, cost, and crew efficiency, over generic sustainability rhetoric.

However, several respondents warn that inspiration alone will not suffice. “Eén of twee goede voorbeelden vanuit de praktijk … schept toch ook wel weer vertrouwen,” one municipal buyer notes (PC12M), while a provincial evaluator stresses the demand for technical justification: “Hoe weet ik dan dat het heel blijft?" (PC1N). In short, public owners require concrete, verifiable examples to justify deviation from traditional approaches.

To further ground the narrative in measurable terms, IFD projections can be substantiated through metrics that directly reflect owner-relevant benefits. Although Heijmans currently lacks a robust internal dataset, clients during the workshop expressed willingness to contribute their own figures, like MKI scores for reused girders. This external collaboration not only strengthens the empirical basis for claims, it also signals sectoral alignment around shared metrics. It functions as a social lever at the institutional and project-system level, targeting desirability and viability in the pre-adoption and early transition phases.

Tangible Reference Project Data

At present, examples of indicators that realistically lie within reach of a single contractor include: (1) the MKI score of reused girders, (2) direct construction site costs per project, and (3) on-site construction time during installation.

These metrics could be captured using existing site logs and life-cycle tools applied in girder re-use pilots. In contrast, more advanced indicators, such as net-present-value of deferred replacement or long-term residual value, require longitudinal data that does not yet exist. Therefore, early pitches should highlight data like these three complex, quite uncertain, but indicative figures while transparently indicating that further metrics are still under development. This approach preserves credibility and gives clients a realistic outlook on evidence maturity.

Even limited proof, however, must be anchored in a live reference project. Public managers increasingly demand that innovation claims be supported by certified examples they can reference during internal reviews and political justification. Hence, a modest, fixed-span pilot bridge, paired with an independent structural certificate, becomes critical. The certifying engineering firm affirms the structural logic and safety of the design, reducing residual uncertainty for risk-averse clients.

Small, Low-Complexity Pilot

Such certification and performance tracking are not without cost. Recalculation, factory audits, sensor monitoring and liability coverage can quickly rise into high-figure territory, an investment only justified when multiple clients later reuse the same dossier. The same applies to the data infrastructure: the overhead of installing and analysing sensors or third-party monitors is manageable only when spread across a series of bridges, not for a single flagship project.

Pragmatic actions are therefore essential.

1. Restrict early claims to a few readily measurable indicators with certain level of dependability.
2. Certification and extensive monitoring of the pilot programme for tackling risk aversity and data gathering.
3. Publicise progress and outcomes with explicitly named essential input of involved clients.

In doing so, Heijmans transitions from vendor pitch to system-level actor, anchoring its message in numbers public clients can confidently repeat across technical assessments, political briefings and audit reviews. When even modest pilots provide certified, reproducible value, the foundations are laid for broader procurement trust, uptake and repeat demand.

Reframing procurement

Proposing Bypassing Contractforms

To shift from bespoke bridge projects to repeatable modular delivery, contractors must help reconfigure procurement itself. A promising route, mentioned explicitly by a municipal programme manager, is to “hack” EU procurement thresholds by bundling demand through long-term, starting with innovation, framework agreements rather than isolated tenders (PC7M). Such contracts allow authorities to pre-approve a supplier for a set of modular assets across multiple years, thus avoiding repetitive procedures while reducing administrative costs. For risk-averse clients, this model offers stability and limits liability, provided the framework is anchored in transparent legal and technical templates. Here, contractors could play a proactive role by co-developing these templates in coalition form, pooling legal expertise, standard interface definitions and shared performance data from pilot projects. However, this route is not without risks. While the theoretical advantages are clear, such modular procurement frameworks are still uncommon in Dutch infrastructure and face barriers both in legal interpretation and political will. Unless multiple authorities commit to aggregating demand in advance, the upfront cost of building such frameworks, both administratively and financially, may outweigh the gains, especially given public buyers' fear of vendor lock-in or perceived loss of design autonomy. As such, the initiative should be timed during the mid-transition phase, when sufficient early pilots and relational trust are in place, but before IFD becomes fully standardised. The dominant lever here is political, situated at the institutional level, requiring formal coordination mechanisms to target the viability of modular procurement as a scalable business case.

Branding

Parallel to this, interviewees note that IFD will not scale unless clients perceive it as a dependable, off-the-shelf solution rather than a one-off tweak. As one provincial specialist put it, “Er is op dit moment geen IFD aanbod,” underlining that even interested clients cannot yet point to a ready system to specify in tenders (PC1P). To fill this gap, contractors like Heijmans could invest in certifying a modular bridge family via an independent engineering firm. This branded reference design, coupled with structural verification and interface documentation, could serve both as market proof and as a basis for framework-compatible procurement. Internally, a dedicated unit, such as an “IFD Solutions” team, would manage the system’s integrity, coordinate supplier interfaces, and maintain a live catalogue of completed pilots. While such branding increases client confidence and reduces technical uncertainty, it also carries high sunk costs. The feasibility of this move depends on whether the broader procurement ecosystem evolves to support repeat purchasing; otherwise, even the most rigorously certified solution risks becoming a stranded asset. Therefore, this system-branding strategy targets the feasibility dimension, requires a formal internal structure, and is best implemented in the pre-adoption phase, before standardisation freezes the design space, but after early pilots have demonstrated technical soundness. The dominant lever is technical, and the mechanism operates primarily at the organisational level.

5.4 Attributing classifications to mechanisms

This section consolidates the twenty-six influence moves identified in Chapter 5.3 into a single analytical matrix (Table X). Each row assigns a mechanism to one of the three C-paths, Cultivate, Configure, Convince, and then codifies five classification variables: dominant lever mix (technical, social, political), primary system level of intervention, degree of formality, DVF dimension addressed, and the earliest phase in which the mechanism can be credibly activated. The resulting layout is intentionally dependency-driven rather than time-driven: a mechanism appears lower in the table only when the conceptual, technical or legal pre-conditions created by rows above it are in place. In this way the matrix visualises the order in which sector actors themselves believe barriers must be cleared if Industrial, Flexible and Demountable (IFD) delivery is to move from curiosity to routine procurement.

C-path	2nd-order code	Mechanism	Implementation moment	Lever [T,S,P]	System level [P,O,I,S]	Formality [in-/formal]	DVF target [D,V,F]
Cultivate	Framing & Awareness	Benefit-first framing	Pre-adoption	S	O / P	Informal	D
		Family thinking		T/S	O	Informal	D & F
		Path-of-least-effort framing		T/P	O	Informal	V
		Neutral-stage promotion		S/P	S / O	Informal	D
	Engineer leverage	Engineer Leverage & Certification		S	O	Informal	D
Convince	Relational lobbying	Understand pain-points		S	P / O	Informal	D
		Long-horizon contact		S	P / O	Informal	D & V
	Co-narrating	Peer legitimacy		S	S	Informal	D
Configure	Rule-setting	“Strive-for” clause + option-out		P	I	Formal	D
	Evidence & Proof	IFD Go/No-Go scan		T	P	Formal	F
	System readiness	Coalition span-classifier		T/S/P	S	Formal	F
	Procurement reframing	Brand & certify IFD catalogue		T/S	O	Formal	F & D
Cultivate	Framing & Awareness	Automatic-urgency narrative	Early transition	T/P	O / S	Mixed	F
Configure	Rule-setting	Embed modular sub-systematics		T	O	Formal	F

	System readiness	Digital passports / QR tags		T	I	Formal	F
		Ordinary-span interface tests		T/S	O	Informal	F
	Innovation inside IFD	Innovation inside IFD		T	I	Formal	F
Convince	Evidence & Proof	Data-does-the-talking		T/S	I / P	Informal	D & V
	Co-narrating	Balanced narrative		T/S	I	Informal	D
	Evidence & Proof	Small certified pilot		T	P	Formal	F
	Scaling & Bundling	3–5-span pilot bundle		T/P	P / O	Formal	V & F
	Relational lobbying	Broader coalition building		T/S/P	S / I	Formal	V & F
Configure	System readiness	System-integrator network	Mid-transition	T	S	Formal	F
	Procurement reframing	Framework “hack” contract		P	I	Formal	V & F
	Scaling & Bundling	Coalition “innovation lot”		T/S/P	S / I	Formal	V & F

Table 13 Overview interview mechanisms attributed with classifications

The chronological overview arranges twenty-six influence mechanisms in a logical build-up: each row follows only once the mechanisms above it have cleared a conceptual, technical, or legal threshold that would otherwise block its deployment.

Several clear patterns emerge:

- Cultivate precedes Configure and Convince. Public owners still need basic familiarity and risk reassurance before they will request IFD in tenders, so framing and peer storytelling dominate the earliest rows.
- Lever mix drifts from Social to Technical, while Political threads throughout. Trust-building opens the door; clients ask for hard proof only after curiosity is triggered, yet rules and budget pressures remain ever-present in Dutch infrastructure. This curiosity could serve as a trigger for contractor investments.
- Influence ascends the system ladder. Mechanisms begin at project level, grow into organisational routines once pilots work, and only then migrate to institutional or sectoral arenas where templates and standards crystallise.
- Formality rises over time. Informal coffee chats and soft “strive-for” clauses come first; formal frameworks and certified catalogues appear only after evidence and legal groundwork accumulate.
- DVF emphasis moves from Desirability to Feasibility to Viability. Clients first ask whether modularity is attractive, then whether it functions, and finally whether it pays back, so early rows focus on framing value, middle rows on technical proof, and later rows on the business case.

These drifts are descriptive rather than prescriptive: they map the prerequisite order sector actors say they must follow when de-risking IFD, not a strict schedule of urgency or importance.

Chapter 5.4 therefore supplies a baseline “dependency map” of IFD influence: it shows what must exist before something else can follow. The next section, 5.5 Practical Recommendations - Strategic Pathway, will invert the lens. There we translate this dependency logic into a proactive sequence of actions, indicating which high-impact mechanisms deserve early, behind-the-scenes preparation and how they can be accelerated or combined to shorten time-to-scale without breaching procurement norms.

5.5 Empirical Refinement of Mechanisms

Section 5.5 brings together our interview findings and the scholarly literature to hone the full repertoire of IFD influence moves. We begin by presenting the validated mechanisms, those for which both theory and practice converge, then turn to the partially validated ideas that require further contextualisation, and finally flag the residual literature levers that, despite their academic pedigree, did not surface in our stakeholder conversations. This structured comparison not only clarifies which tactics are battle-tested, but also highlights gaps and caveats, guiding contractors toward an evidence-based, practically grounded strategy toolkit.

5.5.1 Validated Mechanisms

Table X lists the core mechanisms that emerged both in the IFD literature and across our stakeholder interviews, validated as empirically grounded levers for driving adoption. Each entry pairs an observed mechanism, ranging from Clustered stakeholder approach to Small, certified pilot bridge, with its closest theoretical analogue, summarizes how practitioners substantiated its impact in real-world settings, and cites the seminal reference. These validated mechanisms form the essential toolkit contractors need to cultivate familiarity, configure technical readiness, and convince clients with credible evidence throughout the IFD adoption journey.

Empirical mechanism	Closest literature mechanism	Substantiation	Key reference
Clustered stakeholder approach	Stakeholder workshops	Identical multi-buyer alignment format	Boersma (2018)
Digital passports /QR tags	Lifecycle-data passports	Same traceability goal	Feldmann et al. (2022)
Ordinary-span interface tests	Standardised interface protocols	Technical match	Feldmann et al. (2022)
Framework	Framework agreement	Same multi-asset contract logic	Hoekstra (2023)
Joint client-contractor success story	Visible collaboration by trusted professionals	Same social-proof lever	Martin et al. (2024)
Understand pain-points	Direct contact with specialist contractors	One-on-one feasibility dialogue	Wondimu et al. (2020)
Persistent long-horizon lobbying	Information meetings	Sustained early contractor involvement	Wondimu et al. (2020)
Broader coalition building	Ecosystem governance & trust-building	Matches platform logic	Vosman et al. (2023)
Small, certified pilot bridge	Pilot project	Classic proof-of-concept	Blismas et al. (2009)
Benefit-first framing	Reframing	Shows the tactical focus on *tangible pay-offs* (speed, cost, downtime) to mute innovation-risk perceptions.	Goulding et al., 2014

Family thinking	Reframing	Translates abstract reframing into a *repeatability norm* that positions bespoke design as the exception.	Goulding et al., 2014
Path-of-least-effort framing	Reframing	Adds an *administrative-burden* argument: adopting IFD reduces client workload and hidden staff hours.	Goulding et al., 2014
Scarcity-driven urgency narrative	Reframing	Turns the external labour-/capacity shortage into a persuasive frame, positioning IFD standardisation as the only rational, low-risk default.	Goulding et al., 2014
Balanced narrative	Leadership style	Operationalises transformational leadership by showing how candour builds trust and legitimacy.	Lewis et al., 2017
Data-does-the-talking	Life-cycle-cost metrics	Supplies concrete Dutch MKI scores as the quant the literature assumes but never specifies.	Wuni et al., 2020

Table 14 Overview validated interview mechanisms by literature

5.5.2 Partial validated interview mechanisms

The mechanisms in Table X represent those ideas that emerged from both our interviews and the literature but with nuances in their empirical validation. Each combines a recognized theoretical lever with real-world practitioner endorsement, albeit in a context-dependent or partially instantiated form. The table below pairs each interview-identified mechanism with its closest literature counterpart, summarizes how stakeholder feedback substantiates (or qualifies) it, and cites the key reference that originally proposed the concept.

Interview mechanism	Closest literature mechanism	Substantiation	Key reference
Engineer Leverage & Certification	Indirect approaches	Engineering firms carry modular logic pre-tender	Wondimu et al. (2019)
Early coffee-meetings	Information meetings	Same ECI aim, lower formality, earlier timing	Wondimu et al. (2020)
Peer-province testimonial	Visible collaboration	Swaps "trusted contractor" for peer-public-owner proof	Blismas et al. (2009)
Ordinary-span interface tests	Pilot project	Applies pilot logic to deliberately mundane span	Blismas et al. (2009)
Innovation inside IFD	Modernised codes and streamlined approvals	Grows feasibility of modular techniques by reducing uncertainty and perceived risk	Zhang et al., (2023)
IFD Go/No-Go scan	Scenario-based assessment	Contractor-provided, fixed-fee decision tool	Shahpari et al. (2020)
"Strive-for" clause + option-out	Contractor-idea-promotion	Soft-policy signalling inside tender	Wondimu et al. (2019)
System-integrator network	Supplier base & visible collaboration & Capacity-building for regional fabricators.	Combines capability build-up with public display of teamwork	Zhang et al. (2023)
3-5 span pilot bundle	Contractual portfolio approach	Small-batch precursor to CPA	Hoekstra (2023)
Bold system branding & certification	Customisable module catalogues	Turns catalogue into pre-certified, branded offer	Bakhshi et al. (2022)
Coalition span-classifier tool	Customisable module catalogues	Adds an upstream, coalition-run digital tool that auto-maps existing bridges to the standard module catalogue, turning a static library into a sector-wide, data-driven selector.	Bakhshi et al. (2022)

Table 15 Overview partially validated interview mechanisms by literature

5.5.3 Residual Literature Mechanisms Not Evidenced in Interviews

In addition to the twenty-six mechanisms validated against our interview data, the literature suggests several other potential levers that did not find empirical support in our stakeholder conversations. Table X therefore lists these residual literature mechanisms and our decision on whether, or under what caveats, they nonetheless deserve a place in the broader IFD strategy. For each, we note the lack of interview evidence, the rationale for exclusion (or conditional inclusion), and any specific circumstances under which they might still prove useful.

Literature mechanism	Include in strategy	Substantiation
Front-end partnering	No	Low influence on IFD adoption, post-award collaboration.
Project-delivery arrangements **category** *excluding* Framework Agreement	No	Low contractor influence on choice of arrangements and limited IFD advantages.
Procurement procedures **category** *excluding* Contractual Portfolio Approach	No	Lack of empirical support, add legal complexity without improving volume or risk allocation
Alternative solutions **category**	No	Very limited influence on this category and limited support.
Shared logistics hubs & JIT	No	Needs steady volume, post adoption
Inter-agency coordination	No	Outside of contractor influence
Regulatory coordination	No	Same as above, but NTA working groups and certifying will indirectly influence coordination.
Government R&D & demonstrator funding	Yes	SBIR (Small Business Innovation Research) has earlier been used for IFD related funding, follow-up needed for higher TRL level and adoption.
Demand-side incentives	No	Needs political mandate, takes place after initial adoption.
Supply-side funding & talent	No	Complementary after initial scale up; not within adoption scope.
Cash-flow-aligned payment practices	No	Not perceived as barrier in empirical and scholar research.
Public green-finance incentives	No	Needs political mandate, limited influence.
Integrated Project Insurance (IPI)	No	Makes sense only when alliance-type governance matures; late-transition.
Incentive pain-gain contracts	No	Limited influence.
Cost-benchmark database	Yes	Start (co) design now so audited pilot data can flow in automatically.
One shared database	Yes	Participating with TU/D-PNH collaboration
End-to-end BIM & data integration	No	High payoff but large investment and dependent on market standards, post adoption.
BIM-enabled DfMA	Yes	Software already available; enforce as spec requirement in next modular tender.
Smart QA/QC & digitalised production	No	Needs factory uptake; pilot post adoption.

Table 16 Literature mechanisms not evidenced in interviews

5.6 Practical recommendations - Strategic pathway

Interview evidence in § 5.2.5 repeatedly points to Viability as the decisive adoption trigger, eclipsing both Feasibility and Desirability. Building on the dependency map in § 5.4, this section therefore recasts the descriptive "what-comes-first" ordering into a phased strategy that treats Viability as both gatekeeper and potential failure point. Dutch public clients still de-risk IFD by first cultivating familiarity, then demanding technical proof, and only later formalising change in contracts, but the pathway proposed here exploits low-risk, independently auditable moves to establish Viability credentials early, while the longer-lead, higher-impact instruments are quietly prepared in parallel.

Because current procurement rules offer weak pay-back guarantees, and because genuine Viability mechanisms (third-party cost benchmarks, residual-value exchanges, shared financing structures) are scarce, capital-intensive and easily dismissed as vendor-specific, each horizon is anchored by an explicit go / no-go conversion check. These checks act as kill-criteria, ensuring that investment only scales when auditable savings or cost-recovery thresholds are met; unconvincing numbers halt escalation and trigger redesign instead of sunk-cost drift.

Drawing on the six enabling-condition domains from Chapter 4 and the empirical gaps identified in § 5.2, the validated mechanisms are staggered across five horizons. Every horizon pairs a tightly scoped, low-cost, high-leverage action (highlighted in bold in the tables that follow) with quieter groundwork on the more capital-heavy structural enablers needed to sustain sector-wide Viability. The sequence, as can be seen in figure 5 and more elaborate in figure 6, Ignition; Bias-Flip & Coalition Build; Proof at Scale; Lock-In & Lift-Off; and Sector Normalisation, is unpacked below in terms of mechanisms, assumptions, resource envelopes, and the conversion checks that keep cumulative investment tethered to verifiable economic returns. By front-loading independently verifiable Viability wins and enforcing strict go / no-go discipline, Heijmans can position IFD not as a proprietary gamble but as the default, economically defensible choice when the upcoming bridge-replacement surge accelerates.

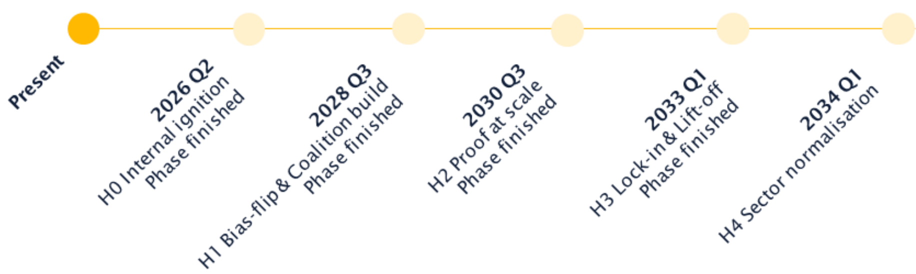

Figure 5 Strategic pathway oversight

Horizon 0
Internal ignition
Present – Q2 2026

CCC-modes:
Configure & internal Convincing

Early on, a certified pilot and a simple performance dashboard are crucial. The pilot offers independent proof of feasibility, while the dashboard provides hard data on cost, CO_2, and reuse performance (viability). Together, they cut through gut-feel resistance and create the (internal) alignment.

Mechanisms

Brand (and certify) (preparation)
Small certified pilot
IFD Go/No-go scan (preparation)
Data does the talking (preparation)
Digital passports/QR tags (preparation)

Conversion to next phase

When evidence data is sufficient for profitable projections and internal alignment has been reached.

Horizon 1
Bias-flip & Coalition build
Q3 2026 – Q3 2028

Coalition building, supported by the coalition span-classifier tool, tackles vendor lock-in fears by pooling client demand and limiting bespoke requests. The clustered stakeholder approach strengthens alignment, while persistent lobbying and informal meetings nurture trust over time. Digital passports and QR tags improve traceability, and framing tools such as peer testimonials, address client concerns. Reliability is proven through ordinary-span interface tests and embedding Heijmans-own innovation in IFD protocols, while project acquisition sets aspirational goals. Finally, engineer leverage and independent certification provide the impartial approval clients require to move forward.

Mechanisms

Coalition building
Coalition span-classifier tool (preparation)
Clustered stakeholder approach
Persistent long-horizon lobbying, Early coffee-meetings
Digital passports/QR tags
Narrative and framing techniques
Innovation inside IFD (preparation)
Ordinary-span interface tests (preparation)
Project acquisition embeds "strive-for" aspiration
Engineer Leverage & Certification

Conversion to next phase

Shift to proof-at-scale once coalitions agree on dimensioning, NTA is refined, interfaces are certified, and major/grouped clients embed IFD in policy.

Horizon 2
Proof at scale
Q3 2028 – Q3 2030

CCC-modes:
Configure & Client Convincing

In this phase, the coalition builds a cost-benchmark and shared database with research and industry partners, creating the data backbone for sector-wide adoption. At the same time, Heijmans pushes the urgency narrative of looming bridge replacements and contractor scarcity in client briefings and industry events, while keeping engineering advisors engaged to spur demand. To enable full DfMA rollout, Heijmans first secures a system-integrator network with key suppliers before developing BIM-enabled production processes. Ordinary-span interface tests prove that protocols work in everyday contexts, while the integrated supply chain reassures clients of reliability. Together, transparent data, demonstrated feasibility, and credible urgency position IFD as the only scalable option under capacity constraints.

Mechanisms

Government R&D & demonstrator funding
Ordinary-span interface tests
Scarcity-driven urgency narrative
Cost-benchmark database (preparation)
One shared database (preparation)
BIM-enabled DfMA (pilot)
System-integrator
Persistent long-horizon lobbying

Conversion to next phase

Lock-in & lift-off begins once interface tests are passed, data platforms launched, the integrator network formalized, and near-term pilot demand secured.

Horizon 3
Lock-in & Lift-off
Q3 2028 – Q3 2033

CCC-modes:
Convince & Cultivate

Heijmans and its coalition deliver a 3–5 span pilot bundle to prove repeatability, co-author success stories with clients for trade media, and populate cost-benchmark and shared databases with full performance data. These actions build trust, demonstrate viability, and equip procurement teams with hard evidence, while lobbying and storytelling push IFD toward becoming default practice.

Mechanisms

Joint client-contractor success story
3-5 span pilot bundle
Cost-benchmark database
(preparation)
One shared database (preparation)
Persistent long-horizon lobbying

Conversion to next phase

Sector normalisation begins once pilots succeed, databases are in use, and formal demand via frameworks or portfolios is secured.

Horizon 4
Sector normalization
2034 →

CCC-modes:
Configure

With pilots proven and tenders live, IFD becomes the default: framework agreements let clients procure certified modules directly, while cost-benchmark and shared databases provide transparent sector standards. Ageing assets and labour scarcity make traditional methods untenable, so procurement shifts from bespoke designs to ready-made IFD solutions, embedding IFD permanently into industry practice.

Mechanisms

Framework agreements
Cost-benchmark database
One shared database
Framework agreement

Figure 6 Elaborate strategic pathway oversight

5.6.1 Internal ignition

Heijmans launches a two FTE IFD Solutions cell, visibly in-house branded to claim the innovation space, tasked to finish the small, already initiated pilot span. Involving a, low pedestrian, certification engineering firm would counter risk-aversion of clients. Every element on that bridge carries a (QR-based) digital passport, showcased and kept in place for eventual replacement of elements, The team drafts a first Go/No-Go IFD scan to set internal guard-rails and scope. A “data-does-the-talking” dashboard then has to be constructed showcasing MKI savings, harvest-and-certification costs, and the share that fail reuse, of girders from projects that have already been done countrywide. Branding, third-party certification, visible passports and hard numbers together flip IFD from idea to accepted house strategy.

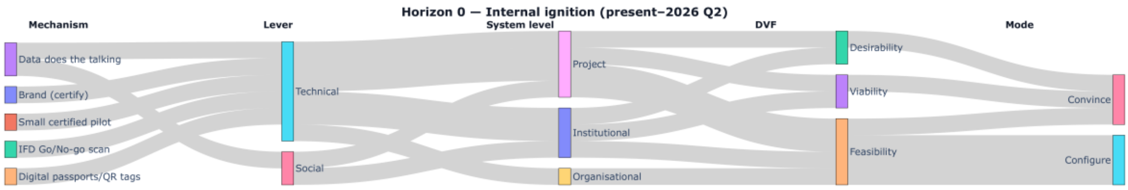

Figure 7 Horizon 0 - Layered Sankey diagram of mechanisms flowing through levers, system levels, DVF and modes (equal-weight links; grouped nodes). See also Table 17.

As figure 7 indicates, Technological levers dominate at Project/Organisational levels, flowing mainly to Feasibility and the Configure/Convince modes. The Data does the talking mechanism is dual-lever (Technical/Social): its Technical path merges with other technical flows into Project/Institutional, while its Social path remains visually distinct, hence the apparent asymmetry. Substantively, the dashboard acts as a co-lever alongside engineering proofs rather than a stand-alone social intervention.

Small certified pilot and Data-does-the-talking (preparation) are pivotal in Phase 0 because public clients insist on bankable proof before considering IFD in tenders (PC10P; PC7M). A certified pilot span delivers impartial, third-party validation of feasibility, while a lean dashboard of MKI, cost and reuse-failure metrics supplies hard numbers that cut through, the often mentioned in interviews, gut-feel resistance and unlock internal alignment.

Horizon	Mechanism (**High perceived impact**)	Lever [T,S,P]	System level [P,O,I,S]	DVF [D,V,F]	Mode [cultivate, configure, convince]
0 Internal ignition (present - 2026 q2	Brand (and certify) (preparation)	T	O	F	Configure
	Small certified pilot	**T**	**P**	**F**	**Convince**
	IFD Go/No-go scan (preparation)	T	P	F	Configure
	Data does the talking (preparation)	**T/S**	**I/P**	**D/V**	**Convince**
	Digital passports/QR tags (preparation)	T	I	F	Configure

Table 17 Strategic mechanisms H0

Conversion to next phase (Bias-flip & coalition build) when internal Heijmans alignment towards IFD is present and data is fully gathered. This mandate and ‘hard’ evidence fuels the bias-flip and coalition building in the next step.

5.6.2 Bias-flip & coalition build

With internal alignment and data in hand, Heijmans shifts from proof to persuasion by standing up a multi-contractor coalition and rolling out practical IFD tools. The team co-develops a Coalition Built Family Harvesting Tool and selects a small number of high-impact IFD initiatives, including the NTA refinement, as a unified program. The coalition then approaches clustered stakeholders for input on this tool, laying the groundwork for standardized dimensioning in the next phase, generating knowledge for product development, and giving the group a powerful, collective voice in the market.

Heijmans itself drives its own outreach using the Phase 0 data: targeting high-interest provinces via a Clustered stakeholder approach, hosting Early coffee-meetings, and sustaining the dialogue through Persistent long-horizon lobbying. When objections surface, Heijmans smothers them with Path-of-least-effort framing, Benefit-first framing, a Balanced narrative, Family thinking, and precise insights drawn from Understand pain-points.

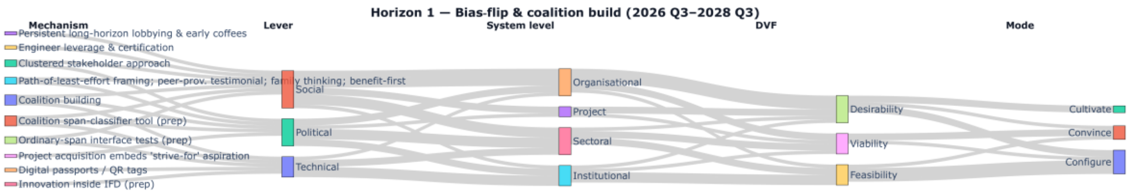

Figure 8 Horizon 1 - Layered Sankey diagram of mechanisms in Bias-flip & coalition build. See also Table 18.

Coalition building and the clustered stakeholder approach tackle vendor-lock-in fears by pooling client demand and capping bespoke requests, an effect demonstrated in the Multi-Actor Alignment section (§ 5.3.1). Preparing Innovation inside IFD protocols and running ordinary-span interface tests prove reliability in everyday contexts, as detailed under Configure → Standardising in § 5.3.2. Finally, Engineer Leverage & Certification employs neutral advisors to stamp these methods with impartial approval, cementing the trust clients say they need (see Cultivate → Engineer Leverage & Certification, § 5.3.1).

As figure 8 shows, Social levers move centre-stage and the first political nudges appear through low-key lobbying. Activity spreads to the institutional sphere as multi-contractor coalitions form. Feasibility and Viability now run in parallel, while Desirability is invoked rhetorically to broaden the tent. *Configure* and *Convince* alternate: tools translate concepts into practice, stories translate numbers into momentum. Yet coalition partners already face free-ride temptations, so transparent cost-sharing becomes a non-negotiable hygiene factor.

Horizon	Mechanism (**High perceived impact**)	Lever [T,S,P]	System level [P,O,I,S]	DVF [D,V,F]	Mode [cultivate, configure, convince]
1 Bias-flip & coalition build (2026 q3 - 2028 q3)	**Coalition building**	**T/S/P**	**S/I**	**V/F**	**Convince**
	Coalition span-classifier tool (preparation)	T/S/P	S	F	Configure
	Clustered stakeholder approach	**S/P**	**O/S**	**D/V**	**Configure**
	Persistent long-horizon lobbying, Early coffee-meetings	S	P/O	D/V	Convince
	Digital passports/QR tags	T	I	F	Configure

	Path-of-least-effort framing, Peer province testimonial, Balanced narrative, Family thinking, Understand pain-points, Benefit-first framing	S/P	P/O	D	Cultivate
	Innovation inside IFD (preparation)	**T**	**I**	**F**	**Configure**
	Ordinary-span interface tests (preparation)	**T/S**	**O**	**F**	**Configure**
	Project acquisition embeds “strive-for” aspiration	P	I	D	Configure
	Engineer Leverage & Certification	S	O	D	Cultivate

Table 18 Strategic mechanisms H1

Conversion to the next phase (Proof at scale) takes place once coalition consensus on dimensioning and pro IFD sentiment is secured, the NTA methodology has been refined and formally approved, the key interface specifications have received independent certification, and larger or clustered clients have signaled serious IFD commitment by embedding IFD aspirations into their procurement policies.

5.6.3 Proof at scale

At the outset of this phase, Heijmans immediately executes ordinary-span interface tests on a variety of subsystems to validate protocols and behaviour under real-world conditions. In parallel, the IFD coalition/Heijmans (preferably coalition) works with governmental bodies and major clients, via SBIR-style calls or innovation-budget bids on large infrastructure programmes, to secure Government R&D & demonstrator funding, while Persistent long-horizon lobbying keeps policymakers and funders engaged.

During testing the coalition drives the creation of a live Cost-benchmark database (preparation) and a one shared database (preparation) in partnership with a fitting research or industry/institutional group, laying the data foundation for sector-wide implementation. Concurrently, Heijmans amplifies the scarcity-driven urgency narrative, highlighting looming replacement surge and contractor scarcity, in client briefings and at industry events, while keeping its advisory-engineering contacts updated to stimulate downstream demand.

To set the stage for a full DFMA rollout, Heijmans first establishes its system-integrator network, starting partnerships with key suppliers. Only once that network is in place does the team begin laying the first bricks of BIM-enabled DfMA, establishing the production processes for potential large scale uptake.

Ordinary-span interface tests answer ENG3's warning that modular protocols "get lost in the paperwork" unless demonstrated on routine girders (5.2.2). Establishing a system-integrator network reassures clients that a coordinated supply chain stands behind those interfaces (5.3.2). Simultaneously, a scarcity-driven urgency narrative leverages the "enorme schaarste" frame to position IFD as the only scalable option under capacity constraints (5.3.1), while preparing a cost-benchmark database and one shared database ensures transparent MKI, OPEX and CAPEX data are ready when clients demand hard numbers (5.3.3).

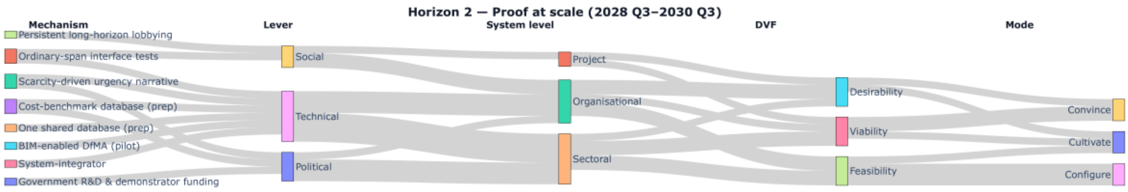

Figure 9 Horizon 2 - Layered Sankey diagram of mechanisms in Proof at scale. See also Table 19.

As Figure 9 makes visible, the centre of gravity migrates to Sectoral/Organisational system levels, with Technical (+Political) levers feeding Viability/Feasibility. The prevailing modes are Configure/Convince, now supplying public proof points, provided failures and costs are reported alongside successes.

Horizon	Mechanism (**High perceived impact**)	Lever [T,S,P]	System level [P,O,I,S]	DVF [D,V,F]	Mode [cultivate, configure, convince]
2 Proof at scale (2028 q3 - 2030 q3)	Government R&D & demonstrator funding	P	S	V	Cultivate
	Ordinary-span interface tests	**T/S**	**O**	**F**	**Configure**
	Scarcity-driven urgency narrative	**T/P**	**O/S**	**F**	**Cultivate**
	Cost-benchmark database (preparation)	**T/P**	**S**	**V**	**Convince**

	One shared database (preparation)	**T**	**S**	**F**	**Cultivate**
	BIM-enabled DfMA (pilot)	T	O	F	Configure
	System-integrator	**T**	**S**	**F**	**Configure**
	Persistent long-horizon lobbying	S	P/O	D/V	Convince

Table 19 Strategic Mechanisms H2

Conversion to the next phase (Lock-in & lift-off) occurs once Heijmans (and its coalition) have successfully completed the ordinary-span interface tests, launched a live cost-benchmark database, prepared the one shared database, formalized the system-integrator network, and secured tangible (pilot) demand for complete IFD projects in the near future (<1year).

5.6.4 Lock-in & lift-off

The team win, deliver and showcases (3-5 span) pilots (bundle), then co-authors a high-profile client, contractor success story, whether from a completed project, a live tender or even a pre-tender design phase, and places it in trade media. At the same time, Heijmans (with coalition parties) begins populating the cost-benchmark database prototype with comprehensive data records and rolls out the one shared database prototype for clustered clients, gradually adding tagged reuse metrics and performance dashboards. These evolving data platforms reinforce technical repeatability, build stakeholder trust and equip procurement teams with defensible evidence.

The 3-5 span pilot bundle delivers on the "batch projects into series" demand identified in § 5.3.2, showing clients consistent performance across multiple assets rather than isolated demos. Populating the cost-benchmark database and one shared database share the same high impact as in the 2nd horizon.

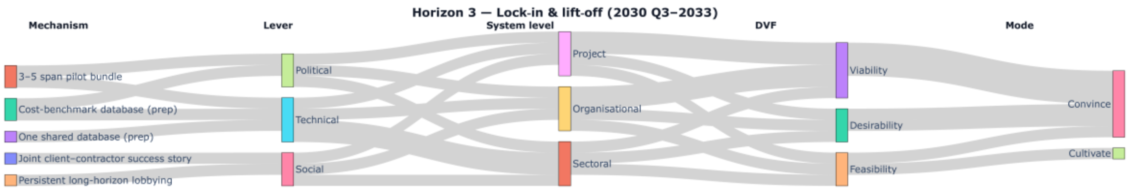

Figure 10 Horizon 3 - Layered Sankey diagram of mechanisms in Lock-in & lift-off. See also Table 20.

In figure 10, Viability now eclipses Feasiblity. Social and political levers, success stories and procurement-criteria lobbying dominate, while technological work recedes into routine maintenance. The prevailing mode remains *Convince*, aimed at embedding the solution in default procurement practice. Because the business case is now front-and-centre, volatility in budgets or discount-rate assumptions could still undo progress, so robustness checks become critical.

Horizon	Mechanism (**High perceived impact**)	Lever [T,S,P]	System level [P,O,I,S]	DVF [D,V,F]	Mode [cultivate, configure, convince]
3 Lock-in & lift-off (2030 q3 - 2033)	Joint client-contractor success story	S	S	D	Convince
	3-5 span pilot bundle	**T/P**	**P/O**	**V/F**	**Convince**
	Cost-benchmark database (preparation)	**T/P**	**S**	**V**	**Convince**
	One shared database (preparation)	**T**	**S**	**F**	**Cultivate**
	Persistent long-horizon lobbying	S	P/O	D/V	Convince

Table 20 Strategic mechanisms H3

Conversion to the next phase (sector normalisation) occurs once these pilots have positive results and databases are in active use and formal demand (e.g. framework or portfolio agreements) are in place to scale IFD across the sector.

5.6.5 Sector normalisation

With pilots proven and tenders live, Heijmans cements IFD as the default. A multi-owner framework agreement goes into effect, enabling clients to procure certified modules directly through standardized contracts. At the same time, the cost-benchmark database graduates to a fully populated portal and the one shared database becomes the sector's primary reference for tagged reuse metrics and performance dashboards.

By now, the renovation-challenge pressure is impossible to ignore: ageing structures and shrinking labour pools make traditional methods untenable. Ready-made contracts plus transparent data mean procurement teams no longer debate bespoke designs, they simply select IFD modules as their go-to solution, embedding IFD permanently into industry practice.

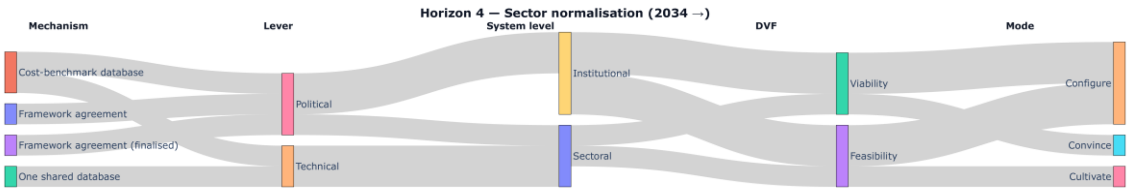

Figure 11 Horizon 4 - Layered Sankey diagram of mechanisms in Sector normalisation. See also Table 21.

In figure 11, most of the movement comes from political levers at the institutional and sector levels. Framework agreements carry the bulk of the flow and channel value into Viability and Feasibility, with Configure as the dominant mode to lock rules and contracts. Technical work supports this through the shared database, which mainly feeds Feasibility and the Cultivate mode to keep the new default in use. A smaller Convince stream remains, largely tied to the cost-benchmark database, to backstop claims with numbers. Together, these streams codify the business case and make IFD the routine choice in procurement.

Horizon	Mechanism (**High perceived impact**)	Lever [T,S,P]	System level [P,O,I,S]	DVF [D,V,F]	Mode [cultivate, configure, convince]
4 Sector normali-sation (2034 - →)	Framework agreement	P	I	V/F	Configure
	Cost-benchmark database	T/P	S	V	Convince
	One shared database	T	S	F	Cultivate
	Framework agreement	P	I	V/F	Configure

Table 21 Strategic mechanisms H4

With this phased playbook in place, Heijmans can move deliberately from proof to performance, only investing in the next horizon once the prior triggers are met, while continuously building client confidence, technical readiness and market momentum. Having front-loaded the critical "make-or-break" wins and laid the groundwork for sector-wide standards, the strategic pathway ensures that IFD emerges not as a risky experiment but as the mainstream approach just as the bridge-replacement surge peaks.

Beyond the contractor perspective, the findings also reveal that the sequence of Cultivate–Configure–Convince is not universal but depends strongly on the structure and dynamics of procurement markets. This broader implication is taken up in the discussion as a scientific contribution that extends beyond the construction sector. The discussion in Chapter 6 will examine these recommendations against broader policy, legal and organisational dynamics, setting the stage for the final conclusions in Chapter 7.

6 Discussion

The previous chapters presented the empirical results and the strategic pathway for accelerating Industrial, Flexible & Demountable (IFD) bridge delivery. Chapter 6 now steps back from those operational details to interpret what the findings mean in a wider academic and managerial context. First, Section 6.1 distils the research's key empirical contributions. Section 6.2 then positions those contributions against established literature on modular construction, demand-side innovation and public-sector procurement, highlighting where the present study confirms, nuances or contradicts earlier work. Section 6.3 acknowledges the study's methodological and theoretical limitations, while Section 6.4 translates the insights into actionable implications for scholars and practitioners. Finally, Section 6.5 outlines promising directions for future research that could further refine or stress-test the proposed pathway.

6.1 Key empirical contribution

The research (i) consolidated documented influence mechanisms into a coherent three-lever, four-level, three-mode schema; (ii) mapped how these mechanisms are actually deployed and perceived during the explorative phase of Dutch bridge projects; (iii) revealed a pronounced gap between the influence contractors *seek* and the latitude public clients *grant*; and (iv) stitched the validated mechanisms into a phased strategic pathway with explicit *go / no-go* conversion checks. No entirely novel levers were discovered, every mechanism appears somewhere in prior literature, but their empirical re-specification for Dutch IFD projects converts scattered concepts into a practicable roadmap.

6.2 Interpretation in light of the literature

Viability as decisive gatekeeper.

The interviews make one point painfully clear: public clients will live with technical grey areas as long as the long-term money story is watertight. That stance echoes the global experience with modular construction: Wuni and Shen (2020) identify uncertain life-cycle economics as a primary barrier to prefabrication adoption, noting that clients consistently cite it as their top concern. Feldmann et al. (2022) corroborate this, highlighting financial considerations as among the most significant, and influenceable, impediments to modular construction. Shahpari et al. (2020) further stress that rigorous life-cycle costing and scenario-based modelling are essential for managing long-term financial risk, yet these tools are frequently overlooked in practice when responsibilities are fragmented or incentives misaligned.

Demand-side innovation theory frames this shortfall as a "missing-market" failure: when credible cost signals are absent, neither buyers nor suppliers can price the new option rationally, so procurement has to step in and manufacture the information (Edler & Georghiou, 2007) Edler et al., 2007. That logic drove our pathway design. The very first conversion check, Phase 0, internal ignition, requires an externally auditable cost-carbon dashboard built on open formulas, not a vendor Excel sheet. Phase 1 upgrades that to a joint cost template co-owned with early-adopter clients; Phase 2 adds a third-party-verified benchmark database. Only once those artefacts survive audit does the pathway allow escalation to coalition building or regulatory lobbying.

The critique cuts both ways. Without these visibility tools, later phases will crash under the weight of economic scepticism, regardless of how elegant the engineering looks. Conversely, if we over-engineer dashboards that remain proprietary, clients may dismiss them as marketing spin, recreating the very “missing market” we set out to fill. Our study therefore positions viability levers as both the scarcest and the most fragile assets in the contractor’s influence portfolio, indispensable for progress, yet easily discredited if transparency falters.

Shifting from tools to politics

The data shows a predictable shift in influence. At the start (“Ignition”) everyone asks, *Does IFD even work?* so small technical pilots and in-house prototypes lead. Mid-way, trust becomes the bottleneck; joint demos and early-adopter alliances supply the social proof that attracts others. By the final stage (“Lock-in & Lift-off”) engineering questions are largely settled, the real fight is over rules. Political levers such as adding IFD points to tender award criteria or writing it into framework contracts determine whether the idea spreads sector-wide.

According to Vuorinen et al. (2019), the people with the most power, legitimacy and urgency change across those stages, engineers matter early, policy actors matter late. Our pathway does list these *formal* political moves, but it leaves out the quieter tactics (off-record lobbying, draft-standard committees, timing a CO_2-pricing argument for a policy window) that usually make formal changes possible. Because interviews rarely capture that behind-the-scenes work, basing the strategy only on recorded statements risks a plan that reaches the pilot phase and then stalls while better-prepared competitors write the rules. In short, the roadmap accounts for the visible political levers but underestimates the invisible ones, so the end-game is only half-covered and the contractor could still lose control at the moment rules are set.

Accounting rules as hidden veto players

Life-cycle models can look flawless on paper yet still die at the finance desk because Dutch public bodies record most civil-works spending on a cash basis. Under that rule, the full outlay for a bridge appears in year 0, no depreciation is booked, and any residual value from future reuse is invisible. Decision-makers therefore see only the up-front cost and discount innovative reuse options that shift pay-back beyond the electoral cycle. Verlaan’s (2017) *Infra-GAAP* study shows how this accounting blind spot skews renewal planning: budgets lurch from boom to backlog, and cost-saving design choices with a long horizon, exactly the promise of IFD, are treated as fiscal luxuries rather than prudent investments.

The same infrastructure of rules could, however, become an enabler almost overnight. If a national CO_2-pricing scheme or a mandatory “carbon shadow price” enters government appraisal (both are under review), accountants would need to book *carbon liabilities* alongside monetary flows. Suddenly, a demountable bridge that retains material value and avoids future emissions shows up as an asset, not a cost. In Davies et al.’s terms, accounting conventions are part of the state’s procurement infrastructure: they either unlock or block public value, not merely record it (Davies et al., 2025).

Two strategic implications follow. First, contractors must treat finance regulations as *design variables*, lobbying for pilot projects that use accrual-based reporting and whole-life carbon accounting instead of assuming the rules are fixed. Second, any viability narrative presented to clients should include a “dual ledger” that shows the project under both cash and accrual/CO_2-priced scenarios, making the hidden veto, and the potential flip to catalyst, explicit. Ignoring this step risks perfect engineering logic being vetoed by an obsolete spreadsheet.

6.3 Ordering influence modes across Procurement Market Archetypes

A further theoretical contribution of this study lies in extending the Cultivate–Configure–Convince (CCC) model beyond the contractor perspective. While the preceding chapters demonstrated how CCC provides a useful lens for structuring influence mechanisms in the explorative phase of IFD bridge projects, the analysis of the interview data indicates that the order in which these phases unfold depends strongly on the configuration of procurement markets. The argument advanced here is therefore that CCC should not be interpreted as a rigid sequence but rather as a market-sensitive repertoire, an interpretation that is subsequently substantiated with insights from the wider literature on demand-side innovation and procurement.

The CCC model itself distinguishes three interdependent pillars: Cultivate, which refers to building awareness, legitimacy and trust; Configure, which concerns the alignment of technical, organisational and contractual frameworks; and Convince, which relates to securing commitment by means of viability evidence and risk mitigation. Interviewees consistently acknowledged the importance of all three phases, yet they stressed that their order varied according to the procurement setting. This finding resonates with broader research on high-capital, regulated sectors such as energy, healthcare and defence, where public procurement functions as a powerful demand-pull instrument for innovation (Edler & Georghiou, 2007).

The five resulting procurement-market archetypes and their corresponding CCC orders are summarised in Figure 12, which visualises how sequencing varies across different procurement contexts.

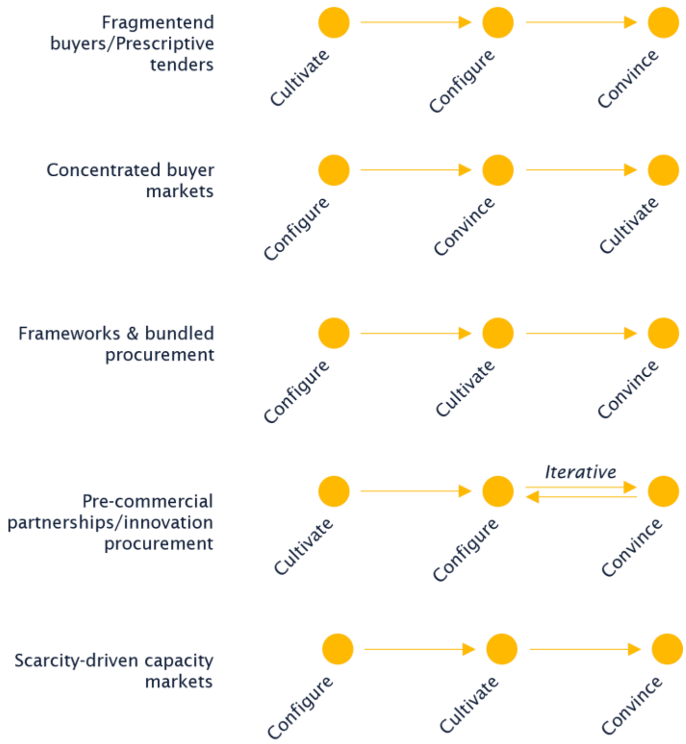

Figure 12 Ordering influence modes across procurement archetypes

In fragmented buyer markets with highly prescriptive tenders, the interviews indicated that current procurement practice leaves little space for IFD solutions. As EXP4 explained, detailed specifications often prevent innovative approaches from being considered at all. In such settings, contractors must therefore begin by cultivating legitimacy and a shared understanding, since no structural opening exists until trust is created among dispersed clients. This dynamic reflects Wuni and Shen's (2019) finding that fragmented demand is a central barrier to modular adoption. Here, the sequence is necessarily Cultivate → Configure → Convince.

By contrast, in concentrated buyer markets dominated by a small number of powerful buyers, such as national agencies or utilities, respondents highlighted that adoption could accelerate rapidly once technical templates and cost dashboards were available. As PC5P observed, large public clients have the capacity to steer the market once they adopt a given standard, after which others tend to follow. In these contexts, contractors must configure their technical systems and contractual templates up front, before convincing buyers with viability evidence. Cultivation still plays a role but follows rather than precedes. Feldmann et al. (2022) underline this dynamic, showing how large buyers set de facto standards across supply chains. Accordingly, the CCC order shifts to Configure → Convince → Cultivate.

A similar configure-first logic was visible in the case of frameworks and bundled procurement. Respondents described the efficiency gains of addressing multiple bridges as a series (PC7M), the use of framework agreements to avoid repetitive tendering (PC11M/PC12M), and provincial efforts to bundle projects into programmes for predictability and scale (PC13P). These procurement forms are explicitly designed for repeatability and pooled demand, which means that contractors must configure repeatable technical systems and contractual models before they can cultivate legitimacy or convince sceptics. Wondimu et al. (2019) confirm this rationale, describing frameworks as instruments that presuppose standardisation and continuity. In such contexts, the sequence is therefore Configure → Cultivate → Convince.

A different dynamic emerged in innovation partnerships and pre-commercial procurement settings, where feasibility was highly uncertain. As EXP4 noted, under such conditions contractors must actively position themselves and initiate new processes with public clients, which requires coalition-building and trust as a first step. Here, cultivation of legitimacy is the entry point, followed by iterative cycles of configuration and convincing as prototypes, audits, and contractual arrangements develop. This reflects Edler and Georghiou's (2007) characterisation of pre-commercial procurement as a staged, risk-sharing process where demand articulation and supplier configuration co-evolve. The resulting CCC order is thus Cultivate → Configure ⇄ Convince.

Finally, in scarcity-driven procurement contexts, such as bridge backlogs under labour shortages, urgency altered the sequence yet again. Respondents emphasised that under such conditions the overriding concern of public clients is to secure deployable capacity quickly (EXP4). Here, contractors must first configure ready-to-use solutions and then immediately convince buyers with feasibility and viability evidence, while broader cultivation occurs only afterwards as solutions prove themselves in practice. Shahpari et al. (2020) stress that under such conditions cost and lifecycle evidence dominate adoption, reinforcing the primacy of Configure and Convince. The CCC sequence in these cases is therefore Configure → Convince → Cultivate.

Taken together, these patterns demonstrate that the CCC model should be understood as contingent on procurement-market structures rather than as a universal ladder. In fragmented markets Cultivate must come first; in concentrated buyer markets Configure initiates adoption; in frameworks and bundles Configure again leads, but is followed by cultivation; in pre-commercial settings Cultivate initiates iterative cycles; and in scarcity-driven markets Configure and Convince dominate in compressed form. The analysis therefore extends innovation diffusion theory by integrating empirical findings from the Dutch bridge sector with established scholarship on demand-side innovation and procurement (Edler & Georghiou, 2007; Wondimu et al., 2019; Wuni & Shen, 2019, 2020; Feldmann et al., 2022; Shahpari et al., 2020).

The scientific added value lies in explicitly coupling each procurement-market archetype to a specific CCC order, thereby offering a diagnostic framework for scholars to analyse how suppliers and system integrators adapt their influence strategies to different institutional conditions. For practitioners, the CCC framework provides a transferable tool for suppliers to align their market-shaping efforts with procurement realities not only in construction but also in other procurement-mediated innovation domains. While previous studies have highlighted the role of procurement in stimulating innovation across health, transport, defence, energy and ICT (Edler & Georghiou, 2007; Uyarra et al., 2014), the present analysis advances this understanding by demonstrating how suppliers and system integrators can sequence their influence strategies in response to different procurement structures.

6.4 Limitations

First, sample bias may overstate contractor influence. The relatively small interview panel was assembled through Heijmans' professional network and invitations at sector conferences, making it likely that participants were already positively predisposed toward IFD. As a result, the data under-represent public-sector skeptics and covert influence tactics, such as back-channel negotiations or informal policy advocacy, that may remain hidden precisely because they challenge prevailing industry narratives. Consequently, our taxonomy of mechanisms may omit important "below-the-radar" strategies that contractors deploy when official channels prove ineffective.

Second, theoretical transfer risks distorting IFD specifics. Because dedicated IFD literature remains sparse, we drew heavily on adjacent modular-construction studies (e.g., Feldmann et al., 2022) to validate and refine our mechanism catalogue. While modular and IFD share technical and life-cycle logics, the Dutch bridge context involves distinct regulatory frameworks, asset-management rules, and stakeholder configurations. Importing modular-construction insights wholesale therefore risks masking IFD's unique barriers, such as infrastructure-scale certification requirements, and may lead to overgeneralised or misaligned recommendations.

Third, uneven academic pedigree weakens some foundations. A portion of the IFD-related sources cited in the thesis are master's theses or policy white papers rather than peer-reviewed articles. Moreover, even the peer-reviewed IFD studies date back nearly a decade, raising questions about their relevance to contemporary digital and sustainability standards. This patchwork of source types and vintages dilutes scholarly rigor and makes it harder to assess which mechanisms remain current versus those that may have been superseded by evolving industry practice.

Fourth, the cross-sectional design can't predict policy volatility. Our findings capture a moment in time, summer 2025, when CO_2-pricing schemes, EU taxonomy updates, and Dutch MIRT rules were still in flux. A sudden mandate on carbon shadow pricing or a shift toward accrual-based accounting could fundamentally reorder the viability calculus that underpins our entire phased pathway. By design, the study cannot anticipate such shocks, meaning that the strategic roadmap may require rapid recalibration in response to new regulations or market signals.

Fifth, untested coalition dynamics. While the pathway hinges on multi-contractor alliances in Phase 1, our study does not observe how these coalitions actually coalesce, what power imbalances emerge, or whether they endure under commercial pressure. In practice, contractors may struggle to agree on shared templates, cost-sharing rules or political positioning, and weaker firms could be sidelined, risks that remain unexamined here.

Sixth, the pathway assumes that Heijmans' early investment in viability levers, such as joint cost templates or third-party audits, will yield a durable competitive edge. However, the public procurement landscape may not reward first-mover efforts with exclusive contracts or price premiums. Once IFD demonstrates clear economic benefits, rival firms can "free ride" on shared standards and dashboards, diluting Heijmans' market advantage. The duration of any proprietary benefit is therefore uncertain, and the cumulative costs of coalition-building, data-platform development, and policy engagement may outweigh short-term gains. Without a mechanism to capture and appropriate payback, through framework exclusivity, licensable tools, or contracting subsidies, Heijmans risks investing heavily in strategies whose returns are neither guaranteed nor easily quantified.

While none of these limitations nullifies the study's core contribution, the structured overview of influence mechanisms and the disciplined sequencing in a strategic pathway, they do constrain how and where the results can be applied. The implications and directions for future research will be discussed in the coming sections.

6.5 Implications

Theoretical

In emerging fields like IFD, the timing of technology adoption hinges on public procurement demands for transparent, viability evidence. Because these signals do not yet exist though desired, contractors can step in to generate the first life-cycle dashboards and residual-value models, which then become the benchmarks that clients and regulators could adopt. This reversal of the usual ‘client defines requirements supplier delivers’ sequence compels all parties to rethink established routines and norms.

Edler and Georghiou (2007) warned of this vacuum almost two decades ago: “Demand is a major potential source of innovation, yet the critical role of demand as a key driver of innovation has still to be recognised in government policy.” Because that recognition is still missing, the current co-creation process is not yet designed to reward or even reimburse the contractors who supply the viability evidence. This study shows that contractors can and do exercise real influence in shaping IFD requirements by supplying this viability evidence, but sustaining the efforts of that influence over time, across the procurement landscape, as formal standards evolve, remains an open challenge.

Practical

For contractors, the most defensible route to drive IFD adoption is to prove the economics up-front and advance only when each stage passes a strict go / no-go test, following the strategic pathway in §5.6.

This “viability-first, gated-escalation” discipline does four things. First, it caps sunk-cost risk by turning each phase into a reversible bet. Second, it speaks the client’s language, procurement officers see the same audited figures you do, eliminating black-box scepticism. Third, a third-party-verified report makes free-riding harder, competitors can use your template, but they can’t reproduce your stamped verification. Yet this credibility boost can backfire: clients may then label the evidence as vendor-specific and insist on a neutral audit before accepting it as a sector standard. In other words, protecting against free-riders can also raise suspicions that your data package is merely proprietary marketing. Fourth, it prepares the ground for future policy shifts; once provinces co-own the template, they become natural sponsors when CO_2-pricing or accrual accounting reforms arrive. In short, **prove the economics first, advance in measured steps, unlock new capital only when the previous viability gate is cleared**, a sequence that maximises credibility, limits financial exposure, and preserves a defensible lead as IFD scales.

6.6 Directions for future research

Financial Scenario Modeling

First, financial modelling of policy and accounting changes is essential. Researchers should build straightforward net present value models that incorporate potential CO_2 taxes, a shift from cash-basis to accrual accounting, or targeted subsidies for material reuse. By running these scenarios over typical bridge lifespans and expected IFD lifespans, we can identify the precise policy thresholds at which IFD projects switch from unprofitable to profitable, or vice versa. Such work will guide both contractors and regulators toward the most effective reforms to support sustainable infrastructure.

Coalition Dynamics Over Time

Second, we must understand how contractor coalitions actually perform over time. Longitudinal case studies, combining simple network diagrams with periodic interviews or diaries, can track whether alliances remain stable, how partners divide costs and benefits, and what governance rules prevent free-riding. This research will test the pathway's assumption that group strategies reliably amplify influence and will reveal the practical conditions under which shared investments translate into shared returns.

Governance of Fragmented Clients

Third, bridging the gap between dozens of fragmented client organisations calls for detailed governance mapping. Scholars should select a region and chart the legal agreements, organisational structures, and meeting routines that local, provincial, and national bodies use when they successfully pool procurement or agree on common technical standards. Understanding these coordination mechanisms will show how to reduce duplicated efforts, harmonise requirements, and unlock efficiency gains across multiple jurisdictions.

Cross-Sector Alignment

Finally, cross-sector coordination deserves rigorous attention. Comparative studies in regions where bridge renewal, energy network upgrades, and other infrastructure projects run in parallel can highlight where schedules overlap, budgets conflict, or permitting processes bottleneck. Interviews with multi-sector planning authorities and simple flow-chart analyses can uncover best practices for synchronising investments, aligning timelines, and preventing one sector's work from stalling another. Together, these research avenues will deepen our knowledge of how IFD adoption pathways interact with policy volatility, coalition dynamics, client fragmentation, and inter-sector dependencies, strengthening both theory and practice.

Taken together, the discussion clarifies three overarching points. First, the real bottleneck in mainstreaming IFD lies not in technology but in credible, client-facing viability evidence and the governance routines that can absorb it. Second, influence mechanisms are stage-specific: what convinces engineers at project ignition differs markedly from what sways policy actors at lock-in. Third, contractors can accelerate systemic change only by coupling transparent economics with coalition-based procurement reform; isolated technical pilots will not suffice. These reflections set the stage for Chapter 7, where the study's main conclusions are synthesised and translated into a concise answer to the overarching research question.

7 Conclusion

This closing chapter consolidates the study's empirical results and theoretical reflections into a coherent end-statement. After six chapters that mapped the structure of the explorative phase, analysed the barriers and enablers of Industrial, Flexible & Demountable (IFD) construction, and tested contractor influence strategies, Chapter 7 synthesises the insights, clarifies their practical consequences, and positions them within the wider infrastructure-management debate.

7.1 Main conclusion

This subsection revisits each research sub-question in turn and shows how their individual answers combine into a single, high-level response to the main research question: How can contractors strategically influence the explorative phase of public bridge-replacement projects to stimulate IFD adoption? By interweaving structural analysis, stakeholder evidence and governance theory this translates detailed findings into an overarching conclusion that is both academically grounded and directly actionable for market actors.

> How is the explorative phase structured in public bridge replacement projects, and what key factors influence the evaluation of potential construction solutions?

The explorative phase in Dutch bridge-replacement is best characterised as an iterative decision spiral, commencing with annual portfolio scans, where asset teams update condition scores, safety risks and remaining service life, and progressing through ambition sessions and variant-matrix workshops (EXP9; PC3P) Although budgets and scopes are formally "signed off," they are routinely back-looped when fresh inspection data or political shifts arise. As one consultant observed, "Je krijgt zelden nieuwe harde data die alles op z'n kop zet; meestal rommelen we door met wat er is" (EXP9), and a municipal asset-manager confirmed, "Ons college komt pas in beweging als er echt bruggen uitvallen; tot die tijd is er weinig politieke druk" Consequently, genuine reopenings are rare, and teams "muddle through" annual update cycles until a true crisis compels reconsideration.
Once structural decline crosses a critical threshold, public clients adhere to a strict reinforcement-first logic: "eerst kijken we of we kunnen versterken of de levensduur verlengen … vervanging is pas de allerlaatste stap" (PC3P). Only when all strengthening options are costed does a replacement brief enter the ambition session, typically involving engineers by default (ENG3) and, on larger contracts, a two-phase Bouwteam where Phase 1 co-designs and prices variants and Phase 2 finalises the fixed-price tender (PC1P).
Three systemic constraints filter which solutions survive to tender:

1. Short political and budgeting horizons. Although some clients nominally plan 70–80 years ahead, binding decisions seldom extend beyond eight to ten years, "meer een papieren werkelijkheid" (PC3P), and are frequently unsettled by annual resets and coalition changes.
2. Premature technical lock-in. When the reference design "crystallises" key parameters, deck depths, connection details, too early, it effectively excludes modular or demountable options: "zet je te veel techniek vast, dan is modulair bouwen later kansloos" (PC13P; ENG3).

3. Institutional fragmentation and risk aversion. Divergent incentives between OPEX-driven asset teams and CAPEX-driven project teams diffuse accountability, while a culture of legal defensibility steers clients toward familiar, cast-in-situ methods (van Wijck et al., 2018; Boersma, 2018) .

Finally, the duration from first portfolio scan to tender publication averages four to eight years for a single bridge, and can extend to a decade for multi-asset corridors, underscoring the sheer time-lag before any innovative solution can be tendered (PC3P; EXP9).

In sum, although the phase's spiral structure affords early design flexibility, its iterative yet infrequent back-loops, coupled with truncated horizons, lock-in dynamics and misaligned institutional incentives, create a constraint-laden arena that systematically filters out novel construction solutions before formal procurement begins.

> What specific challenges and opportunities arise in integrating IFD construction within the explorative phase?

Integrating Industrial, Flexible & Demountable (IFD) methods into the explorative phase faces three interrelated challenges:

1. Cultural and perceptual resistance. Despite proven technical viability, modular approaches often collide with entrenched professional identities and historical biases against prefabrication. Interviewees describe a "gut-feel" conservatism that privileges bespoke, cast-in-situ solutions unless tangible proof of modular benefits exists. Without deliberate social-acceptance interventions, such as multi-actor workshops or visible pilot demonstrations, IFD concepts struggle to gain legitimacy in early ambition sessions.
2. Procurement rigidity and the "proof paradox." Traditional procurement routines emphasise legal defensibility and low upfront cost, creating a paradox: clients demand audited life-cycle savings before specifying modular options, yet contractors cannot demonstrate those savings without early-phase involvement. As a result, functional requirements remain narrowly defined, and alternative-solution tools or idea-competitions often occur only at the tender stage, too late to reshape reference-design locks.
3. Ecosystem fragmentation and data gaps. The sector's fragmented supply chains, absence of integrated digital platforms, and uneven application of modular standards inject coordination risk into early design. Interviewees highlight that without a trusted, certified supplier network, and reliable digital twins or LCC dashboards, public clients default to familiar methods to avoid unquantified risks.

Conversely, the explorative phase also presents distinct opportunities for IFD integration:

- Early contractor involvement routes aren't new or unused. Pilots of a phased design-and-price model allow contractors to co-shape variant matrices before technical lock-in, surfacing modular options when flexibility is highest.
- Leveraging formal pilot projects. Client-sponsored demonstration bridges can provide the "hard data" needed to overcome cultural barriers and the proof paradox, creating credible reference cases that feed back into ambition sessions and variant selection.

- Emerging standards as enablers. The publication and refinement of NTA 8085/8086 provides a ready-made specification framework that public clients can reference in the explorative brief, reducing transaction costs and perceived technical risk for modular proposals.
- Trust-building governance mechanisms. Long-term framework contracts and harmonised requirement sets can bundle demand across multiple assets, giving contractors the volume certainty needed to invest in modular configurations.

In sum, while IFD faces entrenched cultural, procedural and ecosystem hurdles in the explorative phase, targeted interventions, early contractor involvement, pilot projects, standardised frameworks, and coalition-building governance, can convert this “make-or-break” window into a launch pad for modular innovation.

> How can contractors strategically engage and influence the explorative phase to enhance the consideration of IFD construction solutions?

Mapping contractor interventions onto the empirically tested DVF hierarchy: Viability → Feasibility → Desirability, reveals a clear, sequential strategy (Hunsaker & Thomas, 2017).

Viability - Close the business case.
Contractors must first supply bankable life-cycle figures (CAPEX, OPEX, MKI, residual value) before tender criteria harden. As one evaluator observed, “another inspirational deck will fail if it has no figures” (PC10P). Yet cost-only appeals frequently falter under fragmented procurement rules, regulatory constraints and misaligned incentives across asset-management and project teams (Boersma, 2018; Van Wijck et al., 2018). Moreover, political “crisis catalyst” windows, when backlogs mount and closures threaten economic activity, can suddenly override procedural inertia, so contractors must time delivery of their “cost + carbon pack” to coincide with these volatility points through continuous contact(Williams et al., 2022). A leading province’s pilot of 100- to 200-year element-level LCC calculations translates future re-use gains into CAPEX (PC1P), while Rijkswaterstaat’s new aerial-structure guideline lowers perceived technical risk (PC2N). By providing similar input the contractor can shape and speed up IFD adoption. Furthermore by adopting a “seller” mindset that offers Go/No-Go scans, design frameworks and certified modules rather than waiting for tender triggers (Edler & Georghiou, 2007), contractors enable clients to earmark matching budgets and embed IFD metrics into binding award criteria (PC2N).

Feasibility - Demonstrate modular proof at scale.
Next, contractors must resolve the proof paradox by delivering small-scale, certified pilots of modular bridge elements. Although girders sit at TRL 7-8 and the NTA defines interfaces, clients still demand evidence of repeatability and certifiable detachable connections (ENG3). One client insisted on “bridge 20 × 25 m costs € 2 million” certainty (PC8P). A targeted small pilot, completed by end-2025 and coupled with independent structural verification under partial NTA protocols, will lower perceived technical risk and further validate the “plug-and-play” promise.

Furthermore, because engineering consultancies are embedded by default in ambition sessions and variant-matrix workshops, and seen as "safer" early sounding boards than contractors, their technical scopes and interface preferences materially shape which options survive to tender (ENG3; PC1P). Contractors should therefore formalize co-creation by institutionalizing IFD-Studio sessions and data-sharing protocols (Lember et al., 2019), and engage consultancies through joint workshops, co-development of modules or certification partnerships to indirectly embed IFD parameters into engineering deliverables.

Desirability - Embed IFD in procurement rules.
Finally, contractors must convert waning cultural resistance into formal procurement frameworks. Although aesthetic objections "fall away" once architects engage (PC8P), binding mandates remain scarce. By championing "IFD-mandatory" templates and advocating consortium-led lobbying for multi-asset framework agreements that break client fragmentation (Feldmann et al., 2022; Uyarra et al., 2014), contractors secure the volume certainty needed to invest in modular configurations. In parallel, profiling themselves as IFD pioneers, owning the narrative from Day 1 of the replacement wave, captures first-mover advantages when labour-market tightness amplifies their leverage, as scarce capacity drives clients to adopt pre-tested modular solutions (Wuni et al., 2019).

In sum, by sequentially (1) delivering audited life-cycle data at the right political moment, (2) proving modular systems through certified pilots and formalized co-creation with embedded consultancies, and (3) institutionalizing IFD via binding policy, coalition-based procurement and pioneer branding, contractors reframe modular bridge construction as the compelling baseline strategy for Dutch bridge replacement.

How can contractors strategically influence the explorative phase of public bridge replacement projects to stimulate the adoption of Industrial, Flexible, and Demountable (IFD) construction?

The research confirms that contractor influence succeeds only when it is calibrated to the decision dynamics of public clients in the explorative phase. Influence anchored in verifiable value, rather than promises or price alone, creates early legitimacy, while tangible demonstrations transform acceptance into practicality. Once credibility is established, aligning that proof with procurement norms converts preference into policy.

Yet such progress will not emerge spontaneously. A forward-leaning contractor strategy is indispensable, because moving to Industrial, Flexible & Demountable (IFD) bridges is less a product swap than a reinvention of the entire front-end process. Heijmans is already modelling that stance: its certified mini-pilot bridge and recurring multi-actor workshops give public clients a concrete demonstration of modular feasibility. Certifying bodies and advisory engineers, who translate ambitions into the measurable parameters that define tenders, therefore hold pivotal power; their buy-in must be secured, not sidelined.

Given that most Dutch bridge owners are small and dispersed, working through client clusters and broader coalitions is the only realistic way to scale. Coalitions signal shared intent, help navigate procurement-law constraints on contractor-driven innovation, and reassure owners that emerging standards will be open rather than proprietary. In turn, the approaching renovation wave offers a ready test bed: IFD can absorb large, repetitive replacement volumes more efficiently than bespoke construction, provided the sector steps beyond its own fragmentation and presents a united front of value, proof and policy alignment.

Effective practice therefore relies on a balanced governance posture: evidence-led oversight satisfies financial and regulatory actors, while collaborative engagement with designers, certifiers and clustered asset owners preserves the flexibility required for project-specific complexities. This blend turns modular bridges from an intriguing option into the rational default across replacement programmes.

Doing nothing is not an option. When the replacement peak arrives, contractors lacking proven value, visible proof and policy alignment will encounter capacity shortfalls, while early movers, Heijmans prominent among them, will be positioned not merely as builders of bridges but as shapers of the living environment, equipped to deliver the Netherlands' next generation of infrastructure.

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Author’s statement on the use of AI tools

During the writing of this thesis I used several AI-enabled tools as supports for thinking, drafting, and figure production, not as sources of evidence or substitutes for analysis. Specifically, I used ChatGPT for brainstorming alternative framings, sharpening research questions, stress-testing arguments, rewriting and polishing my own draft passages (clarity, concision, structure) and generating the code/HTML for the Sankey diagrams in §5.6 from my own mappings. I used NotebookLM to query my own notes and summaries (e.g., to surface connections and open questions) and Elicit to organise literature searches and extract metadata/summaries of papers already selected. ATLAS.ti served as the primary qualitative analysis environment; where I explored its AI-assisted suggestions (e.g., clustering or naming hints), these were treated as advisory prompts only.

For interview coding, AI played an advisory role: I asked for critiques of codebook structure, overlap checks, and alternative labels. All coding decisions, theme derivations, and interpretations were made by me following the protocol in §3.5, and every quotation was checked against the transcript.

I did not accept AI-generated references. All citations included in the thesis come from works I read and verified. Where AI produced text or figure code, I edited and validated it for accuracy and fit; responsibility for the final content rests with me.

To protect confidentiality, interview materials shared with external tools were anonymised/de-identified and limited to what was necessary. No sensitive personal data were uploaded.

Appendix A: Interview structure

Interview IFD, afstuderen Paul van Casteren

Opname

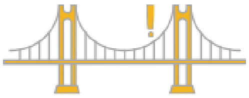
Informed consent:
Uw naam, exacte functie en transcriptie worden in alle rapportages geanonimiseerd; alleen het type organisatie waartoe u behoort (bijvoorbeeld een grote gemeente, rijksdienst of expert van anoniem consortium) wordt vermeld om de resultaten in context te plaatsen. Is dit akkoord in deze vorm of wenst u iets anders?

Introduceren

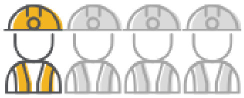
Aannemersinvloed op de toepassing van Industrieel, Flexibel en Demontabel (IFD) Bouwen

De Nederlandse infrastructuur staat voor een grote vervangingsopgave, onder druk van verouderde assets, personeelstekorten en duurzaamheidsambities. Dit onderzoek richt zich op de vraag hoe aannemers in een vroeg stadium van besluitvorming kunnen bijdragen aan toekomstbestendige brugoplossingen door het strategisch uitoefenen van invloed.

Probleem



In veel geïndustrialiseerde landen speelt een grootschalige vervangingsopgave van bruggen.



De bouwsector kampt met aanzienlijke tekorten aan personeel en capaciteit.

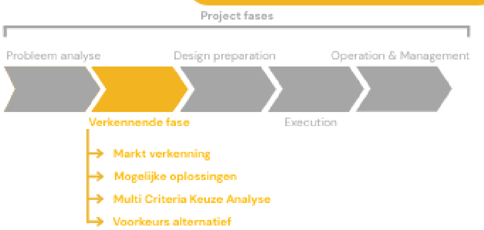
Innovatie behoefte

Er is behoefte aan efficiënte en duurzame bouwoplossingen voor brugvervanging.

Industrieel, Flexibel en Demontabel (IFD) Bouwen

Implementatie van IFD

De explorative fase van brugvervangingsprojecten is bepalend voor de lange termijn prestaties van infrastructuur. Toch stimuleren traditionele publieke aanbestedingspraktijken vaak onvoldoende innovatieve bouwconcepten, zoals Industrieel, Flexibel en Demontabel (IFD) bouwen. Hierdoor hebben aannemers beperkt ruimte om IFD-oplossingen in te brengen, wat leidt tot gemiste kansen.



Onderzoeksvragen

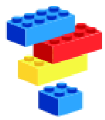
Centrale Onderzoeksvraag:
Hoe kunnen aannemers strategisch invloed uitoefenen in de explorative fase van publieke brugvervangingsprojecten om de toepassing van Industrieel, Flexibel en Demontabel (IFD) bouwen te stimuleren?

Deelvragen:

1. Hoe is de explorative fase van brugvervangingsprojecten georganiseerd en welke factoren bepalen de evaluatie van mogelijke bouwoplossingen?
2. Welke specifieke kansen en belemmeringen bestaan er voor het integreren van IFD binnen deze vroege projectfase?
3. Op welke manieren kunnen aannemers strategisch betrokken raken en invloed uitoefenen om de overweging van IFD-oplossingen te versterken?

Wat is IFD Bouwen?

Industrieel, Flexibel en Demontabel (IFD) bouwen combineert prefabricage, aanpasbaarheid en herbruikbaarheid. Het stelt infrastructuurbeheerders in staat om sneller, duurzamer en circulair te bouwen. Kenmerkend zijn efficiënte off-site productie, flexibele ontwerpen die inspelen op toekomstige veranderingen en onderdelen die eenvoudig gedemonteerd en hergebruikt kunnen worden.



Invloedssfeer Aannemer

Aannemers kunnen invloed uitoefenen op verschillende strategische niveaus binnen de explorative fase:

- Projectniveau: Technische inbreng leveren en IFD-kansen zichtbaar maken.
- Organisatieniveau: Samenwerking versterken en geïntegreerde oplossingen ontwikkelen.
- Institutioneel niveau: Risico's en informatie-asymmetrie rondom IFD verkleinen.
- Sectoraal niveau: Bijdragen aan innovatieagenda's en dialoog over aanbestedingspraktijken.

De effectiviteit van deze beïnvloedingsstrategieën is afhankelijk van de context en vormt de kern van mijn verdere onderzoek.

Strategisch Belang voor Heijmans

Indien Heijmans erin slaagt om IFD-oplossingen vroegtijdig te positioneren in brugvervangingsprojecten, ontstaan aanzienlijke kansen binnen de golf aan vervangingsopgaven. Vroegtijdige aansluiting bij publieke ambities verstevigt de positie van Heijmans als koploper in modulaire en circulaire infrastructuur, passend bij haar rol als duurzame bouwer van gezonde leefomgevingen.

1. **Functie/rol binnen de organisatie en bekendheid met IFD**

Wat is uw functie/rol binnen de organisatie, en bent u bekend met/wat is de link met IFD?

2. **Structuur verkennende fase**
   Kunt u de opeenvolgende stappen en beslismomenten in de verkennende fase van een recent brugvervangingsproject schetsen?
3. **Contactmomenten opdrachtgever ↔ markt**
   Wanneer en hoe vindt er in die vroege contact plaats tussen u als opdrachtgever en aannemer?
4. **Verzamelen & selecteren alternatieven**
   Hoe worden alternatieven voor brugvervanging in de overweging in kaart gebracht en op welke criteria worden deze geselecteerd?
5. **Gewenste uitkomst → huidige acties**
   Stel dat de verkennende fase zó wordt ingericht dat het haast vanzelfsprekend is om voor IFD te kiezen. Welke concrete acties of initiatieven voert uw organisatie op dit moment uit om dat ideaalbeeld dichterbij te brengen? Wat beschouwt u daarbij als de logische eerstvolgende stap?
6. **Belangrijkste voordelen van IFD**
   Wat beschouwt u als de meest overtuigende voordelen van IFD, voor u als opdrachtgever? Rangschik deze naar impact, en licht toe waarom.
7. **Barrières & kansen**
   Welke contradicties of barrières heeft u ervaren bij IFD-integratie? Waar zit het/de pijnpunt(en) precies?
8. **Volwassenheid (DVF) van IFD adoptie**
   Bekijk de drie aspecten hieronder, bedenk dat deze een schaal van 1 (zeer lage volwassenheid) tot 10 (volledig ingebed) hebben. Beantwoord elke vraag voor volgende drie aspecten:

• Desirability/wenselijkheid - Markt- of maatschappelijke vraag
• Viability/levensvatbaarheid - Robuustheid businesscase
• Feasibility/haalbaarheid - Technische & ketengereedheid

- *Beschrijf in een aantal zinnen hoe een situatie met 'score 10' er voor dit aspect in uw organisatie uitziet.*
- *Noem één of meer concreet voorbeeld (iets tastbaars) dat uw organisatie al die kant op beweegt.*
- *Welke volgende acties van de aannemer (individueel of collectief) zijn het belangrijkst om dichter bij uw Visie-10 te komen? Binnen welk tijdsbestek?*

9. **Aannemer-geïnitieerde beïnvloedingsmethoden**
   Welke methoden heeft u gezien waarmee aannemers de verkennende fase richting IFD principes sturen?

10. **Publieke trajecten die door aannemers zijn te beïnvloeden**

Welke door publieke opdrachtgevers geïnitieerde instrumenten of trajecten kunnen aannemers actief beïnvloeden om verder te komen in het IFD adoptie proces?

11. **Juiste persoon**

Vindt u dat u de juiste persoon was die ik had moet interviewen in uw organisatie?

Extra:

12. **Krachtigste volgende stap**

Wat is volgens u de meest impactvolle volgende stap om IFD-adoptie bij brugvervangingen te versnellen?

13. **Lerend vermogen**

Hoe legt uw organisatie de lessen uit zulke acties vast, en met wie wordt die kennis gedeeld?

Einde

Appendix B: informed consent form

Informed Consent – Research Participation
You are being invited to participate in a research study titled **"Strategic Influence of Contractors in the Explorative Phase of Bridge Replacement Projects"**. This study is being conducted by **Paul van Casteren**, a Master's student at **TU Delft, Faculty of Civil Engineering and Geosciences**, in collaboration with the Dutch construction company **Heijmans**.
The purpose of this study is to examine how contractors can strategically influence the early, explorative phase of public bridge replacement projects to stimulate the adoption of **Industrial, Flexible, and Demountable (IFD)** construction methods. Your participation will involve taking part in a **semi-structured interview**, which will last approximately **45–60 minutes**.
The data collected in this study will be used for academic purposes, including the completion of a **Master's thesis**, potential **academic publication**, and **educational presentations**. During the interview, you will be asked about your professional opinions and experiences related to contractor strategies, innovation in construction, and the implementation of IFD concepts.
Although we take all reasonable steps to ensure confidentiality, participating in online or digitally recorded interviews always carries a minimal risk of a data breach. To mitigate these risks:

- Interviews will be recorded via **MS Teams** or a secured audio device.
- All personal identifiers (e.g., name, email, job title) will be stored securely on **TU Delft OneDrive**.
- Transcripts will be anonymised before analysis, and only anonymised data will be stored on Heijmans' secured project drive.
- Only the direct research team at TU Delft (Paul van Casteren, **ir. J.P.G. Ramler**, and Prof. P.W. Chan) and designated contacts at Heijmans will have access to this data.

If you are an expert whose name adds value to the interpretation of the findings, your name may be mentioned in the thesis, but only with your **explicit written consent**.
Your participation in this study is entirely **voluntary**. You may decline to answer any question or withdraw from the study at any time without any consequences. If your interview data is **not anonymised**, it may be possible to withdraw your data upon request until **August 15th, 2025**, after which anonymisation and integration into results will make individual removal impossible.
For any questions about the study or your data, please contact:

- **Paul van Casteren** (Researcher)
- **ir. J.P.G. Ramler** (Responsible Supervisor)

By signing the digital consent form or proceeding with the interview, you confirm that you understand the information provided above and voluntarily agree to participate in this research study.

PLEASE TICK THE APPROPRIATE BOXES	Yes	No
A: GENERAL AGREEMENT – RESEARCH GOALS, PARTICPANT TASKS AND VOLUNTARY PARTICIPATION		
1. I have read and understood the study information dated [*DD/MM/YYYY*], or it has been read to me. I have been able to ask questions about the study and my questions have been answered to my satisfaction.	☐	☐
2. I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions and I can withdraw from the study at any time, without having to give a reason.	☐	☐
3. I understand that taking part in the study involves: Participation in a semi-structured interview, which will be **audio/video-recorded** (via MS Teams or a secured device). The recording will be **transcribed to text** and subsequently **anonymised** for analysis.	☐	☐
4. I understand that I will not be compensated for my participation.	☐	☐
5. I understand that the study will end 1 September 2025, or upon successful defence and archiving of the thesis.		

B: POTENTIAL RISKS OF PARTICIPATING (INCLUDING DATA PROTECTION)		
6. I understand that taking part in the study involves the following risks: minimal risk related to breach of confidentiality or professional re-identification. I understand that these will be mitigated by secure storage, pseudonymisation, and limiting access to only the TU Delft research team and authorized Heijmans staff.	☐	☐
7. I understand that taking part in the study also involves collecting specific personally identifiable information (PII): name, email, phone number (for admin purposes only) and associated personally identifiable research data (PIRD): recorded opinions on innovation strategies and experiences in bridge replacement projects. With the potential risk of my identity being revealed through job role or examples cited; mitigated by anonymisation and removing context-specific identifiers.	☐	☐
9. I understand that the following steps will be taken to minimise the threat of a data breach, and protect my identity in the event of such a breach: Anonymisation and secure storage on TU Delft OneDrive, limited access to data (research team only), recordings stored separately from consent information and encryption and institutional data protocols.	☐	☐
10. I understand that personal information collected about me that can identify me, such as my name or where I work, will not be shared beyond the study team.	☐	☐
11. I understand that the (identifiable) personal data I provide will be destroyed ultimately after the research project concludes (no later than 01/10/2025)	☐	☐
C: RESEARCH PUBLICATION, DISSEMINATION AND APPLICATION		
12. I understand that after the research study the de-identified information I provide will be used for TU Delft Master's thesis (and possibly academic publications or conference presentations)	☐	☐
13. I agree that my responses, views or other input can be quoted anonymously in research outputs	☐	☐
14. **I agree that my real name can be used for quotes in research outputs**	☐	☐
D: (LONGTERM) DATA STORAGE, ACCESS AND REUSE		
16. I give permission for the de-identified summaries and/or transcripts that I provide to be archived in the TU Delft repository so it can be used for future research and learning.	☐	☐

Signatures

________________________ ________________________ ________

Name of participant [printed] Signature Date

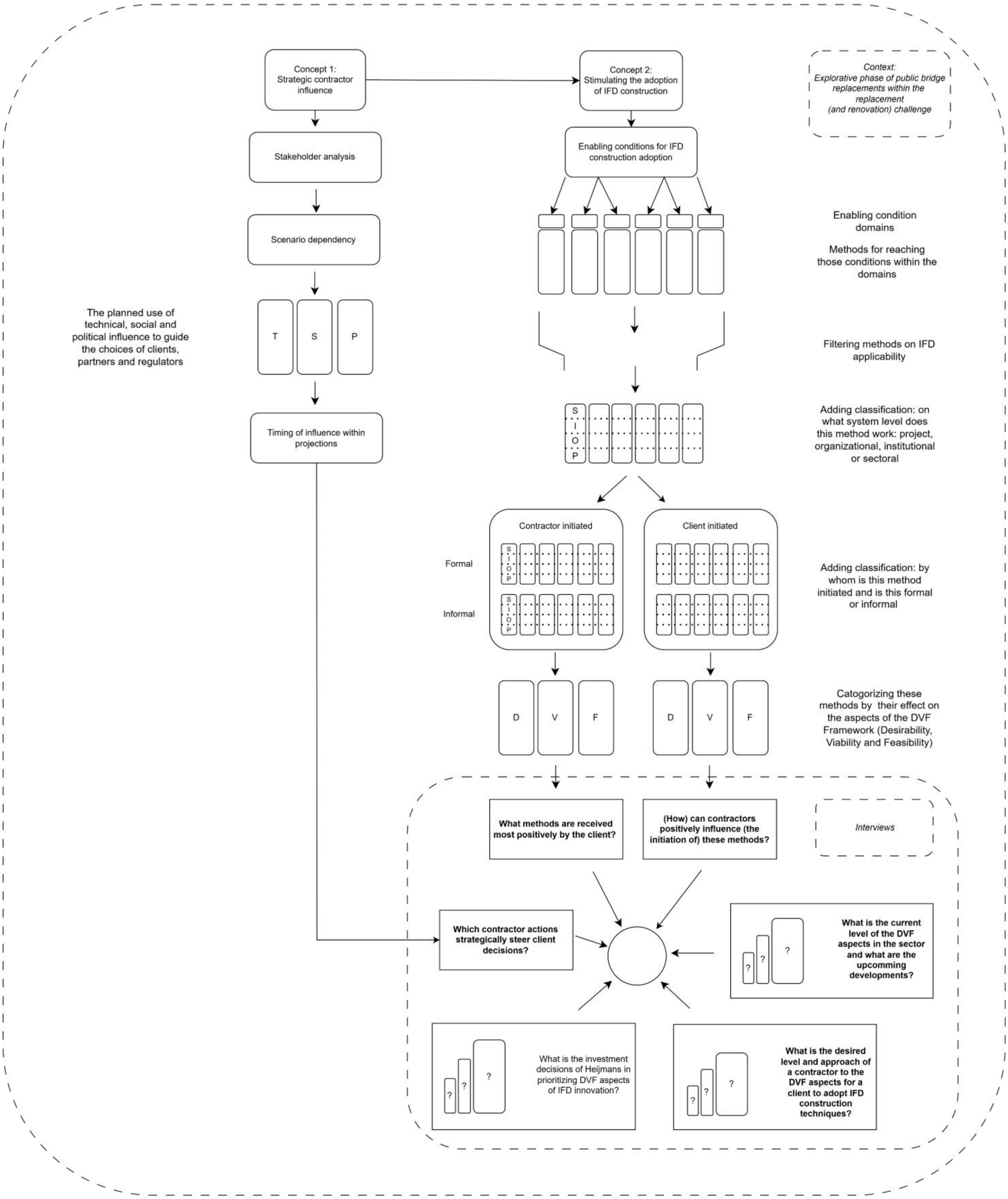
I, as researcher, have accurately read out the information sheet to the potential participant and, to the best of my ability, ensured that the participant understands to what they are freely consenting.

________________________ __________________ ________

Paul van Casteren Signature Date

Study contact details for further information: ir J.P.G. Ramler

Appendix C: Conceptual model



Appendix D: Mechanisms literature

Social Acceptance and Cultural Perceptions Mechanisms

Stakeholder workshops

- Initiator & Formality: Mixed, informal
- System Level: Organisational
- Strategic Lever: Social
- DVF-framework attribution: Desirability
- Description: Stakeholder workshops involve structured interactions between clients, designers, and other relevant stakeholders, aiming to align perceptions, clarify mutual expectations, and foster shared understanding regarding innovation adoption in construction projects. Such workshops support the establishment of collective goals, clarify stakeholder roles, and address cultural resistance by educating participants about innovative practices (Boersma, 2018; Goulding et al., 2014).
- IFD Relevance: Stakeholder workshops directly support IFD adoption by improving stakeholder alignment on the principles and practicalities of IFD construction methods, thus mitigating cultural resistance and increasing willingness to adopt IFD solutions in projects (Goulding et al., 2014).

Pilot Project

- Initiator & Formality: Client, formal
- System Level: Project
- Strategic Lever: Technical, social
- DVF-framework attribution: Desirability, Feasibility
- Description: A pilot project involves the initial application and demonstration of innovative construction techniques or methodologies, within a real-world context. This approach serves as a practical demonstration, allowing stakeholders to observe tangible benefits, evaluate performance, manage risks, and build confidence through direct exposure to the implemented innovation. Pilot projects address skepticism by showcasing actual outcomes and providing empirical evidence, thus improving acceptance and supporting knowledge transfer within the industry (Blismas et al., 2009; Goulding et al., 2014).
- IFD Relevance: Pilot projects are particularly relevant for IFD construction as they allow clients and stakeholders to directly experience and evaluate the advantages of Industrial, Flexible, and Demountable approaches, reducing cultural resistance, clarifying technical feasibility, and fostering social acceptance by demonstrating real-world viability and tangible value (Blismas & Wakefield, 2009; Goulding et al., 2014).

Visible collaboration by trusted contractors and design professionals

- Initiator & Formality: Contractor/Designer, informal
- System Level: Project/Organisational
- Strategic Lever: Social
- DVF-framework attribution: Desirability

- Description: Visible collaboration among trusted contractors and design professionals involves openly demonstrating cooperation and integrated teamwork between reputable stakeholders. Such collaborative visibility helps to mitigate cultural skepticism and resistance by enhancing stakeholder trust and aligning the new construction approaches with industry expectations. Demonstrating practical examples of successful partnerships in modular and offsite projects fosters confidence, reduces uncertainty, and promotes acceptance among hesitant stakeholders (Blismas & Wakefield, 2009; Martin et al., 2024).
- IFD Relevance: Visible collaboration among trusted contractors and design professionals involves openly demonstrating cooperation and integrated teamwork between reputable stakeholders. Such collaborative visibility helps to mitigate cultural skepticism and resistance by enhancing stakeholder trust and aligning the new construction approaches with industry expectations. Demonstrating practical examples of successful partnerships in modular and offsite projects fosters confidence, reduces uncertainty, and promotes acceptance among hesitant stakeholders (Blismas & Wakefield, 2009; Martin et al., 2024).

Leadership Style
- Initiator & Formality: Client/Contractor, informal
- System Level: Organisational/Project
- Strategic Lever: Social, Political
- DVF-framework attribution: Desirability
- Description: Effective leadership styles, such as transformational, entrepreneurial, and network governance leadership, significantly enhance the innovation capacity of organizations by motivating teams, supporting risk-taking, and promoting collaborative stakeholder engagement (Lewis et al., 2017; Ozorhon et al., 2014).
- IFD Relevance: Appropriate leadership is essential for fostering an organizational culture that supports the adoption of IFD construction methods, by effectively aligning stakeholder interests and overcoming resistance to innovative practices (Lewis et al., 2017; Ozorhon et al., 2014).

Reframing
- Initiator & Formality: Client/Contractor, informal
- System Level: Project/Organisational
- Strategic Lever: Social
- DVF-framework attribution: Desirability
- Description: Reframing involves shifting perceptions and redefining traditional views and attitudes towards construction practices by emphasizing new advantages, values, and benefits. It addresses cultural resistance by reshaping stakeholder perspectives, highlighting positive experiences, and positioning innovative approaches as desirable and credible alternatives (Goulding et al., 2014).
- IFD Relevance: Reframing is highly relevant for the adoption of Industrial, Flexible, and Demountable (IFD) construction by changing stakeholder mindsets, effectively overcoming skepticism, and clearly communicating the long-term value and practical benefits of IFD methods (Goulding et al., 2014).

Procurement Mechanisms

[INTRO] + exception categories

Basic ECI Approaches

Basic Early Contractor Involvement (ECI) approaches refer to low-threshold mechanisms that allow contractor knowledge to inform public infrastructure planning before the start of formal procurement. These mechanisms are typically informal, non-binding, and initiated either by the client or the contractor. Their strength lies in procedural flexibility and broad applicability across project types, making them particularly useful in the explorative phase, when early scoping and system-level decisions significantly affect long-term performance and lifecycle outcomes (Wondimu et al., 2019; Williams et al., 2022). Depending on the specific method, these approaches operate at varying strategic levels. Some, such as indirect approaches, function outside of project-specific contexts and aim to embed constructability or modularity thinking at the organizational or sectoral level (Wondimu et al., 2019; Rahmani et al., 2022). Others, like workshops or information meetings, are typically project-bound but can generate wider institutional learning when applied consistently (Boersma, 2018; Uyarra et al., 2014; Papenhuijzen et al., 2020). Across this spectrum, basic ECI approaches provide clients with a legally robust and procedurally light-weight toolset for engaging with market knowledge in support of Industrial, Flexible, and Demountable (IFD) construction, provided timing, transparency, and follow-through are ensured.

Indirect approaches

– Initiator & Formality: Client-initiated, informal.
– System Level: Organizational/sectoral.
– Strategic Lever: Technical
– DVF-framework attribution: Feasibility, embedding modularity rules and constructability criteria in pre-competitive instruments de-risks technical delivery (Wondimu et al., 2019). Viability, standardized guidelines reduce transaction costs and enable repeatable business models across projects.
– Description: Use of internal personnel or contractor-background consultants to develop handbooks, modular design standards, and technical guidelines without targeting specific tenders (Wondimu et al., 2019).
– IFD Relevance: Considered highly suitable, these approaches enable codification of constructability and modularity principles in pre-competitive instruments, allowing public clients to support IFD adoption across multiple projects without engaging in direct procurement.

Information meetings (market consultations)

– Initiator & Formality: Client-initiated, informal.
– System Level: Project (with potential for institutional learning).
– Strategic Lever: Technical and social
– DVF-framework attribution: Feasibility; stress-testing technical and procedural options before tendering, information meetings reduce uncertainty around modular design concepts (Wondimu et al., 2020). Viability and desirability are supportive too: Insights from market

intelligence help shape award criteria and risk allocations that strengthen the business case for IFD solutions (Wondimu et al., 2020). Early alignment of client needs with supplier capabilities increases market interest in modular or sustainable alternatives, as seen in Dutch practice (Boersma, 2018)

- Description: Pre-tender dialogues to test feasibility, gather market intelligence, and refine award criteria, permitted under Directive 2014/24/EU (arts. 40–41) and guided by PIANOo (2016). When well-timed and transparent, they can inform procurement outputs (Wondimu et al., 2020; Papenhuijzen et al., 2020).
- IFD Relevance: Generally suitable, evidence from Dutch practice suggests that early dialogue through information meetings has supported modular or sustainability ambitions (Boersma, 2018). Their effectiveness, however, depends on follow-up capacity and the ability to translate informal insights into formal specifications (Boersma, 2018).

Workshops

- Initiator & Formality: Client-initiated, informal (becomes formal if insights influence a tender).
- System Level: Project-system, organizational and, when thematic, sectoral.
- Strategic Lever: Social, interactive co-creation that builds trust, aligns expectations and shapes requirements through real-time dialogue.
- DVF-framework attribution: Feasibility, by iteratively refining technical specifications and constructability criteria in live sessions, workshops reduce uncertainty and de-risk modular design concepts.
- Workshops are interactive, real-time sessions held before the publication of a contract notice to explore technical, procedural, or procurement-related issues (Wondimu et al., 2020). In Dutch procurement guidance, such sessions are encouraged in early phases and must be documented transparently if their insights influence the tender content (PIANOo, 2016). They may take various forms, from broad market dialogues to small-scale expert discussions, and are used to refine specifications, assess feasibility, or shape award criteria. According to Papenhuijzen et al. (2013), intensifying the interaction format (e.g., using one-on-one conversations or thematic group discussions) increases the quality of feedback and strengthens the market's ability to deliver value. While typically project-specific, repeated use of workshops within an organization can foster internal procedural learning and improve the structuring of future tenders.
- IFD Relevance: Regarded as suitable, when applied during the explorative phase, workshops can support early alignment on constructability, modular feasibility, and award logic. Their effectiveness depends on the client's capacity to translate informal input into actionable procurement outcomes (Uyarra et al., 2014).

Direct contact with specialist contractors

- Initiator & Formality: Client-initiated, informal.
- System Level: Project
- Strategic lever: Technical, targeted validation of niche constructability and modular assembly techniques.
- DVF-framework attribution: Feasibility, one-on-one consultations clarify technical bottlenecks (Wondimu et al., 2020). Viability, early technical intelligence informs risk allocation and cost estimates.
- Description: One-on-one consultations with technical subcontractors (e.g., in modular lifting or reversible joints) to assess constructability or feasibility before tendering. Permitted under EU

rules if neutrality and transparency are upheld (PIANOo, 2016; Wondimu et al., 2019). Boersma (2018) shows how such input may influence the choice of procurement procedure.
- IFD Relevance: Context-dependent, this method can be valuable for addressing technical bottlenecks in IFD but requires procedural safeguards and strong client-side expertise to manage potential risks of bias (PIANOo, 2016).

Contractor idea promotion
- Initiator & Formality: Contractor-initiated, informal.
- System Level: Project-system
- Strategic Lever: Technical & Political
- DVF-framework attribution: Desirability: Fresh modular or demountable concepts can capture client interest and broaden solution space (Boersma, 2018).
- Description: Market actors proactively suggest concepts or solutions during planning, without a formal call for tenders (Boersma, 2018). This can include modular product proposals or alternative delivery models.
- IFD Relevance: Context-dependent, while unsolicited ideas may lead to IFD-oriented innovations, their influence depends on institutional openness, fair treatment of non-participating firms, and the ability to integrate proposals without procedural distortion (Boersma, 2018).

Front-end partnering
- Initiator & Formality: Client-initiated, formal.
- System Level: Project-system
- Strategic Lever: Social & Political, establishes joint governance, open-book accounting and shared risk/reward to align incentives.
- DVF-framework attribution: Viability, the formal gain-share/pain-share structure and transparent cost controls create a robust business case and incentivise efficiency (Wondimu et al., 2019)
- Description: A structured process of post-award collaboration, typically involving open-book contracting or pain/gain-sharing prior to construction (Wondimu et al., 2019). Its aim is to optimise implementation rather than design.
- IFD Relevance: Probably not suitable, as this approach is introduced after design commitments are made, it provides little opportunity to influence the early modular decisions that are essential to IFD adoption.

Project Delivery Arrangements

[INTRO]

Framework agreement
- Initiator & Formality: Client-initiated, formal.
- System Level: Project-system, organizational and sectoral.
- Strategic lever: Technical
- DVF-framework attribution:

- Description: Framework agreements are multi-use contractual instruments that allow public clients to predefine terms and conditions with one or more contractors over a fixed period, under which project-specific contracts (call-offs) can be awarded without repeating full tendering procedures (Laryea et al., 2016; Wondimu et al., 2016). As a delivery structure, they enable continuity of collaboration, repeat interaction, and strategic coordination across multiple projects. When used in conjunction with early contractor input, framework agreements support technical knowledge accumulation, iterative learning, and standardization, features aligned with ECI at both organizational and sectoral levels (Wondimu et al., 2019; Eriksson et al., 2022). In the Netherlands, they are increasingly explored as part of a Contractual Portfolio Approach (CPA) to manage asset replacements through bundled, standardized interventions (Hoekstra, 2023). However, as Caldwell et al. (2005) emphasize in their analysis of NHS Procure21, framework agreements may fail to achieve their intended strategic impact if not supported by strong leadership, active performance management, and local commitment. In such cases, they risk being used primarily for administrative convenience, circumventing procurement procedures, rather than as vehicles for innovation, standardization, or long-term supplier engagement.
- IFD Relevance: Considered highly suitable (green). Although not always explicitly linked to modular or demountable construction, framework agreements provide structural alignment with IFD objectives by enabling standardization, lifecycle coordination, and early integration across multiple projects (Hoekstra, 2023; Wondimu et al., 2019).

Public-Private Partnership

- Initiator & Formality: Client-initiated, formal.
- System Level: Project-system and organizational.
- Strategic lever:
- DVF-framework attribution:
- Description: PPPs are long-term contractual arrangements in which public authorities delegate the responsibility for designing, financing, building, and often maintaining or operating infrastructure assets to private consortia (Wondimu et al., 2019; Liu et al., 2023). Typically structured as DBFM or DBFO contracts, PPPs integrate technical and financial decision-making over the asset lifecycle. When competitive dialogue is applied in the pre-award phase, PPPs can allow contractor input during functional specification and risk assessment (Wondimu et al., 2019). Lifecycle incentives embedded in the contract design, including performance-based remuneration, can promote efficiency and innovation in long-term operation and maintenance (Hueskes et al., 2017; Arata et al., 2016). However, PPPs often limit early design flexibility due to bid comparability requirements and fixed output specifications, thereby constraining space for upstream innovation. High transaction costs and institutional rigidity further reduce the potential for IFD-compatible experimentation unless innovation is explicitly embedded in evaluation criteria and delivery models (Lember et al., 2019; Liu et al., 2023).
- IFD Relevance: Context-dependent, PPPs can support IFD adoption where modularity contributes to lifecycle performance and maintainability, but only if functional flexibility and early contractor engagement are structurally embedded. Without this, PPPs may reinforce rigid contracting and restrict the iterative design processes critical for demountable or flexible infrastructure (Arata et al., 2016)

Partnering

- Initiator & Formality: Client-initiated and through either semi-formal partnering charters or formal multi-party agreements (Lahdenperä, 2012).
- System Level: Project
- Strategic lever: Technical
- DVF-framework attribution: Feasibility: Early contractor involvement, BIM co-location and integrated planning routines de-risk constructability (Bygballe et al., 2019). Viability: Gain-share/pain-share and open-book accounting align financial incentives for efficiency (Lahdenperä, 2012; Bygballe et al., 2019). Desirability: Co-created solutions tailored to client and end-user needs enhance market appeal (Lahdenperä, 2012).
- Description: A relational contracting model where the client and key delivery partners agree, via a charter or formal alliance, on shared project goals, governance structures and incentive mechanisms. Partnering typically begins in early design, with contractors contributing constructability expertise, cost estimates and innovative proposals; governance is maintained through joint steering committees, integrated planning sessions and open-book performance reviews (Bygballe et al., 2019; Engebø et al., 2019).
- IFD Relevance: Moderate, partnering's early integration of contractor know-how and shared risk models directly supports modularity and demountability by embedding flexibility into design decisions, ensuring that IFD solutions are both technically robust and commercially viable, however these partnering are probably suitable for more developed markets. There its continuous feedback loops further enable adaptive refinement of IFD components throughout the front-end phase (Bygballe et al., 2019).

Integrated Project Delivery

- Initiator & Formality: Client-initiated, formal multi-party agreement signed early in design, legally joining owner, architect, contractor and specialists under one contract (Wondimu et al., 2020; Lahdenperä, 2012)
- System Level: Project
- Strategic lever: Technical
- DVF-framework attribution: Feasibility, early co-design and joint planning sessions de-risk modular integration and constructability. Viability, a single target cost and open-book accounting align incentives under a gain-share/pain-share model.
- Description: Unlike partnering or alliancing, IPD's single-contract model dissolves the typical owner-designer and designer-contractor interfaces into one legal entity. All participants share governance, risks and rewards in a joint target-cost envelope, co-locate in a common BIM environment, and hold regular integrated planning sessions. This one-team contract is IPD's hallmark, eliminating siloed decision-making and enabling truly collaborative front-end design refinement (Wondimu et al., 2020; Lahdenperä, 2012).
- IFD Relevance: Moderate, IPD's multi-party contract and integration mandate early co-design, aligning risk and reward to underpin modularity, flexibility and demountability.

Alliance

- Initiator & Formality: Client-initiated, formal
- System Level: Project
- Strategic lever: Political & Technical

- DVF-framework attribution: Viability, a single “target-cost” envelope with full gain-share/pain-share on total project outcomes creates the strongest financial incentives for efficiency and innovation (Engebø et al., 2019)
- Description: Alliancing is a formal multi-party agreement that, unlike partnering’s add-on charters or IPD’s segmented, single-contract model, abolishes back-to-back subcontracts, pools all costs into one risk/reward envelope, and requires unanimous “best-for-project” decisions via an alliance board with continuous opportunity management (Lahdenperä, 2012; Engebø et al., 2019).
- IFD Relevance: Moderate, the unified risk/reward framework and board-level governance drive collective investment in modular, flexible and demountable designs, embedding iterative refinement of component interfaces into front-end decision-making (Engebø et al., 2019).

Design & Build

- Initiator & Formality: Client-initiated, formal
- System Level: Project
- Strategic lever: Technical
- DVF-framework attribution: Feasibility, early contractor accountability for buildability reduces constructability uncertainty and rework (Hoekstra, 2010). Viability, empirical studies show D&B projects achieve relatively lower schedule growth and comparable cost performance with other project delivery arrangements, underpinning a robust business case (Sullivan et al., 2017)
- Description: Under D&B, the owner procures a design-build firm via one contract; that firm undertakes schematic design, detail design and construction in sequence or overlap, bearing responsibility for both functional performance and constructability. This reduces coordination interfaces but limits the owner’s direct design control (Sullivan et al., 2017)
- IFD Relevance: Moderate, D&B’s integrated technical accountability supports the feasibility of modular components by embedding buildability early, yet its single-entity model may under-emphasize flexibility and demountability goals unless the contractor explicitly targets IFD principles in their design remit as part of the clients’ specifications.

Building Team

- Initiator & Formality: Client-initiated, (semi-)formal
- System Level: Project
- Strategic lever: Social, trust-based collaboration and joint planning routines leverage contractor know-how in real time, aligning expectations through interactive workshops and continuous dialogue rather than through “hard” contractual mandates.
- DVF-framework attribution: Feasibility, early contractor involvement embeds buildability into the design, reducing technical uncertainty and rework.
- Description: Building Team, in which client, designers and contractor enter a model agreement to progress through structured phases, design, pricing and execution, working as a unified team while retaining individual liabilities (Sewalt, 2019). Because the contractor only joins once the tender is let, schematic design responsibility shifts forward only modestly into post-award planning.
- IFD Relevance: Low-Moderate. Though Bouwteams improve buildability and cost realism through early contractor input, they commence too late to shape the conceptual modular “envelope” essential for true IFD adoption. Their value lies in refining demountable details,

but not in establishing system-level modular frameworks before design lock-in (Sewalt, 2019).

Procurement Procedures

[INTRO]

Negotiated procedure

- Initiator & Formality: Client-initiated, formal
- System Level: Project
- Strategic lever: Technical, employs contract clauses, performance targets and formal negotiation of technical solutions to lock in efficiencies and manage risk.
- DVF-Framework attribution: Feasiblity and viability, structured negotiations clarify technical uncertainties, de-risk constructability of modular components (Wondimu et al., 2025) and drives cost-efficiency by aligning financial incentives through negotiated terms (Wondimu et al., 2019).
- Description: A multi-stage procurement route where prequalified bidders submit initial proposals, engage in parallel negotiation sessions to refine specifications and award criteria, and then submit final bids evaluated on price and quality (Wondimu et al., 2025).
- IFD Relevance: Medium–High, its formal technical negotiations allow IFD requirements to be embedded in tender documents pre-award, though it requires strong client capacity to convert dialogue into precise modular and demountable specifications.

Competitive Dialogue

- Initiator & Formality: Client-initiated, formal
- System Level: Project
- Strategic lever: Social–technical hybrid, structured rounds of dialogue build trust and refine technical specifications in tandem, leveraging both relationship-building and formal negotiation of solutions (Hoezen et al., 2012).
- DVF-Framework attribution: Feasiblity and desirability, Iterative dialogue reduces technical uncertainty by testing and co-developing modular concepts before final bids (Uttam et al., 2015). Continuous stakeholder engagement aligns solutions with client and end-user needs, enhancing market appeal.
- Description: A multi-stage procurement route in which prequalified bidders first submit outline solutions, then engage in closed-door dialogue sessions with the client to refine requirements and propose alternatives. After the dialogue phase, final tenders are submitted and evaluated on best-overall value (Uttam et al., 2015).
- IFD Relevance: High, by embedding iterative co-development of technical specifications within formal dialogue, Competitive Dialogue enables the early definition and validation of modular, flexible and demountable solutions, ensuring IFD requirements are fully integrated into the tender design before award (Hoezen et al., 2012).

Innovation Partnership

- Initiator & Formality: Client-initiated, formal

- System Level: Project
- Strategic lever: Technical, the procedure “puts the rules in writing”: functional problem definition, phased go/no-go gates, IP and risk clauses, and a final MEAT-based award are all codified in the contract documentation (Koopmans, 2021)
- DVF-Framework attribution: Feasibility, Contract-funded R&D, iterative testing and TRL-gated go/no-go decisions systematically de-risk novel technologies before full procurement (Koopmans, 2021). Viability, the same contract fixes price corridors and commercial terms for large-scale roll-out once performance targets are met, aligning financial incentives for both client and supplier (Koopmans, 2021).
- Description: The client publishes only the functional “grand challenge”, pre-selects candidates, then awards parallel R&D contracts. Partners develop, prototype and test until agreed TRL milestones; after the final gate the client places a production order with the successful partner(s), all within the original procedure (Koopmans, 2021).
- IFD Relevance: High, Innovation Partnerships let public clients co-finance and co-shape modular, demountable bridge concepts at low TRL, mature them through controlled pilots, and secure a guaranteed route to market once feasibility and cost targets are proven, directly supporting IFD adoption (Brinkerink, 2019).

Two-Stage Tendering

- Initiator & Formality: Client-initiated, formal
- System Level: Project-system
- Strategic lever: Technical, risk-sharing clauses, target-cost formulas and go/no-go gates codify how the parties negotiate price, allocate risk and share savings (Lahdenpera et al., 2010))
- DVF-Framework attribution: Feasibility, early, open-book design-to-cost sessions and target-cost negotiations reduce technical and delivery risk. Desirability, collaborative concept optimisation lets the team tailor functions, layouts and disruption profiles to stakeholder preferences, raising market and user appeal (Røfstado et al., 2025).
- Description: In a two-stage tender the client first conducts a capability-plus-price competition to appoint a preferred contractor (Stage 1). That contractor then collaborates with the client to develop roughly 70 % of the design under open-book conditions and to negotiate a target cost. If the parties agree on that cost, the same team proceeds straight to construction (Stage 2); if not, the client may terminate the process and re-tender the works, preserving competitive pressure while still gaining early constructability input (Røfstado et al., 2025; Lahdenperä, 2010).
- IFD Relevance: Moderate, stage 1 offers a window to embed modular and demountable (IFD) concepts, yet failure to close the target-cost deal, as in the Norwegian hospital case, can force a re-tender and nullify those early IFD gains (Røfstado et al., 2025).

Contractual Portfolio Approach

- Initiator & Formality: Client-initiated, formal
- System Level: Organisational
- Strategic lever: Political, by aggregating budget authority and future workload, the owner uses its resource power to negotiate long-term risk/reward terms and learning requirements; technical and social effects follow from that procurement power (Hoekstra, 2023).

- DVF-Framework attribution: Viability, stable demand curve reduces tendering costs and enables risk pooling across works. Feasibility, repetition along a bundled portfolio accelerates learning-by-doing and supports standardisation (Hoekstra, 2023).
- Description: The CPA bundles multiple, technically comparable assets (e.g., bridges or tunnels) into one procurement package. A single or limited set of contractors is selected on best-value criteria in the first tender; follow-on "secondary works" are awarded through pre-agreed mini-competitions, performance gates or carousel allocation. Bundling similar works first, then progressively more complex ones, allows the team to "learn forward", spread fixed mobilisation costs and manage risk at portfolio, not single-project, level (Hoekstra, 2023).
- IFD Relevance: High, a long, predictable series of works gives contractors the volume certainty needed to justify factory tooling, standard module catalogues and cross-project design templates, key enablers of industrialised, flexible and demountable (IFD) construction. Portfolio-wide performance targets also align incentives for modular repeatability while leaving room to refine details between iterations (Hoekstra, 2023).

Alternative solutions

[INTRO]

Announced With Alternative Technical Solutions

- Initiator & Formality: Client-initiated, formal
- System Level: Project
- Strategic lever: Technical, the client codifies several technical pathways in the contract, using contractual rules and comparative pricing to steer design choices.
- DVF-Framework attribution: Feasibility, parallel costing of design variants uncovers constructability and risk trade-offs before award, de-risking the preferred option. Desirability, offering functionally equivalent variants lets bidders tailor proposals to end-user preferences, increasing market appeal.
- Description: The owner's tender documents specify two-or-more technically distinct design alternatives. Bidders must submit a compliant offer for every variant; the client then selects the most advantageous combination of price, risk profile and lifecycle value (Wondimu et al., 2019)
- IFD Relevance: High, by obliging bidders to cost demountable or modular variants alongside conventional ones, the approach mainstreams IFD concepts, enabling robust comparison of lifecycle performance and encouraging contractors to develop flexible, industrialised solutions.

Allowed Variant Solutions

- Initiator & Formality: Client-initiated, formal
- System Level: Project
- Strategic lever: Technical, influence is exercised by a written clause that widens the design space within the contract rules.

- DVF-Framework attribution: Feasibility, allowing variants lets contractors tailor construction methods to what they can confidently deliver, revealing buildability risks before award (Wondimu et al., 2019)
- Description: During the tender phase bidders price the reference design and any authorised variant(s); the client evaluates each on MEAT criteria and may award to a variant if it offers better value or lower risk (Wondimu et al., 2019).
- IFD Relevance: Moderate, variants give room to propose modular or demountable (IFD) options, but because they arise only at tender stage they cannot reshape earlier specification/conceptual choices.

Idea Competition

- Initiator & Formality: Client-initiated, informal
- System Level: Project
- Strategic lever: Social, relies on open, trust-based idea sharing rather than contract clauses; the client creates a "social arena" for market creativity (Wondimu et al., 2019)
- DVF-Framework attribution: Feasibility, early contractor concepts surface technical options and risks before design lock-in (Havenvid, 2015)
- Description: The owner poses a functional challenge and invites brief concept sketches. A small honorarium or recognition is given; winning ideas may be refined in later, formal procurement phases (Wondimu et al., 2019)
- IFD Relevance: Moderate to high. Because it occurs at the very start, an idea competition can uncover modular or demountable (IFD) concepts while design freedom is greatest; its impact depends on the client's follow-through in subsequent tenders (Havenvid, 2015).

Industry Ecosystem & Supply-Chain Integration Mechanisms

[INTRO]

Supplier base

- Initiator & Formality: Mixed and mostly formal
- System Level: Sectoral/Institutional
- Strategic lever: Political, budget authority and regulatory power, granting market access, training funds and certification, to steer supplier behaviour and expand capacity
- DVF-Framework attribution: Viability and feasibility, a larger, certified pool "diversifies the product portfolio and enhances market competitiveness," driving economies of scale and more predictable pricing (Zhang et al., 2023). Certification screens supplier quality, lowering technical and delivery risk across the modular supply chain (Zhang et al., 2023).
- Description: Skill-development programmes and a formal supplier certification system. These steps widen the pool to include firms able to produce technically demanding concrete or steel modules while balancing cost and quality through credential checks and periodic audits Zhang et al., 2023.
- IFD Relevance: High, Industrialised, Flexible & Demountable solutions rely on a robust, competitive supply base. Expanding and certifying suppliers secures manufacturing capacity for modular components, supports standard-interface development, and gives contractors

the confidence to invest in demountable designs, directly boosting both the feasibility and commercial viability of IFD adoption .

Joint Crew Up-Skilling

- Initiator & Formality: Prefabrication consultant, acting on behalf of the client, initiates a formal contract-based training programme that jointly enrols crews from design, manufacturing and site-assembly teams Dang et al., 2023).
- System Level: Project and organisational
- Strategic lever: Social
- DVF-Framework attribution: Feasibility**, e**nhancing skills directly enlarges the technical and managerial feasibility space by ensuring crews can execute prefabricated processes reliably.
- Description: The mechanism orchestrates joint sessions in which designers, producers and on-site contractors receive aligned instruction on prefabrication standards, tooling and coordination protocols. Such collective learning mitigates fragmented know-how, shortens learning curves and improves cross-phase integration (Dang et al., 2023).
- IFD Relevance: Moderate, embedding IFD concepts in these joint sessions should lower knowledge-related adoption barriers.

Ecosystem Governance & Trust-Building Mechanisms

- Initiator & Formality: A public or hybrid platform-orchestrator
- System Level: Sectoral and Institutional
- Strategic lever: Social / political
- DVF-Framework attribution: Viability, stable, trust-based governance improves the likelihood that heterogeneous actors remain engaged long enough for business-case and institutional arrangements to mature *(Vosman et al., 2023).*
- Description: Joint steering groups, open knowledge platforms, and conflict-mediation protocols, that foster transparency and fair risk-benefit sharing across projects. Recurrent, informal touch-points (workshops, community-of-practice meetings) gradually build mutual trust, enabling partners to coordinate without relying solely on rigid contracts. This trust reduces transactional barriers and accelerates collective experimentation and scaling (Vosman et al., 2023).
- IFD Relevance: Integrating these trust-building routines into IFD adoption could reduce perceived partner risk when committing to flexible, demountable design strategies. A governance environment that already rewards openness and long-term reciprocity should make stakeholders more willing to trial, learn and iterate IFD solutions across multiple assets.

Long-Term Strategic Partnerships

- Initiator & Formality: Mixed
- System Level: Organisational, institutional and sectoral
- Strategic lever: Social/political
- DVF-Framework attribution: Viability, durable alliances secure commitment and risk-sharing long enough for business cases to mature (Vosman et al., 2023).
- Description: Multi-actor frameworks or programmes that run for several years, organise regular joint sessions, and keep knowledge circulating across projects; formal contracts set

the envelope, but relational routines (joint steering, open data sharing, conflict mediation) "do the real work" (Vosman et al., 2023)
- IFD Relevance: Stable, trust-rich alliances provide the continuity needed to plan, disassemble and re-use IFD components across successive assets.

Standardised Interface Protocols / Open-Platform Design
- Initiator & Formality: Sector-wide working groups or public-client consortia, formal
- System Level: Institutional and sectoral
- Strategic lever: Technical
- DVF-Framework attribution: Feasibility and viability, common interfaces make multi-vendor coordination and on-site assembly practically doable. Furthermore they enlarge the supplier base, mitigating the supply barrier that the study flags as strongly interconnected with cost hurdles (Feldmann et al., 2022)
- Description: Standardised interface protocols prescribe dimensioning, connection details, and digital data schemas so that volumetric or panelised modules from different manufacturers "click" together without bespoke re-engineering. Feldmann et al. (2022) note that modular construction realises its promise "*when there is high standardization and repeatability*", yet current uptake is hampered by limited supplier capacity and concerns over design freedom.
- IFD relevance: Interchangeable interfaces unlock circular life-cycles: components can be disassembled and re-used across successive projects without costly custom adaptation, directly supporting Industrialised Flexible Disassembly objectives.

Shared logistics hubs & just-in-time delivery
- Initiator & Formality: A coalition of third-party logistics providers, freight forwarders and consolidators acting for the main contractor, formal
- System Level: Project and organisational
- Strategic lever: Technical
- DVF-Framework attribution: Feasibility and viability, shared hubs guarantee on-time, right-quantity arrivals; they cut inventory and handling costs, outcomes that JIT supply chains consistently deliver (Yang et al., 2020)
- Description: The partners locate a city-edge consolidation centre where off-site-fabricated components from multiple vendors are pre-sequenced and loaded onto smaller "milk-run" vehicles that deliver to site exactly when cranes or crews become available (Yang et al., 2020)
- IFD Relevance: Industrialised Flexible Disassembly (IFD) depends on clean, damage-free modules arriving and leaving the site. A shared JIT (Just In Time) logistics hub can schedule both delivery and reverse-logistics pick-up of reusable elements, lowering on-site congestion and ensuring components are tracked and returned into future projects' material loops, thereby complementing IFD adoption.

Capacity-building for regional fabricators
- Initiator & Formality: Public clients and government bodies, formal
- System Level: Organisational

- Strategic lever: Technical lever with social spill-overs: initiatives fund machinery upgrades, digital production lines and worker up-skilling, directly tackling production capability gaps (Zhang et al., 2024).
- DVF-Framework attribution: Feasibility, more capable factories can fabricate to tighter tolerances and schedules; Viability, a broader, quality-assured vendor pool lowers cost risks and market entry barriers (Zhang et al., 2024).
- Description: The mechanism subsidises fabricators to invest in automated lines, mandates staff participation in joint training, and introduces a government-run certification that signals compliance with MiC/IFD standards. Regular workshops and a digital supplier database share best practices.
- IFD Relevance: Capacity-building is framed as enabling upgrading the MC supply chain to achieve economies of scale (Zhang et al., 2024).

Institutional Readiness/Capacity Mechanisms

[INTRO]

Inter-agency coordination

- Initiator & Formality: Government bodies, formal
- System Level: Institutional
- Strategic lever: Political lever. It removes fragmented rule-making and conflicting mandates by creating a shared governance platform backed by high-level policy authority (Zhang et al., 2024).
- DVF-Framework attribution: Feasibility, unified permitting procedures reduce approval time and uncertainty, directly enlarging the feasible space for modular/industrialised projects; Viability is reinforced because lower regulatory risk improves business-case robustness.
- Description: The task-force sets common performance standards, provides a single digital submission portal, and runs joint inspections so firms no longer duplicate paperwork across agencies. Regular coordination meetings and shared data dashboards ensure continuous policy learning and quick conflict resolution (Zhang et al., 2024)
- IFD Relevance: IFD projects often move components for reuse or refurbishment. A harmonised, inter-agency framework makes it easier to certify reused modules, issue transport permits, and recognise prior product-testing, thereby cutting red-tape at both assembly and disassembly stages.

Regulatory coordination

- Initiator & Formality: Government/regulatory agencies, formal
- System Level: Political
- Strategic lever: Institutional
- DVF-Framework attribution: Unified, predictable regulations cut approval time and uncertainty, expanding feasibility, and lower compliance risk, thereby strengthening business-case viability for modular projects (Zhang et al., 2023).
- Description: The task-force consolidates dispersed permits into a one-stop digital portal, publishes a cross-border MiC code, and synchronises on-site and factory inspections. It also

negotiates size-and-weight exemptions for module transport and simplifies customs declarations, directly addressing regulatory bottlenecks identified in Hong Kong (e.g., vehicle-length limits) and the UK (“lack of regulatory framework”) (Zhang et al., 2023; Martin et al., 2024).
- IFD Relevance: High, IFD relies on moving, recertifying and re-using modules across borders. A harmonised regulatory regime means components can be *approved once, traded many times*, cutting corners at assembly and recovery stages and thus accelerating IFD adoption (Zhang et al., 2024)

Modernised codes and streamlined approvals

- Initiator & Formality: Governmental bodies, formal
- System Level: Institutional
- Strategic lever: Political
- DVF-Framework attribution: External governance mechanisms that raise visibility and feasibility of modular diffusion by reducing uncertainty and perceived risk.
- Description: Introduce up-to-date, performance-based modular codes that: unify structural, fire-safety and MEP provisions across jurisdictions; embed digital deliverables (BIM/IoT) for remote factory inspection; provide a single “pre-acceptance” path so compliant module designs receive one-off approval valid for all subsequent projects; and provide a single pre-acceptance path so compliant module designs receive one-off approval valid for all subsequent projects (Zhang et al., 2024; Wuni et al., 2020)
- IFD Relevance: An essential enabler for the IFD production model because predictable approvals are a prerequisite for early design-freeze, factory investment and repeatable module manufacture.

Government R&D and demonstrator funding

- Initiator & Formality: Governmental bodies
- System Level: Institutional and sectoral
- Strategic lever: Political
- DVF-Framework attribution: Feasibility, grants and demonstrators generate validated technical knowledge and performance data, expanding the feasible set of modular/IFD solutions that industry trusts and regulators accept (Zhang et al., 2023)
- Description: Typical instruments include competitive R&D calls for smart MiC/IFD tooling, land or capital subsidies for prototype factories, and government-led pilot buildings that serve as “living labs.” These pilots provide real-world evidence, while exhibitions and open-house tours disseminate lessons and stimulate demand (Wuni et al., 2020; Zhang et al., 2024).
- IFD Relevance: IFD relies on novel demountable connectors, tracking software and take-back logistics, all of which require upfront experimentation. Government R&D funding absorbs this early risk and demonstrator projects showcase reuse cycles in action, accelerating industry confidence and adoption.

Finance & Risk Mechanisms

Demand side incentives

- Initiator & Formality: Governmental bodies
- System Level: Institutional and sectoral
- Strategic lever: Political
- DVF-Framework attribution: Viability guaranteed public demand *improve project business cases*, lowering perceived financial risk and making MiC commercially viable (Zhang et al., 2023).
- Description: The mechanism couples: planning bonuses with procurement mandates that require MiC in government developments. This creates an immediate market, offset cost premiums and signal long-term policy commitment, which interviewees ranked as the top political opportunity for supply-chain enhancement (Zhang et al., 2024).
- IFD Relevance: High, predictable, incentive-driven demand pipeline gives suppliers the confidence to invest in demountable, reusable component lines; bonuses could be extended to award flexible disassembly, directly accelerating IFD adoption.

Supply-side funding & talent packages

- Initiator & Formality: Governmental bodies
- System Level: Institutional and sectoral
- Strategic lever: Political
- DVF-Framework attribution: Viability, capital support lowers sunk-cost and scale-up risk for new plants, while talent incentives secure the skilled workforce needed for consistent output, strengthening the commercial viability of the MiC/IFD supply base (Zhang et al., 2024).
- Description: Zhang et al. (2024) recommend “innovative funding schemes” and allied talent-attraction policies; interviewees add that scaling up a certified supplier base “diversif[ies] the product portfolio and enhances market competitiveness,” so long as quality is policed through certification.
- IFD Relevance: High, the mechanism directly shortens the learning curve for suppliers to pivot toward Industrialised Flexible Disassembly.

Cash-flow-aligned payment practices

- Initiator & Formality: Client
- System Level: Project and organisational
- Strategic lever: Social, adjusting payment timing restructures the relational and trust dynamics between client, main contractor and modular suppliers; it is a non-technical change that removes a key interpersonal/contractual friction noted by practitioners (Zhang et al., 2024)
- DVF-Framework attribution: Viability, by matching outflows (fabrication costs) with inflows (stage payments), the mechanism improves working-capital viability for suppliers and reduces default risk across the chain (Zhang et al., 2023)
- Description: Zhang’s survey lists “MiC introduces significant changes to the payment terms and cash flows” as a salient constraint to modular supply-chain enhancement (Zhang et al., 2024). Amending standard contracts so that progress-payments are released against off-site production milestones (rather than on-site installation) reduces working-capital pressure on fabricators and contractors, thereby neutralising the concern.
- IFD Relevance: High, liquidity-synchronised payments de-risk upfront spend, enabling wider IFD uptake and more stable supplier capacity.

Life cycle cost metrics

- Initiator & Formality: Mixed and formal
- System Level: Project and organisational
- Strategic lever: Technical, a quantitative tool that converts MiC/IFD performance into a single monetary indicator, overcoming the “cost” dominance identified in productivity rankings (Shahpari et al., 2020)
- DVF-Framework attribution: Viability, demonstrates that MiC can reduce total life-cycle cost, one of the headline benefits motivating adoption (Wuni et al., 2020)
- Description: LCC of IFD is yielding a lower discounted total than in-situ construction when discounted to present value (Wuni & Shen, 2020; Shahpari et al., 2020).
- IFD Relevance: High, tagging objects with standardised LCC attributes lets designers auto-compare disassemblable modules against conventional options, making the economic case for flexible, reversible assemblies clear early on.

Cost-benchmark database

- Initiator & Formality: Mixed and formal
- System Level: Institutional and sectoral
- Strategic lever: Technical, creation of a shared information infrastructure to close the “higher initial and overall cost” evidence gap that Rahman identifies as the top barrier (Rahman, 2014)
- DVF-Framework attribution: Viability, greater price certainty lowers perceived financial risk and eases financing decisions (Rahman, 2014)
- Description: Create an open-access cost-benchmark database that pools audited project accounts (preliminaries, structure, fit-out, logistics, de-install etc.) for different off-site systems. Pan & Sidwell report that the “lack of public cost data and information on off-site construction is … a most critical inhibiting factor” to wider uptake (Pan et al., 2011), while Rahman finds higher initial and potentially higher overall costs rank above all other barriers in stakeholder surveys (Pan et al., 2011).
- IFD Relevance: High, by adding fields for disassembly, recovery and salvage values, the same benchmark lets decision-makers see the total-life-cycle economics of demountable components. Making these figures visible early reduces perceived financial risk and strengthens the business case for IFD solutions.

Public green-finance incentives linked to MiC carbon savings

- Initiator & Formality: Governmental bodies and formal
- System Level: Institutional and sectoral
- Strategic lever: Political
- DVF-Framework attribution: viability, it offers a financial promotion to accelerate adoption while directly rewarding sustainability outcomes.
- Description: A dedicated green-finance facility ties preferential financing terms to quantified carbon-saving benchmarks (e.g. tonnes-CO_2-eq per m^2) achieved through MiC (Xin, 2022).
- IFD Relevance: High, cheaper, mission-aligned capital into the IFD construction paradigm, de-risking early adoption costs and scaling MiC factories, digital-twin LCA platforms and low-carbon logistics fleets.

Integrated Project Insurance (IPI)

- Initiator & Formality: Governmental bodies or private sector alliance parties, formal.
- System Level: Organisational and institutional
- Strategic lever: Political
- DVF-Framework attribution: By insuring outcomes rather than liabilities, IPI removes uncertainty over fault-based claims and duplicative professional-indemnity costs, strengthening the economic *viability* of alliancing arrangements (CMS et al., 2019).
- Description: Traditional, party-specific insurance models undermine the "shared-risk, trust" ethos of alliancing. IPI replaces them with one policy underwritten for all members, creating a no-blame/no-claim environment. Professional-indemnity disclosures become unnecessary when litigation is off the table, and alliance teams can focus on project performance rather than fault apportionment (CMS et al., 2019)
- IFD Relevance: High, blame-free, outcome-focused insurance framework assures all stakeholders, from modular fabricators to end-of-life recyclers, that risks around disassembly and reuse are shared and covered, thereby de-risking the circular lifecycles central to IFD.

Incentive/pain-gain contracts

- Initiator & Formality: Client, formal
- System Level: Project
- Strategic lever: Political
- DVF-Framework attribution: Viability, by sharing cost underruns and overruns, the mechanism improves the financial feasibility of adopting innovative methods, making investments in new technologies more economically sustainable (Eriksson et al., 2022).
- Description: Under this approach, the client and delivery team agree on an initial target cost. Any actual cost below or above that target is split between all participants according to pre-agreed proportions (gainshare/pain-share), creating a no-blame environment and motivating joint efforts to reduce costs and pursue innovation (Eriksson et al., 2022).
- IFD Relevance: High, for industrialised and modular construction, sharing both the risks and rewards of off-site production investments lowers barriers to entry, knowing that cost savings accrue collectively and overruns are not borne by a single party. This alignment of financial incentives can significantly accelerate IFD adoption across complex infrastructure projects.

Scenario based assessment

- Initiator & Formality: Public clients, formal
- System Level: Project and organisational.
- Strategic lever: Technical, introduces rigorous, quantitative decision support to replace heuristic judgments, aligning stakeholders around transparent performance projections (Shahpari et al., 2020)
- DVF-Framework attribution: Feasibility, by numerically comparing productivity outcomes across alternative construction scenarios, it reduces uncertainty about off-site methods and thereby expands the implementable solution space (Shahpari et al., 2020)
- Description: Scenario-based assessment uses structured, comparative exercises to evaluate different construction delivery options, against a consistent set of performance criteria (e.g., productivity, cost, quality). By presenting stakeholders with ranked outcomes under plausible

scenarios, it guides early decision-making toward the solution that best balances benefits and risks (Shahpari et al., 2020).

- IFD Relevance: High, embedding IFD-specific metrics (e.g., disassembly duration, component reuse rate) as alternative inputs allows direct comparison of flexible-disassembly designs against conventional scenarios, guiding early design and procurement toward solutions that optimize both productivity and demountability.

Technology & Data Mechanisms

One database

- Initiator & Formality: Mixed, formal
- System Level: Institutional and sectoral
- Strategic lever: Technical It builds a shared information infrastructure, closing data silos and enabling real-time module tracking across stakeholders (Zhang et al., 2024)
- DVF-Framework attribution: Feasibility and viability, by reducing information asymmetry and coordination costs, a unified database makes modular/IFD processes more practicable for all supply-chain actors (Zhang et al., 2024)
- Description: A central, open-access digital repository captures and normalizes critical data, module designs, QA/QC inspection results, production schedules and logistics-clearance records. Stakeholders can query, verify and synchronize module information throughout design, manufacture, transport, assembly and eventual disassembly (Zhang et al., 2024)
- IFD Relevance: High, Industrialised Flexible Disassembly depends on precise, bidirectional traceability of components. A single database underpins digital-twin models, automates compatibility checks, and ensures that demountable modules meet reuse specifications, thereby unlocking scalable IFD workflows.

End-to-End BIM & data integration

- Initiator & Formality: Client and governmental bodies
- System Level: Project and organisational
- Strategic lever: Technical, leverages digital technologies (BIM, IoT, blockchain) to enable real-time collaboration, transparency and traceability across the modular supply chain (Zhang et al., 2023).
- DVF-Framework attribution: Feasibility, mandatory BIM and a unified database address information gaps and streamline regulatory workflows, making modular supply-chain integration more practicable (Zhang et al., 2023).
- Description: Zhang et al. (2024) report that requiring BIM for pre-submission reviews and establishing a dedicated MiC supply-chain database were both rated as effective measures for enhancing supply-chain functionality (Zhang et al., 2024). Technical solutions including service-oriented platforms integrating blockchain, IoT and BIM further support cross-stakeholder data exchange (Zhang et al., 2024)
- IFD Relevance: High, a fully integrated BIM-and-data environment underpins IFD by ensuring that design-for-fabrication data flows seamlessly into off-site manufacturing and on-

site assembly, reducing clashes, rework and enabling tighter tolerance control across the entire lifecycle.

BIM-enabled design-for-manufacture-and-assembly (DfMA)

- Initiator & Formality: Governmental bodies
- System Level: Project and organisational
- Strategic lever: Technical
- DVF-Framework attribution: Feasibility, by embedding manufacturability checks and clash detection into the BIM workflow, coordination errors and rework are minimised, making modular production practicable at scale (Li et al., 2021)
- Description: A federated BIM model is able to iterate with fabricators via shared data platforms, closing the design-manufacture feedback loop before any physical production (Kolugala et al., 2022); BIM's collaborative networks ensure cross-discipline communication of manufacturing requirements and change-orders (Li et al., 2021).
- IFD Relevance: High, embedding DfMA in BIM ensures that every modular component is both factory-optimised and designed for future disassembly: manufacturing tolerances, connector details and demountability instructions reside in the digital model, thus underpinning the reversible, circular workflows central to IFD.

Smart QA/QC & digitalised production

- Initiator & Formality: Public regulators or governmental bodies
- System Level: Institutional and sectoral
- Strategic lever: Technical, by embedding QA/QC, the mechanism reduces assembly errors and rework, directly improving the practicability of factory-made modules (Zhang et al., 2024)
- DVF-Framework attribution: Feasibility, by embedding "digital techniques for remote inspection of module production", the mechanism reduces assembly errors and rework, directly improving the practicability of factory-made modules (Zhang et al., 2024).
- Description: A standardized QA/QC framework is codified in joint practice notes and enforced via digital cameras, RFID/IoT sensors and a shared dashboard. Production data, dimensional tolerances, surface-finish readings and non-destructive-test results, are uploaded in real time, enabling rapid virtual sign-off and flagging deviations before modules leave the factory (Zhang et al., 2024).
- IFD Relevance: Reliable, time-stamped QA records are vital for Industrialised Flexible Disassembly: they ensure that demountable components meet reuse specifications and feed into digital-twin models that automate disassembly sequencing, thus underpinning circular lifecycle management.

Customisable module catalogues

- Initiator & Formality: Contractor(s) or supplier(s)
- System Level: Project and organisational
- Strategic lever: Technical
- DVF-Framework attribution: Feasibility, customisable module catalogues embed manufacturability rules and standardized interfaces directly into the BIM environment, reducing design iterations and coordination errors and thus expanding the technical feasibility space for modular construction (Bakhshi et al., 2022; Wuni & Shen, 2020).

- Description:
- IFD Relevance: A BIM-hosted, parametric library of validated modules, each tagged with DfMA metadata, lets designers and clients interactively configure buildings by selecting pre-engineered units. This ensures that every chosen module meets manufacturing and transport constraints, slashing design iterations and coordination errors (Wuni & Shen, 2020; Bakhshi et al., 2022).

Lifecycle data capture for circular-reuse passports

- Initiator & Formality: Mixed
- System Level: Project and organisational
- Strategic lever: Technical, leveraging IoT sensors, BIM integration and blockchain-style ledgers to automate the capture, verification and updating of lifecycle data at every stage (design, fabrication, installation, operation, decommissioning).
- DVF-Framework attribution: Feasibility, by ensuring timely, accurate component data, passports reduce informational barriers and make circular-reuse workflows technically practical and reliable.
- Description:
- IFD Relevance: