Toward Commitment-Driven Enterprise Digital Twins

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Abstract. Enterprises are increasingly challenged to make sense of proliferating digital traces in ways that are semantically coherent, organizationally actionable, and institutionally aligned. This research introduces CoEDiT—a commitment-driven enterprise digital twin—conceived as a reflexive modeling infrastructure that integrates conceptual abstraction, semantic technologies, and empirical data analytics. Grounded in Action Design Research, CoEDiT operationalizes a dialectical loop wherein social commitments serve as ontologically grounded constructs that link strategic intention to operational execution. Applied to air navigation services, the approach demonstrates how latent coordination structures can be surfaced and organizational learning sustained through the semantic reinterpretation of transactional data. Beyond its practical instantiation, CoEDiT contributes to current debates in Information Systems and Business Informatics by proposing a socio-technical modeling grammar that supports institutional sensing, strategic seizing, and organizational transformation. In doing so, it recasts enterprise modeling not as a representational end, but as a dynamic capability for reflexive adaptation in reindustrialized contexts.

Key words: Reflexive digital twin; Ontology-driven conceptual modeling; Business analytics; Semantic representation; Action design research; Institutional sensemaking.

1 Introduction

The Capgemini 2025 report [1] reveals a strategic pivot toward resilient, tech-enabled, and sovereign manufacturing in Europe and the US. Amid geopolitical and supply chain pressures, firms are accelerating reindustrialization via reshoring, nearshoring, and friendshoring. Digital and sustainable technologies are pivotal in reducing both costs and emissions, with organizations projected to invest $4.7 trillion in reindustrialization initiatives over the next three years. Success depends on integrating digitalization, sustainability, skilled labor, and adaptive rightshoring strategies.

Concurrently, conceptual modeling is increasingly aligned with data analytics to enhance explainability, semantic clarity, and data quality. Models now serve

not only as design artifacts but as dynamic structures that interpret, contextualize, and validate data-driven outputs. This includes annotating datasets, exposing biases, modeling uncertainty, and supporting the explainability of black-box systems. Conceptual modeling thus reinforces the trustworthiness and relevance of data analytics in complex domains [2].

These parallel developments highlight a shared imperative: the need for coherent, reflexive systems that support informed decision-making under uncertainty. Bridging digital manufacturing ecosystems with conceptual and analytical rigor demands a new modeling paradigm attuned to continuous learning and sustainable adaptation. This research addresses that challenge by asking: **How can a dialectical modeling loop combining commitment-driven conceptual modeling, semantic representation, and data analytics support lean organizational learning for sustainability in reindustrialized contexts?**

The dialectical modeling loop is conceived as a lean, reflexive infrastructure for organizational learning, centered on the continuous interplay between formal models, semantic coherence, and empirical feedback. Anchored in Action Design Research, it is operationalized through the CoEDiT artifact—a commitment-driven enterprise digital twin. Rather than representing enterprise behavior as static processes, CoEDiT models it as networks of evolving social commitments, which are ontologically grounded and semantically rich. These commitments serve as units of analysis that integrate normative expectations with situated interdependencies. Coupled with data mining and institutional sensemaking, the loop enables adaptive reconfiguration by iteratively aligning conceptual representations with observed behaviors and emergent goals. In doing so, it sustains an ongoing reinterpretation of enterprise essence as enacted through commitments within dynamic reindustrialized environments.

This research contributes to enterprise modeling literature by introducing a novel commitment-based modeling paradigm that integrates ontological formalism, semantic expressivity, and analytic adaptability within a single learning-oriented infrastructure. It extends the role of enterprise models from design-time artifacts to epistemic scaffolds for situated decision-making and transformation, particularly in sustainability-driven reindustrialization. The paper is structured as follows: Section 2 situates the research within related work on conceptual modeling, data analytics, commitment ontologies, and methodological reflexivity. Section 3 outlines the Action Design Research methodology and details the design, enactment, and evaluation of the CoEDiT artifact. Section 4 demonstrates the approach through an interpretive case study in air navigation services. Section 5 reflects on the method's implications, limitations, and avenues for future research. Section 6 concludes by synthesizing the contributions and reaffirming the value of commitment-driven modeling for sustainable enterprise transformation.

2 Related Work

2.1 Conceptual Modeling and Data Analytics

Conceptual-modeling scholarship increasingly converges with data-analytics research to tame the opacity of data-driven systems and to supply the semantic scaffolding demanded by explainable AI and data governance agendas [2]. Maass & Storey [3] theorize a bidirectional pairing in which conceptual schemas guide machine-learning pipelines while learnt patterns reciprocally refine the schemas, thus linking epistemic transparency with discovery. Schuetz & Schrefl [4] extend this insight across the business-intelligence pipeline, arguing that higher-level models can reduce costly data wrangling and render analytics artefacts intelligible to non-programmers. Together these works recast conceptual models from static blueprints into dynamic mediators that bridge abstraction and implementation in complex, data-intensive contexts.

Design-oriented studies translate this convergence into actionable frameworks. Nalchigar & Yu [5] provide a model-based method for eliciting requirements and structuring analytics architectures; their practitioner evaluation shows improved stakeholder communication and system validation. Park et al. [6] tackle big-data quality by embedding relevance, comprehensiveness, and prioritization criteria into the IRIS conceptual framework, thereby transforming heterogeneous datasets into coherent virtual big-data models. These contributions foreground conceptual modeling as a vehicle for assuring data quality and aligning analytics design with organizational goals.

Collectively, the literature demonstrates that conceptual abstractions enhance explainability, data quality, and stakeholder alignment, yet it treats the organization largely as a static backdrop. The CoEDiT digital-twin framework advances this discourse by modelling enterprises as evolving networks of social commitments expressed in OntoUML and instantiated as RDF knowledge graphs. Its dialectical loop extends prior work from design-time guidance to runtime learning, enabling reindustrializing firms to continuously realign strategic intent, operational data, and sustainability imperatives within a lightweight, reflexive infrastructure.

2.2 Commitment Ontologies, Enterprise Transactions, Methodological Reflexivity

Commitments have long been proposed as the ontological glue that links individual intentions to collective action. Castelfranchi's seminal work [7] reframes organizational coordination as the deliberate management of commitments among autonomous agents, a view operationalized by Telang and Singh [8] through formal criteria for compliance and verification. Enterprise Ontology [9] crystallizes this stance in the DEMO (Design and Engineering Methodology for Organizations) methodology, positing the enterprise as a closed system of actor transactions whose essence is captured by mutually constitutive commitments.

The DEMO Basic Transaction Pattern (BTP), illustrated in Fig. 1, models the minimal structure of a business transaction by distinguishing three sequential phases—order, execution, and result—each unfolding across two ontological domains: the coordination world (speech-act commitments) and the production world (material fact creation). This dual-layered articulation explicates how a social commitment unfolds from request (rq), through promise (pm) and declaration of execution (da), to final acceptance (ac). As such, BTP furnishes a rigorous semantic backbone for commitment-centered digital twins, rendering the progression of social commitments both observable and ontologically grounded. For extensions beyond this minimal structure, refer to the standard and complete transaction patterns detailed in [9].

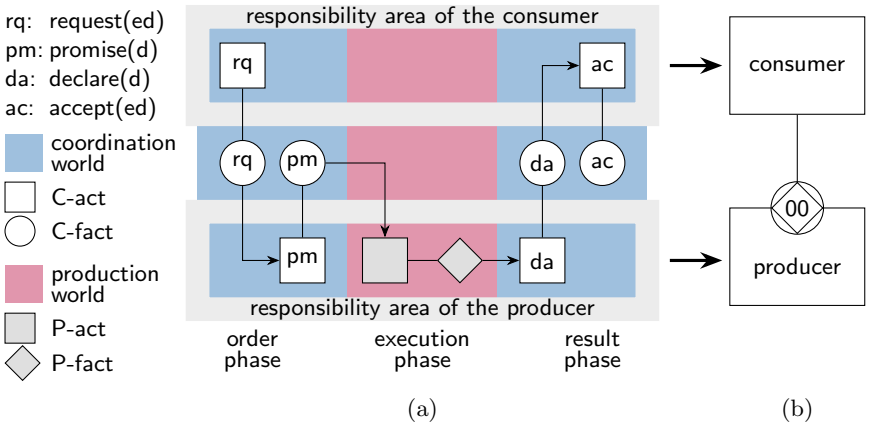

Fig. 1. (a) The DEMO Basic Transaction Pattern (BTP) models a transaction's progression across coordination and production worlds—from *request* to execution and eventual *accept*—thereby articulating the enactment of social commitments. (b) In the DEMO Specification Language, symbols representing interactions between consumer and producer roles are open to both structural and operational interpretations. Adapted from [9, 10].

Ontological refinements further clarify this pattern. Poletaeva et al. [11] recast the BTP within the Unified Foundational Ontology [12], decoupling structural from behavioral aspects and modelling commitments as OntoUML relators. Service-oriented research has sharpened the commitment lens. Nardi et al.'s [13] UFO-S ontology characterizes a service as the interplay between capability provision and normative engagement: service delivery is possible only because providers and consumers bind themselves through explicit or implicit commitments. Their follow-up analysis of ArchiMate [14] reveals that mainstream architecture languages inadequately capture this duality, prompting a modelling strategy that weaves commitment-based and capability-based views

across business, application and technology layers. These results generalize the argument that any multi-layer enterprise representation needs a coherent commitment semantics to remain semantically tractable when moving from strategic intent to operational realization.

Methodological pluralism emerges as a parallel research theme. Kostova et al. [15] critique attempts to reconcile heterogeneous information-system methodologies into a single overarching framework, proposing instead a set of systems-thinking heuristics that promote ongoing, context-sensitive translation among viewpoints. Their interpretivist stance resonates with the phenomenological approach of Jonsson and Enquist [16], who emphasize that conceptual models must reflect the lived, evolving perspectives of enterprise actors rather than abstract, universal structures. Their notion of agreements as socially situated phenomena aligns closely with commitment-based modeling, offering a concise ontological structure that contrasts with the more granular and taxonomically dense models of OntoUML/UFO. Taken together, these interpretive and phenomenological contributions reorient conceptual modeling from a representational exercise toward a reflexive practice—one that privileges lived meaning, shared intentionality, and semantic coherence as foundations for adaptive and accountable information systems.

Across these streams, a consistent narrative unfolds: commitments provide a theoretically robust and empirically actionable unit of analysis that spans micro-level interaction, meso-level service coordination and macro-level organizational design. The reviewed literature converges on three design imperatives for contemporary enterprise modelling. First, ontological clarity is necessary to prevent semantic drift when commitments traverse architectural layers or disciplinary boundaries. Second, modelling grammars must support both integrity constraints (to safeguard internal consistency) and derivation constraints (to enable automated reasoning). Third, methodological reflexivity—anchored in interpretive heuristics—must be built into modelling practice so that commitment structures remain open to revision in volatile, sustainability-driven contexts. These imperatives underpin CoEDiT's ambition to extend enterprise digital twins from descriptive mirrors to epistemic infrastructures for continuous, commitment-centered transformation.

3 Methodology

The methodological stance adopted in this research is Action Design Research (ADR), underpinned by constructivist epistemology and interpretive paradigm. The designed artifact is a commitment-driven enterprise digital twin (CoEDiT) conceptualized as both a conceptual modeling script and an enterprise knowledge graph. The aim of this section is to outline the instantiation of the four stages of the ADR [17]: (1) problem formulation, (2) building, intervention, and evaluation, (3) reflection and learning, and (4) formalization of learning.

Problem formulation. The problem to be addressed is not the scarcity of data or analytical tools [18], but the absence of integrative, reflexive modeling

frameworks that can bridge the transactional and trace data and institutional purpose by making explicit the essence of enterprise functioning. Employing Delcambre's reference framework for conceptual modeling [19], we address this challenge by a multi-purpose, multi-language, multi-level conceptual script continuously evolving in response to socio-technical phenomena within enterprise setting. Unlike conventional static representational models, CoEDiT employs a reflexive method to mediate effectively between formal abstraction and the fluid dynamics of institutional practices. Within the broader taxonomy of digital twins, CoEDiT aligns conceptually with the Digital Twin of an Organization [20] or cognitive digital twins [21]. But it significantly departs from typical applications oriented towards physical systems (cf. [22]) by explicitly targeting social commitments as the foundational ontological elements of enterprise essence [9].

Building, intervention, and evaluation (BIE). While the BIE stage culminates in CoEDiT as a realized artifact, its core innovation lies in the organizational intervention that reflexively reconfigures the enterprise's structure of commitments—rendering each instantiation not a final product but a provisional resolution shaped by context-specific dynamics. To unpack the interplay between artifact construction, institutional transformation, and epistemic validation, the following sections detail the methodological foundations underlying CoEDiT's development, enactment, and evaluation.

Building. To articulate CoEDiT's distinctive characteristics as a conceptual script, we apply Mayr and Thalheim's [23] schema for eight conceptual model (CM) attributes, adapting attribute names for terminological consistency while retaining the original numbering for reference. The *modeled original* (CM1) is a network of social commitments [7] within an enterprise. As these commitments are not objective features of the world but interpretive constructs, our methodology is firmly rooted in constructivist epistemology and interpretive research tradition. The emergent, situated, and often tacit nature of commitments calls for a careful balance in *model focus* (CM5): formalization ensures ontological clarity, while representational flexibility preserves semiotic fluidity. This methodological tension anchors our approach, requiring reflexivity in how commitments are elicited, represented, and refined.

In its *modeling intention* (CM2), CoEDiT aligns with other conceptual models—facilitating retrospective understanding, perspective communication, and prospective design—yet crucially redefines 'design' as inseparable from use: it entails the dynamic shaping of commitment networks through human-centered interpretation and enactment (UML) and machine-interpretable semantic specification and validation (OWL). This shift naturally leads to the *model affordances* (CM3). Anchored in a machine-interpretable knowledge graph, CoEDiT serves both human and artificial agents—enabling compliance monitoring, semantic querying, constraint validation, and execution of formal specifications. Crucially, its organizational impact hinges on fostering sensemaking: how users perceive, enact, and adapt affordances, shaped by their roles, expertise, and intentionality [24]. Extending this, the *model environment* (CM4) operates in individual and organizational contexts: for practitioners, it demands cross-disciplinary fluency

and interpretive engagement; for the enterprise, it bridges formal models with the lived complexity of institutional practice, power dynamics, and normative tensions. In this role, CoEDiT can augment enterprise's management control systems [25] by translating strategic intent into traceable commitments and surfacing misalignments between declared purpose and operational behavior—thereby functioning as both a diagnostic and interactive mechanism for organizational steering.

Concerning *model grammar* (CM6), CoEDiT is grounded in a conceptual grammar ensemble, prominently comprising OntoUML (ontology-driven conceptual modeling), RDF (serialization), OWL (inferencing), SHACL (validation), and SPARQL (reasoning and querying). The method involves translating, mapping, and aligning across these diverse modeling grammars. Instead of enforcing strict unification, CoEDiT embraces dialectical synthesis—maintaining diversity while supporting integrated and reflexive modeling across layers and purposes [15]. Within CoEDiT's *concept space* (CM7), social commitments form the core constructs, interpreted variably as definitive [12], sensitizing [26], or ideal-typical [27] constructs depending on contextual needs. Fig. 2 illustrates how commitments are framed in a service-oriented architecture using OntoUML grammar. For *concept relationships* (CM8), the primary relational primitives–'initiate,' 'access,' and 'wait'–give rise to three coordination structures: interaction, interstriction, and interimpediment [9]. The articulation of these relational networks constitutes the substance of intervention, intertwined with reflection and learning. Beyond these foundational elements, additional concepts or relationships may be incorporated if they are theoretically grounded or methodologically justified, thereby enriching understanding and analytical depth.

Intervention. In the case of CoEDiT, the organizational intervention unfolds as a reflexive redesign of enterprise social commitments through a dialectical interplay between conceptual modeling, semantic representation, and data analytics. The CoEDiT artifact operates both as a conceptual script (via OntoUML) and a machine-interpretable knowledge graph (via OWL). UML, grounded in software engineering practice, emphasizes structural and behavioral integrity constraints central to internal consistency and external compliance. Conversely, OWL, rooted in formal logic and semantic web methodologies, prioritizes derivation constraints through formal axioms designed to support logical inference and automated reasoning [28]. This epistemological divergence between integrity and derivation constraints becomes methodologically significant in facilitating dialectical interplay and reciprocal shaping between abstraction and empirical validation. Data mining functions diagnostically, anchoring modeling in extracting patterned regularities from empirical traces while surfacing latent coordination structures–interaction, interstriction, and interimpediment–that inform institutional sensemaking. Together, these elements constitute a reflexive infrastructure that enables the continuous reconfiguration of enterprise commitments in response to emergent institutional realities.

This reflexive infrastructure positions CoEDiT not merely as a modeling tool, but as a generative layer within the enterprise's management control sys-

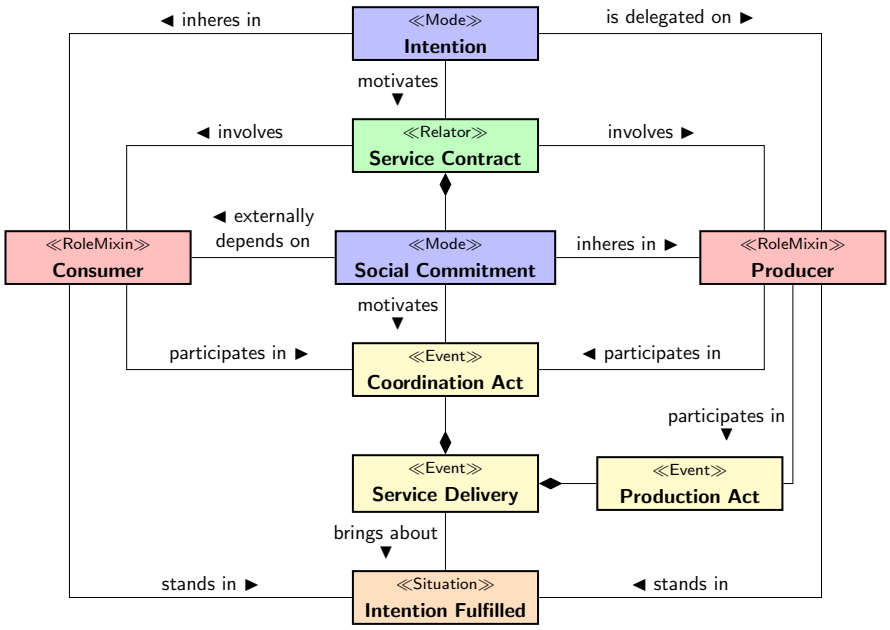

Fig. 2. Simplified OntoUML meta-model depicting a social commitment between a consumer and a producer, capturing both the structural dimension of the service contract and the behavioral dynamics of service delivery—from intention through coordination and production acts to intention fulfillment.

tems [25]. Aligned with Simons' *Levers of Control* framework [29], CoEDiT can inform diagnostic control through semantic constraint validation, interactive control via real-time rearticulation of commitments, belief systems by rendering institutional purpose explicit, and boundary systems through formal rule encoding. In this capacity, CoEDiT supports a dynamic coupling between strategic intent and operational execution, enabling enterprises to continuously align evolving commitments with shifting regulatory, technological, and organizational environments.

Evaluation. Interpreting and configuring CoEDiT's modeling ensemble involves situated choices guided by reflexive sensemaking, encompassing, among others, formal alignment, contextual framing, ontological anchoring, and semantic articulation of enterprise commitments. These interpretive choices are evaluated through inference to the best explanation (IBE), a method guided by the criteria of unification, explanatory depth, and simplicity [30]. Grounded in Peircean abduction, the evaluative process frames the generation of explanatory hypotheses as a rational response to surprising observations, thereby establishing the epistemic basis upon which candidate models are formulated for subsequent assessment via IBE [31]. To support this process, verification and validation techniques must be built into the design of domain-specific modeling

methods [32, 33]; in CoEDiT, this means ensuring syntactic, semantic, and pragmatic validity through integrated checks for rule conformity, conceptual clarity, and alignment with institutional context. Together, these evaluation mechanisms sustain the coherence and credibility of the modeling process, ensuring that each CoEDiT instantiation functions not merely as a representational artifact, but as a rigorously grounded hypothesis about the organization's evolving structure of commitments.

Reflection and learning. In the CoEDiT framework, reflection and learning constitute a recursive, epistemically guided process that deepens the intervention through continuous reinterpretation. Aligned with the principle of guided emergence, this stage moves beyond solution delivery to critically reassess the problem framing, conceptual assumptions, and representational choices underpinning the ensemble artifact. Relational primitives such as 'initiate,' 'access,' and 'wait' are recontextualized as interpretive constructs, surfacing coordination patterns as focal points of organizational sensemaking. Rather than resolving tensions, this stage sustains them dialectically—supporting lean learning by iteratively aligning commitment-based representations with evolving sustainability imperatives in reindustrialized enterprise settings.

Formalization of learning. This stage distills the situated insights gained through iterative enactment of the dialectical loop—Conceptual Modeling → Data Mining → Reflexive Sensemaking → Conceptual Refinement—into a transferable conceptual framework (Fig. 3). Rather than stabilizing an artifact, formalization renders the reflexive process itself reproducible across contexts. CoEDiT, understood as a conceptual modeling script, is inherently ephemeral: each deployment alters the commitment structure it seeks to model, and in doing so, renders itself partially obsolete. This self-exhausting quality is not a weakness but a feature—it affirms the script's role as a catalytic scaffold for transformation, not a durable blueprint. By abstracting this dynamic into generalizable modeling patterns, formalization yields design principles that guide future interventions in socio-technical systems facing similar tensions of coordination, accountability, and change.

Crucially, what formalization preserves is not the artifact in its instantiated form, but the reflexive logic of its operation—the capacity to surface, interrogate, and reconfigure an organization's evolving "theory of the business" [34, 35] as a network of social commitments. Each CoEDiT instance constitutes a provisional resolution of institutional meaning, shaped by contextual pressures and learning trajectories. The generalized outcome is not a static artifact but a modeling grammar and method ensemble, enabling commitment-driven diagnostics across domains and contributing to the refinement of theories of enterprise modeling, institutional learning, and socio-technical design.

Framed through the lens of the guiding inquiry, the methodology embeds this dialectical modeling loop within a constructivist Action Design Research cycle. Commitment-driven modeling supplies the normative core, semantic representation ensures interpretability and machine-actionability, and data analytics anchors the model in empirical traceability. Together, these elements support

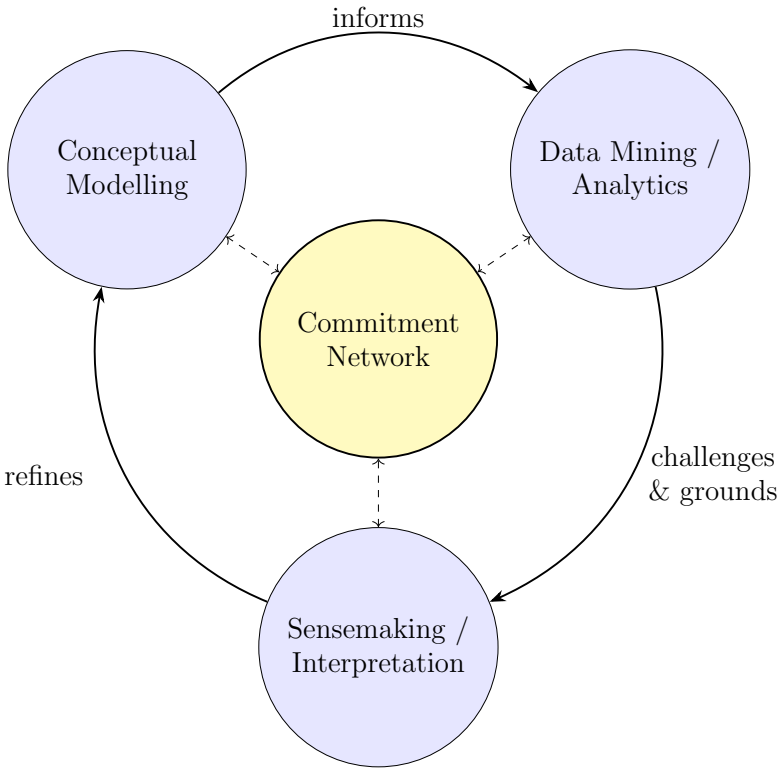

Fig. 3. Conceptual modeling framework underpinning the enterprise digital twin. Organizational insight emerges not from either modeling or mining alone, but from their dialectical interplay, mediated by reflexive sensemaking. Source: authors.

lean organizational learning by aligning enterprise commitments with evolving institutional and sustainability demands—offering a reflexive infrastructure for adaptive reindustrialization.

4 Demonstration

Imagine turning a budgeting spreadsheet into a living map of commitments between organizational units. CoEDiT does exactly that. To illustrate the feasibility and expressiveness of the proposed approach, we conducted an interpretive case study grounded in the domain of air navigation services. The empirical scaffold consists of a constructed dataset inspired by Implementing Regulation 2019/317 [36], which governs cost-efficiency in European air traffic management [37]. The fictionalized data simulates an Air Navigation Service Provider (ANSP) budget over a fiscal year, comprising 125 entries (see a sample in Fig. 4) distributed across organizational units, service categories,

and cost types. All underlying research data and modeling artifacts are publicly accessible in accordance with the FAIR principles, curated at `https://lustraka.github.io/resources/pechar/`, ensuring transparency, reusability, and alignment with open science practices. Although abstracted from real-world entities, the dataset maintains structural fidelity to regulatory logic and operational practice. Its function is not to produce generalizable empirical claims, but to serve as a plausible, bounded arena for modeling intervention. By transforming this compliance-oriented financial data into a semantic network of commitments, we demonstrate how enterprise digital twins can surface latent coordination structures and render institutional interdependencies intelligible through ontological modeling and semantic reasoning.

Index	bYYe001	bYYe002	bYYe003
Service	201 Air Traffic Management	201 Air Traffic Management	201 Air Traffic Management
OrganizationalUnit	1000 Corporate Services	1000 Corporate Services	1000 Corporate Services
CostType	a Staff Costs	b Operating Costs	c Depreciation Costs
AmountEUR	8752200	624800	18485100
AmountEnRouteEUR	6867900	585300	15084600
AmountTerminalEUR	1884300	39500	3400500
AccountingPeriod	YYYY	YYYY	YYYY

Fig. 4. Initial budget entries from the input dataset exemplify the flat, operational data structure of conventional spreadsheets. These entries serve as the empirical substrate for initiating the dialectical-reflexive modeling loop within the CoEDiT framework. Source: authors.

4.1 Conceptual Modeling

The analytical shift is captured in the reinterpretation of a conventional budget line as a commitment relator within the OntoUML meta-model. In typical budgeting spreadsheets, cost entries encode the amount, organizational unit, service, and cost type—without exposing their underlying semantics. This flat data structure (Fig. 4) privileges operational expedience but obscures the normative and teleological dimensions of budgeting activity. In contrast, the commitment-oriented meta-model (Fig. 5) reinterprets the budget entries as manifestations of institutionalized commitments. Here, each `BudgetEntry` connects an `OrganizationalUnit` (as agent) to a `Service` (as intentional output), within the context of a given `AccountingPeriod`. A `Service` contributes to a `Chargeable Service` and requires human effort, subservices, and infrastructure captured through a `CostType`.

4.2 Data Analytics

To surface intra-organizational coordination in the absence of explicit linkage data, we employed a pragmatic heuristic: the organizational unit with the highest financial contribution to a service was provisionally designated as its proxy

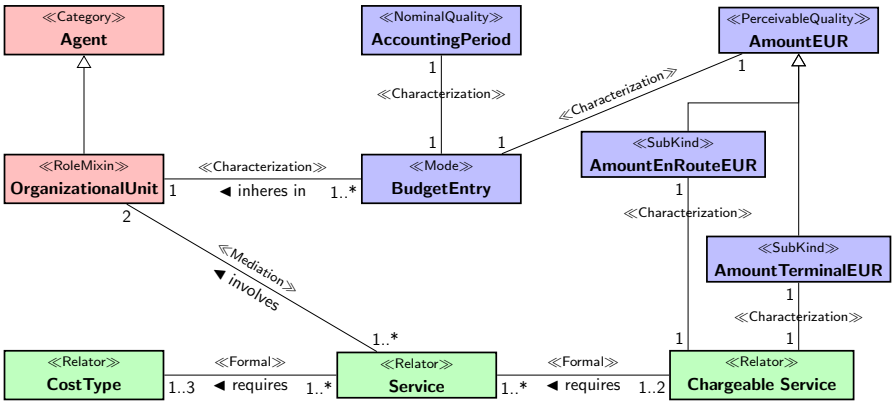

Fig. 5. OntoUML-based conceptual model reinterpreting budget entries as institutionalized commitments linking organizational units, services, and cost types within a specified accounting period. Source: authors.

agent. While simplificatory, this assumption enabled the reconstruction of inferred `deliversTo` relations—rendering visible an otherwise latent topology of operational interdependence. As illustrated in Fig. 6, this approach reflects a reflexive modeling move: treating financial traces not as definitive indicators but as situated proxies for institutional roles within evolving coordination patterns. As inverse properties of the 'initiate' links that underpin the interaction structure, the `deliversTo` relations reveal an emergent topology of enterprise management dynamics, as materially expressed through financial allocations within management accounting practices. While methodologically expedient, this inference foregrounds a critical modeling tension: should semantic roles be derived from quantitative dominance, or from explicit organizational declarations? Such tensions are not resolved here; rather, they are rendered analytically visible—subject to reflection, challenge, and refinement.

4.3 Reflexive Sensemaking

CoEDiT's dual role as both a conceptual script and a knowledge graph becomes operationalized through its RDF-based instantiation. Fig. 7 exemplifies how a single budget entry—initially flat and syntactic—can be reconstituted as a web of typed semantic relations. Leveraging RDF's affordances for integration, interoperability, and reasoning, each element of the budget entry (organizational unit, service, cost type) is ontologically anchored, interlinked, and externally referenced. This semantic rearticulation not only enables alignment with domain ontologies and regulatory vocabularies, but also supports advanced queries, inference, and cross-context reuse.

The current demonstration foregrounds one possible reading of the coordination structure but does not claim completeness. Interpretive questions—such as

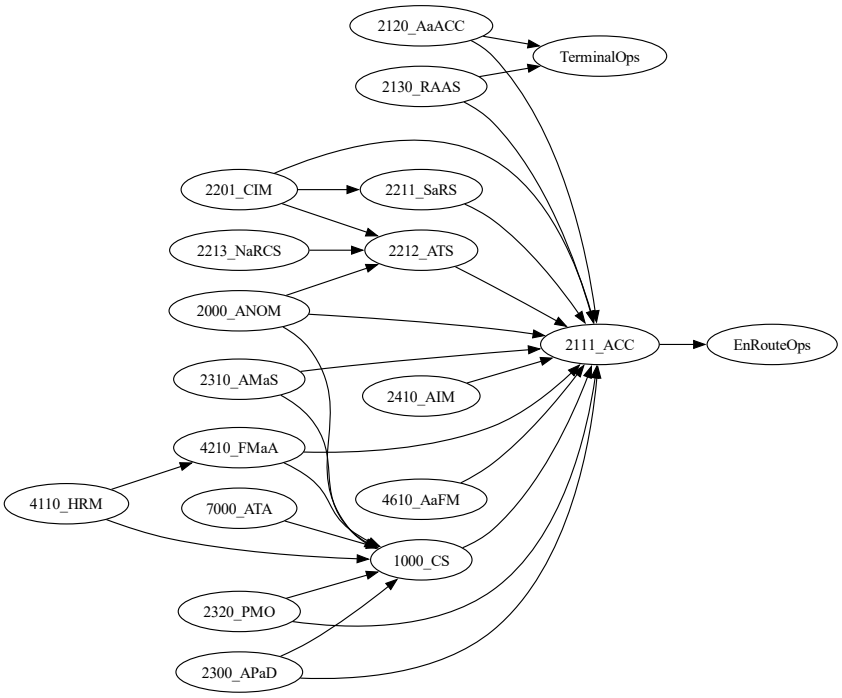

Fig. 6. Inferred coordination network visualizing `deliversTo` relations between organizational units, derived by assigning service ownership to the highest financial contributor per service. This heuristic reconstruction reveals latent patterns of inter-unit operational alignment. Source: authors.

how well the inferred topology in Fig. 6 aligns with actual managerial roles, or what additional commitments or data dimensions might clarify the enterprise's institutional logic—remain open. In keeping with the reflexive ethos of CoEDiT, the published artifacts are offered as an invitation for further exploration, enabling readers to generate their own insights through reuse and reinterpretation. For example, while the current analysis centers on financial commitments, derived from cost allocations and dominance patterns, a more granular investigation of cost types could expose additional dimensions—such as labor distribution, infrastructure reliance, or service integration—that reflect deeper layers of organizational obligation.

4.4 Conceptual Refinement

In this demonstration, conceptual refinement consolidates earlier interpretive moves by translating situated inferences into formal constructs. One example is the shift along the intension–extension axis, where nodes connected by

`deliversTo` edges are reframed as candidate transaction types within the coordination structure. This step does not extend the analysis but stabilizes it—elevating provisional insights into semantically defined elements that can support subsequent modeling iterations. This prepares the ground for the next round of the dialectical loop, where these refined constructs serve as reusable semantic anchors—guiding further data interpretation, model adaptation, and institutional inquiry.

As a final note, this demonstration is offered not as evidence of generalizable findings but as proof of feasibility. Its aim is illustrative: to show how commitment-driven modeling can be applied to real-world inspired artifacts and yield expressive, machine-interpretable representations of institutional structure. The goal is to demonstrate that enterprise digital twins need not be limited to physical or process models—they can represent commitments, obligations, and normative interrelations with ontological rigor. This expands the epistemic reach of digital twins from system traceability to institutional intelligibility, paving the way for reflexive organizational learning in reindustrializing contexts.

5 Discussion and Future Work

The cost budget demonstration crystallizes the dialectical modelling loop by showing how an ostensibly instrumental spreadsheet of budget entries can be re-read as a living network of commitments. Translating numerical cost lines into OntoUML relators surfaced latent coordination patterns and immediately fed them back into the conceptual model, exemplifying the iterative spiral of Conceptual Modelling → Data Mining → Reflexive Sensemaking → Conceptual Refinement that anchors CoEDiT's epistemic stance. In this sense, the demonstration is not merely illustrative; it performs the theory by enacting the very reflexivity the loop prescribes.

Revisiting the **research question**—*How can a dialectical modeling loop combining commitment-driven conceptual modeling, semantic representation, and data analytics support lean organizational learning for sustainability in reindustrialized contexts?*— we argue that the dialectical loop functions as an epistemic infrastructure that integrates abstraction, traceability, and reflexivity. Commitment-driven modeling articulates normative intent, semantic representation ensures logical consistency and interpretability, and data analytics provides empirical grounding. Their interplay fosters a recursive learning process in which institutional commitments are not only documented but critically examined and reconfigured in light of operational realities. This infrastructure supports sustainable reindustrialization by enabling organizations to iteratively align strategic intent, compliance obligations, and resource flows under conditions of volatility.

The study advances three inter-related **theoretical contributions**. First, it reframes enterprise digital twins from descriptive mirrors of reality into epistemic infrastructures centered on social commitments, extending the reach of twins from system traceability to institutional intelligibility. Second, it introduces

a method ensemble that dialectically synthesizes integrity-oriented ontology-driven conceptual modeling (UML) with derivation-oriented reasoning (OWL) and data analytics (Python), operationalized through a reflexive Action-Design-Research cycle. Third, by mapping commitment analytics onto Simons' Levers-of-Control [29], CoEDiT positions conceptual models as an operational layer within management control systems [25], thereby enriching theory on how organizations steer between strategic intent and emergent practice [35]. Underpinning these contributions is a latent but pivotal constructivist-interpretivist stance [15, 26, 27] that frames models and data not as objective artifacts but as situated mediators of meaning, emphasizing that organizational learning arises through the reflexive negotiation of institutional reality.

Practically, the work offers (i) an actionable script for converting mundane compliance spreadsheets into FAIR knowledge graphs, (ii) lightweight heuristics—such as designating the highest financial contributor as provisional service owner—that expose hidden coordination without heavy data engineering, and (iii) openly shared artefacts (code, dataset, ontology) that lower the barrier for replication and pedagogical uptake. These contributions render commitment-driven modelling accessible to practitioners who face acute sustainability and transparency pressures yet lack extensive semantic-technology expertise.

Several **limitations** delimit the scope of inference. Evidence rests on a single, fictionalized case that functions as a plausibility proof rather than empirical generalization; real-world messiness, power asymmetries, and data incompleteness remain to be confronted. The proxy-ownership heuristic simplifies organizational reality and may misclassify service responsibility where financial dominance diverges from enacted authority. Moreover, bi-directional UML↔OWL transformation and live analytics are only semi-automated, leaving room for human error and interpretive drift. Automated bi-directional transformation between UML and OWL are feasible [38], although not demonstrated in this study.

Future research should therefore extend the CoEDiT framework beyond its demonstrated use in the budgeting context to examine its potential across other organizational domains—such as procurement, service delivery, and compliance—where latent commitments shape institutional behavior. Applying the framework across diverse enterprises and industries would test its versatility in modeling heterogeneous coordination patterns and institutional logics. Comparative deployments could elucidate how commitment structures differ across organizational cultures and regulatory regimes, offering insight into the portability and limits of commitment-centric modeling. Moreover, the repurposing of operational data for semantic modeling raises important ethical questions around consent, transparency, and representational fairness—particularly when financial traces are interpreted as proxies for institutional intent. Future work should therefore develop normative guidelines for responsible data transformation [18], ensuring that the shift from syntactic to semantic representation remains accountable to affected stakeholders. Finally, incorporating an employee-centric perspective [39, 40] would enrich the framework by examining how actors interpret, negotiate, and resist modeled commitments—surfacing the lived experience

of enterprise transformation and ensuring that digital twins remain instruments of dialogical engagement, not surveillance.

6 Conclusion

This study advances a commitment-driven approach to enterprise digital twins by embedding conceptual modeling within a dialectical loop of semantic representation, data analytics, and organizational sensemaking. Through the CoEDiT artifact, commitments are reframed as dynamic, ontologically grounded constructs that anchor reflexive organizational learning in reindustrialized settings. Rather than prescribing static models, CoEDiT supports the continuous rearticulation of enterprise purpose through traceable commitments, fostering sustainable adaptation.

From a broader disciplinary perspective, CoEDiT contributes to ongoing debates about the evolving identity of Information Systems and Business Informatics. As digitalization increasingly permeates organizational life, calls intensify for integrative frameworks that reconcile technical artifacts with institutional dynamics and economic constraints [41]. CoEDiT responds by offering a sociotechnical modeling infrastructure that integrates formal abstraction, empirical mining, and reflexive interpretation—recasting enterprise modeling as a dynamic capability for institutional sensing, strategic seizing, and organizational transformation [42, 43].

In doing so, CoEDiT addresses the central research challenge by demonstrating how commitment-centered modeling infrastructures can align institutional intention with operational reality—enabling digital twins to engage with, rather than merely represent, enterprise transformation.

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@prefix gufo: <http://purl.org/nemo/gufo#> .
@prefix pecha: <http://data.europa.eu/eli/reg_impl/2019/317#> .
@prefix pechar: <https://lustraka.github.io/resources/pechar/> .
@prefix schema: <http://schema.org/> .
@prefix ses: <https://eur-lex.europa.eu/eli/reg/2024/2803/oj/> .
@prefix skos: <http://www.w3.org/2004/02/skos/core#> .
@prefix xsd: <http://www.w3.org/2001/XMLSchema#> .

pechar:bYYe001 a gufo:IntrinsicAspect, pechar:BudgetEntry ;
    pechar:AccountingPeriod "YYYY" ;
    pechar:AmountEUR 8752200 ;
    pechar:AmountEnRouteEUR 6867900 ;
    pechar:AmountTerminalEUR 1884300 ;
    pechar:CostType pechar:aStaffCosts ;
    pechar:OrganizationalUnit pechar:1000_CS ;
    pechar:Service pechar:201AirTrafficManagement .

pechar:aStaffCosts a gufo:Relator, schema:DefinedTerm ;
    schema:description "Naklady na zamestnance"@cs ;
    schema:inDefinedTermSet pechar:CostsByNature ;
    schema:name "a Staff Costs" .

pechar:1000_CS a gufo:RoleMixin, schema:DefinedTerm ;
    schema:description "Organizational unit 1000 Corporate Services"@en ;
    schema:inDefinedTermSet pechar:OrgUnits ;
    schema:name "1000 Corporate Services" ;
    pechar:deliversTo pechar:2111_ACC .

pechar:201AirTrafficManagement a gufo:Relator, schema:DefinedTerm ;
    schema:inDefinedTermSet pechar:CostsByService ;
    schema:name "201 Air Traffic Management" ;
    skos:related ses:AirTrafficManagement ;
    pechar:hasTopContributor pechar:2111_ACC .

ses:AirTrafficManagement a schema:DefinedTerm ;
    schema:description "(9) 'air traffic management' or 'ATM' means the
    aggregation of the airborne and ground-based functions and services,
    namely air traffic services, airspace management and air traffic
    flow management, including flight procedures design, required to
    ensure the safe and efficient movement of aircraft during all
    phases of operations." ;
    schema:isPartOf ses:art_2 ;
    schema:name "air traffic management" ;
    schema:termCode "ATM" .
```

Fig. 7. A fragment of RDF serialization of a budget entry modeled as a commitment relator, linking organizational units, services, and cost types. The representation illustrates semantic enrichment through ontological typing (gUFO) and external referencing (e.g., ELI, SKOS), supporting machine-actionable interpretation of budgeting commitments. Source: authors.