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Designing Routines for Industrial Digitalization

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Abstract

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Industrial digitalization and its promises propel manufacturing firms to pursue digital reality. When changing ways of working, organizational actors often introduce digital artifacts to create a preferred situation where digital technology creates and shapes physical reality.

This thesis focuses on how a change initiative, interpreted as routine design, could change organizational routines. Routines are dynamic and the dynamics of routines present a puzzling situation for routine designers. Routines are not things. Instead, routines are generative systems that give rise to learning. Digital technology is also generative. At the same time, to design routines is to interrupt the current dynamics, which routine designers are not always able to intentionally change. Not much is known about how organizational actors design the so-called live routines. This thesis offers insights by addressing two puzzles: the puzzle of generativity to make live routines, and the puzzle of recursiveness to make routines alive.

Through a longitudinal study over three years, a change initiative denoted the MBD (Model-based Definition) project was observed at a Swedish gas turbine manufacturer. Aiming toward a preferred situation of a digital thread, the team designed model-based ways of working for manufacturing and assembly during an agile development of a PLM (Product Lifecyle Management) system. The case studied was analytically approached, using two modes of analysis: an in-the-flow prehensive analysis zooming in on design actions and an after-the-fact reconstructive analysis zooming out to understand evolutionary routine change.

The empirical findings suggest that the puzzle of generativity was addressed through the team's design actions to (re)configure sociomaterial assemblages. The team removed stoppers in problematic situations that indicated breakdowns within the envisioned sociomaterial assemblages. The findings also suggest that the puzzle of recursiveness was addressed through intentional variation, spatial retention, and temporal retention during which a digital artifact transformed and successively exerted its influence on routines.

A spatiotemporal multiplicity of routines was observed. Theoretically, when focusing on routines as patterns of action, the findings suggests that live routines are a duality of both one (routine) and many (ways of working) in which new many are designed and a one is materialized.

Keywords: Organizational routines, Routine dynamics, Routine design, Digital materiality, Process ontology, Process study, Digital thread, PLM, MBD, Gas turbines

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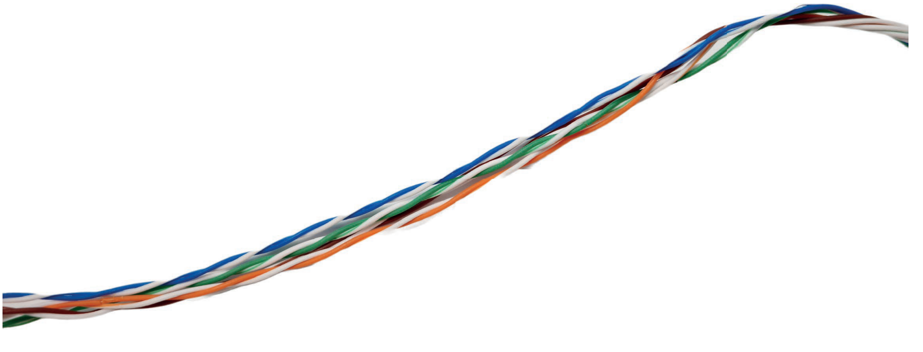
List of Acronyms

BOM	Bill of Materials
A-BOM	Assembly-Bill of Materials
E-BOM	Engineering-Bill of Materials
M-BOM	Manufacturing-Bill of Materials
BOP	Bill of Process
A-BOP	Assembly-Bill of Process
E-BOP	Engineering-Bill of Process
M-BOP	Manufacturing-Bill of Process
CAx	Computer-aided Technologies
CAD	Computer-aided Design
CAE	Computer-aided Engineering
CAM	Computer-aided Manufacturing
DWI	Digital Work Instructions
ERP	Enterprise Resources Planning
IS	Information Systems
IT	Information Technology
MBD	Model-based Definition
MES	Manufacturing Execution System
NC	Numerical Control
PDM	Product Data Management
PLM	Product Lifecycle Management
PMI	Product Manufacturing Information
SOP	Standard Operating Procedure
UML	Unified Modeling Language
VR	Virtual Reality
VSR	Variation and Selective Retention

Prologue

The concept of change is not an external, normative principle that imprints itself upon phenomena; it is an inner tendency according to which development takes place naturally and spontaneously. Development is not a fate dictated from without to which one must silently submit, but rather a sign showing the direction that decisions take. Again, development is not a moral law that one is constrained to obey; it is rather the guideline from which one can read off events. To stand in the stream of this development is a datum of nature; to recognize it and follow it is responsibility and free choice.

Hellmut Wilhelm, 1975, in *Change, Eight Lectures on the I Ching* (p.19)



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1 Introduction

> Sven (180327): I think that is what everyone is struggling with, to define a new way of working for many businesses. I think what you always end up with: “How do we implement it? How do we handle change management? And how is this affecting the old way of working? And how do we make sure that we don't end up in the old tracks again?”.

Working as a project manager at a Swedish gas turbine manufacturer “TurbineCo” (a pseudonym), Sven (a pseudonym) was occupied with these questions. He was responsible for realizing the promise of industrial digitalization through a change initiative called the MBD (Model-based Definition) project. He led a team to design model-based ways of working to increase the use and reuse of digital representations (such as 3D models) for managing a product’s lifecycle, especially in the stages of manufacturing and assembly.

Like the MBD project, there are other change initiatives in the manufacturing industry, through which the teams work out what the potential of industrial digitalization entails in practice, what new possibilities could be enabled by digital technology, and how those possibilities could be introduced to the way in which organizational actors accomplish work, i.e., organizational routines.

1.1 Industrial digitalization

As an empirical phenomenon, industrial digitalization is endorsed by global movements like Industry 4.0 and Smart Industry. Several Swedish governmental agencies have released reports on the potential of digitalization and outlined key directives and strategies for new industrialization in the late 2010s. In a governmental report from 2016, entitled *Smart Industry – a Strategy for New Industrialization for Sweden* (N2016.06), for example, authors from the Swedish Ministry of Enterprise and Innovation assert that “digitalization is changing everything” (p.12) and “the potential of digitalization must be exploited” (p.17). In relation to Industry 4.0, “companies in the Swedish industrial sector are to be leaders of the digital transformation and in exploiting the potential of digitalization” (p.30).

On the face of it, the role of digital technology is similar to IT (Information Technology). In her groundbreaking book, *In the Age of the Smart Machine*, Zuboff (1988) characterizes IT with a duality of automating and informating. She studies the new form of work that the smart machine engendered in the context of computerized paper mills. In her own words (Zuboff, 1988, p.9):

> As information technology is used to reproduce, extend, and improve upon the process of substituting machines for human agency, it simultaneously accomplished something quite different. The devices that automate by translating information into action also register data about those automated activities, thus generating new streams of information.

As Zuboff (1988) points out, this duality of automating and informating would eventually reconfigure work and transform the relationship between technology and humans in organizations. She could not have been more accurate.

Indeed, digital technology also exhibits the capacities of automating operations and generating information from such operations. But digital technology shows potential for transforming how reality is shaped. In this regard, information systems have been seen as reflecting an existing physical reality. Many scholars in the IS (Information Systems) literature have formed a consensus that a tipping point has been reached in the past decade (Baskerville et al., 2020; Nambisan et al., 2020). The rhetorical shift from information technology to digital technology signifies that "digital technology now creates (or helps to create) the physical environments in which we live" (Baskerville et al., 2020, p.510).

For example, in the manufacturing industry, the potential of digitalization could be manifested in a digital factory where digital technology is creating and shaping the physical factory. In this vision of digital reality, the digital product information is created first, and the physical product second. It travels through every aspect of the product lifecycle, including, for example, design, manufacturing, assembly, and maintenance. This is where a *digital thread* emerges, integrating the digital and the physical through technological advances in additive manufacturing, artificial intelligence, cloud computing, the industrial Internet of Things, robotics, virtual reality, etc.

This vision of digital thread hinges on the connectivity of machines and production systems within cyber-physical systems to continuously generate, share and analyze data. For example, physical factory is monitored and recorded using sensors, while such data create a digital mockup of the factory, upon which new insights are generated. A digital thread could make factory *smart*, for instance, when design and manufacturing activities can take place concurrently, when production downtime can be predicted, and when logistics and supply chains can be tracked and traced in real time.

Governmental reports and visions like digital thread underscore a digital imperative. Brynjolfsson and McAfee (2014) argue that this digital imperative is unprecedented when this convergence of the digital and the physical occurs at such a speed and scale, to the extent that the digital reality is shaping the world and becomes the principal reality instead of a mere representation. Granted, digital reality has been integral in everyday life and work for decades. Baskerville et al. (2020, p.511) extend this point and demonstrate a reality where "the digital version is produced first; the physical version second". This so called "digital first" world enables novel forms of human-technology relationship in which human experiences are computed and mediated by the interactions between both digital and physical realities (Baskerville et al., 2020; Nambisan et al., 2020).

This digital imperative in the manufacturing industry is often associated as something preferred, for productivity, for innovation, for a nation's competitiveness, and for global challenges like climate change. These positive promises are what Swedish policy makers intend to bring about in their 2022 report *Industry of the Future*: A *Strategy for Green and Digital Transformation* (Swedish Ministry of Enterprise and Innovation, 2022), as an update to the strategies entailed in Smart Industry (N2016.06).

But industrial digitalization is not without controversy. The digital imperative is also a harbinger of more radical changes of work. The so-called digital Taylorism is met with concerned voices from LO or Swedish Trade Union Confederation (2011), when human practices are dehumanized. New forms of workplace surveillance (Zuboff, 2019), exacerbating the fear of how technology at large, can control and threaten human experiences. The emergence of Hyper-Taylorism transforms humans as caretakers of technology, and, in turn, influences not only how work is performed, but also the meaning of work (Andersson et al., 2021).

To adapt to an ever-digitalizing and ever-digitalized world, a vision of digital factory like digital thread represents a preferred situation that propels manufacturing firms to digitalize. To weave a digital thread, digital technology is the needle. Responding to this call-to-action, like TurbineCo, some Swedish manufacturing firms have started designing new ways of working, through developing, evaluating, experimenting, and implementing digital technology. Organizational actors explore a myriad of emerging digital artifacts to understand the organizational consequences of digitalizing mundane frontline jobs, like those on the manufacturing and assembly shop floor.

The empirical departure point of this monograph is centered around the MBD project at TurbineCo. As a discrete manufacturer who produces made-to-order gas turbines, TurbineCo handles tens of thousands of paper drawings and 3D models of gas turbines. A common practice for a manufacturing firm is to have designated usage of paper drawings and 3D models (e.g., drawing-based ways of working and model-based ways of working). Historically, at TurbineCo, 3D models are prevalent in R&D and marketing, while paper drawings have been the primary source of information and representation of the component in other stages of the product lifecycle, such as manufacturing and assembly.

During the 2010s, technology vendors have been developing software and hardware to provide and improve digital and physical infrastructure for more complex models. In other words, 3D models with its associated annotations and data sets can become the primary representation of the physical component (see Figure 1. for an example), which can also be used to generate paper drawings when needed. This practice to use 3D models to define and provide specifications for components is called MBD.

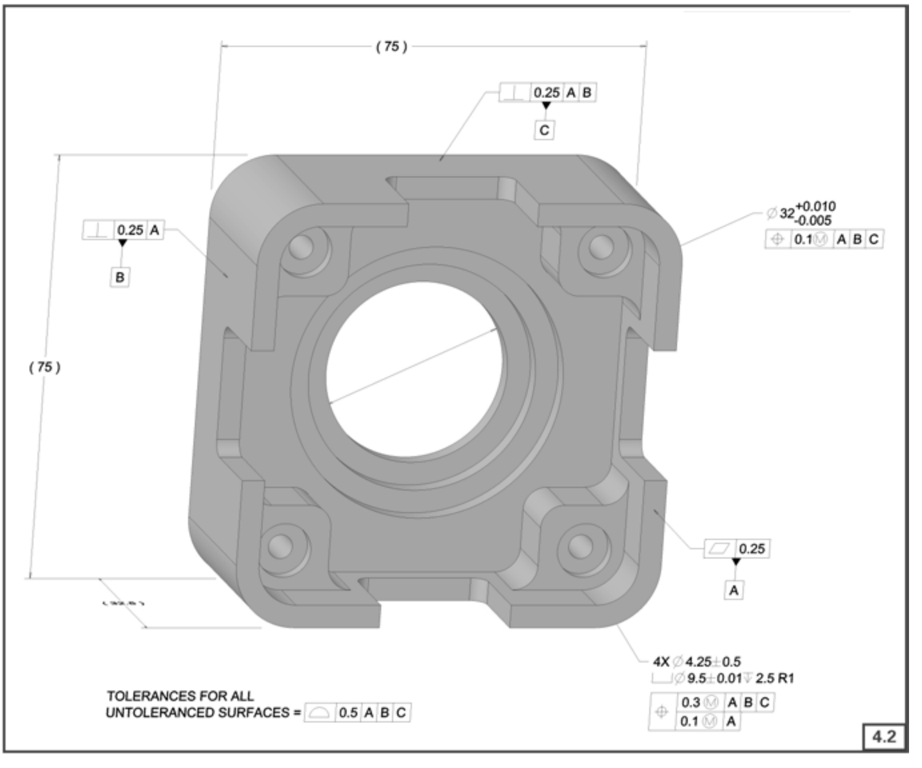

Figure 1. Example of a 3D Model with annotations

Adapted from Figure 4-1 Example of an Annotated Model Used in MBD (ASME Y14.47-2019, p.5). Color in the digital version. Reprinted from ASME Y14.47-2019, by permission of The American Society of Mechanical Engineers. All rights reserved.

A vision of digital thread is built upon a continuous convergence between digital and physical realities, with 3D models as the sole representation. Under TurbineCo's own digital imperative "make digitalization work", project manager Sven, and a few dedicated team members, comprising the actual workers in manufacturing and assembly, underwent this MBD project between 2017 and 2020. They designed new ways of working, i.e., model-based ways of working that used 3D models as the main information carrier, in tandem with the introduction of a novel digital technology, i.e., new applications in a PLM (Product Lifecycle Management) system, called PLM+ (a pseudonym).

The MBD project at TurbineCo was a change initiative, focusing on increasing the use of 3D models in manufacturing and assembly routines. This is an exemplar of how organizational actors approach the elusive nature of industrial digitalization and direct digital technology in influencing organizational activities. The marriage between the digital and the physical poses opportunities and challenges for how organizational actors accomplish their tasks, i.e., organizational routines.

1.2 Designing routines

The concept of organizational routines holds a key to explain economic and organizational change (Nelson & Winter, 1982). At first glance, organizational routines have some colloquial associations with being stable, fixed, and mundane things. Reconceptualizing organizational routines as a source of both stability and change, Feldman and Pentland (2003, p.95) distill a core definition as "repetitive, recognizable patterns of interdependent actions, carried out by multiple actors". They adapt Latour's (1986) ostensive-performative distinction to understand the internal dynamics of routines as the interactions between the ostensive (routine in principle) and performative (routine in practice) aspects.

Since then, an international research community of routine dynamics emerged (Feldman et al., 2016; Feldman et al., 2019; Feldman et al., 2021). During the past two decades, the routine dynamics literature has advanced the understanding of routines beyond things, as dynamics, constitutive of ostensive, performative, and material aspects (D'Adderio, 2011) or correspondingly a process of patterning, performing, and materializing (D'Adderio, 2021; Feldman, 2016; Feldman et al., 2016; Feldman et al., 2021).

The focal change initiative, the MBD project, can be understood as routine design, or "intentional efforts to change one or more aspects of a routine to create a preferred situation" (Wegener & Glaser, 2021, p.301). To put this theoretical phenomenon in the context of industrial digitalization, change initiatives in manufacturing firms intentionally introduce digital technology to influence routines to, for example, achieve a digital thread.

Pentland and Feldman (2008), in their pioneering piece *Designing Routines: On the Folly of Designing Artifacts, While Hoping for Patterns of Action*, detail a change initiative in which managers (re)designed work processes using digital technology. They study how and why the design of a digital artifact was successful, but its implementation led to nowhere. In fact, such initiatives may design "dead" routines. Drawing upon Cohen's (2007) reading of Dewey (1922), they underscore a live-dead distinction of routines, in which routines controlled by the designers are seen as most dead. Extending their insights, D'Adderio (2011, p.206) separates the routines that are "rigid, mindless, and are typically codified in artifacts", as "dead", while "flexible, mindful, and involve the contribution of actors, their experience and learning", as "live".

The internal dynamics of routines present a twofold puzzling situation for change initiatives like the MBD project. Firstly, routines are generative systems (Pentland & Feldman, 2008; Feldman et al., 2021) and in the context of industrial digitalization, digital technology also entails generativity (Zittrain, 2006). As Yoo et al. (2012, p. 1399) explain:

> Generativity means that digital technologies become inherently dynamic and malleable. Organizational theories that may have assumed (either explicitly or by oversight) that technology is fixed and immutable now must consider the possibility that the technology providing the basis for organizational functioning is dynamically changing, triggering consequent changes in organizational functioning.

To design live routines is to bring out generativity that gives rise to learning for new actions or patterns of action. But, if routines designers conflate routines with rigid and mindless things, the designed routines may be dead (Pentland & Feldman, 2008).

Secondly, to intentionally change routines is to interrupt the internal dynamics and reorient them to a preferred situation (Bucher & Langley, 2016; Wegener & Glaser, 2021). Introducing the design routines disrupts the ongoing routine dynamics. The routine dynamics literature has indicated challenges with interventions taken place outside the routines (i.e., from without) while routine performances are ongoing. Bucher and Langley (2016), for example, coin the term the puzzle of recursiveness, to attend to the issues with intentional routine change. They underscore the importance of bounded social settings like reflective and experimental spaces where new concepts of routines are developed and integrated within the original routines.

Inspired by Bucher and Langley (2016), I call the first part of the situation to make live routines as the puzzle of generativity. I borrow their terminology to describe the second part to make routines alive also as the puzzle of recursiveness. In the empirical setting of the MBD project, the puzzle of generativity relates to how routine designers create novel model-based ways of working for manufacturing and assembly through introducing PLM+. Subsequently, the puzzle of recursiveness corresponds to how they introduce model-based ways of working to the ongoing drawing-based ways of working.

To address the potential of industrial digitalization and its implications for organizational activities like routines, I focus on a routine design process and ask: *how do organizational actors design live routines?*

Current discussions in the routine dynamics literature reveal some directions. To tackle the puzzle of generativity, Wegener and Glaser (2021) suggest a pragmatist design perspective to combine a scientific perspective (Simon, 1996/2019) and a reflective practice (Schön, 1983) to approach routine design. Glaser (2017) studies design performances, or "organizational actions to create an artifact in order to intentionally change (or influence) a routine" (p.2133), and such nonroutine actions hold keys to create sociomaterial assemblages of actors, artifacts, theories, and practices that lead to changes in routines. On the other hand, the puzzle of recursiveness can be addressed via evolutionary routine change (Bucher & Langley, 2016) that consist of intentional variation and selective retention during nonroutine interactions.

Following the calls from the routine dynamics literature (Feldman et al., 2021), I aim to participate in the emerging discussions relating to a processual theorization of routines (Tsoukas, 2021), materiality (D'Adderio, 2021), and routine design (Wegener & Glaser, 2021). More specially, I set out to investigate a process of routine design in which routine designers aim at making live routines and making routines alive, to address the puzzle of generativity and the puzzle of recursiveness respectively.

1.3 Outline

To understand the theoretical underpinnings of routine design, in Chapter 2, I detail the development of routine dynamics literature, with an emphasis on the latest processual turn (Feldman, 2016; Feldman et al., 2021; Tsoukas, 2021) and materiality (D'Adderio, 2008, 2011, 2021), especially digital materiality (Yoo et al., 2010; Yoo et al., 2012; Baskerville et al., 2020; Nambisan et al., 2020) and its organizational consequences. Then, I elaborate on the current discussions relating to live routines, including the emerging conversations on routine design and two accompanying puzzles that concerns creation and retainment of generativity and selective retention of intentional variations.

In Chapter 3, I inspect some methodological choices that lead to my appropriation of a process study. I use two analytical modes to examine routine design from inside (Langley & Tsoukas, 2017). A prehensive mode (in-the-flow) is first used when I followed the MBD project as it unfolded to analyze the puzzle of generativity. A reconstructive mode (after-the-fact) is adopted to understand a solution for the puzzle of recursiveness (Bucher & Langley, 2017).

I introduce the case company TurbineCo in Chapter 4, including the previous undertakings that have led to the formal MBD project. Continuing in Chapter 5, I detail the MBD project, and the manufacturing and assembly routines before and after the introduction of PLM+. In addition, I also reveal how the project is managed according to agile frameworks.

The happenings of the MBD project are narrated in the two time periods in Chapter 6 and Chapter 7. In both chapters, I first detail the progression of the MBD project as it unfolds. Thereafter, I turn to a prehensive analytical mode to address the puzzle of generativity to make live routines. I present the design actions when the routine designers converse with the situation (Schön, 1983). Particularly, I detail how the team members deal with some situational backtalks, empirically known as stoppers (e.g., “blockage” in Bucher & Langley, 2016), indicating breakdowns in the formation of sociomaterial assemblages.

Chapter 8 records my reconstructive analysis in understanding the puzzle of recursiveness. I observe a new type of design artifact which I call routine prototype, as a result of intentional variations. I unpack how a digital artifact (like PLM+) transforms and exerts its influence on routines through successive instantiations in a chain of materializations (Latour 1986; D’Adderio & Pollock 2020; Glaser et al., 2021). Next, I introduce a new qualitative multiplicity of routines that I call spatiotemporal multiplicity. I focus a multiplicity of patterns, as a duality of one (routine) and many (ways of working), to explain how spatial retention and temporal retention make routines alive.

In Chapter 9, I summarize my theoretical and empirical findings to participate in the flourishing discussions on routine design. I extrapolate the insights from prehensive and reconstructive analyses to underscore the role of designing and materializing in relation to routine change. I offer some directions for future research in the routine dynamics literature. I also revisit and revise Pentland and Feldman’s (2008) guidelines for designing live routines.

2 Theoretical framework

The marriage between the digital and the physical world in the manufacturing industry shows potential for transforming how work is conducted. Visions like digital thread become a digital imperative and propels manufacturing firms to explore and adapt novel digital technology to change how they accomplish work, i.e., organizational routines.

In this chapter, I first outline a brief genealogy of the routine dynamics literature. Next, I discuss materiality and digital materiality in the generative system of routines. Then, I elaborate on a type of change initiative, termed as routine design and the relevance of the live-dead distinction of routines. Finally, I converge these discussions to propose two puzzles, namely the puzzle of generativity to make live routines and the puzzle of recursiveness to make routines alive. I ask: *how do organizational actors design live routines?*

2.1 Dynamics of routines

Organizational routines (hereinafter routines) hold the key to how work is conducted. Stene (1940, p.1129) provides one of the early definitions:

> Organization routine is that part of any organization's activities which has become habitual because of repetition, and which is followed regularly without specific directions or detailed supervision by any member of the organization.

Since then, the very concept of routines has been examined in different literature streams in management and organization studies. Each stream has somewhat different definitions on what routines are: are they a source of inertia, or a source of dynamics?

To tackle this ambiguity, in the following chronological review, I explore some key analogies of approaches in which the theoretical phenomenon of routines is examined. As I am positioned in the routine dynamics literature, based on the literature reviews by Becker (2004), Parmigiani and Howard-Grenville (2011), *Handbook of Organizational Routines* (Becker, 2008), and the latest *Cambridge Handbook of Routine Dynamics* (Feldman et al., 2021), the lineage of routines literature can be traced back to a behavior-based view

(Simon, 1947; March & Simon, 1958; Cyert & March, 1963), a capabilities-based view (Nelson & Winter, 1982; Cohen et al., 1996), a practice-based view (Feldman, 2000; Feldman & Pentland, 2003), and a process-based approach view (Feldman et al., 2016; Feldman, 2016; Howard-Grenville & Rerup, 2016) of routines.

2.1.1 A behaviorist view

Herbert Simon, James March, and Richard Cyert are key figures in the Carnegie School. In their three foundational works: *Administrative Behavior*, *Organizations,* and *A Behavioral Theory of the Firm*, they bring cognitive underpinnings such as bounded rationality to the forefront. They investigate the coordinated actions among individuals and groups in organizations, and how people tend to satisfice, instead of optimizing when making decisions in business firms. Without explicating the term routines, they juxtapose routine-based behaviors to habits (Simon, 1947, pp.88–89), performance programs (March & Simon, 1958, pp.141–150), and standard operating procedures (SOP) (Cyert & March, 1963, pp.120–134) as fixed organizational responses to stimuli.

Routines as habits. Individuals are boundedly rational. As Simon (1947, p.88) notes, habits allow "the conservation of mental effort by withdrawing from the area of conscious thought those aspects of the situation that are repetitive". Therefore, the execution of such standardized practices is unconscious, and individuals can direct attentions to novel aspects in the situation. Extrapolating this from an individual to an organizational level, Simon (1947) concurs with Stene's definition of routines, to handle "recurring questions".

Routines as performance programs. Triggered by environmental stimuli, an organization develops appropriate habitual responses to those known and recurring stimuli. March and Simon (1958, p.141) coin the term performance programs to refer to those sets of responses. Most organizational behavior is governed by performance programs, when the responses do not call upon extensive search, elaborate problem solving, or choice making. Such performance programs serve as control and coordination devices in organizations.

Routines as standard operating procedures. Organizational memory consists of learnt sets of behavioral rules, or standard operating procedures (SOP). Cyert and March (1963) categorize rules at two levels of generality: general choice procedure and specific standard operating procedure. The former incorporates three principles in decision-making, namely, to avoid uncertainty, to maintain rules and to use simple rules. The latter ones are treated as stable and attend to repetitive activities, such as task performance rules, continuing to maintain records and reports, information-handling rules, and plans. SOPs are often seen as a collection of if-then statements.

In short, the conceptualization of routines in the Carnegie School centers around how organizations respond to stimuli. Such responses, referred to as analogies such as habits, performance programs, or SOPs, are automatically activated upon previously experienced environmental triggers, with limited cognitive interventions. The Carnegie School recognizes routines as repetitive and recurring, and they serve as standardized reactions toward triggers.

All these analogies represent regularities (Becker, 2004). In his categorization, Becker (2004, p.662) considers habits as behavioral regularities or "recurrent interaction patterns". Rule-based analogies of routines, like performance programs and SOPs, are equated with cognitive regularities or patterns.

Routines in a behaviorist's view are inert. They are mindless and preserve cognitive resources. However, some ambivalent nature of routines is also suggested, especially the role of human agency. On the one hand, agency is overlooked. The habitual responses have fixed structures that are mechanistic. On the other hand, the Carnegie School acknowledges that not all responses are passive. Agency comes in the picture when certain stimuli like external shocks or crises occur. For example, in the case of performance programs, March and Simon (1958, p.26) suggest:

> Behavior in the organization is not determined in advance and once for all by a detailed blueprint and schedule. Even if it is highly routinized, the routine has the character of a strategy rather than a fixed program.

2.1.2 A capabilities view

Nelson and Winter's (1982) *An Evolutionary Theory of Economic Change* is a milestone in explicating the role of routines in relation to organizational and economic change. In contrast to the traditional neoclassical economics' emphasis on supply and demand, routines are foregrounded to explain and understand the evolutionary organizational and economic change. Nelson and Winter (1982, p.14) define routines as "all regular and predictable behavioral patterns of firms", and routines are likened to skills and genes.

Routines as skills. Nelson and Winter (1982) start with subsuming individual skills as an analogy of routines. An individual skill is "a capability for a smooth sequence of coordinated behavior that is ordinarily effective relative to its objectives, given the context in which it normally occurs" (p.73). It is programmatic. It is a form of tacit knowing (see Polanyi, 1962). It involves an automatic, non-deliberate selection of choices. Though skills and routines share similar characteristics, Nelson and Winter (2002) clarify that the term "skills" is reserved for the individual level and "routines" for the organizational level, e.g., "routines are the skills of an organization" (Nelson & Winter, 1982, p.124).

Routines as genes. In biology, the basic unit of heredity is a gene. Routines (as genotypes, or "representations" in Cohen et al., 1996) are heritable from one occasion to another, with similar characteristics. Routines (as phenotypes, or "expressions" in Cohen et al. 1996) are selectable as the environment favors some over others. Nelson and Winter (1982) suggest that, as a result, firms may continue employing past routines in the future, and firms' behaviors in the future are expected to have a resemblance to routines of the past.

Similar to the Carnegie School, Nelson and Winter (1982)'s characterization recognizes some specificity of routines. Skills suggest that routines can be a repository for organizational learning and memory, storing tacit knowledge. While with the genetic view, routines are programmatic to best fit the environment, which stabilizes organizations (see Hodgson, 2003). It is worth noting that even though in their view, organizational behavior is routinized, they acknowledged that there are stochastic elements in business behavior for which the notion of routines cannot account (Nelson & Winter, 1982, p.15).

Two camps of scholars derive from Nelson and Winter's work. A *capabilities perspective*, continuing the economist approach, treats routines as opaque entities and building blocks for capabilities. Scholars in this camp are interested in "what routines do (coordinate, create and change) and how they lead to firm performance" (Parmigiani & Howard-Grenville, 2011, p. 418). *A practice perspective,* rooted in sociology, treats routines as constitutive of structure and agency, and scholars are intrigued by the internal dynamics, or "how routines operate" (Parmigiani & Howard-Grenville, 2011, p. 418).

Routines as capabilities. Nelson and Winter (1982, p.52) broadly define organizational capabilities as "the range of things a firm can do at any time", and Winter (2003, p.991) notes:

> An organizational capability is a high-level routine (or collection of routines) that, together with its implementing input flows, confers upon an organization's management a set of decision options for producing significant outputs of a particular type.

Within the economy of the firm, routines are entities that connect organizational inputs to outputs, which are defined as "executable capability for repeated performance in some context that been learned by an organization in response to selective pressures", by the scholars attending the routines conference at the Santa Fe Institute (Cohen et al., 1996, p.683).

Parmigiani and Howard-Grenville (2011) summarize three treatments of routines from this perspective. Firstly, capabilities are depicted as bundles of routines. As micro-foundations, routines are key inputs to desired outputs (Teece, 2007; Felin et al., 2012). Secondly, the capabilities perspective also continues with the analogy of genes to explain stability and change in a changing environment. Dynamic capabilities or meta routines are the explanandum to organizational change (see Teece et al., 1997; Zollo & Winter, 2002; Winter, 2003).

And lastly, routines serve as repositories of organizational memory and learning. Zollo and Winter's (2002) piece on learning and dynamic capabilities is an epitome of this stream. They define two sets of organizational activities to which learning mechanisms are critical: operational routines, which ensures the functioning of the firm; and dynamic capabilities, which modify the operational routines. They identify a set of mechanisms, namely the behavioral experience accumulation, and the cognitive knowledge articulation and codification, to describe a cyclical evolutionary process of organizational knowledge.

According to Parmigiani and Howard-Grenville (2011), the capabilities perspective treats routines as entities and black-boxes the internal dynamics. This perspective emphasizes on the knowledge that routines embody, less so on the actions through which routines are performed. In other words, the agential influence on routines is backgrounded, and one of the key assumptions of the capabilities perspective is that "routines operate as intended" (p.420).

2.1.3 A practice view

The aforementioned analogies affirm the idea that routines are an integral part of organizations, and they provide both stability and change in organizations (Becker, 2004). However, the underlying assumptions of those perspectives are that routines themselves are rather fixed, automatic, or unchanging (Feldman, 2000; Feldman & Pentland, 2003). Also, they are short of articulating how these routines are accomplished and changed (Feldman & Orlikowski, 2011). To this end, Martha Feldman and Brian Pentland draw upon sociologists such as Pierre Bourdieu (1977, 1990) and Anthony Giddens (1984) to create another path in the routines lineage. This practice turn explicates the structure and agency within the black box of routines and brings back the role of human agency (Feldman &Pentland, 2003; Parmigiani & Howard-Grenville, 2011).

Routines as practice. Feldman details the origin story of a theory of routines as practice[1] and her appropriation of a practice lens in the piece with Orlikowski (Feldman & Orlikowski, 2011). In their view, a practice lens concerns "the everyday activity of organizing" (p.1240) and builds on the following three principles.

The first principle reads "everyday actions are consequential in producing the structural contours of social life." (Feldman & Orlikowski, 2011, p.1241). By foregrounding action, Feldman (2000) highlights the importance of human agency involved in creating the routines. The actions are situated in the contexts of institutions, organizations, and personal circumstances.

Secondly, duality (two mutually interdependent entities), instead of dualism (two mutually exclusive entities in opposition to each other), is used to theorize the interdependent relationship in systems of action. The dichotomous concepts: action/structure and stability/change are understood as the main dualities in routines (Feldman & Orlikowski, 2011).

And thirdly, a practice lens also explores the interrelation between phenomena, or "relationality of mutual constitution" (Feldman & Orlikowski, 2011, p.1242). For example, mutual constitution manifests in the inseparability of agent and institution, as well as change and stability.

Considering all these three principles together, it becomes clear why Feldman and Pentland (2003, p.95) have made the following description of routines:

> Routines, like other social phenomena, embody a duality of structure and agency (Giddens, 1984; Bourdieu, 1977, 1990). An organizational routine consists of two related parts. One part embodies the abstract idea of the routine (structure), while the other part consists of the actual performances of the routine by specific people, at specific times, in specific places (agency). Each part is necessary, but neither part alone is sufficient to explain (or even describe) the properties of the phenomenon we refer to as 'organizational routines.'

Routines as ostensive and performative aspects. When discussing the paradox of whether power is a consequence or a cause of collective action, Latour (1986) introduces a translation model instead of a diffusion model to study power as a consequence. In doing so, he explains what it entails to have an ostensive or performative definition of society. To put them in simpler terms, each view includes a framework of understanding to study the social link. The ostensive centers around what society is in principle and the performative

[1] The relationship between the concepts in practice theory and routines is discussed in Feldman et al. (2021) and Feldman (2021). Practice theory is also ambiguous and calls for a separate investigation, which is beyond the scope of this dissertation. To paraphrase, routines are particular practices (Feldman, 2021, p. 23).

what society is in practice. By shifting toward the latter, power is explained by a translation model, as locally composed. As Latour elaborates (1986, p.273, emphasis in the original):

> This shift *from principle to practice* allows us to treat the vague notion of power not as a cause of people's behavior but as the consequence of an intense activity of enrolling, convincing and enlisting.

Instead of adopting a structurationist lingo of structure and agency in routines, Feldman (2000) and Feldman and Pentland (2003) build upon the vocabularies in Latour (1986), explained by Pentland and Feldman (2005, p.795):

> Because it focuses attention on the collective performances and on the ability of both participants and observers to create the ostensive aspects from these performances. Latour's (1986) language best expresses the aspects of organizational routines that are needed to explain their generative properties, as observed in empirical field studies.

On the subject of routines, Feldman (2000) and Feldman and Pentland (2003) appropriate the ostensive aspect of a routine as routine in principle. It is the shared idea and perception of what the routine is. The ostensive aspect is usually not monolithic, as it encompasses subjective understandings from each routine participant's own viewpoint. The performative aspect is then routine in practice. It is the enactment: the specific actions in specific time and space. In the lineage of Bourdieu's (1977, 1990) theory of practice, routines are considered inherently improvisational (Feldman & Pentland, 2003). Therefore, the seemingly never-changing routines can, in fact, generate endogenous change, and the same routines at times are ever-changing depending on the context (Pentland et al., 2011).

Both ostensive (cognitive) and performative (behavioral) aspects are integral to the understanding of routines, as the behavioral and cognitive regularities are entwined (Becker, 2004). The performance of a routine is guided by, accounted for, and referred to by the ostensive, while the shared understanding is created, maintained, and modified by the performative (Feldman & Pentland, 2003). This mutual constitution is recursively related, and routines thus become dynamic. Hence, the name of this stream: routine dynamics.

This practice view of context is consistent with Lucy Suchman's notion "situated action" (Suchman, 2007). In other words, actions are situated in patterns and context of particular, and concrete circumstances (Feldman et al., 2021). Howard-Grenville and colleagues (Howard-Grenville, 2005; Howard-Grenville, 2021) have explored this situatedness under the label "embeddedness". According to Howard-Grenville (2005), routines are embedded in organizational context, which consists of technological, coordinative, and cultural structures. Such context is first conceived as separable yet critical to the routine, while Feldman et al. (2016) and D'Adderio (2014, 2021) argue for an inseparable and entangled relation between routines and their context, i.e., "routines are not simply embedded in context, they are also enacted through context" (D'Adderio, 2014, p. 1347).

The routine dynamics literature (hereinafter the routines literature) subscribes to the following definition of organizational routine: "Repetitive, recognizable patterns of interdependent actions, carried out by multiple actors" (Feldman & Pentland, 2003, p.95). This definition is consistent with previous perspectives and captures the multifaceted nature of routine. First of all, it is recurrent. As Becker (2004, p.646) states, "in fact, one would be hard pressed to call something happening only once a routine". Secondly, it is the core "family resemblance" that makes the pattern regular and observable. Lastly, it is a collective endeavor, where multiple interests, understandings, and goals converge.

In contrast to viewing routine as a source of stability, which is associated with notions of inertia, inflexibility, and mindlessness, the relationship between the duality of the ostensive and the performative aspects account for both stability and change in routines (Feldman & Pentland, 2003; Feldman et al., 2016; Feldman, 2016). On the one hand, there is a change in stability. Routines are effortful accomplishments (Pentland & Rueter, 1994). The variety and flexibility in performances require efforts from the participants to maintain the stability in the ostensive patterns. On the other hand, there is stability in change. Routines are emergent, i.e., they come about only through being performed by actors (Parmigiani & Howard-Grenville, 2011, p.421). Similar actions accomplished in routine performances may witness the emergence of new patterns (Feldman, 2000). As Feldman and Orlikowski state (2011, p.1245):

> Stability and change are different outcomes of the same dynamic rather than different dynamics. Change may be engaged in order to promote stability, and stability may be essential to bringing about change (Tsoukas and Chia 2002, Farjoun 2010).

To conclude, the practice view on routines emphasizes "the internal workings of specific routines in specific organizational contexts." (Parmigiani & Howard-Grenville, 2011, p.421). Instead of fixed things, routines are conceptualized as generative systems, i.e., "they hold the seeds of their own continuity or change" (Parmigiani & Howard-Grenville, 2011, p.422). They are mutually constituted by the recursive interactions between the ostensive and the performative aspects (see Table 1. below). Routines, as both effortful accomplishments (different actions for similar patterns) and emergent accomplishments (similar actions for different patterns), is a solution to Birnholtz et al.'s

(2007) “Paradox of the (n)ever changing world”: a standoff between Ecclesiastes (there is no new thing under the sun) and Heraclitus (one does not step into the same river twice) (Parmigiani & Howard-Grenville, 2011). In practice, effortful and emergent accomplishments are often entangled (Feldman et al., 2016).

Table 1. Routines as aspects

Aspect	Ostensive	Performative
i.e.	Routine in principle	Routine in practice
Elaboration	Abstract pattern/generalized idea of a routine that guides, accounts for and refers to routine participants' performance of a routine.	Specific actions/actual performances by specific people, in specific times and places.

Based on Feldman and Pentland (2003, p.101) and Pentland and Feldman (2005, p. 795)

2.1.4 A process view

Before delving into the development of routines, I have to address that so far, all analogies of routines have been entitative.

In its core, the emergent and generative nature of routines is processual (Feldman, 2016). A practice perspective has a close affinity to process perspective and the routines literature possesses forms of process theorizing, from focusing on agency (Feldman, 2000; Feldman & Pentland, 2003) to action (Feldman, 2016; Feldman et al., 2021; Tsoukas, 2021). The 2016 volume in Perspectives on Process Organization Studies, *Organizational Routines: how they are created, maintained, and changed* (Howard-Grenville et al., 2016), saw an emerging perspective in viewing routines as process.

Feldman and Pentland (2003), in their reconceptualization of routines, foreground agency (Emirbayers & Mische, 1998). Routines are dynamic, through how the ostensive aspect develops over time from routine performance, while the performative aspect varies between each enactment (Feldman & Pentland, 2003). This ostensive-performative distinction opens the black-boxed internal dynamics of routines, but also a pandora's box. There have been critiques within the routines community on Feldman and Pentland's appropriation of Latour's (1986) ostensive-performative distinction.

Firstly, based on Simpson and Lorino's (2016)[2] reading of Latour (1986), they argue that “the ostensive and the performative are ontologically distinct and incommensurable perspectives that defy efforts of integration into a single

[2] Simpson and Lorino (2016) offer more processual critiques than the selected ones. I have only included those related to Feldman and Pentland's appropriation of Latour (1986).

unified theory” (p.51). Indeed, the ostensive and the performative approaches are in fact “oil and water”: either definition can be used to study power and society, but they “cannot be blended together” (p.51). Feldman and Pentland’s effort in creating a unifying ostensive-performative distinction does not address this ontological incommensurability.

Following this line of thought, just as Latour (1986, p.272) indicates: “we have to shift from an ostensive to a performative definition of society.” The ostensive and the performative aspects are not on an equal footing. There is a preferred candidate for explaining the nature of society, which contradicts Feldman and Pentland’s unifying ostensive-performative theoretical umbrella.

Furthermore, even though Latour (1986, p.276) cautions that the ostensive definitions may be imbued with independence and be mistaken as “what is glued for the glue”, some routines are described in the way that the ostensive aspects at times are treated as if they exist independent of the performative aspects (Howard-Grenville & Rerup, 2016, p.333). This is the opposite to what Feldman and Pentland have intended, i.e., “the introduction of the term ‘ostensive’ drew attention to the relationality of performances and patterns and the constitutive nature of action in patterns” (Feldman 2016, p.27).

Actions and patterns of action. Recognizing the impediments of the ostensive-performative distinction, routine dynamics scholars have employed new theoretical and rhetorical insights to underscore actions in routines.

A first step of this movement is to foreground the notion of actions in patterns of action. Feldman (2016) discusses the possibility of viewing routines as an entity to a continuity of becoming, which brings back actions as the focal point of routines. Actions are doings and sayings, which are constitutive of practices (Schatzki, 2012; Feldman, 2016). A process-based assumption of routines also echoes with the three tenets of practice: consequentiality, duality, and relationality (see previous section). Firstly, actions are consequential. Actions in routines are to be enacted and also to determine how organizations operate. Secondly, action transcends dualisms, including stability and change, mind and body. For example, the dualism of stability and change is understood as a change in stability and stability in change (see Tsoukas & Chia 2002; Farjoun, 2010). Lastly, instead of treating actions as (micro-)foundations of routines, the focus is on “relations within which things become” and “the ways that such phenomena as people, materiality, emotion, history, power and time are connected in enacting organizational routines” (Feldman, 2016, p.37).

Actions (re)create ostensive and performative aspects. The performative aspect, or specific actions that people make, by definition, is understood as actions. The ostensive aspect, on the other hand, can be understood as patterns

(Feldman et al., 2016), or "specific actions (doing and sayings) involved in creating patterns or patterning" (Feldman, 2016, p.39).

A second step entails a rhetorical move[3] that allows routines to be expressed as actions, instead of entities. By attending to the acting and enacting of routines, Feldman (2016, p.39) suggests that this move puts the focus on "the doings involved in the creating of both performative and ostensive aspects", and recommends the gerunds, or the "-ing" forms of nouns that derive from verbs, i.e., performing and patterning correspondingly. The switch to patterning signifies the dynamic nature of the ostensive aspect (Howard-Grenville & Rerup, 2016), especially on how "patterns emerge, stabilize, vary and change" (Turner & Rindova, 2018, p.1255) and "how do we create recognizability?" (Feldman, 2016, p.39). Patterning then concerns both process of pattern creation (Feldman, 2016) in which templates of patterns are created, and pattern recognition (Turner & Rindova, 2018), in which routine participants reenact patterns.

In the routines literature, there are at least two ways of analyzing patterning: a sequence-based and an action timing-based. A sequence-based patterning can be construed as "experienced regularities across performances" (Dittrich & Seidl, 2018, p.113), or a "diachronic progression of action patterns" (Pentland & Goh, 2021, p.323). The patterns are constructed through creating and maintaining the orders of actions when performing a routine, involving routine participants' attention to each other's expectations (Danner-Schröder & Geiger, 2016) and updating goals for routines (Dittrich & Seidl, 2018). A sequence-based patterning is based on an internal temporal perspective and focuses on event time, while a timing-based patterning emphasizes instead the clock time of actions, external to routines. In other words, instead of relying on the specific actions and their order as the signal, a timing-based patterning focuses on the recurrent timing of actions and how such consistency affects routine performance to reply to the reproduction of timing (Turner & Rindova, 2018).

In short, a process perspective explores "how routines are performed by specific people in specific settings (Feldman, 2000)" (Howard-Grenville et al., 2016, p.2). As Feldman et al. (2016, 2021) indicate, in routine dynamics literature, the conceptual development of organizational routines has demystified routines as fixed things, as entities, and has moved toward a "stronger process theorizing" as ongoing and unfolding processes. A rhetoric shift is to use the gerunds "patterning" and "performing", in replacement of the ostensive-

[3] In my view, this also means that routines literature has found some better "metalanguages to define collective action" (Latour, 1986, p.276).

performative distinction. The focal point is the doing involved in patterning and performing (Feldman, 2016) (see Table 2. below).

Table 2. Routines as a process

Action	Patterning	Performing
i.e.	Pattern creation and pattern recognition	Doings and sayings
Elaboration	Specific actions involved in creating and maintaining patterns	Specific actions in specific times and places.

Based on Feldman (2016, p.39) and Turner and Rindova (2018)

2.2 Materiality in routine dynamics

In the behaviorist view and the capabilities view, there are traces of materiality. For example, the analogy of a performance program in March and Simon (1958) has its roots in computer science, in which the human actions are likened to the ones by computers and algorithms. SOPs are documented, as representations of the routinized pattern. In the capabilities view, Cohen et al. (1996) concur that the expression-representation of practices and rules can be codified in computer programs.

A practice view of routines gives rise to empirical studies, observing situated actions and analyzing patterns of action (Feldman et al., 2016). As recorded by many empirical studies, behind those actions, there is an assemblage of organizational actors and artifacts, or humans and technology, i.e., both human and nonhuman agents. The role of nonhuman agents, however, has been contested, with some contradictory findings (Parmigiani & Howard-Grenville, 2011, p.439): "Sometimes they matter a great deal; at other times, they only minimally encode a routine and do even less to influence its ongoing use." This begs the question: how do actors and artifacts shape actions?

To understand technology, digital or not, in the context of organizations, a starting point is to define technology. But to give a unified definition has proven to be a difficult task (Arthur, 2009). Various English dictionaries (such as Cambridge, Collins, Macmillan, and Oxford) have defined technology as both a branch of scientific knowledge, and an application of this knowledge, as in machinery and equipment, for practical purposes. These are consistent with Arthur's (2009) definitions:

- As a singular: "a means to fulfill a human purpose" (p.28), as in an artifact.
- As a plural: "an assemblage of practices and components" (p.28), as in X technology: information technology, digital technology.

- As a general: “the entire collection of devices and engineering practices available to a culture” (p.28), as in technology, human-technology relationship.

Therefore, the meaning of the term technology is context dependent, and, in an attempt to simplify and disambiguate, in this monograph, a technology-singular is referred to an object like a tool, an artifact, or a machine, a technology-plural is indicated with a prefix, like information technology (IT), digital technology. Finally, when technology appears standalone, for instance, in human-technology relationship, technology is understood as a general and collective, as a discipline of systematic thinking or *technologia*.

2.2.1 Artifacts at the center of routines

The form of an artifact is not monolithic, ranging from “written rules, procedures and forms to the general physical setting (e.g., a cubicle farm)” (Pentland & Feldman, 2005, p.796). In her typology, Cacciatori (2012) details four types of artifacts through dimensions of speaking-silent and generic-occupational, which have the potential for problem solving and conflict. In this meaning, written rules and procedures are “speaking” and can be specific to occupations, while the physical setting is silent and generic. She further highlights how actors bundle artifacts to form systems to resolve conflicts.

The canonical artifact SOPs contain written formal rules, which can serve as proxies for the ostensive aspects of routines. These artifacts are treated as physical manifestations of routines (Pentland & Feldman, 2005), which are in essence routines’ artifactual representations (D’Adderio, 2003, 2008, 2011). The role of artifacts in Feldman and Pentland’s (2003) ostensive-performative distinction, however, is missing due to a potential forceful conflation of artifacts with the ostensive or performative aspect of routine, which would, in turn, reinforce the idea of routines as things. For example, according to Pentland and Feldman (2005), SOPs can be easily mistaken as the ostensive aspect, while log data like job logs and history records can be mistaken as the performative.

Therefore, despite their importance in reflecting routines, such artifactual representations should not be confused with the expression of routines (D’Adderio, 2003, 2008, 2011). The role of artifacts in Feldman and Pentland’s original conceptualization was treated with caution, as “indicators of the ostensive and performative aspects” (Pentland & Feldman, 2005, p. 803). As an example, Pentland and Feldman, in their 2008 paper, indicate a failed software implementation project called “SeminarPro” for routine participants bypassed the software intended to facilitate their routine performances. Pentland and

Feldman (2008) caution about the categorical mistake of artifacts vis-à-vis patterns of action. I will return to this categorical mistake in the next section.

Artifacts are also considered as a structure that frame actions, providing the contextual background to enable or constrain patterns of action (Pentland & Feldman, 2005; Howard-Grenville, 2005; Pentland & Feldman, 2008). As mentioned previously, Howard-Grenville (2005) introduces the notion "embeddedness" to describe how the enactment of routines hinges on organizational structures, including the technological ones. Specifically, Howard-Grenville (2005, p.630) states, "technological structures result from the physical properties of technical artifacts, and they guide and constrain the actions of users or creators of the artifacts (Orlikowski, 1992; DeSanctis & Poole, 1994)".

To conclude, early studies in the routines literature consider artifacts as a representation of routines, or provide structure for organizational routines. Artifacts are considered external to the generative system. Accordingly, when depicting the role of artifacts in relation to routines, artifacts are often at the discretion of the actors and are located in the periphery of routine dynamics (see Pentland & Feldman, 2005, p.795).

2.2.2 The material aspect

D'Adderio (2008, 2011, 2021), in her series of works, illuminate more nuanced roles of artifacts. In her 2011 piece, she applauds the first "Copernican revolution" in routines theory through re-conceptualizing routines as generative systems and acknowledges that "artifacts have been treated as either too solid to be avoided, or too flexible to have an effect." (D'Adderio, 2011, p.197). Then, she proceeds with a small "Copernican revolution" by bringing artifacts to the center of routines.[4]

Continuing to investigate the representation-expression distinction: between artifactual representations of routines (such as SOP and artifact-embedded rules and procedures), and actual performances,[5] D'Adderio (2008, 2011) introduces the notion of performativity,[6] (see Gond et al., 2016 for a review) to

[4] On the surface, this inclusion of a material aspect in routine dynamics seems to contradict the third practice principle "relationality of mutual constitution" (Feldman & Orlikowski, 2011, p.1242). Feldman et al. (2021, p.12) clarify this as the following: "Mutuality, however, does not necessarily mean dyadic but does mean that the relationality cannot be one-sided."

[5] As D'Adderio (2008) acknowledges in footnotes 4 and 6, her investigation builds upon Cohen et al.'s (1996) representation-expression distinction, although it is compatible with the ostensive-performative distinction.

[6] Performativity and performance are two distinct concepts. According to Orlikowski and Scott (2014, p.873), "Performativity assumes that notion of performance but points to a further claim: that reality is enacted through performance."

the routines literature, with a strong influence from Callon (1998, 2007) and MacKenzie (2003, 2006). Starting from Callon and MacKenzie's appropriation in financial markets theory, in which they investigate performativity as bringing economic theory into being and shaping reality, D'Adderio (2008, 2011) propose a performativity framework, which centers the performative role of rule-following activity. Theories and models like SOPs and rules, in this meaning, do not only describe but also alter the actual practices.

In order to investigate the mutual adaption of theories (the artifactual representation of routines) and actual processes (routine performances), she takes four important keys in bringing artifacts and their performation to the center of routines. First of all, action and cognition are stretched across actors and artifacts. Some previous discourses in the routines literature background the role of the nonhuman agents. Returning to Science and Technology Studies and Actor-Network Theory, D'Adderio (2011, p.209) concurs that "knowledge and actions are rarely individual; they mobilize entities, humans, and non-humans, which participate in the creation of knowledge or the performance of actions". By borrowing the notion of "distributed agency" from Callon and Muniesa (2005), D'Adderio emphasizes the artifact's role of mediator in the co-creation of action, and she takes a step further to argue that "the actor's knowledge, skills, and competences *depend on* – and are at the same time *configured by* – the tools and artifacts they encounter or involve into their routinized performances" (p.210). For example, in Glaser's (2017) design performances, "distributing agency" is referred to as the process of deciding which actor or artifact performs which type of action and how.

Secondly, digital artifacts like information systems are bundles of inscriptions. Again, in the Science and Technology Studies tradition, scholars are interested in "scripts", like rules and assumptions embedded within artifacts during the design and use of technology. More specifically, this creation of scripts and delegation to artifacts is called inscription (see Callon, 1990). According to D'Adderio (2011, p. 212):

> Creating scripts involves the socio-technical process of 'inscription' (Latour, 1992) by which dominant interests or 'programs for action' are reflected in the form and functioning of a technology. Inscriptions are ways in which specific functions can be delegated to artifacts and technologies.

Such scripts however are not neutral, and can embody views, intentions, rationales, and logics, contradicting vis-à-vis routines. In the context of routine transfer and replication, when scripts that reflect truce in one setting are transferred to another, conflicts and misunderstandings may occur. D'Adderio (2014) in her case of the dilemma of replication and innovation describes how artifacts (rules, models and exceptions lists) were created to support the routine template and exposed the idiosyncratic understandings of the routine participants.

Thirdly, artifacts are not passive; they influence actions without actors' awareness. This corresponds to the term "power of default" (or "those properties of software that inhibit customization", see Koch, 1998 in D'Adderio, 2003, p.344). In the case of software, D'Adderio (2008, p. 774; 2011, p.215-216) clarifies that in theory, it is possible to bypass software-embedded control, but in practice, except for the case of disuse, it is difficult to ignore the inscribed SOPs, for the following four reasons:

- "The way we do things around here": the embedded assumptions, rules, procedures are taken for granted and become routine participants' habitual background (cf. Bourdieu, 1977).
- The enmeshed relationship between human and technology: software is difficult to avoid when they are pervasive in the organization.
- The automation and information (cf. Zuboff, 1988) of digital technology: software "make information more visible" and in turn make it easier to control actions.
- The resource-intensive customization: the amount of investment and time to tailor software can become a roadblock.

And lastly, the influence of artifacts extends beyond enabling and constraining (see Pentland & Feldman, 2005), and there are degrees of influence in between the theoretical extremes of description and prescription. Inspired by Callon's notion of performativity, and MacKenzie's appropriation of which in the market for financial derivatives, D'Adderio (2008) introduces a fined-grained performativity framework to classify the degrees of artifacts on routines: "generic performativity", "effective performativity", "Barnesian performativity", and "counter-performativity" (see Table 3. below).

Table 3. Degree of performativity

Degree of performativity	Elaboration
Generic performativity	SOP/rule is used in the process
Effective performativity	SOP/rule has an effect on the process
Barnesian performativity	SOP/rule makes process more like its depiction
Counter-performativity	SOP/rule makes process less like its depiction

Based on D'Adderio (2008, pp.783–784)

In other words, this performativity framework contrasts prescription (full influence) and description (no influence) of artifactual representation on routine performance. According to D'Adderio (2021, p.92, emphasis added):

> The influence of formal rules/SOPs on routines is the outcome of iterative cycles of performation through which the SOP/rule *frames* the routine in practice, making performances more similar, or more compatible, to the SOP/rule; this generates *overflows*, which make performances less similar to, or compatible with, the SOP/rule, which may lead in turn to *reframing* of the performances by the SOP/rule.

The underlying agential unit is no longer constituted by actors or artifacts alone. Again, building upon performativity theory, D'Adderio and colleagues (D'Adderio, 2011; Glaser, 2017; Glaser et al., 2021) have suggested that the performativity of artifacts is bundled with actors and other heterogeneous ensembles. It is through building such sociomaterial assemblages[7] (Deleuze & Guattari, 1987; Suchman, 2007; DeLanda, 2016) that the material aspect exerts influence on shaping the ostensive and the performative aspects.

Assemblages are "arrangements endowed with the capacity to act in different ways, depending on their configuration" (Çalışkan & Callon, 2010, p. 9) and may include "actions, instruments, tools norms, values, bodies, emotions, etc." (D'Adderio, 2021, p.92), or "actors' intentions, emotions and actions, digital and physical artifacts, etc." (Feldman et al., 2021, p.10).

Following this train of thought, in order for a SOP to have an effect on routine performance, it has to configure a sociomaterial assemblage that may support the assumptions embedded. As D'Adderio (2008, p.784) states: "artifact-embedded SOPS and rules thus do not simply describe, do not often prescribe, mostly they are performed".

When adopting the ostensive-performative distinction, D'Adderio (2011, p.223) concludes by stating:

> Focusing on the relationship between artifacts and ostensive, we were able to capture the micro dynamics by which specific ostensive views are selected and become embedded into artifactual representations of routines (i.e. rules and procedures), and, by focusing on the relationships between artifacts and performative, we were able to capture the micro dynamics by which artifacts influence (and are influenced by) performances.

2.2.3 Digital materiality

To some extent, the aforementioned explorations center around formal artifacts like SOP and its embeddedness in digital artifact. For instance, the artifactual representation of routines explored in D'Adderio (2008) is embedded in a software called PDM (Product Data management). The materiality of

[7] In the routines literature, some authors use Callon's (1998, 2007) sociotechnical agencement. I use the term sociomaterial assemblage to refer to the same concept.

digital artifact, since the late 2000s, has been improving to the point of conceptualization of a new digital era, defined as "the second machine age" (Brynjolfsson & McAfee, 2014), or the dawn of "the fourth industrial revolution" (Schwab, 2017).

Understanding digitalization and digital technology requires unpacking artifacts as black-boxed entities. In scholarly discourses, there is an onslaught of concepts with *digital* as a prefix. A non-exhaustive list includes digital innovation (see Yoo et al., 2010; Nambisan et al., 2020), digital work (see Orlikowski & Scott, 2016), digital entrepreneurship (see Nambisan, 2016), digital marketing (see Kannan et al., 2017), and digital globalization (see Nambisan & Luo, 2021). As sharply recognized by some scholars in IS (see Nambisan et al., 2020), the meanings of "digital" in different disciplines are not the same.

Baskerville et al. (2020) question the fundamental role of information system and digital technology at large. Instead of merely representing and reflecting the physical reality, digital technology increasingly creates and shapes physical reality, thus, the term "digital first", and hence, an ontological reversal.

First and foremost, materiality is manifested in both physical and digital (or material and immaterial) forms. Digital materiality, according to Yoo et al. (2012, p.1398), refers to

> What the software incorporated into an artifact can do by manipulating digital representations. […] The uniquely powerful affordances of digital technologies (Kallinikos et al., 2010) allow designers to expand existing physical materiality by 'entangling' it with software-based digital capabilities (Yoo, 2010; Zammuto et al., 2007).

Building on Yoo et al. (2010) and Yoo et al. (2012), here I detail some key differences in digital technology's characteristics from the earlier ones, namely homogenization and heterogenization of data, reprogrammability, and its self-referential nature.

Homogenization and heterogenization of data. The native language of anything digital is a binary digit or bit. Digital signals represent data in binary digits of 0s and 1s, instead of a continuous analog signal. This conversion is called *digitization*, or the encoding of analog information into digital format (Yoo et al., 2010, p.725). Data are generated at an unprecedented volume, velocity, and variety (Brynjolfsson & McAfee, 2014, p.62). I take the argument further by adding heterogenization of digital object, meaning that digital objects[8] take forms (formats) in text, sound, photos, and videos. In other words, the shape of data is homogenous, but the form of digital object is heterogenous.

Reprogrammability. The design of many digital devices is based on the von Neumann architecture, which consists of a central processing unit (CPU) and a memory unit (RAM), where instruction data and program data are stored. This architecture is versatile regarding the manipulation of data per different instructions. Therefore, even though hardware is not easy to change after production, software, and the functions it performs can be added after it is produced. Such reprogramming can be done by programmers when they issue regular updates to the software. Some more skillful users can also code new functions on their own initiative. This malleability is called "a procrastinated binding of form and function", according to Yoo et al.'s (2012, p.1399) reading of Zittrain (2006).

Self-referential nature of digital technology. A digital artifact tends to bundle with other artifacts to create network externalities, which echoes with Cacciatori's (2012) concept of systems of artifacts, when an occupation-specific artifact (Excel) interacts with other artifacts like procedures and technical drawings. Cacciatori's (2012, p.1560) further notes that "by bundling different types of artefacts, agents reinforce and extend the patterns of action that each supports and extend the influence of their particular communities to other occupational groups within the organization".

These characteristics are the prerequisites for the emergence of a new product architecture of digital artifact, i.e., a layered modular architecture, which is conceived as a hybrid of both a modular architecture of physical product and a layered architecture of IT (Yoo et al., 2010). This layered modular architecture manifests in four layers, namely devices, networks, services, and contents, which is essentially a nearly decomposable system (Simon 1996/2019).

A digital artifact like a software becomes an aggregation of layers which are modules of physical and/or digital properties, extending beyond the conventional conceptualization of what an IT artifact consists of. It is no longer counter intuitive that even in this ever-digitalizing world, physicality is also pervasive: digital technology requires the physicality of the device layer and network layer, as the carrier of the immaterial digital objects in the content layer and service layer.

[8] Digital objects are "objects that take shape on a screen or hide in the back end of a computer program, composed of data and metadata regulated by structures or schemas" (Hui, 2016, p. 1).

If *digitization* is the encoding of analog information into digital format, *digitalization* entails "the possible subsequent reconfigurations of the socio-technical context of production and consumption of the product and services" (Yoo, 2012, p.137). Characteristics like homogenization and heterogenization, reprogrammability, and self-referentiality have implications for digitalization, namely features of semiotic binding and ontological reversal (Baskerville et al., 2020; Nambisan et al., 2020).

Semiotic binding. Historically speaking, the role of digital technology is to create a world that mirrors the physical reality. As argued by Baskerville et al. (2020, p.514),

> For information systems, this notion implies dual realities, one embodied by the physical world in which we live, and the other embodied by digital codes and signals in networks and computer processing devices. Human experience is shaped in the intertwined duality of both realities.

The heterogenous digital objects, in essence, are representations of the physical world. To make use of such representations, they need to be interpreted and contextualized in a sociomaterial setting, e.g., by the scripts inscribed by the designers of digital artifacts and by the users of such digital artifacts. These contextualized representations are socially mediated. The interpretations are "unaccounted" and "indeterminate" (Nambisan et al., 2020, p.6) and present openness for semiotic interpretations.

Ontological reversal. In the extant IS literature, this representational role from physical reality to digital reality is *a priori*. Baskerville et al. (2020, p.509) propose "digital first" to signify the situation in which "digital technologies are now creating and shaping physical reality". Scholars need to reconsider the relationship between the physical reality and digital reality when digital objects are created first, leading subsequent physical activities to the extent that the digital is more real than the physical, so that the physical does not always exist, or is "digital only". For example, Baskerville and colleagues use the example of e-ticketing, which is essentially "a reservation in the form of bits in an airline's computer system" (p.511). A delayed flight will enact algorithms to rebook, reroute and create new *bits* in the computer system. The *real* ticket is then in the form of bits, and any temporary recreations like hard copies and e-tickets become potentially obsolete. Therefore, "it is the digital version that is real; only the digital version in the airline's reservation system gives a passenger the right to travel" (p.511).

Digital reality in this case becomes the principal aspect of this relationship between the physical and the digital, extending the physical-to-digital with digital-to-physical. As a result, Baskerville et al. (2020) also use the term computed human experience to showcase how digital technology penetrates all aspects of experience, and this human experience is shaping and being shaped by both the digital and physical realities. As Baskerville et al. (2020, p.517) conclude:

> Digital technology is now directly shaping our world and our physical and existential experiences in it (Dourish, 2001; McCullough, 2004; Yoo, 2010). Our digital world is one in which these digital tools and their effects become taken for granted. Computed human experience today is one where the digital and the physical are seamlessly and inseparably interwoven.

Inspired by Iivari's (2007) analysis on the archetypes of IT application, I characterize the focal function of digital technology as to *digitalize*: the creation of a digital reality and the subsequent conversion, and reversal in relation to the physical. Thus, being digital entails more than being IT.

Accordingly, the "IT part" of digital technology is not brand new. IS scholars focus on the novelty and the potential for changing work practices. A fundamental difference between IT and digital technology is generativity. Again, in the context of digital innovation, Nambisan et al. (2020, p.7) explain the distinction:

> In the classic story of IT, we assume that a specific technological 'box' does something for the actor; in the 'digital innovation' story, digital does first what IT can do, but it also enhances the flexibility and speed of actors to improve or create new outcomes (in unpredictable ways) through generativity (Fürstenau, Baiyere, & Kliewer, 2019; Lyytinen, Sørenson, & Tilson, 2018).

The layered modular structure and the abovementioned characteristics make digital technology dynamic and mutable, and subsequently digital materiality "presents new possibilities for creating experiences, relationships, processes, and organizational forms." (Yoo et al., 2012, p. 1399). In other words, digital artifacts are not things, and the pervasive digital technology brings generativity to all aspects of organizations and society at large (Brynjolfsson & McAfee, 2014; Lyytinen et al., 2020).

Using the example of the PC and the Internet, and the grid of PC and network in combination, Zittrain (2006, p. 1981) pins four criteria of generativity: "capacity for leverage across a range of tasks, adaptability to a range of different tasks, ease of mastery, and accessibility." According to Zittrain (2006, pp.1980–1982),

> Generativity denotes a technology's overall capacity to produce unprompted change driven by large, varied, and uncoordinated audiences […] Generativity increases with the ability of users to generate new, valuable uses that are easy to distribute and are in turn sources of further innovation.

2.2.4 PLM and digital thread

In the following, I situate the abovementioned terms and concepts in an illustration of the focal digital artifact of this monograph – PLM (Product Lifecyle Management) system and the ontological reversal manifested in the manufacturing industry – digital thread.

Digital thread is an exemplification of how the characteristics of a collection of digital technology could reconfigure the human-technology relationship in industrial firms. In the manufacturing industry where the physical reality persists, digital thread is how the physical and digital become interwoven and enable a potential ontological reversal. PLM is one of the needles in weaving this digital thread, hosting all product data across the product lifecycle.

Traditionally, Enterprise Resource Planning (ERP) system is a fertile ground for IS and organization scholars to investigate the automation, information and transformation role (Zuboff, 1988) of IT/digital artifact in organizational life (see Pollock & Williams, 2012). Comparatively speaking, the presence of PLM or its early incarnation PDM has been less attended to.

Granted, PDM/PLM is more prevalent in manufacturing firms, and its history can be traced to the early 2000s. Its ability to automate and informate has been witnessed in D'Adderio (2003), as a PDM "is designed to store, control and distribute the whole of the enterprise-wide information and (codified) knowledge required for product development and beyond" (p.324). PDM then serves as a repository of both declarative (know-that) and procedural (know-how) memories.

PLM first and foremost is a product management methodology that integrates different forms of product data, people and digital artifacts across the entire product lifecycle, from design, manufacturing, assembly, to maintenance. The design of PLM follows the separation of form (physical devices) and function (modules), meaning user interfaces accessible from different physical devices including computers, smart phones, and tablets and some machineries, e.g., NC (Numerical Control) machines. PLM vendors offer basic modules to manage BOM (Bill of Materials), BOP (Bill of Process), technical documents, and quality and compliance, etc. These models can be customized, and new modules can be added after its implementation.

In this regard, ERP and PLM are two traditional pillars of manufacturing. PLM provides not only a repository of product information, but it also becomes a backbone of the digital platform for a larger ecosystem, together with Computer-aided technologies (CAx), ERP, Plant engineering software, Manufacturing Execution System (MES), Office, and other digital artifacts. In

Table 4. below, I illustrate how the characteristics of digital technology are manifested in PLM.

Table 4. Characteristics of digital technology

Characteristic of digital technology	Elaboration	Example: PLM
Homogenization and heterogenization of data	Digital objects in the same shape of binary numbers with different forms	Product data like texts, images, drawings, models, videos, etc.
Reprogrammability	Separation of hardware and software	Customizable modules in PLM, accessible from devices like computers, smart phones, tablets, NC machines, etc.
Self-referentiality	Network effects of digital artifacts	CAx, ERP, Plant engineering software, MES, Office, etc.

Based on Yoo et al. (2010) and Yoo et al. (2012)

Regarding the separation between form and function, there is another separation between content and network. By that, PLM is able to host product data in the same shape of binary numbers with different forms and across different network modes, as a manifestation of a layered modular architecture (see Table 5. below).

Table 5. Layered modular architecture

Layer		Elaboration	Example: PLM
Content		Digital objects	Product data like BOMs, BOPs, texts, images, drawings models, videos, etc.
Service		Application functionality	SaaS, IaaS
Network	Logical transmission	Network standard	Bluetooth, Wi-Fi, Zigbee, etc.
	Physical transport	Hardware	Modem, System on a Chip, etc.
Device	Logical capability	Operating system	IOS, Android, Windows, Linux, etc.
	Physical machinery	Hardware	System on a Chip, sensor, battery, display, camera, speaker, microphone, memory, etc.

Based on Yoo et al. (2010) and Yoo et al. (2012)

Apart from automating and informating, the transformating effect of PLM is its facilitation of collaboration as early as design. That is to say, in the manufacturing context, PLM may enable concurrent engineering when products are designed and produced at the same time. The product data, however, is created and used with different objectives. For example, the Engineering Parts List used in the automotive company in D'Adderio (2003) is used in both Engineering and Production. While Engineering uses the list to elicit the entire list of parts that belong to a vehicle, Production uses it to verify the prototypes of fully built vehicles.

Ontological reversal, on the other hand, is what excites scholars and practitioners. PLM enables a digital thread that alternates a continuous and spontaneous interaction between the physical and digital reality. However, in discrete manufacturing where the physical reality is prevalent, to realize a digital reality is a challenging task. In Table 6. below, I illustrate how the characteristics of digital technology are manifested in PLM.

Table 6. Features of digital technology

Feature	**Elaboration**	**Example: PLM**
Semiotic binding	Contextualization of representations	Product data are used differently across product lifecycle
Ontological reversal	The primary role of the digital reality over the physical reality	Digital factory, as the main representation over the physical factory

Based on Baskerville et al. (2020) and Nambisan et al. (2020)

In the manufacturing industry, visualization has been transformating. Designers start with digital mock-ups in CAD to define its physical counterpart, be it 2D drawings or 3D models, and save the product data in PDM/PLM. Visualization through 3D models can be seen in studies by Thomke (1998), D'Adderio (2001), Becker et al., (2005), Bailey et al. (2012), and Leonardi (2012) to list a few. They have documented how visualization, apart from the well-known benefits of reduced cost and lead time, has the potential to introduce other profound changes in the organization.

Thomke (1998) and D'Adderio (2001), in their papers, detail some virtual prototyping techniques and more specifically, their roles in knowledge integration in the context of new product development. Becker et al. (2005) investigate the impact of visualization in a case study in the automotive industry. Through the making of a virtual simulation tool, problem solving strategy adds an abduction dimension through virtual experimentation, apart from deduction from the laws of physics and induction from physical experimentations. Drawing from a study of an automotive company, Leonardi (2012) illustrates a simulation technology called "CrashLab". It creates new information from digital crash tests to predict what would happen in a physical test, which is otherwise difficult to generate.

Product digital twin is an advanced version of visualization that the flow of representation is bidirectional (both the digital and the physical are interacting with each other). In this sense, a product digital twin is a dynamic digital mockup with its physical counterpart. The informating capability of the product digital twin is then on a real-time basis, in which PLM plays a pivotal role. In Bengtsson et al.'s (2020) historical study of a military aircraft manufacturer, they show how virtual modeling and how "virtual online evaluation" (see Gavetti & Levinthal, 2000) informed an incrementally realistic digital reality, with which developers were able to narrow the gap between reality and representation.

The vision with digital thread is beyond the concept of product digital twin. When sensors, machines, and instruments extend the network of digital artifacts, the increased amount of data collection and mapping techniques can create a digital mockup of the entire factory. A digital twin of the factory then includes, for example, the manufacturing process. This is a real-time dynamic mirroring of the entire factory and requires humongous amounts of the heterogenous data via AI and machine learning.

Following the trajectory of the datafication of a physical factory, digital factory becomes the principal reality, which has the capability to reduce downtime, improve productivity, and efficiency. One of the most transformating effects is predicative analytics, when simulation of the entire factory can be performed, and problems can be identified preemptively. This, in turn, may change the unpredictive nature of engineering change.

2.2.5 Digital artifacts at the center of routines

Circling back to the routines literature, scholars are also recognizing some characteristics of digital materiality and examine digital artifacts beyond the embedded rules and SOPs.

Routines scholars have attended to enterprise systems like ERP in their capacity to bring about integration and control in organizations (Volkoff et al., 2007; Goh et al., 2011; Berente et al., 2016). In Volkoff et al.'s (2007) investigation of an ERP implementation at a precision industrial product manufacturer, apart from routines, organizational elements like roles and data are also embedded into the digital artifact. Such embeddedness means that routines, roles and data have not only material aspects, but they also interact with their ostensive and performative aspects. Through the lens of critical realism, they explain how technology-mediated change comes about in a mid-range process theory, recording how the material aspects mutually affect the ostensive and performative aspects in the stage of structural conditioning, and how the material aspects constrain/enable them in the stage of social interaction and lastly, how the material aspects are readjusted to them in the stage of structural elaboration/reproduction.

In the context of health IT, Goh et al. (2011) document the introduction of an enterprise system called a computerized document system to replace a drawing-based one to handle clinical documentations at a large hospital. They identify stages in the implementation process in which routines and digital artifact interact via symbolic expressions and functional affordances. They also underscore agency in the form of leadership and personal innovativeness in a virtuous co-evolution cycle between routines and digital artifact.

Berente et al. (2016) showcase how dynamically adjusting routines over time reconcile as a shock absorber between digital technology and local practices. As detailed in their longitudinal study of the implementation of ERP at NASA, the ostensive aspect, or the management's goals embodied by the material aspect, caused misalignments with the performative of the routine participants. As a result, all three aspects of routines undergo dynamic adjustments to a variety of changes, and this "shock absorbing" mechanism of routines ensures organizational goals through sacrificing integration and control at the local level.

Apart from the enterprise system, digitalization has given rise to a new generation of digital artifacts with more agentic properties, meaning they are "designed to make rational and autonomous decisions" (Baird & Maruping, 2021, p.317). For example, algorithms, or "abstract, formalized description[s] of computational procedure[s]' (Dourish, 2016, p.3)" (Glaser et al., 2021, p.315), have gained popularity among the routines scholars.

Glaser (2017), for example, zooms in on algorithms and how they automate decision making using game theory to increase the randomness of patrol schedules. He studies two pilot projects where the law enforcement agency enlisted help from a research organization to embed Bayesian-Stackelberg game-theoretic (theories) algorithms in Excel (artifacts) for patrol officers (actors) to influence law enforcement routines (practices). Glaser (2017, p.2133) records four design performances, namely abstracting grammars of action, exposing assumptions, distributing agency, and appraising outcomes, through which organizational actors create an artifact in order to intentionally change (or influence) a routine.

Apart from embedding rules and procedures, algorithms have self-referential characteristics and are embedded in a sociomaterial context of assemblages of actors, artifacts, theories, and practices (D'Adderio, 2011). The algorithm "Autoswap" in D'Adderio and Pollock (2014) is an example of an assemblage of vendor and integrator, Inventory control system in ERP, "Lean Production" and "Just-In-Time" lean practices to direct and automate sequences of actions in dealing with faculty computer boards.

2.2.6 Materializing

As mentioned previously, the routines literature has started adopting a processual view on routine dynamics. The performativity of digital artifacts also invites a process theorizing, and material aspects become a process of materializing (Feldman et al., 2021; D'Adderio, 2021) to the internal dynamics of routines. In the lineage of the processual perspective, actions do not preclude materiality (Feldman, 2016), as actions and materiality are mutually constituted and inseparable (Orlikowski & Scott, 2008) or imbricated (Leonardi, 2011). Therefore, a dyad becomes a triad of patterning, performing, and materializing (Feldman et al., 2021, p.12).

The performativity framework is an important shift toward the analytical integration of human and technology through the agential unit of sociomaterial assemblage. I concur with Glaser et al. (2021, p.7) that

> The power of the artifact here is described as its ability to put together an assemblage of socio-technical or sociomaterial features which supports the realization of logics, goals, and intentions embedded over time in the artifact itself (D'Adderio, 2011).

Referring to Latour's model of translation (1986), D'Adderio and Pollock (2020) make the case of routine transfer as transformation, instead of replication. Imitation of routines is seen as "a process in which something is *created and transformed* across a chain of 'translators' which help adapting the object or idea to fit the new context and therefore support its materialization" (D'Adderio & Pollock, 2020, p.3, emphasis in the original). In their case study of a transfer project of manufacturing routines, the translating practices emerged to migrate one location's idiosyncrasy to align with the other location. Such translation is a type of "semiotic binding" (Nambisan et al., 2020) that was not one-off; instead, it was constant to prevent drifts.

When discussing digital work, Orlikowski and Scott (2016, p.89) analyze:

> How the doing of work is configured by specific materializations through specific technologies in particular times and places. […] The ways in which these specific materializations are consequential, in other words how, when, where and for whom/ what they make a difference in the world.

Some materializations involve digital platforms and algorithms and data they operate upon. In Orlikowski and Scott's (2016) example of a review on TripAdvisor, a hotel cleaner's work was connected to the platform in the following materializations: a negligence in cleaning led to a negative review on TripAdvisor; the review in question, among other reviews, was incorporated in the algorithmic ranking of the hotel, which affected the guests' expectations and how cleaners conducted their work.

Similarly, based on Callon (1986) and Latour (2005), Glaser et al. (2021, p.4) discuss the case of an algorithm as a chain of socio-technical translations or a chain of materializations, through which rules and assumptions of algorithms are materialized:

> One materialization, for example, might convert an abstract logic into a mathematical model or formula. Another materialization might involve translating this formula into code which can be executed by a machine (e.g., a computer). A further materialization might concern translating this code in the form of software scripts so that it can be embedded into a software application. Yet another materialization might involve the software application being adopted and becoming embedded in new and different organizational and institutional con- texts. Put simply, this progressive (and/or simultaneous) chain of materializations enables the original algorithm constructed in a narrow way (logic plus code) to come to life and be transported through many different—and often unpredictable—instantiations.

Drawing on Latour's (1986) mode of translation, Orlikowski and Scott (2016), D'Adderio and Pollock's (2020) and Glaser et al.'s (2021) appropriations, I understand materializing or a chain of materializations as a sociomaterial process in which a digital artifact's influence on routines is exerted and transformed across specific materializations at specific times and places (see Table 7. below).

Table 7. Materiality and routines dynamics

	Material aspect	**Materializing**
i.e.	An artifactual representation of routines (rules and procedures)	A chain of materializations
Elaborations	Degree of influence of the artifact on routines	Degree of influence of the artifact on the routines at a specific time and place

Based on D'Adderio (2011), Orlikowski and Scott (2016), D'Adderio & Pollock (2020), and Glaser et al. (2021)

2.3 Designing live routines

Routine dynamics scholars are interested in the duality of stability and change. "How do routines emerge and change?" is among one of the most prolific areas in which routines scholars uncover the inner workings of routines (Feldman et al., 2016, p.510). A specific focus is on how the dynamics of routines, consisting of the ostensive, performative, and material aspects or the processes of patterning, performing, and materializing lead to both stability and change (Feldman et al., 2021).

One of the cornerstones of the routine dynamics literature is the exploration of internal variations. For example, Feldman's (2000) observation on the routines of a student housing organization records four types of change responses originated from the intentions of routine participants to align their actions to outcomes: through repairing actions that do not achieve intended outcomes, repairing actions that produce unintended and undesirable outcomes, expanding actions that create new possibilities, and striving for ideal outcomes.

Apart from intentional changes from the inside of routine dynamics (i.e., from within) (Dittrich & Seidl, 2018), interventions can be introduced via (digital) technology from the outside (i.e., from without). Organizations may intentionally create and introduce (digital) artifacts to influence routines, confined in the form of projects and change initiatives, such as Pentland and Feldman's (2008) SeminarPro project to change seminar organizing routines, Goh et al.'s (2011) computerized documentation system implementation project to digitalize clinical documentations, Gupta et al.'s (2015) redesign project to replicate sign and banners routines across chains, Cohendet and Simon's (2016) "Always playable" project to recombine game development routines, and Glaser's (2017) pilot projects to change patrolling routines, to name a few.

2.3.1 Routine design

These efforts, according to Wegener and Glaser (2021, p.301, emphasis in the original), can be interpreted as, routine design:

> We suggest that such change initiatives can be understood using the label *routine design*, which we define as *intentional efforts to change one or more aspects of a routine to create a preferred situation*.

Etymologically speaking, the term design in the context of routines evokes questions (Pentland & Feldman, 2008; Glaser, 2017; Wegener & Glaser, 2021). To begin with, the English word "design" is ambiguous, sharing two word-classes[9]. The verb design has its root in the Latin verb *designare*, "to make, shape" in the late 14 century, making its way to the Italian verb *disegnare* in the 16th century and acquired "to intend" and "to draw". These verbs made into French, then in English in both verb and noun.

[9] The definitions and etymology of design are based on Pentland and Feldman (2008), etymonline.com, and Cambridge dictionary.

The meanings of both word classes can be divided roughly into two categories, with the first focusing on the artisan roots of design as a liberal art (form-giving), and the second on a pragmatist perspective of design as purpose and intent (problem-solving). The first category refers to the artistic work of planning to show the look and function of a product like a building, or a garment before it is made. "To design" in this sense means to artistically plan and fashion, and "a design" refers to outcomes from design actions, such as drawings. The second category of its meaning shares the notion of plan, purpose, and intention, with "to design" meaning to do or plan something with a specific purpose or intention in mind and "a design" as the intention and how something is planned or made.

For both categories, the verb form of design entails the act of producing the noun form of design. Routine design, in this context, refers to both nonroutine actions like design actions (i.e., organizational actions to intentionally change or influence a routine; cf. Glaser, 2017) and designed routines (i.e., aspects of routines that are influenced/changed during a routine design process).

The story becomes complicated when routine design takes place and studies have shown that routines maintain their current patterns of actions when (digital) technology is introduced. As Pentland and Feldman (2005, p. 797) state:

> Managers create such artifacts [rules and standard operating procedure] in an effort to shape actual work practices, but the practical effect of any particular rule or procedure is often quite remote from its original design or intention.

The cautionary tale in Pentland and Feldman (2008) exemplifies that intentional variations introduced by digital artifact SeminarPro were "dead" to the participants. In other words, the design of the digital artifact was successful, but the design of routines was a failure.

2.3.2 Live/dead routines

The distinction between live and dead routines was introduced by Cohen (2007). Drawing from John Dewey, Cohen reflects on the human faculty of habit and its interplay with the faculties of emotion and cognition. Routines, or routine habits, in Dewey (1922), are reserved for the pathological extreme "dead habits" that is "rigid, mundane, mindless or explicitly codified" (Cohen, 2007, p.779). In Pentland and Feldman's (2008, p.240) reading, a key lies in how generative the routines are:

> Dead routines are artifacts; they are rigid, mindless, and can be explicitly stored. The classic example is the sequential list of actions that is developed by people who do not enact the routine and is largely if not totally ignored by those who do enact the routine. […] Dead routines can be designed by

> whatever means seems convenient and adequate. Live routines are another matter entirely. Any organizational routine that involves people, who are capable of learning from experience, is at least partially a 'live routine'. The key distinguishing factor, following Dewey, is that the experience of the participants naturally and inevitably gives rise to learning. In our terms, live routines are generative: enacting them naturally and inevitably gives rise to new actions (performances) and sometimes new patterns of action. Managers may or may not want to capitalize on this inherent capability of routines, but they cannot erase it unless they are willing and able to 'kill' the routine through total automation.

Returning to the case of SeminarPro, despite a successful design, routine participants from two outreach programs (Labor and HR) objected to the designers' intention that SeminarPro would support a common database for both. In a processual reading of this, SeminarPro failed to materialize. The participants preferred control over their own work to maintain their identity; instead, new sociomaterial assemblages were formed, consisting of standalone spreadsheets. Pentland and Feldman (2008) caution against the misconception of routines as things and the subsequent conflation between patterns of action and artifacts; the former controlled by actors are most "alive", and the latter controlled by the designers are most "dead".

D'Adderio (2011, p.206-207) also picks up the live-dead distinction and in her reading:

> While 'dead routines' tend to be rigid, mindless, and are typically codified in artifacts, tools, and technologies, 'live routines' are flexible, mindful, and involve the contribution of actors, their experience and learning. […] The connotation 'dead', when attributed to a routine, does not result in obscuring the nature and role of artifactual representations of routines and their own internal mechanisms (dead meaning not so much inconsequential, but hardened, solidified). […] These routines may certainly be dead, but they nevertheless retain traces of previous lives, and, because of this, they are worthy of study and attention.

Routines are dynamic (Feldman et al. 2021, p.13) and such dynamics are challenging to routine designers. Returning to Pentland and Feldman's (2008) case of SeminarPro, the designed routines were dead since the designers conflated routines with rigid and mindless artifacts (Pentland & Feldman, 2008, p.240). At the same time, the designed routines from without were rejected by the routine participants and they instead designed from within and enacted new routines. That is to say, for a lack of a better word, the designed routines were killed by the dynamic routines.

This, to paraphrase Bucher and Langley (2016, p.595), is when the dynamics of routines turn from an explanation of change into a puzzling situation for routine designers to design live routines. On the one hand, when using digital artifacts to influence routines, routine designers need to design routines that are generative, which give rise to learning, and subsequently variations like new actions and/or patterns of action. On the other hand, the designed routines need to be reoriented to the routine dynamics while current dynamics are still being reproduced.

Inspired by Bucher and Langley (2016), I call the first part of this puzzling situation a puzzle of generativity to make live routines and to also use their terminology, the second part a puzzle of recursiveness to make routines alive. The routines (and adjacent) literature offers some ways forward to addressing these two puzzles, as detailed below.

2.3.3 The puzzle of generativity

Pentland and Feldman (2008, p.241) conceptualize live routines as generative systems that "can produce a wide variety of performances depending on the circumstance". Their conceptualization is constitutive of the ostensive and performative aspects, in which (digital) artifacts like SeminarPro are located at the periphery. As established earlier, subscribing to a processual view, (digital) artifacts are at the center of routines' generative system. In fact, they are not things; they are generative as well. I concur with Yoo et al. (2012, p.1399) that the assumption of digital technology as a fixed entity needs to be challenged:

> Organizational theories that may have assumed (either explicitly or by oversight) that technology is fixed and immutable now must consider the possibility that the technology providing the basis for organizational functioning is dynamically changing, triggering consequent changes in organizational functioning.

Similarly, the generativity in Leonardi's (2011) study is termed as flexible technologies and he showcases that human agency and material agencies are imbricated, through which changes in routines and technologies are produced.

The routines literature has through a practice view and a processual view explored different constitutive of the dynamics of routines (Feldman & Pentland, 2003; Dionysiou & Tsoukas, 2013; Feldman, 2016; Feldman et al., 2021). The inherent dynamics of digital technology are also foregrounded, i.e., materializing in the context of routines (D'Adderio & Pollock, 2020; Glaser et al., 2020). Questions emerge when both dynamics of routines and digital technology are indeterminate and ever-changing: *how are generative systems of routines and digital technology created from without*? To address this issue, I suggest focusing on the routine design process and the design actions directed at (re)configuring sociomaterial assemblages and facilitating materializing.

Routine design process. I follow Wegener and Glaser's (2021) suggestion that the routines literature can follow a pragmatist design perspective that combines both two paradigms of problem solving (Simon, 1996/2019) and reflection-in-action (Schön, 1983).

The concept of design, including its dualistic nature, is extensively explored in Simon's scientific perspective on design in *The Sciences of the Artificial*. The verb may mean: "Everyone designs who devises courses of action aimed at changing existing situations into preferred ones" (Simon, 1996/2019, p.111) (which inspires the definition of routine design). Alternatively, it may mean "conceiving of objects, of processes, of ideas for accomplishing goals, and showing how these objects, processes, or ideas can be realized", as described in *Problem Forming, Problem Finding and Problem Solving in Design* (Simon, 1995, p. 246). Simon's conceptualization on design is a problem-solving process. He emphasizes the role of the designer and how designers make design choices and more importantly discover and generate alternatives. Ultimately, to satisfice ends like goals and constraints, design actions often lead to means like artifacts, as good-enough solutions to the problems at hand. These outcomes may include "synthetic or artificial objects—and more specifically prospective artificial objects having desired properties" (Simon, 1996/2019, p.4).

The positivist and empiricist undertone of Simon's work on design has been challenged in design studies. Complementing this scientific perspective, Wegener and Glaser (2021) also include a reflective perspective originated from Schön (1983), as the other key component to the pragmatist underpinning on design studies (see also Dorst & Dijkhuis, 1995) to understand routine design.

Schön's (1983) *The Reflective Practitioner* introduces reflection-in-action to counter a "positivist epistemology of practice". Instead, he highlights the situated nature of problem solving. Through this constructivist lens, to design is construed as "a reflective conversation with the situation". A situation is "defined by the subjects' perception of the current state, goals and possibilities for action, and his/her way of dealing with 'thrownness'." (Dorst & Dijkhuis, 1995, p.264). Each situation is unique and invites connections between means and ends, research and practice, and knowing and doing, instead of separations in a "positivist epistemology of practice".

In contrast to Simon's notion of "problem solving" of a predefined set of objectives and constraints, the essence of Schön's "reflection-in-action" expands problem forming to the framing of the situation and its underlying problem and its setting. According to Schön (1983, p.40, emphasis in the original), problem setting is:

> The process by which we define the decision to be made, the ends to be achieved, the means which may be chosen. […] Problem setting is a process in which, interactively, we *name* the things to which we will attend and *frame* the context in which we will attend to them.

Thus, means and ends are framed interdependently. A practitioner is not an objective being to the world; instead, they shape reality and become a part of it. Intentions emerge during routine design. When design actions bring about unintended consequences, the situation talks back, and the designer, in turn, forms a new understanding and intentions.

Design actions has made appearance in the routines literature, as nonroutine actions. Obstfeld (2012) studies such design actions in "creative projects" and, more specifically, the trajectories are aimed at an envisioned and possible future. In such nonroutine scenarios, design actions resemble what Nelson and Winter (1982, p.171-172) would call "search" in order to modify routines intentionally or to find new routines in the face of environmental jolts and shocks. These search processes are, to some extent, uncertain and contingent. Similarly, some of the intentional efforts from without share the essence of the teleological motor of change (Van de Ven & Poole, 1995). These actions involve cycles of goal formulation, implementation, evaluation, and modification of actions or goals.

When there is an aspiration, such as an envisioned outcome (Obstfeld, 2012) or a preferred situation (Wegener & Glaser, 2021), the open-ended-ness can be managed through framing the situation and the problem (Schön, 1983). In design literature, Dorst (2011, p.525) details the inner workings of framing as "the creation of a (novel) standpoint from which a problematic situation can be tackled".

Returning to Glaser's (2017) example of intentionally changing patrol routines with a game-theoretic artifact, the design performance of exposing assumptions records how routine designers framed the psychology of terrorists/fare evaders through reflecting with the actors, and how they applied the zero-sum game in this setting and inscribed their collective understandings in the artifact.

Conditions for materializing. In this sense, when designing generative systems of routines and digital technology to derive at a particular outcome, routine designers (re)configurate sociomaterial assemblages to create conditions for digital artifact's materializing.

The formation of sociomaterial assemblage is temporary. Its configuration, or arrangement with a plethora of sociomaterial features (Feldman et al., 2021), is shaped and re-shaped upon each materialization. This echoes with one of the key characteristics of digital technology, i.e., reprogrammability. The use and delivery of data and digital objects are instantaneous and emergent when called upon. Describing the components in a layered modular structure, Yoo (2012, p.142, emphasis in the original) suggests that "the *procrastinated binding* of these components at the time of consumption, not at the time of production, further makes the ontology of digital artifacts inherently generative and dynamic", and subsequently data and digital objects are a result of "the pre-formatted, automated, and contingent 'live actions'" (Kitchin & Dodge, 2011, p. 27).

In Glaser et al.'s (2021) example, one of the bibliographical moments of algorithm, translating an algorithm to other contexts, involves a wide range of heterogenous actors and their respective assumptions-embedded artifacts. The configuration of sociomaterial assemblage may differ from: a) how an algorithm is envisioned, b) how it is applied in a focal context, and c) how it is transferred to another context.

Accordingly, a sociomaterial assemblage is enacted at a specific time and place, and its performativity is transitory. In other words, even the same digital artifact in the same sociomaterial assemblage may have different degrees of influence on routines, based on the conditions (D'Adderio & Pollock, 2020).

To operationalize sociomaterial assemblage, I follow Glaser (2017), and the heterogenous arrangement consists of goal-seeking organizational actors, sometimes conflicting goals (Salvato & Rerup, 2018); skillful practices, informed by occupational or professional training (Kho & Spee, 2021); (digital) artifacts with rules and intentions embedded (Callon, 1990; D'Adderio, 2008; Sele, 2021); and guiding theories (D'Adderio, 2008). Assemblages are embedded in sociomaterial structures (D'Adderio, 2014; Glaser, 2017) (Howard-Grenville & Lodge, 2021).

2.3.4 The puzzle of recursiveness

Routines are recurrent activities (Becker, 2004). To make designed routines alive, a second puzzle associated with routine design concerns the (re)orientation of the dynamics of routines. I borrow Bucher and Langley's (2016) terminology and call this the puzzle of recursiveness. To investigate the recursive structures of social phenomena, Bucher and Langley (2016, p.595-596) ask:

> How can new concepts that go beyond local, spontaneous variations be intentionally developed while original concepts are still in place and are being

> reproduced by ongoing routine performances? Conversely, how can performances reorient according to new concepts when they are guided by original ones?"

When studying patient treatment routines in the surgical clinics of two large European teaching hospitals, Bucher and Langley (2016) discover that the nonroutine interactions of routine participants are confined in the reflective space to generate intentional variations of envisioned routines (in other words, ostensive aspect of changed routine) and in the experimental spaces to test and select those intentional variations and, consequently, seed those variations in the performative aspect.

However, different from how they explore the dynamics of routines with a performative lens in bounded social settings (i.e., reflective and experimental spaces), I deploy a processual view of routines and explore their multiplicity vis-à-vis recursiveness.

The dynamics of routines hinges on their multiplicity, or as Feldman et al., (2021, p.12) put it: "Without multiplicity, there are no dynamics.". The routines literature initially employs a quantitative understanding of routines, meaning an emphasis on the multiple actors, artifacts and how they constitute multiple patterns and actions. Gradually, and more recently, based on a relational ontology, a qualitative understanding (see Bergson, 1950) can be witnessed in D'Adderio and Pollock (2020) and Pentland et al. (2020), referring to how variations "relate to form a distinctive whole" (Pentland et al., 2020, p.3). Pentland et al. (2020) explore process multiplicity in a duality of one and many, in which the one is a singular sequence of actions and the many is variations from "space of possible paths" or "the complete set of ways a process could be performed based on observed data" in Pentland et al. (2020, p.9). This is similar to the concept of "grammar of actions" or "a set of possibilities from among which members accomplish specific sequences of action" in Pentland and Rueter (1994, p.485). D'Adderio and Pollock (2020) also advocates for a fluid ontology, in which the one is a single routine, and the many are different variations (versions) of the same routine. In their own words: "We characterize routines as ontologically fluid and only coming together as 'one routine' with great effort and as a temporary, challenged achievement" (D'Adderio & Pollock, 2020, p.14).

Following this train of thought, the multiplicity in Dionysiou and Tsoukas (2013) is critical to understand how routines are (re)created from within. Drawing on Mead's (1934) symbolic interactionism, Dionysiou and Tsoukas (2013, p.201) find that:

> Endogenously generated stability in routines is accounted for in terms of shared schemata and mutually coherent action dispositions (ostensive), whereas flexibility is accounted for in terms of the radial structure of the ostensive and the always open and flexible nature of action/interaction (performative) advanced by symbolic interactionism.

They then detail the role of the prototypical (central) core of the ostensive aspect that provides a baseline of a shared and generic understanding of roles, upon which the variations take place. Recursiveness is established when routines make connections to enable shared understandings of routine participants including "what actions will be taken in a specific instance of a routine" and "why the routine is being performed or the purpose of the routine" (Feldman & Rafaeli, 2002, p.321).

When routines are (re)created from without, Cohendet and Simon's (2016) notion of "reservoir of routines" describes their focal routine multiplicity. Cohendet and Simon (2016) witness exogenous interventions in the face of environmental jolts like crisis of creative efficiency. At Ubisoft's Montreal videogame studio, some project management routines were broken after the fallout of the cancellation of a blockbuster due to a lack of originality. This disruption prompted the introduction of principles "fail faster" and "follow the fun", as inspired by similar common practices in other game studios to reconfigure routines through breaking, partitioning, and recombing aspects from different routines. It is worth noting that the ostensive and the performative aspects of the new routines were sourced from within. That is to say, there is an existing "reservoir of routines" from which variations emerge and recursiveness hinges on the routine recombination.

Following this line of thought, I approach the multiplicity and the puzzle of recursiveness into two interrelated directions: one concerning the generation of variations and one concerning selective retention. More specifically, in the context of routine design, my questions are: *how are variations generated from without and how are variations selectively retained in the multiplicity of routines from within?* In order to do so, I first explore the appropriation of Variation and Selective Retention (VSR) in the routines literature.

Intentional variation. Drawing from Campbell (1965, 1994), Feldman and Pentland (2003) apply the model of VSR to understand endogenous change within the routines; "specifically, performances are variations that are selectively retained in the ostensive aspects of the routine" (Feldman & Pentland, 2003, p.112). They exemplify the inherent improvisational aspect of practice and the importance of attending to the situation in an academic hiring routine, in which special arrangements may be requested to accommodate the complex context in question. In other words, each performance, taking place in particular contexts and circumstances, is an opportunity for variation, and, in turn, organizational actors maintain and change their grammar of actions.

Variations can be generated through learning (see Cohen et al., 1996). In communities like teams, the learning mode hinges on unintended learning-by-doing process, while in the knowing communities (such as the epistemic community and the community of practice), learning is intentional. Members may articulate, search, and codify new best practices (Cohendet & Llerena, 2008). In their case study of the recruitment routine at Learning Lab Denmark, Rerup and Feldman (2011) showcase how routine participants in a knowing community conducted trial-and-error (experiential) learning. They introduced different measures, such as using creative contracts, creating an employee handbook and new employee form, rewriting employment ads, hiring contract coordinators, and creating an ambassador model, in order to pursue ends like recruiting specific types of employees and in order to reconcile the tensions between the espoused and enacted schemata. Bresman (2013) on the other hand details the process of external (vicarious) learning in drug development routines, in which one group identified and translated the knowledge developed by another group and adopted it and continued with the changed routines.

Deken et al. (2016, p.660) coin the term routine work, or "actors' efforts through which they direct routine performances toward their intended outcomes and respond to emerging consequences of earlier routine work". Three types of routine work, i.e., flexing, stretching, and inventing, are involved in generating progressively novel variations of actions and outcomes, or "innovations-in-the making" (Deken & Sele, 2021). In the context of industrial digitalization, they detail how actors in AutoCo flexed routines to change existing patterns, stretched the application of patterns to actors unfamiliar with them and invent brand new patterns.

When adopting a processual turn, the ongoing interactions between performing and patterning may generate variations. Dittrich and Seidl (2018) demonstrate that there is room for patterning when performing routines. For example, they trace variations in performance to variations in the ends and/or means in such performance and challenge the assumption held by many of the abovementioned studies, namely that routine participants choose means to accomplish pre-defined ends. In their ethnographic study at a pharmaceutical company, they focus on intentional actions emerging from routines of production and operations. From the possibilities engendered by an unfolding situation, routine participants foreground means through performing, and may create new ends-in-views different from the initial goals. Subsequently through patterning, actors update goals for the routine. Therefore, this emerging intentionality facilitates a new means-ends relationship (i.e., how means influence ends), which may lead to progressive means-ends cycles and continuous routine change.

Selective retention. Greater variety, in line with Feldman and Pentland's (2003) application of VSR, is a prerequisite for change (Pentland et al., 2011), not change per se. This is because such performance or pattern variation may be idiosyncratic and does not necessarily mean that a change in routines has occurred (Feldman & Pentland, 2003; Howard-Grenville & Rerup, 2016). The organizational context in which routines are embedded in may also circumvent perpetual improvisation (Howard-Grenville, 2005). In addition, when variations amass, managerial actions can be required to select and retain the desired variations (Grand, 2021); however, such intentional efforts to reorient to the ostensive from the performative can be challenging (Rerup & Feldman, 2011).

Patterning, understood as "interrelating stability and change", is a power tool to understand endogenous change and explain the difficulties associated with exogenous change (Tsoukas, 2021, p.43). Goh and Pentland, in their two articles (2019 and 2021), have shown how patterning can be a motor of routine change (cf. Van de Ven & Poole, 1995). Other than variation in performances, they specifically investigate variations in paths, or possible sequences of actions of how a routine could unfold (Pentland et al., 2020). In other words, the focus shifts from routine performance to how they are performed one step at a time. Each step-by-step routine performance is an instance of path. When routines unfold, they may follow or deviate the paths as performed before. Through patterning, Goh and Pentland (2019) showcase in videogame development routines how paths are added and dropped during sprints. This point reoccurs in Pentland et al. (2020) where patterning is related to variations of paths, through the expansion and contraction of the space of possible paths.

Artifacts or artifactual representations play an important role in evolutionary routine change. D'Adderio (2008) provides the performativity framework outlined previously, in which the endogenous interactions between artifactual representation (such as artifact-embedded rules and SOPs) and performances are conceptualized as iterative cycles of framing (selective retention), overflowing (variation), and reframing (selective retention). Accordingly, routine evolution is an ongoing convergent and divergent process between rules and actions.

Similarly, the emerging discussion in materializing (D'Adderio, 2021) points at examining the becoming of sociomaterial assemblages, especially how artifact-embedded variations may exert their influence in routine dynamics through a progressive and/or simultaneous chain of materialization (D'Adderio & Pollock, 2020; Glaser et al., 2021).

2.4 Summary

This chronological review on the concept of routines has showcased how different perspectives theorize routines from a thing to a process. Within the routine dynamics tradition, the understanding of the role of (digital) artifact advances from being passive and opaque from the outside of the routines to an essential component in materializing.

Routine design has an important role to understand how routines are changed to create a preferred situation (Wegener & Glaser, 2021). However, one of the caveats is the designed routines may be dead, when routine designers conflate patterns of action with things, and when routine participants disregard the digital artifacts and subsequently the designed routines (Pentland & Feldman, 2008).

I observe the routine design challenges associated with the dynamics of routines in two puzzles: the puzzle of generativity and the puzzle of recursiveness.

Live routines are generative. The generativity gives rise to performance variations under different circumstances. Digital technology is also generative when a digital artifact's influence on routines is exerted and transformed through a chain of materializations. The puzzle of generativity concerns the design of generative systems of routine and digital technology: *how are generative systems of routines and digital technology created from without*?

Following Pentland et al. (2020, p.5), I use multiplicity as a noun, not an adjective: live routines *are* a multiplicity, not live routines *have* multiplicity (see also Deleuze & Guattari, 1987). Variations can take place in the repertoire of different elements of routines, like of actions, paths, and patterns. Variations are not necessarily routine change. The puzzle of recursiveness concerns the intentional variation and selective retention: *how are variations generated from without and how are variations selectively retained in the multiplicity of routines from within*?

Upon addressing these puzzles, I aim to answer the research question: *how do organizational actors design live routines?*

3 Methodology

Routine design, by design, concerns a change process. A process study tackles questions on how "things" unfold and change over time. Studying a change process has changed my understanding of change and my personal relationship with change. As detailed in the preceding chapter, the routines literature has moved toward adapting a stronger processual view of routines over the past 20 years; a similar metaphysical transition can be witnessed in my approach with routines, especially how I research routine design.

My research process shifts between field and desk, and I experienced several aha moments. I first outline some perspectives on how I became a process researcher, by introducing process ontology of change and concepts used in understanding and studying routine design. Next, I unveil the backstage of the efforts in alternating between field and desk research to become a routines researcher. I zoomed in on and zoomed out from this longitudinal case study of three years in two analysis modes: a prehensive analysis and a reconstructive analysis, each with a difference theoretical focus on the theoretical phenomenon of routine design to understand "what is going on here?" and "what is this a case of?" (Tsoukas, 2018). Lastly, I reflected upon methodological choices I made and how they were solidified in this research.

3.1 Becoming a process researcher

Langley (1999, p.692) states "process research is concerned with understanding how things evolve over time and why they evolve in this way (see Van de Ven & Huber, 1990)". This study of routine design deploys process research on how and why routines change over time. An ideal empirical context for this type of study is a firm where I could have the access to observe a setting where there are ongoing routine changes.

3.1.1 Initiation

Prior to my Ph.D. research, a research project on MBD (Model-based Definition) was initiated by my main supervisor-to-be in December 2016. The research project members conducted seven interviews with various informants from TurbineCo (a pseudonym), to gain a general understanding of the organization, including the products, project management of turbine as well as how 3D models were utilized. The gate opener at TurbineCo introduced Sven, the project manager of the MBD project, to the research project team, who detailed the experience with 3D models and a model-based way of working. My main supervisor-to-be envisioned how this MBD project would become a generative empirical context for a doctoral project, and Sven also acknowledged the benefits of having a researcher documenting the process independently. They negotiated the access to the "field" and worked on the necessary authorizations with the CEO of TurbineCo and signed non-disclosure agreements to fruit a doctoral project.

That was the situation before my Ph.D. journey commenced in September 2017. I caught up on the interviews but kept an open mind going into the field. In November 2017, my main supervisor and I conducted our very first one-day field visit to formally initiate the data collection of my doctoral project. He introduced me to Sven and took the lead in keeping up with the happenings since his last visit. Some practical concerns regarding the interview language were also addressed, and we agreed to use English to this end.

We discussed our expectations and what my involvement as a researcher would entail when observing the unfolding of the MBD project. Sven's motivation was to get a viewpoint on what the team was doing from outside the manufacturing industry; otherwise, the team would not see their own problems. He also saw it as something positive when a researcher could document the project. This reminded me of a Chinese idiom: the spectator sees the chess game better than the players.

For the following four one-day visits between December 2017 and April 2018, apart from building rapport with Sven, I also met two other team members, namely Nils, CAM programmer and Tomas, Design engineer, who represented two main manufacturing and assembly roles affected by the MBD project. Sven also offered guided tours to different offices and manufacturing workshops, both conventional manufacturing and additive manufacturing, so that I got a good understanding of the complexity of a machine like a gas turbine and the current way of working.

3.1.2 Motivation of a single case study

Despite not being able to select the research site myself, this was about the time when I started to realize that TurbineCo was an ideal research site for a longitudinal single case study.

Firstly, the sociomaterial context of TurbineCo provided an intriguing setting where organizational actors, digital artifacts, and physical artifacts were interwoven. Secondly, the MBD project at TurbineCo was an exemplar of how a Swedish manufacturing firm engaged with industrial digitalization, especially to achieve a digital thread. 3D models were regarded as the foundation for digital thread, while at TurbineCo the dependence on paper drawings and documents hindered the potential of 3D models in manufacturing and assembly work. As a first step to reduce the reliance on paper drawings, TurbineCo decided to adopt MBD, by the means of an implementation of a PLM (Product Lifecyle Management) called PLM+.

Thirdly, it was a unique opportunity to observe how change would unfold in real time. The project work coincided with my Ph.D. timeline, and both were scheduled to last a few years. By relying on real-time data, as Van de Ven suggests (2007, p.208), I could "maximize the probability of discovering short-lived factors and changes that exert an important influence."

A common concern associated with theory building from a single case is how the particular would represent the universal, in terms of the validity of idiographic explanations (Tsoukas, 1989) or the generalizability of small-N study (Tsoukas, 2019). To facilitate (external) validity and (heuristic) generalizability, I contemplated what the MBD project could potentially offer and arrived at two strategies. One was to follow both the progress in manufacturing and assembly so that there would be opportunities for within-case comparisons. The other one was to schedule my visits according to the release schedule so that I could get a clearer view from the informants of what transpired for the current release.

3.1.3 Theorizing process

Almost in parallel to the initiation of the empirical study, I attended courses to (re)learn the art and craft of doing research. The first aha moment came upon reading Van de Ven's (2007) *Engaged Scholarship* that change could be studied using a variance or a process perspective, but each would have different ontological (concerning existence: what the nature of existence is) and epistemological (concerning knowledge: what we can know and how we can know it) assumptions of change.

In the Western world, the mode of thought is dominated by a substance ontology of change that views the world's particulars as being (Rescher, 1996). This tradition can be traced to empiricism and rationalism relating to Aristotelian logic and Platonic idealism respectively (see James, 1909).

Concepts are a naming exercise through which a thing is defined, identified and located in a system of causal relations (Chia, 2003). As a result, "the literal, the visible and the articulated" (Chia, 2003, p.958) are rendered in entitative languages like an alphabetic one to create a precise representation of reality, in which the fixed and stable "things" take the ontological superiority. The statements of what is and what is not, or the subject-predicate dualism are prevalent. As Langley and Tsoukas (2016, p.3) point out "Consider, for example, the phrase 'the student is reading' (Farmer, 1997, p.64). The process of 'reading' is happening to the entity 'the student.'" For the unfixed and unstable, it is a difficult but manageable task to provide an identity through activities like "reading". Such a world can be modelled, and the world is stable enough to be modelled through language; hence, change is then happening to things.

If the departure point for understanding the ultimate reality is not logic and rationality, if it is not comprehensible via intellectual analyses, what else can it be? In Eastern thoughts, a physical material thing has an illusionary appearance. In this worldview, disorder, instability, and uncertainty are the primordial conditions. Eastern modes of thought privilege the "the invisible, the tacit and the unspeakable" (Chia, 2003, p.958) and emphasize flow, movement, and transformation. The world does not change. It becomes.

As Langley and Tsoukas (2017, p.4, emphasis in the original) continue with the example of "the student is reading", there are limits with alphabetic languages:

> The student is not an unchanging substance, unaffected by her experiences, but, on the contrary, is constituted by her experiences: reading is one process among others that constitutes the student. In fact, taken to its logical limits, the student does not exist apart of her experiences – she *is* her experiences (Farmer, 1997, p.65)[…] Change is not something that happens to things, but the way in which reality is brought into being in every instant.

For non-alphabetic languages, words shall not be taken literally as they hint something unspeakable beyond concepts and ideas. The Chinese language, for example, uses pictograms and ideograms to convey symbolic meanings embedded in the shape of stokes of the characters. A pedagogical example would be a Chinese equivalent of change, namely 变化, with two characters, 变 and 化. The pictogram of 变 in Swedish Sinologist Cecilia Lindqvist's (1989) book *Tecknens Rike* or *The Empire of Sign* is construed as two people with one up and one down as if they were lying head to toe. Both characters' etymology can be traced to *the Book of Changes* or *I Ching*, which took shape around 500 B.C.E. According to *I Ching*, each character refers to an aspect of change: 变 means the emergence of the new, while 化 means the gradual transformation in *The Commentaries* on hexagram the Creative ䷀ (see Wilhelm, 1951/2003, p. 371).

The process inquiry of change in the West begins with Heraclitus. Interestingly many in the West are familiar with Heraclitus' aphorism "Panta rhei" or everything flows. In the East, Confucius famously said in *Antalects* (9.17): "Everything flows on and on like this river, without pause, day and night."[10] A number of Western philosophers after antiquity also question the centrality of substance, such as Leibniz, Hegel, Bergson, James, and Whitehead (and many more in Helin et al., 2014).

Whitehead especially has a closer affinity to Asian modes of thought, as evidenced in this quote (1929/1978, [PR 11]):

> The philosophy of organism seems to approximate more to some strains of Indian, or Chinese, thought than to western Asiatic, or European thought. One side makes process ultimate; the other side makes fact ultimate.

When reading Whitehead (1929/1978), I concurred with my own lived experience that my cultural patterning preserves this privilege of becoming, which, to be frank, was a connection I would not have made before being exposed to a process ontology of change.

To sum up, a substance and a process ontology of change subscribe to different assumptions of the world: a substance/entity or a process/becoming view. Instead of privileging stability, I orient to the impermanence or "ontological restlessness" of reality (Chia, 2003).

3.1.4 Studying process

When thinking about process in the context of process organization studies, this substance-process distinction is critical to understand the nature of change. Process may be treated as an epiphenomenon of entities, and change, in turn, is construed as a transient process between two stable states. This is considered a "synoptic" (Tsoukas & Chia, 2002) or "weak-process" (Bakken & Hernes, 2006) perspective and views process as "happening to things" (Langley & Tsoukas, 2017, p.3). Lewin's (1947, pp.34-35) change management model "Changing as Three Steps: Unfreezing, Moving, and Freezing" represents an epitomic stage model of change, which treats the subject of change unchanging. This was the prevalent view on routine change before the routines literature. Routines were black boxed and treated as stable entities and changes happen to them (Parmigiani & Howard-Grenville, 2011).

[10] 逝者如斯夫，不舍昼夜。 Translation by Wilhelm (1951/2003, p.lv)

On the other hand, process can also be regarded as a primary condition of reality. This strong process perspective sees change as imminent and the world ever becoming. Rest or standstill is an aspect of change. Things are "momentary instantiations of processes" (Cloutier & Langley, 2020, p.3). One of the fundamental pieces in this tradition is Karl Weick's (1979) *The Social Psychology of Organizing*. Without explicitly framing his work as a process study, Weick (1979, p.3) approaches organization as organizing:

> A consensually validated grammar for reducing equivocality by means of sensible interlocked behaviors. To organize is to assemble ongoing interdependent actions into sensible sequences that generate sensible outcomes.

By framing phenomena as gerunds (i.e., "-ing" forms) instead of nouns, the phenomenon of organizing, is seen as emergent, self-transformative, and in flux through organizing. In the latest processual turn, as elaborated in detail in Chapter 2, patterning, performing, and materializing become the theoretical foci in routine dynamics (See also Tsoukas, 2021).

The use of strong/weak in this context is not to signify the value of each approach; rather, it is the treatment of the ontological role of entity and process. The approaches constitute a continuum of process theorizing, and each constitutes different ways of identifying and analyzing process depths.

Being foreign to TurbineCo did not hinder my becoming as an engaged scholar (Van de Ven, 2007). The setup of my Ph.D. project allowed me to engage with those who experience the process firsthand and study it from within, or according to Langley and Tsoukas (2017, p.8, emphasis in the original): "studying a phenomenon from *within* involves an effort to capture the evolving meaningful experience – the *qualia* – of those involved in it, through eliciting first-person accounts or partaking oneself in that experience."

Situated in a process in real time, I had the opportunity to study such experience while it was unfolding (in-the-flow) and also in retrospect when particular results materialized (after-the-fact). Based on my reading of Howard-Grenville et al. (2016), Langley and Tsoukas (2017), Nicolini (2009), and Van Hulst et al. (2017), I intended to approach my observed process through zooming in on the "moment-by-moment improvisations" and zooming out to the "long-term change over time" (Langley & Tsoukas, 2017, p.11). When zooming in, I could record how present events prehended (Whitehead 1929/1978) previous ones by the MBD project members and when zooming out, I could focus on the big picture of how routines evolved over time. The idea of prehension, tracing back to Whitehead, in this context, means "actors always define and act in their actual event through their engagement with past, present and anticipated events." (Hussenot & Missonier, 2016, p.531). The zooming-in and zooming-out became prehensive analysis and reconstructive analysis, as detailed in the next section.

3.2 Becoming a routines researcher

At the outset, with a head start in data collection, I understood the project as introducing new model-based ways of working to replace the prevalent drawing-based ways of working by means of some customized applications from a new PLM system, PLM+. During my bachelor's studies, I worked on projects with 3D/4D models in the construction industry (e.g., building information modeling), in addition to my generalist's training in both management and organization, and software and system development. Therefore, the empirical context was not totally foreign to me.

3.2.1 Conducting process research

The MBD project work was organized according to the biannual releases (Release 1 at 17Q4, Release 2 at 18Q1, Release 3 at 18Q3), and later quarterly releases (Release 3.1 at 18Q4, Release 3.2 at 19Q1, Release 3.3 at 19Q3, Release 3.4 at 19Q4, and Release 3.5 at 20Q1) of PLM+, which became the anchors of my theorization of events (see Appendix 1. for sources of data collection). As motivated earlier, to strengthen the validity and generalizability, Sven and I synchronized my upcoming sojourns at TurbineCo according to the release schedule from May 2018. We also agreed that I should be allowed to stay longer to be immersed in the MBD project. These long visits lasted between two to four days. More team members were introduced to me: namely Robin, Manufacturing engineer; Vincent, Production engineer; and Mats, CAM programmer. I also met their line managers: Josefin, Line manager in assembly; Emma, Line manager in manufacturing; a sponsor (Erik, Coordinator), and a representative from IT (Bo, IT Support). Apart from revisiting manufacturing workshops, Sven and Erik showed me the assembly workshops, where I saw turbines being assembled from the ground up.

As a frequent visitor onsite, I was required to comply with even stricter secrecy and safety measures onsite. For these sojourns, I occupied free office cubicles when I was not meeting or observing the informants. I carried around a notebook to record research activities and quick reflections from interviews and observations, and other spontaneous informal talks. Upon returning to the hotel, I transformed the notes into entries in my field diary.

In the beginning of my study, when I was coding the project team's work in real time, I could not distinguish between the type of actions and how the releases would unfold in the future. I focused instead on the empirical facts of the project and created an important research output: an ever-changing case document. This included different empirical narratives, namely TurbineCo's organization, the MBD project, new ways of working and the included challenges. As the informants' project work was organized by the releases, a sequence of events was first established, including the happenings that led to the MBD project, and project work for past and ongoing releases (see Appendix 2. for synopses of the happenings). This case document was updated after each visit.

Upon a deeper understanding of the project and the change process, Sven and my main supervisor decided to expand my role at TurbineCo. For the research project, I helped to organize and invite the MBD project team to a workshop on MBD in August 2018. Research outputs like the case document, literature reviews, conference papers, ideas, and short essays were presented to Sven to catch up with my doctoral project.

To be even more engaged (Van de Ven, 2007) in TurbineCo's digitalization journey, the conversation on evaluation brought a two-year change management survey to fruition. With help from my supervisors, we adapted and translated questions from the organizational change recipients' beliefs scale (Armenakis et al., 2007) to examine the buy-ins among workers in manufacturing and assembly on PLM+ and digitalization at large through five dimensions: discrepancy, appropriateness, efficacy, principal support, and valence. We designed this survey as a panel study, with the intention of comparing the buy-ins through an annually recurring survey. The first round took place in March and April 2019. My main supervisor and I presented primarily descriptive results from the survey to a group of line managers and mid-level managers from manufacturing and assembly in May 2019. The survey data did not make an appearance in this monograph, but it enriched my understanding of the context, especially on digitalization beyond a buzzword.

These visits activated my heuristic iterations of data collection and data analysis. In parallel to data collection, I started to code immediately upon returning to my dwelling. Some of the inductive analysis was captured in my field notes, while some were recomposed into new questions. After each visit, I transcribed and coded the interviews and broadly divided the empirical themes. In turn, I updated the case document, and created memos on specific themes, e.g., the ways of working and a timeline of PLM+.

In late 2019, my supervisors and I contemplated a stopping point in data collection, as the scheduled releases were drawing to an end. The MBD project would be continued in a different format at the same time as TurbineCo was undergoing a major reorganization. I was rather hesitant. As Langley expressed in her presentation at the 2016 *Academy of Management Annual*

Meeting (see Gehman et al., 2018), I concurred that for a process study, it would be rather arbitrary to decide a stopping point when "things" continued unfolding. Little did I know that the timing to conclude presented itself, albeit in an unexpected way.

I scheduled another long visit in December 2019 but had to cancel due to a change of plans. Sven and I tried to connect online instead, and it turned out to be a rehearsal of the new normalcy of remote working. We went ahead with the second edition of the change management survey (Armenakis et al., 2007), which took place between January and February 2020. The remaining three visits were done via digital means due to the Covid-19 pandemic. The MBD project was affected, but the final release was rolled out as planned. Sven and I decided to cancel the workshop with managers, but we reviewed the result presentation together in April 2020. Upon receiving some more pieces of real-time information from the interviews, I closed the books on data collection.

As the informants and I built rapport during the past two years, the switch to an online-based interaction was proceeded with no major hindrance. However, due to the technical setup, I decided not to continue with non-participant observations. As the project was reaching an end, this physical distance in a way facilitated the gradual zooming out from the granular design actions to trace how routines have changed. In April 2022, Sven and I reconvened in person after almost two years to exchange progress in our respective projects, through which I sought and received closure.

3.2.2 Collecting process data

Process data "consist largely of stories about what happened and who did what when-that is, events, activities, and choices ordered over time" (Langley, 1999, p.692). In this sense, process data is a flow of lived experience. For researchers, when collecting process data, this focus is on engaging people who have lived and experienced the events firsthand and how "the experience of action and its consequences changes the agent" (Tsoukas, 2021, p.38).

Before my fieldwork commenced, seven interviews were conducted during three visits by my main supervisor and colleagues. The MBD project started in late 2016, and I followed the project in real time as it unfolded between 2017 and 2020. I made quarterly visits, coinciding with the release rollouts, so that I could follow up on the recent release and the planning for the next one. In total, 17 physical visits and 3 virtual visits were made (see Table 8. for an overview and Appendix 1. for a detailed list of the visits). To anonymize the release schedule, the releases are referred to in the text by the format of year and quarter. For example, 17Q4 means the fourth quarter of 2017.

Table 8. Overview of data collected

Interview	65 interviews (including 7 interviews by colleagues)
Observation	10 observations on project work 4 observations on weekly scrum meetings
Document	31 documents

See Appendix 1. for the list of interviews, observations, and documents

My main supervisor was a mentor who guided me through the first few semi-structured interviews before I was left to my own devices. Drawing upon my own curiosity about the project and digital technology, I would follow up with questions about the applications in PLM and their embeddedness in the socio-material context (Howard-Grenville & Lodge, 2021). The interviews would often pivot organically to the benefits of applications and thereby new ways of working, as seen from the different occupational roles, affected by the project. Apart from active listening, notes were taken during these interviews, recording some emergent empirical themes originating from the informants' narrations.

In total including the seven interviews done by my colleagues, we carried out 65 semi-structured interviews (around 68 hours). I managed to interview all the team members and some other relevant organizational actors. To prompt narratives, a generic interview guide was prepared on three main themes with the team members:

- Recent development of the MBD project
- Current project work
- Perceived change in manufacturing and assembly work (if any)

For other informants, apart from these themes, more questions were also posed regarding their work responsibilities and digitalization-related changes at TurbineCo.

During seven of the long visits, I was able to conduct non-participant observations on the project work, to see their project work and some paper or model-based ways of working in action. I was invited to observe a version of scrum stand-up meetings, in which the team members answered three questions regarding their progress, their tasks at hand, and their perceived obstacles. I also conducted some non-participant observations impromptu. During some interviews, informants at times would need to interact with their colleagues in their "day job", in which their current ways of working were enacted. These observations and my quick impression from the field were captured in my field notes.

I was recommended a reading list of internal and external documents on the MBD theory, model-based practices, and the project; however, due to secrecy, many of them were returned after the stays. Meanwhile, I collected industry standards, annual reports of TurbineCo and IndustryCo (between 2010 and 2020), and other relevant news articles on TurbineCo.

3.2.3 What's going on here?

Tsoukas (2018, p.385) states:

> Organizational and management research adopting small-N research designs is conducted within a space demarcated by two questions: 'What is going on here?' and 'What is this a case of?' The first question calls for situational specificity, the second for theoretical reasoning.

When immersed in the empirical context, I was lost in the situational specificity. The informants were generous with elaborating their lived experience, about what they were doing and what happened. Such stories pointed at different units and levels of events, experienced by one or more informants, each of which could lead to different theoretical and practical insights. Needless to say, I was swamped with different kinds of information. Empirically, it was evident that I was observing the project team's actions on X. The ultimate goal of these actions on X was to enable a digital thread.

At first, I had an impression of an IT implementation project, and thought the X was PLM+. After all, the MBD project was organized as a subsidiary taskforce to the overall PLM+ implementation project, and the team was focusing on MBD-related features in the CAD-CAM chain and Digital Work Instructions (DWI) suites (see Chapter 5).

I became hesitant about this framing when I realized how the team talked about their project work. The MBD team referred to themselves as the Business while the IT architects and the implementation team as the IT. The MBD team did not participate in the actual development process; rather, they provided requirements and conducted comprehensive tests (see Chapter 5). Moreover, the MBD team themselves referred to X as "ways of working", and the project to them entailed a transition from a drawing-based to a model-based "way of working" in manufacturing and assembly.

This was when I realized how organizational routines, especially the routine dynamics literature, could provide the theoretical lens to illuminate the empirical phenomenon. The key theoretical focus is not what routines do, but how routines are done (see Tsoukas, 2021). This X referred to routines. In other words, the project team tried to create new patterns of action for manufacturing and assembly.

In the routines literature, the actions associated with changing patterns of action can be referred to as designing. Pentland and Feldman (2008) was one of the first to articulate the problems associated with routine design, which I also observed at TurbineCo. I was then inspired by Glaser's (2017) work on design performances, which detailed the creation of a digital artifact to intentionally change routines.

The next task was to find a process vocabulary that could describe routine change. I found Bucher and Langley's (2016, p.599-600) vocabulary between an original routine and an envisioned routine helpful in distinguishing between a current state and a future state of routines (though I appropriated the aspects as in the agential unit of sociomaterial assemblages, actions or patterns, not as ostensive and performative):

> The original routine refers to abstract understandings of the pattern of interdependent actions (the ostensive aspect or "concept" aspect). An envisioned routine is the routine that actors aim to enact in the future, and which therefore only exists as a concept or an envisioned ostensive aspect.

Nelson and Winter (1982) note that patterns of action are opaque rather than transparent, with tacit elements making it difficult to capture. Inspired by existing methods in routine dynamics literature such as sequence analysis (Gaskin et al., 2014) and narrative network (Pentland & Feldman, 2008; Goh et al., 2011), I appropriated *Business Process Model and Notation*, a modeling language from Business Process Management (Dumas et al., 2018) to visualize the flow within in a drawing-based and model-based way of working, including actors and artifacts (such as drawings and models) and digital artifacts (such as PLM, CAD/CAM, ERP). At the same time, I created a text description on ways of working to accompany the graphical representations. My understandings were presented to the informants in this format, and there were many iterations until we agreed on what the ways of working were and what the changes would be.

TurbineCo had some documentations on the drawing-based ways of working, which was reminiscent of SOP. For manufacturing, Mats, CAM engineer depicted the entire manufacturing process in 2012, which I only got a hold of after I created my visualizations. Nils, Mats and I were surprised by how similar the ways of working remained throughout the years. Furthermore, I was also relieved that we had chosen the same "grain size" (see Cohen et al., 1996). Based on Mats' work, I fine-tuned the ways of working in both manufacturing and assembly in a table format (see Chapter 5).

3.2.4 Analyzing process data

Process data, be it from real-time or retrospective, is difficult to analyze and manipulate (Langley, 1999). If process data consists of a flow of lived experience, my first task of theorizing is to reconstruct the lived experience of the informants. In the influential piece *Strategies for Theorizing from Process Data*, Langley (1999) details seven strategies. I selected the narrative strategy to construct detailed stories, and the temporal bracketing strategy to organize the flow of stories and to enable a subsequent systematic ordering of events.

I operationalized these two strategies after each and every sojourn. As a digital native, I enlisted help from digital technology upon returning to the desk. Voice recognition application was used to transcribe the interviews. Next, I listened to the audio while correcting the text in Word, where I highlighted some quotes and divided the text into thematic narratives. Finally, I imported interview transcripts, observation notes, field notes and field diaries to NVivo for a second round of coding of empirical facts, happenings, and project work.

I observed that as the MBD-related features went live after Release 3, the team encountered what they coined as “stoppers”, which literally stopped some steps in the envisioned model-based ways of working from coming alive. The informants also used “stoppers” to describe some moments before the MBD project that “stopped” TurbineCo from using models as the main source of information.

This was a surprise to me. Up until that point, I thought the MBD project was going according to plan. This was when the second aha moment came, and I realized that this discovery would be a sign of mystery (Alvesson & Kärreman, 2007) or anomaly (Sætre & Van de Ven, 2021).

So far, my analysis was inductive. While focusing on the situational uniqueness (“what’s going on here?”), my accounts became descriptive. The mere “labeling” and “mapping” exercise in the first-order narrative accounts, albeit empirically ground, were not theoretical insights. Data analysis was more than recognizing and describing *patterns* in the empirical data. To deal with the theoretical open-endedness (Tsoukas, 2018), to generate hunches (Sætre & Van de Ven, 2021) and to explain why and how these stoppers emerged, and their significance (or lack of), I resorted to the routines literature. I embarked on a theorizing process to understand a process of routine design under different two different modes of analysis.

3.2.5 What is this a case of?

Shortly after my aha moment, I started to search in the routines literature with the question "what is this a case of?" in mind. The project work reminded me of "designing routines and designing artifacts" (Pentland & Feldman, 2008), "design performances" (Glaser, 2017) and "purposeful/purposive actions" (Dittrich & Seidl, 2018). This informant-centric term "stopper" was reminiscent of "blockage" in Bucher and Langley (2016), and "disruption" in Cohendet and Simon (2016).

Similar to how Bucher and Langley (2016) used blockages to guide data analysis, I used stoppers for partitioning releases into two main time periods: in the first Period (Period I), I captured the preparation work for Release 1 up to the work in-between Release 3 and Release 3.1 when the team discovered the stoppers; and then in the second period (Period II), I followed the rest of the project work when the team worked toward removing the stoppers while making progress to introduce model-based ways of working.

Then, a third aha moment hit me. The live-dead distinction in Pentland and Feldman (2008) could be of help to analytically understand how and why the stoppers "killed" the model-based ways of working. The liveliness of the routines lay in the improvisational actions (Feldman, 2000) and the indeterminate digital artifacts (Nambisan et al., 2020). But how could organizational actors like team members in the MBD project to create and maintain the generativity of both? Inspired by the analytic concept of puzzle of recursiveness in Bucher and Langley (2016), I referred to this as the puzzle of generativity.

Prehensive analysis. I enacted a prehensive analysis mode to study routine change in-the-flow and from within (Langley & Tsoukas, 2017). Since I was embedded in what the informants were doing at the moment, I draw special attention to the stoppers. In other words, this prehensive analysis allowed me to detail how the informants prehended the events (Whitehead, 1929/1978) in the MBD project that led to the stoppers in Period I and where they subsequently acted upon them in Period II.

It became clear to me that the stoppers emerged in Period I when the team members intended to introduce digital technology to influence routines, especially when digital technology and routines were becoming in tandem, i.e., the puzzle of generativity. While the project work was unfolding, I foregrounded the actions associated with their design actions to change routines that led to the stoppers and how they dealt with them.

Together with my main supervisor, we worked on a conference for the routine dynamics track in the 35th *European Group for Organizational Studies*

(EGOS) colloquium in 2019 to record our up-to-date theorizing routine design, by zooming in on the design actions (Sun & Tell, 2019). We got the nod from the attendees and received helpful feedback. More importantly, more references were recommended within the routines literature, especially relating to an emerging discussion on routine design. This was also when I was invited to attend events organized by the Routines.Research.Community[11] to keep in touch with the state-of-the-art research and to bounce off ideas with fellow students of routines.

Continuing with the focus on design actions, together with my main supervisor, we worked on another conference paper for the 37th EGOS colloquium in 2021, zooming in on some reoccurring design actions of problem forming and problem solving (Sun & Tell, 2021).

When following the project in-the-flow and from within, I understood it as routine design (Wegener & Glaser, 2021), i.e., in between the releases, the MBD project had different design actions to change routines to create a preferred situation. Then I zoomed in on how the team conversed with the situation (Schön, 1983) and set problems in six different frames to create conditions for materializing (see Chapters 6 and 7). I also captured the moments when the situation talked back, and in some frames when stoppers emerged.

Reconstructive analysis. So far, the analytical focus was not on the internal dynamics of routines, but on the design actions. Indeed, in the prehensive analysis, the choice of foregrounding design actions had a downside, I had yet to address the puzzle of recursiveness (Bucher & Langley, 2016).

I zoomed out to understand the routine changes in manufacturing and assembly (see Chapter 8). With the outcome at hand, I revisited the progress of three years. This bird's-eye view went beyond the idiosyncrasies of the team members' design actions. I entered a reconstructive mode of analysis (Langley & Tsoukas, 2017) to unpack why routines changed (or not changed) upon the completion of the MBD project.

Different from Bucher and Langley's (2016) observation on space, mine was on the routine prototypes and routines. When zooming out from granular actions and focusing on those design artifacts, I understood the puzzle of recursiveness as intentional variation and selective retention. Specifically, I identified four routine prototypes, through which the MBD project team was able to enact successively steps in a chain of materializations or materializing (Latour, 1986; D'Adderio & Pollock, 2020; Glaser et al., 2021). Relating back to the stoppers and the six frames, I was able to detect the efforts to make

[11] https://www.researchgate.net/project/RoutinesResearchCommunity

routines alive (Cohen, 2007; Pentland & Feldman, 2008, D'Adderio, 2011) and address the puzzle of recursiveness (Bucher & Langley, 2016).

Upon reviewing chapters in *Cambridge Handbook of Routine Dynamics*, I had one more aha moment, when I realized TurbineCo's way of categorizations of paper and model-based way of working (see Chapter 5) was an empirical manifestation of routine multiplicity (Feldman et al., 2021). The terms I used to describe the being of ways of working (ex situ, in actu, in potentia, see Chapter 8) hinted at a novel understanding of qualitative multiplicity. The efforts of designing and materializing could be associated with the duality of one and many.

I summarize these analysis modes in Table 9 below.

Table 9. Analysis modes

Analysis mode	**Prehensive**	**Reconstructive**
Researcher's approach	From within	From within
Researcher's focus	In-the-flow	After-the-fact
Empirical observation	Doings and sayings of design	Routine prototypes and routines
Analytical concept	Puzzle of generativity	Puzzle of recursiveness
Analytical focus	Design actions	Evolutionary routine change

Based on Langley and Tsoukas (2017)

With solutions to the puzzle of generativity and the puzzle of recursiveness at hand, I dived back into the routines literature to identify relevant discussions and compare my findings. To narrate the new qualitative duality of one and many, I once again returned to Whitehead (1929/1978) and appropriated his wording of a macroscopic and microscopic process in the context of routines. I also decided to revise Pentland and Feldman's (2008) guidelines for designing live routines (see Chapter 9).

3.3 Reflections on methodology

To persuade with this case study (Siggelkow, 2007), I made some conscious choices during the unfolding of this process study. In the following, I reflect upon the write-up of the monograph and how I have ensured ethics and trustworthiness.

3.3.1 Composition

To make it accessible to readers from the outside, the empirical and the theoretical contexts were explained explicitly in Chapter 1. I included an empirical illustration of PLM to exemplify the characteristics of digital technology in Chapter 2. I also included a brief discussion on digital thread to foreshadow what was to come.

When it comes to presenting and reporting my findings, I approached it in what Berends and Deken (2021) call as an "inductive composition". I first presented the narratives and allowed them to speak (see Chapters 6 and 7). Then, I analyzed them in the succeeding analyses with theories and the concepts that I derived from Chapter 2. The shortcomings of this approach, as reflected by Berends and Deken (2021), could be solidified in one question "Why am I reading all this?". Qualitative process research reported in the form of a monograph also posed challenges to persuade the readers, especially when the descriptions were thick and rich and if readers were foreign to the theoretical and/or the empirical context.

I adopted a storytelling style that would seem to be repetitive, but it was with the intention of ensuring that the big picture would not be lost. The narrative accounts in Chapters 6 and 7 followed a repetitive structure to tease out the main storyline, and I analyzed the periods prehensively. I included transitional text in each chapter to have a quick "check-up" with the readers and to reiterate my understanding and my interpretation.

3.3.2 (Re)writing

This monograph has undergone some major transformations especially during the few months before the submission deadlines. But some text dated back to the early stage of my Ph.D. studies, and some in the succeeding empirical chapters were upcycled from the case document.

My writing process was everything but creative. It resembled rather a note-taking process. Notes contained mostly my understanding of papers I have read and voices from the field, following this structure: "Feldman and Pentland (2003): …" or "Sven (YYDDMM): …". I expanded the notes by "snowballing", meaning whenever a paper referred to another relevant one, I would take notes from the referred source, or when an informant mentioned some events, I would conduct keyword searches in NVivo.

As a result, the manuscript was a bricolage of words, ideas, and quotes from papers, books, interviews, observations, etc. Admittedly, notes-taking had its advantages when I wanted to backtrack to the source. In the empirical chapters, it was considered as a practice to be transparent. It was also convenient, for example, when I searched in NVivo using the informant's name and date of the interview.

This note-like style was more evident in the draft I prepared for the final seminar. While some readers might be able to tease out my voice and my ideas (like my supervisors), it was not the case for some others. The notes became too disruptive, even for me as a researcher. This was when my identity as a writer emerged, and I started to (re)write the text with readers in mind. I removed ideas and quotes that were not relevant to my main arguments to stay focused on the discussions that I aspired to take part in. I started to be more assertive and formulated my ideas as my own. Another step I took to make the text more reader-friendly was storytelling in a chronological manner. I believe the temporal coherence (Berends & Deken, 2021) in a process study would be more intuitive when discussions in the literature were presented as how they progressed, and when storytelling of the events was presented as if they were unfolding.

3.3.3 Language

But another *stopper* to be more reader friendly was a personal one. Communicating ideas in a second language (i.e., an alphabetical one), communicating academic ideas in a second language (i.e., not colloquial but descriptive, analytical, persuasive, and critical) and communicating process ideas in a second language (i.e., the wind blows, but what is the wind but the blowing?[12]) were difficult feats. I did not have the same sensitivity to the nuances of words and expressions, and I did not amass an adequate process vocabulary. Arguably, rewriting did help with the former two difficulties when I started to recognize my own "patterns of expression". An example of this was my usage of the noun "visionary", pointed out by the opponent of the final seminar. My intention with the word was to simply describe those organizational actors who envisioned. However, when used in the empirical context, there was a positive connotation associated with the person and the very act, which may, in fact, not represent what they or the acts were perceived as at all.

The last difficulty was tricky as certain words had an entitative connotation than a processual one, and the very structure of the English language is shaped by a substance thinking (Whitehead, 1929/1978). To overcome this, I relied on comments from readers and proofreaders versed in process thinking to spot semantic inconsistencies and suggest alternatives (and the fault would be all mine, if there were to be any remaining inconsistencies).

[12] This example was from Feldman's presentation at the 6th PROS symposium; see also Mesle and Dibben (2017).

3.3.4 Ethics

Since the project was initiated by my main supervisor, there were non-disclosure agreements in place. I brought up some ethical considerations during my first visits. I wanted to get first-hand confirmations on my engagement in the MBD project and ask if I would have access to sensitive information. Together with my main supervisor, Sven and I agreed from the get-go some practices regarding data collection and data storage. When doing interviews, for every new informant, my role as an independent researcher was made clear by Sven and myself. Before each interview taping, I asked the informants for their consent and put the voice recorder in eyereach. As for observations, I always informed the informants before proceeding with note-taking. The recordings, transcriptions, observation notes, and such were stored in a cloud storage solution provided by the University, which could only be accessed by my supervisors and myself.

Sven and I also decided to mask the identity of the company and the people involved. When transcribing the interviews, I maintained confidentiality by only coding the informants by their roles. But TurbineCo, PLM+, and many other pseudonyms were introduced eventually to protect the identity but still to provide a sense of "aliveness" in the empirical stories. Originally, I contemplated to including screenshots of ERP and PLM+ to illustrate the differences between drawing-based and model-based ways of working. These were removed, however, due to a complicated process to obtain permission from respective software vendors and a potential risk that the case company would become identifiable.

Though my role was expanded when I initiated the two-year change management survey, my status as an independent researcher was not compromised. I received no compensation from TurbineCo for the survey.

3.3.5 Trustworthiness

When eliciting lived experiences from the informants and reconstructing them through the researcher's lens, a common concern is related to the validity of the findings. To seek and demonstrate qualitative rigor, I relied on an appropriation of an inductive concept development process proposed by Gioia et al. (2012). The informants were considered as "knowledgeable agents" that construct their realities and I encouraged their own sense-making process through open-ended questions. Their realities were re-constructed by the researcher as first-order presentations, using informant-centric terms in narratives (Langley, 1999) and second-order analyses using researcher-centric terms, and in my case, prehensive and reconstructive analyses, including tables of theoretical summary (Cloutier & Ravasi, 2021). Such analyses and adjacent discussions were then presented to the readers and were co-constructed by them.

Through a naturalist stance, Lincoln and Guba (1985) dissect the concept of trustworthiness and offer some criteria and techniques to promote internal and external validity, reliability, and objectivity. I deployed some of their measures according to the relationship between reality vis-à-vis different lenses used by the informants, the researcher, and the readers (see also Creswell & Miller, 2000).

Reality constructed by the informants. I triangulated among different data sources. In interviews, for example, with different informants, I iterated the same questions to compare their responses. On the rare occasions when I experienced discrepancies, I managed to find opportunities to ask the same questions (but worded differently) at another time. The non-participant observations I conducted were complementary to how informants described their project work and current/envisioned ways of working. The documents I got a hold of were beneficial in reviewing the planning of the MBD project and the tasks the team had at hand.

I also had a prolonged engagement in the field (Lincoln and Guba, 1985, p.301). This allowed for temporal triangulations across different interviews, especially when examining how the planned events were executed. Being involved since the beginning of the MBD project, I also developed a personal rapport with the informants. They felt more comfortable in sharing information, and, in turn, I felt more engaged with their reality. Toward the end of these long visits, they were appreciative of the opportunities to reflect on the project in a different way when I discussed with them regarding their perspectives on the progress of the project.

Just as Sven envisioned, I was able to tease out multiple process narratives, and the informants were able to be *reflective* and made sense of their lived experiences in a new light. However, I was not "going native" and refrained from giving away my opinions, as such would influence informants' understanding of the situation. Apart from Sven, I did not mention any of the output from my scholarly work in the conversations with the rest of my informants.

Reality reconstructed by the researcher. When collecting data, I presented excerpts from the case document, and also text and graphical descriptions on ways of working in manufacturing and assembly to various informants for "member checks" (Lincoln & Guba, 1985, p.314), so that my interpretations and my usage of the informant-centric terms could be confirmed. In addition, during the closing phase of my Ph.D. research, I reconnected with Sven and arranged for an interview to catch up on the aftermath of the MBD project and share my findings. Later, we also kept e-mail correspondences in which he was able to confirm some of my doubts that emerged during the (re)writing process.

Reality co-constructed by the readers. During my Ph.D. journey, my supervisors were a sounding board for ideas, and they helped me to understand what I claimed to do and if I managed to do so. Apart from my supervisors, this "peer debriefing" (Lincoln & Guba, 1985, p.308) was done with my colleagues at the Department, the routines research community, and the opponent in my final seminar, where hard questions were asked regarding my interpretations of the informants' lived experience.

To guide the readers into the MBD project, I described the empirical context and the events leading up to the project in great detail so that the readers could immerse in the richness and the particularities of the *becoming* of TurbineCo and the MBD project in the succeeding two empirical chapters. Next, I used rich and thick descriptions in narrating the happenings during the MBD project to help the readers understand the complexity by creating a sense of "déjà vu" (Langley, 1999).

4 TurbineCo

The research site TurbineCo is a Swedish gas turbine manufacturer. Apart from the unique opportunity to follow its routine design through the MBD project, the context is also fitting for studying industrial digitalization. Digitalization depends on electricity, which can be generated by gas turbines. When connected to a generator, gas turbines generate electricity and power up the digital world.

In this chapter, I first detail some empirical backgrounds of TurbineCo, including its products, organization and digital landscape. I then introduce the role of paper drawings, 3D models, and the concept of MBD. More especially, I unpack how TurbineCo appropriated MBD in five model maturity levels, with different constellations of data sets of drawings and models. Next, I unpack the happenings that took place before and gave rise to the MBD project.

4.1 Gas turbines

A gas turbine consists of three main elements:

- A compressor: where the pressure of the gas is increased, including parts like a rotor.
- A combustor: where the compressed gas is mixed with fuel and the exhaust temperature rises to around 500°C, including parts like a burner.
- A power turbine: where the combustion gas is transformed into mechanical rotations, including parts like a stator.

There are also some auxiliary systems, such as the air intake system, exhaust system, starting system, and fuel system, to assist and ensure the intended operations of these main elements.

A complete gas turbine by itself contains more than ten thousand parts, like a Chinese puzzle that one person can solve by themself. In contrast to the automotive industry, where mass production is the dominant production method, a gas turbine is not standardized and is not a volume product. Instead, it is unit-produced and highly tailored to the needs of the end customer, hence a discrete product. For example, a gas turbine can be used for electrical power generation and mechanical drive. The production of electricity involves transformations from natural gas and/or other fuels into energy, which through a generator is then converted into electrical power. For power producers, the electricity is then transmitted and distributed from power plants to end users, while for the process industry, the electricity is used directly to supply the plant.

Apart from power generation, a gas turbine can also function as a mechanical drive for pumps and a compressor for gas injection, on offshore oil and gas platforms, or onshore production and pipelines. Depending on the application, industrial gas turbines can be cased in packages, whose sizes can range from a studio to a three-bedroom apartment and can weigh more than 150 tons. Aeroderivative gas turbines, on the other hand, are smaller and weigh much less and can be cased in mobile units.

TurbineCo specializes in industrial and aeroderivative gas turbines, ranging from small to medium sizes (15-to-60 megawatt, MW). It manufactures four main industrial gas turbine models and receives commissions for aeroderivative gas turbines. Each model has a few variants to match their applications. A majority of TurbineCo's clients purchase gas turbines for power generations. Persistent performance with the minimal downtime of gas turbine is one of the unique selling points that TurbineCo takes pride in. TurbineCo also commits to reducing the NOx emissions to single-digital levels, to meet strict emission regulations.

It is detailed in the *History of TurbineCo* that the Swedish sites of TurbineCo, including its previous incarnations, have manufactured more than 1,000 gas turbines over the years, many of which are actively in use in the Swedish and international markets. A gas turbine can be sold for SEK 100–150 million. Around 60 and 90 units of gas turbines are commissioned yearly. A typical production cycle would take up to one year to complete.

4.2 Organization

In the *History of TurbineCo*, the lineage of TurbineCo can be traced to some Swedish ancestral business pursuits of steam and gas turbines. In the 20th century, they developed several cutting-edge steam and gas turbine models. After many changes in ownership, it was acquired by a multinational industrial conglomerate IndustryCo (a pseudonym) in the early 2000s and joined by sibling sites around the globe. Apart from the power generation business, IndustryCo has also been an industrial leader in Digital Factories, supplying many pioneering digital solutions to TurbineCo throughout the years, including CAD/CAM and a backbone for digital thread, PLM.

Several major reorganizations have occurred since the acquisition. One of the notable ones took place in 2011 when parts of the steam turbine business were transferred to one of the sister sites, so that TurbineCo could concentrate its production capacity on gas turbines. Minor reorganizations concerning mainly the reporting structure happened almost every fiscal year. During the concluding phase of the data collection, another major reorganization was scheduled to carve out the power generation business.

TurbineCo has its main offices and production facilities in a Swedish industrial town of Rotorstad (a pseudonym), while having some production facilities in another Swedish industrial town of Statorstad ((a pseudonym), and some offices scattered across Sweden. TurbineCo also has a close partnership with North American site Motorville (a pseudonym) (see Figure 2. below for an illustration). At the time of the study, TurbineCo's Swedish sites employed around 2500 people, and TurbineCo's yearly revenue was around SEK 10 billion (Document, TurbineCo's Annual Report FY18–19).

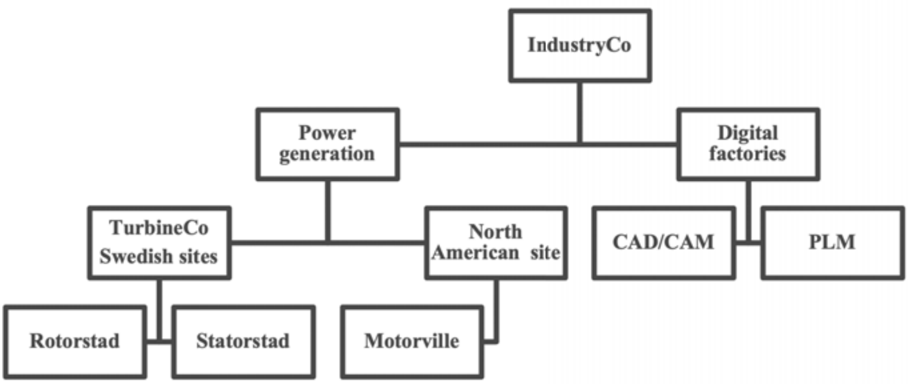

Figure 2. IndustryCo's organizational structure

TurbineCo is organized as a matrix organization, consisting of vertical silo organizations, and horizontal project organizations. The silo organization of TurbineCo is permanent, including R&D, order engineering, sales, procurement, manufacturing, assembly, delivery, and service. Collectively, these departments are referred to as *the Business,* as they are the functions that generate income one way or another. Departments like corporate communication, accounting, HR, and IT that are of support nature, are not considered as being part of the Business. The Business mirrors a linear sequence of a product lifecycle, with the stages that come after any given stages being referred to as *downstream* activities, and those before as *upstream* activities.

The silos of R&D, manufacturing, and assembly are integral to this dissertation. To facilitate collaborations, these departments and their sub-units are not dispersedly located. For example, for R&D, different engineering disciplines have their designated areas in the same open office landscape. For manufacturing and assembly, workers collaborate with each other between the shop floor and office.

R&D. The R&D department continuously develops new parts and refines existing models, divided by the main elements and the auxiliary system. For example, in the compressor unit, they are responsible for rotors, blades, casing, etc. Collaborations happen frequently with interfacing systems, in this case, the combustor. The auxiliary system has interfaces with all the other elements. Moreover, for each part, there are groups for various engineering disciplines, engineering and analyzing aerodynamics, fluid mechanics, strength of materials, mechanical integrity, and so on.

Manufacturing. In general, between 20% and 30% of the parts are manufactured in-house, like simple assemblies of rotor and stator. In addition, TurbineCo manufactures parts and components for its sibling sites and spare parts for older steam turbines (Interview, Josefin, Line manager, 181114). TurbineCo is also a pioneer in additive manufacturing to produce static parts like burners in the combustion and metal powder in rotating parts like blades (Interview, Sven, Project manager, 180327).

Assembly. The assembly department is organized by the subassemblies, namely core turbine assembly, mechanical assembly, and electrical assembly. A team of production engineers and assembly workers specializes in one subassembly. Each turbine has its workstation in the assembly workshop. For some turbines, only parts of the assemblies are conducted in-house, and the rest of the parts are assembled onsite (Interview, Vincent, Production engineer, 181114).

4.2.1 Project organization

The project organization, on the other hand, is temporary. There are two main gas turbine-related projects, namely delivery and development projects. Both can range from a full-scale gas turbine to a specific part in a gas turbine. A project manager selects team members across the R&D department from the line organization and relocates them to a coworking space. Individuals from other departments in the Business are involved temporally during different stages of the projects.

In a delivery project, once TurbineCo scores a contract, it takes up to a year to customize, manufacture, assemble, and install a gas turbine solution. Apart from the customer's requests, other conditions like the purpose of the turbine, and the geographical location would determine the design of the components and their surrounding auxiliary system.

A gas turbine development project, on the other hand, requires a few more years of dedication to develop, test, and build, and often takes a decade to finalize the design of a brand-new gas turbine. These projects are more explorative, ranging from pilot studies on a new market or experiments on the latest trends in the power sector.

Meanwhile, updating existing gas turbine models happens on a more regular basis. Almost every year, there are development projects to upgrade the best-selling models to match the market demand for performance.

An overarching stage-gate project management process guides those projects. Each project follows five stages, namely project initiation, design, sales preparation, design implementation, and validation. During project initiation, the development team conducts some feasibility studies. The R&D department reviews existing designs, picks and chooses the desired features, and proposes options in the design stage. The sales department then plans the commercialization accordingly. In design implementation, more departments, like manufacturing and assembly, are involved in implementing the designs. Finally, the turbines are monitored and tested in the stage of validation before further commercialization.

4.3 Digital landscape

At TurbineCo, a quintessential desk setup comprises multiple monitors to display a plethora of digital artifacts like CAD/CAM,[13] ERP, and PLM.

CAD/CAM stands for Computer-aided Design and Computer-aided Manufacturing. TurbineCo has been using an integrated CAD/CAM solution provided by IndustryCo (Interview, Bengt, Project manager, 170126).

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[13] CAD/CAM is often associated with CAE (Computer-aided Engineering), which facilitates different types of engineering analysis and calculations. I have excluded the discussion on CAE, as it is not addressed in the study.

CAD has revolutionized the ways of drafting in engineering design and manufacturing practices so that 2D drawings, 2D and 3D models can be created, modified, and analyzed. CAM assists the manufacturing operations. One of the most common use cases is to generate machine-readable Numerical Control codes (NC codes) for NC machines, from CAD models, so that CAM programmers and operators can skip coding on paper and typing the codes to the NC machines.

At the R&D department, the CAD/CAM program is connected to a server and can access and update the latest product data. While some installations of CAD/CAM at the manufacturing are native to the computer, meaning they are local installations without connection to the latest product data.

ERP, or Enterprise Resource Planning, manages the flow of data, concerning business resources like cash, raw materials, and production capacity. Some of the most used applications are, for example, materials management, manufacturing and production planning, supply chain management, sales, and distribution.

While the purpose of CAD/CAM is to create digital representations of components and NC codes, the PLM (Product Lifecycle Management) system manages and stores these representations and their associated data generated throughout a product's entire lifecycle. This philosophy is similar to ERP, however, instead of managing data generated by business activities, PLM concerns the product and production-related data, through applications such as systems engineering, product management, and manufacturing process management.

These digital artifacts are highly sophisticated, entailing a long learning curve and specialized training. As a result, not all employees are avid users in every digital artifact. For R&D, most are skillful at CAD/CAM and PLM while having a basic understanding of ERP. At manufacturing and assembly, fewer engage with these digital artifacts, and among those, many are experts in CAD/CAM and ERP, not PLM. Therefore, internally at TurbineCo, there is a disparity of experience, which also affects the accessibility onsite. In the manufacturing and assembly workshop, the workers have limited access to stationary computers, and the Wi-Fi signal is weak.

As a part of IndustryCo's digital landscape, all three are used by TurbineCo and its sibling sites in power generation, meaning those sites share the same interfaces and can access each other's data. However, some functionalities are locally configured and overseen by the local IT department.

4.3.1 Overview of MBD

Standardized ways of working are integral for TurbineCo to adhere to industry standards and quality assurance. Many workers have learnt them through on-the-job learning and guidance from colleagues (Interview, Sven, Project manager, 180523).

There are some generic documents (like SOP) of the manufacturing process, entitled *The Manufacturing Way at TurbineCo*. In assembly, there are generic guidelines on how to select bolts and perform certain assembly techniques. Many workers also keep and update their personal notes, to reflect upon those more specific ways of working.

4.3.2 Ways of working

Two ways of working are reported at TurbineCo, namely a drawing-based and a model-based. The difference lies in how the parts and components are represented, how their associated information is communicated among the colleagues within and across departments,[14] and, to some extent, how the information is communicated across digital artifacts. A drawing-based way (also known as drawing-centric or document-based) has a paper or a 2D drawing (hereinafter drawing) as the leading document, while a model-based way (also known as model-centric) uses a 3D model (hereinafter model) as the leading document instead.

Drawing. A drawing uses lines and numbers to describe a part. It is a blueprint and contains specific and unambiguous definitions of the shape and size of a part. It is more than just a graphic representation. By combining different view directions, type of lines, and other textual annotations, the following information of the part can be conveyed:

- Geometry
- Dimensions
- Tolerances
- Material
- Finish

International standard organizations like ASME (The American Society of Mechanical Engineers) and ISO (The International Organization for Standardization) have issued and maintained various standards to ensure uniformity in

[14] Drawings and models are not the only artifactual representations of turbine. Physical prototypes, of a specific component to a scale model of the turbine, can be produced in order to simulate and validate the design.

those specifications and interpretations: ASME Y14 series and ISO 01.100.20 mechanical engineering drawings.

At TurbineCo, prior to the introduction of CAD/CAM in the 90s, the drafting process would involve engineers drawing on a Universal Drafting Machine with drafting equipment. Nowadays, apart from the early conceptual design phase in which a pen and paper are involved, most drafting process results in 3D models of the part in CAD/CAM. To export a drawing, views are selected, and annotations and information blocks are added.

Model. A model is a 3D representation of the part in one or more model co-ordinate systems. Models have varying degrees of graphic completeness, with some hollow models, and with some missing mechanical details like threads and holes. In other words, parts are not always modeled on a one-to-one level compared to a drawing.

When associated with PMI (Product and Manufacturing Information), a model can serve a similar role as a drawing, and the non-geometric information would be visualized in 3D. Therefore, the concept of a model expands to its associated PMI and a model becomes a data set.

According to one of the leading vendors of CAD/CAM, PMI may include:

- Geometric dimensions & tolerances (GD&T)
- Dimensions and symbols
- Datum feature symbols, datum targets
- Feature control frames
- Surface finish
- Metadata
- Security markings
- Bill of Materials (BOM)
- Other user-defined PMI

3D modeling is a quintessential engineering practice. Different tools in CAD/CAM bring 2D sketches into 3D. Many commercial CAD/CAM also has PMI Application to convert drawing information. The model can then be exported as a CAD file, an image, or even a 3D PDF (in which the model is interactive).

A model is often created by one person, who becomes the owner of the model. It is reviewed and approved by the peers and is stored in PLM. Should there be any changes, the new revisions will be reviewed and approved again and updated in PLM (Interview, Sven, Project manager, 171220).

MBD. When a model and its associated PMI is utilized in all stages in a product lifecycle, it is often referred to as Model-Based Definition (MBD). According to ASME-Y14.47-2019 (p.4), MBD is defined as

> An annotated model and its associated data elements that define the product in a manner that can be used effectively without a drawing graphic sheet.

Some notable adaptors and advocators of MBD are from the aerospace and defense industry. Boeing has successfully used MBD in developing new aircrafts and has even extended its MBD-related requirements to its partners and suppliers (Boeing, 2010, 2017). In Sweden, Saab, a Swedish aerospace and defense company, has used MBD in the development of fighter system, Gripen E (Saab, 2016).

At TurbineCo, a model-based way of working is only prevalent in engineering. Designers and engineers collaborate extensively via the models within and across turbine elements. For manufacturing and assembly, almost all work is drawing-based.

4.3.3 Model maturity level

TurbineCo is keen on exploring MBD. The switch from drawing to model in manufacturing and assembly, however, is not overnight. In reality, a model-based way of working does not equate to a total elimination of drawing-based. TurbineCo appropriates MBD with more fluidity and articulates the nuances in practice.

Deriving from *ISO 16792:2015* "§ 3.2 Classification codes for drawings and data sets" and "Annex A Classification codes for drawings and data sets", TurbineCo establishes a framework for model maturity to define the gradual transition from drawing to model (see Table 10. below). When the maturity level increases, the completeness of the model increases, which would eventually have a one-to-one relationship to the part it represents. The lower levels (1–2) regard the drawing as the original and the leading document for communication. A model-based way of working starts from a level 3 as the model becomes quality assured. The higher levels (4–5) regard model data set as the original and can become the leading document, and accordingly, the model can be considered as a digital twin. Such levels are required in the aerospace and defense industry, see, for example, Section B MBD-related requirements in *Model Based Definition Checklist* by Boeing (2010).

Table 10. Model maturity level at TurbineCo

Maturity level		Drawing	Model	Example at TurbineCo
Drawing-based	Level 1 Drawing with an optional data set	Drawing is the original and is the leading document.	Optional or no model.	A drawing only
	Level 2 Data set with drawing and simplified model	Drawing is the original and is the leading document.	A complementary model includes some data set.	A drawing and a complementary model
Model-based	Level 3 Data set with model and drawing	Drawing is the original and is the leading document.	A quality-assured model includes some data set.	A drawing and a quality-assured model
	Level 4 Data set with model and simplified drawing	Drawing can be the leading document.	Model (and its data set) is the original and can be the leading document.	An interchangeable drawing and model
	Level 5 Data set with model only	No drawing.	Model (and its data set) is the original and is the leading document.	A model with PMI only

4.4 The situation before the MBD project

The MBD project set out to introduce a model-based way of working to manufacturing and assembly. Before I dive into the process of routine design, I take a closer look at the happenings prior to the MBD project, and what digital thread would entail in manufacturing and assembly.

4.4.1 The IGT100 development project in the late 2000s

The inspirations for the MBD project could be traced back to the development of a new industrial gas turbine model IGT100 (a pseudonym). In the early 2000s, models were prevalent at R&D but were used for design purposes only. Some project managers at TurbineCo witnessed the potential of the model in other lifecycle stages.

To address a new market, a new turbine IGT100 development project was commissioned in the late 2000s. Bengt, Project manager, selected a team of some 250 individuals from the line organization in R&D, manufacturing, assembly, and service (Interview, Bengt, Project manager, 170126).

Bengt saw a unique opportunity to test out digital twins. His move coincided with two recent developments in digitalization. Firstly, a new CAD/CAM was introduced to TurbineCo, supplied by IndustryCo, which enabled up-to-date modeling techniques. Models of the turbine and its outer package could be created in the same software environment, for the first time. As a result, digital twins could be generated for the entire turbine, instead of just the core engine. Secondly, a visualization lab was established near Rotorstad, supported by the local university and the municipality. It provided the sought-after hardware to visualize digital twins in a VR (Virtual Reality) environment (Interview, Axel, Lead engineer, 170601).

These product digital twins were first validated through a pilot study. The development team visualized a subassembly of another industrial gas turbine model, the IGT200 (a pseudonym). They witnessed how models in VR could realistically simulate the narrow parts inside of the turbine, and its accuracy was later proved in the actual subassembly. They also realized that this novelty would call for new ways of creating models in the new CAD/CAM (Interview, Axel, Lead engineer, 170601).

When the development work of IGT100 commenced, the project work alternated between the locations at Rotorstad and the visualization lab. Before each biweekly visit, designers and engineers at R&D were notified to finalize and freeze their models. The completeness of models increased when the whole turbine, including its package and its main elements (i.e., the compressor, the combustor, and the power turbine), was represented. Such digital twins, specifying thousands of parts and components, would be too heavy for stationary computers to load, taking up to a day! Therefore, a lightweight version would be exported to a drive and visualized at the lab (Interview, Axel, Lead engineer, 170601).

The technical setup at the visualization lab comprised a widescreen and three projectors, two for casting digital twins, and one for casting slides with extra geometry information. It was also an interactive experience for the representatives from different disciplines and lifecycle stages. With two projectors displaying different views, the team could turn and twist, zoom in and out the digital twin to review the design. For example, the modeling of the pipes was color-coded. It was not only aesthetically pleasing, but also functional for designers to visualize different interfaces among the elements (Interview, Axel, Lead engineer, 170601).

Apart from visualizing R&D-related project work, digital twins were used to validate the internal structure and design alternatives for assembly and service, instead of solely relying on physical mockups and disconnected models of the components. Representatives from assembly and service and field maintenance were incorporated early in the conceptual stage, evaluating the design alternatives based on the performance and ease of assembly/service. Therefore, new feedback loops were created in the project, and engineering changes would happen more proactively and less on an ad-hoc basis.

For example, Bengt, Project manager and Axel, Lead engineer, described some scenarios when fine-tuning the design of IGT100. All subassemblies in the assembly were simulated as early as in R&D. Assembly workers were given some animated instructions, supported with text and other documents, instead of the generic ones that they would otherwise receive. The cost for assembly was notably reduced. On the other hand, service engineers could configure and evaluate different compositions of mechanical components, like pipes, inside of the 3D model. Subsequently, they could envisage potential collisions and provide feedback for improvements to the designers.

Digital twins were also used in marketing materials. At trade fairs, visitors used 3D goggles to take a virtual tour inside of the turbine, first of its kind. Bengt, Project manager, specifically recalled one occasion at an industrial trade show where they showcased the digital twin of IGT100 and its visualization process, and they even received praise from some competitors!

These model-based ways of working in manufacturing and assembly, created within the framework of this development project of IGT100, were considered close to a model maturity level 3. Many models were quality assured, and manufacturing used some models to create tools (Interview, Sven, Project manager, 180327).

Some of these practices proliferated and changed R&D, especially the ones concerning the creation and use of models. Shortly after the successful development of IGT100, many internal awards were given to encourage innovativeness and foresight with digital twin. TurbineCo also demonstrated its ingenuity among its sibling sites and within IndustryCo's power generation business.

4.4.2 The stoppers in the early 2010s

The success of the IGT100 development project propagated the idea of using models as the single data source of product information for some 250 individuals in the project. For the rest of TurbineCo, digital twin, however, flew under the radar. The ways of working in the manufacturing and assembly for delivery projects continued to be drawing-based in the early 2010s. MBD was considered a few steps ahead of the rest of the line organization and faced a few technical and organizational stoppers (Interview, Sven, Project manager, 170126).

The technical stoppers in the model-based way of working were related to digital technology and the models. Firstly, TurbineCo lacked the proper hardware and software backbone for the entire lifecycle. For the shop floor workers, to begin with, they had limited access to computers that could display the models. Next, the information flow between R&D and downstream stages was also cut off due to the information islands. In other words, the 3D environment from R&D often stopped at the interfaces when CAD and CAM were not connected. CAM was used as a native (standalone) system at the manufacturing and assembly, meaning that CAM was treated as a local installation and had no integration to the other systems. Individuals could decide for themselves how they collected models from PLM and how often they checked the updates (Interview, Sven, Project manager, 190129).

Some organizational stoppers had to do with division of work, legality, and costs associated with MBD. First of all, designers, focusing on their R&D work, had limited knowledge of the downstream stages. As a result, the models might not contain all the necessary information needed for manufacturing and assembly. Drawings and other technical documents were needed to present the non-geometric product information. On the other hand, some manufacturing and assembly workers had limited experience with 3D models and lacked competence in understanding what information was conveyed, in which case the information in drawings was considered more straightforward. (Interview, Josefin, Line manager; Bengt, Project manager, 170126).

Next, the consensus in the industry at that time was that drawings were considered legal documents. Accordingly, drawings had to be accurate at all times, and any changes were well documented. Models were not always quality assured as they conformed to fewer contractual obligations.

And lastly, TurbineCo was vigilant about the cost-related issues. After all, a systematic upgrade of hardware and software would be an enormous investment, not to mention additional training costs. Such a decision had to be a top-down one from IndustryCo. Considering all these stoppers, the manufacturing and assembly departments in the early 2010s continued with drawing-based ways of working, remaining at a model maturity level 1 (for legacy turbines without any models) and a level 2 (for other turbines).

4.4.3 The lead-ups in the early 2010s

Even though drawings remained as the main information carrier in manufacturing and assembly, with some increasing problems in sight, MBD was brought back into the picture. Some project managers at TurbineCo realized that the root cause of non-conformance in delivery projects could be attributed to the relationship between representation (be it drawing or model) and the physical part, which was not one-to-one. Before they concluded MBD as being a potential remedy, those project managers relied on some consultants to explore the business case.

A consulting report on models at 12Q1. Two years after the IGT100 development, a group of external consultants was invited to investigate the business case of the models. Their report, entitled *3D Model-based Value Definition*, concluded some key benefits when using the models in the entire life cycle: when the product and design data are connected, it becomes the single source of quality-assured product information, which can potentially reduce the lead time and time-to-market. In the report, some best practices of MBD regarding each lifecycle were specified, together with some challenges. For example, for design and engineering, it would take longer to gather all the information required before releasing the models, which, in turn, would increase the cost.

New organizational visions at 14Q2. IndustryCo presented their new organizational visions for the rest of the 2010s, in which digitalization was set forth as one of the most critical strategic focuses. As IndustryCo had dual roles in Industry 4.0, both as a technology vendor and a customer.

First and foremost, IndustryCo, as a technology vendor, owned a portfolio of state-of-the-art digital artifacts to enable a digital thread. Those visions reassured the strategic emphasis on the continuous development of digital technology. Secondly, for other business areas, like TurbineCo’s power generation, the ambition was to go beyond the talk of Industry 4.0 and to implement novel digital technology so that the physical and digital realms of production would be integrated in a digital thread. Against this backdrop, TurbineCo then created its imperative called "*make digitalization work*" to encourage explorations and applications of digital technology.

And thirdly, the visions also suggested harmonization and consolidation of business areas. TurbineCo was tasked with integrating expertise from a recent acquisition of the aeroderivative product line called AGT100 (a pseudonym). Consequently, their collaboration with other sibling sites was also strengthened.

A video demonstration on assembly at 14Q4. To "make digitalization work", the R&D department at TurbineCo continued to explore models on the side. Their interest lay in the business case of models and MBD in downstream stages. Supported by the head of R&D, a technology consultancy firm was hired to produce a video demonstration, showcasing how models in new assembly routines could solve the increasing interface between R&D and assembly. A new PLM solution served as the main repository, where up-to-date information like drawings, models, and work instructions was displayed in one place, instead of switching among multiple digital artifacts and paper sources. This new PLM was suggested as a potential technical backbone for MBD (Interview, Sven, Project manager, 171220).

4.4.4 The business cases in the mid 2010s

A few years after the IGT100 development, an increasing digital divide was reported between R&D and manufacturing and assembly. Information islands emerged between the representations. More specifically, some hard copies of drawings and disconnected models did not correspond to the recent changes of the design, due to the drawing-based way of working in manufacturing and assembly.

Unlike the automotive industry, where the parts and components were standardized, each made-to-order turbine had different configurations of parts and components. A myriad of drawings was printed for each turbine. Version numbers on the drawings were the key identifier of change. Heavy paper binders could be spotted beside the machines on the shop floor, which contained hundreds of hard copies of drawings and other technical documents.

The models and other digital representations were stored on a few computers on the shop floor, which were not updated unless informed by the respective owners of the drawings. To make the matter worse, there were constant engineering changes every day, sometimes up to a hundred times per day per component. Therefore, it was not surprising that even the drawings were not always up to date. (Interview, Josefin, Line manager, 170126).

As a result, there were increasing costs related to reworks and non-conformances in the manufacturing and assembly workshop. In the worst-case scenario, communication-related problems could lead to contract violation when promising something that could not be delivered (Interview, Bengt, Project manager, 170601).

A pet project on assembly at 15Q4. An R&D manager who worked with assembly recognized this opportune timing to further explore digital technology and to “make digitalization work”. He received some support from the Swedish sites’ CEO and the head of R&D to start a “pet project” in assembly (Interview, Sven, Project manager, 190523).

Meanwhile, TurbineCo expedited its collaboration with IndustryCo and discussed the implementation of digital artifacts, such as PLM. After all, the internal policy “IndustryCo first” implied that TurbineCo should prioritize the available digital artifacts in IndustryCo’s portfolio. After consulting with representatives from IndustryCo, the R&D manager decided to choose IndustryCo’s own PLM (which later became PLM+) and its adjacent applications as the technical backbone for their explorations.

The project occupied him and his team for a few hours per week to experiment with new features to visualize models and work instructions in assembly. During the first six months, the project was run by the R&D manager, who later left TurbineCo. One of his close team members Sven inherited the project and became the new project manager.

An official MBD project at 16Q4. Sven had a broad network at TurbineCo and lobbied for more financial resources. Eventually, an official MBD project was started to “make digitalization work”. Sven, together with his team member Tomas, Design engineer, continued the project work. Tomas was assigned 20% (one day per week) on the project.

IndustryCo helped to provide a testing environment, installing the out-of-the-box versions of PLM and CAD/CAM. Since the vast assembly workshop was not equipped with mobile devices, the team purchased some tablets to explore assembly workers’ user interface with PLM. They consulted with some assembly experts and prepared some simplified digital work instructions for subassemblies of the core turbine. Those tests were perceived positively by the experts and workers involved (Interview, Tomas, Design engineer, 180424 & 180522).

Meanwhile, to expand the project to manufacturing, the team explored new features (the CAD-CAM chain suite, see Chapter 5) as the technical backbone for storing and transferring all the necessary PMI. The models with supplementary PMI could be used in manufacturing to generate NC codes. Sven pitched to the middle managers in manufacturing, regarding the business case of MBD and the envisioned changes in the digital landscape and ways of working. Tomas explored the features in the CAD-CAM chain, especially PMI through some video demonstrations (Interview, Sven, Project manager, 171220; Interview, Tomas, Design engineer, 180522).

These efforts paid off and the scope of the project was expanded to include manufacturing after Sven secured more funding, and TurbineCo's CEO and CFO were invited to the steering committee. One of their ambitions was also to showcase how TurbineCo could break new grounds and take the lead in digitalization, among its sibling sites (Interview, Sven, Project manager, 171122).

An implementation project of PLM+ at 16Q4. Shortly after, IndustryCo announced the planning for the implementation project of a new primary system PLM+ for its power generation business. The implementation was motivated first of all to handle the amount of product data generated every day. With the increased exchanges and collaborations among sibling sites, the incumbent PLM was becoming insufficient. Secondly, it served mainly as a design and production data repository for R&D and manufacturing, though models retrieved from PLM were stored in CAM natively. In other words, those models were saved on local computers and had to be manually updated if revisions were needed. This was a digital divide identified as a stopper previously at TurbineCo. Lastly, another important reason for adopting PLM+, was that the incumbent PLM was not well-integrated with ERP, which created issues when managing BOM (Bill of Materials) and BOP (Bill of Process) (Interview, Sven, Project manager, 171122).

BOM and BOP are some of the key production-related data communicated across the product lifecycle, managed via both ERP and PLM.[15] A BOM includes a list of materials and assemblies required to manufacture a part, specifying the descriptions and the quantities of materials. Drawings and models can also be attached. A BOP details the sequence of operations to manufacture or assemble a part, and the work areas and machines required. Those

[15] ERP and PLM offer different functionalities. PLM in general could offer more track and trace. For instance, instead of just knowing the quantity of the materials consumed, tools used in an M-BOM in ERP, in PLM, the same M-BOM could display in which component(s) the materials have been consumed and the tools have been used.

operations are also accompanied by drawings, models, and other technical instructions.

A BOM and BOP are, in essence, different representations of how the same part is structured, but they serve different ends and vary in the granularity of information in R&D, manufacturing and assembly. The R&D engineer creates an E-BOM (Engineering-BOM, as-developed) in PLM and transfers it to ERP. An E-BOM reflects how the turbine is functionally designed, i.e., the composition of the components and parts. An E-BOM may also indicate the alternatives allowed for the component in question, such as its materials (e.g., titanium, aluminum, and nickel) and suppliers. Once released into ERP, it would trigger a workflow for the manufacturing engineer to create an M-BOM (Manufacturing-BOM, as-planned) including components, fixtures, and tools needed to manufacture the parts, and an M-BOP (Manufacturing-BOP), including the operations and links to NC codes in ERP. For assembly, the production engineer creates an A-BOM (Assembly-BOM, as-built), including components, equipment, and tools needed to assemble the parts, and an A-BOP (Assembly-BOP), like the assembly sequences and the work areas in ERP. (Interview, Sven, Project manager, 171220).

In other words, an M-BOM and A-BOM are defined based upon an E-BOM. Their basic structures could be duplicated from the E-BOM, and new resources required will be added to the M-BOM and A-BOM. Subsequently the M-BOP is defined upon the M-BOM, while the A-BOP is defined upon the A-BOM (See Figure 3. below for an example of the relationship).

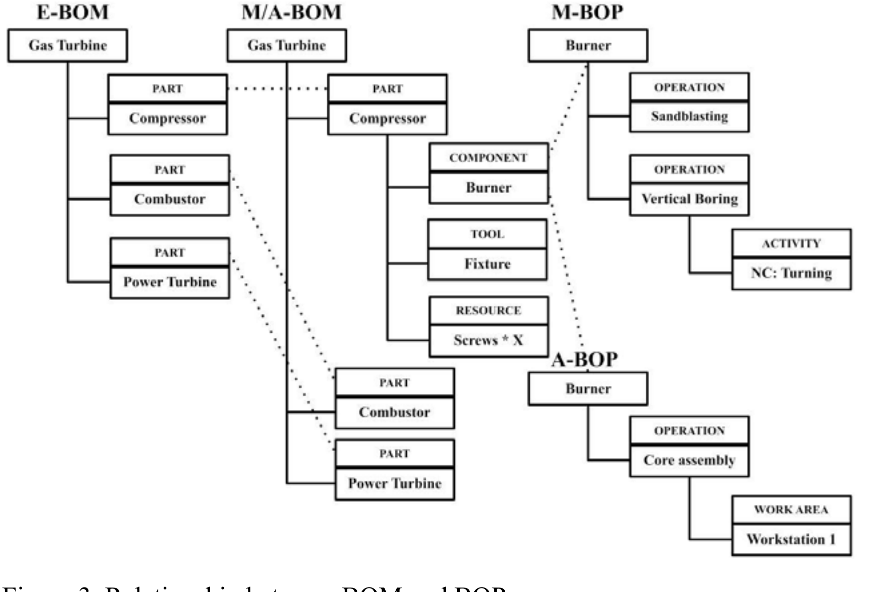

Figure 3. Relationship between BOM and BOP

With the incumbent PLM, though deriving from the E-BOM in PLM, the M-BOM and A-BOM generated in ERP were treated as information islands. The E-BOM in PLM was connected to the M-BOM and A-BOM in ERP via an internal weblink. Once an E-BOM was updated, their associated M-BOM and A-BOM were not updated directly. Instead, the manufacturing engineer and the production engineer had to use the link to check what the revisions were and manually update the M-BOM and A-BOM. In such a way, the E-BOM and M-BOM, and the E-BOM and A-BOM were linked but not connected (Interview, Sven, Project manager, 171220).

This interface revealed a fundamental division of work between PLM and ERP. Currently, only the E-BOM was managed in PLM, while the rest in was managed through ERP. ERP was considered as the primary system to manage the workflow and to create and manage the BOM and BOP, while PLM was considered as the secondary system.

After the implementation, TurbineCo envisioned a new type of relationship between ERP and PLM, as indicated in the document *PLM+ Scope Outline*. PLM+ would introduce a range of new applications to take advantage of the product and production data. Since PLM+ and ERP overlapped in some functionalities, decisions needed to be made to choose one as the primary system and another as the secondary. The goal was that PLM+ would replace ERP with PLM as the primary system to handle both the BOM and BOP, while ERP kept its role, which was to trigger workflows[16] and manage the resources (See Figure 4. below for a comparison).

[16] ERP is still the primary system for triggering workflows, as other departments in the Business like procurement need M/A-BOM to purchase materials.

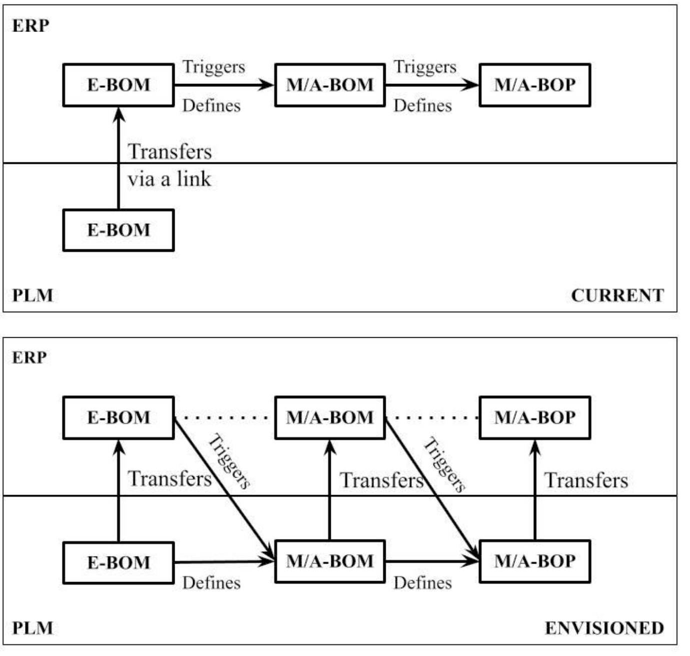

Figure 4. The current and envisioned ERP-PLM relationship

Since PLM+ would already provide the technical backbone, Sven lobbied further to include the MBD project in the scope of the PLM+ implementation instead of a separate project. He succeeded and the MBD project officially became a part of the PLM+ project at 17Q2, in which the funding would last for the first releases (Interview, Sven, Project manager, 171122).

In the next chapter, I reveal what this new relationship between ERP and PLM entails for manufacturing and assembly.

5 MBD project

The MBD project emerged in the circumstances in which the people, the technology, and the need for data came together to "make digitalization work". Workers in TurbineCo witnessed increasing problems with drawing-based ways of working in manufacturing and assembly. They realized the business case for MBD. PLM+, as one of the backbones for MBD and digital thread, had the potential to remedy the problems, to handle the amount of product data, and to establish a new relationship between PLM and ERP.

In the following text, I first introduce the current situation when the MBD project commenced and especially the drawing-based ways of working in manufacturing and assembly. Next, I outline how the two suites in PLM+, namely the CAD-CAM chain suite and the DWI (Digital Work Instructions) suite, could bring about a preferred situation of model-based ways of working in manufacturing and assembly respectively. Finally, I describe the setup of the project, the people involved and how it was managed based on agile development.

5.1 Current situation

Before the MBD project, the maturity level in manufacturing and assembly was mainly at a level 2, i.e., a drawing-based way of working. Level 1 also existed for older turbines (legacy components). Not all the information in drawings was represented in models. Quality assured models were sent back and forth only in R&D, while drawings were still the overall leading document in the rest of the lifecycle stages. Only for certain development projects (like the IGT100 project mentioned in Chapter 4), the level was close to a level 3 (Interview, Sven, Project manager, 200603).

5.1.1 Manufacturing

In the manufacturing department, there were around 500 employees, among which the roles of Manufacturing Engineer, CAM programmer, and Operator would be affected by the MBD project (see Table. 11 below).

Table 11. The manufacturing roles affected by MBD

Role	Core responsibility	Headcount
Manufacturing engineer	Defining how a part is manufactured and coordinate workflow on the shop floor	20
CAM programmer	Creating NC codes	20 (Some rotated the role as a CAM programmer and an operator.)
Operator	Operating NC machines	100

After receiving production orders from ERP, a manufacturing engineer decided on the order of production and allocates the NC machines, with the help of R&D engineers and CAM programmers. The manufacturing engineer then calculated the lead time and any costs associated with manufacturing activities. For those small-sized or similar to previously manufactured parts, the production could take place within a few days. For the bigger ones, it could take up to two months (Interview, Nils, CAM programmer, 180524).

Groups of CAM programmers and operators worked together on some 25 NC machines. Each group specialized in specific NC machines, or specific NC operations (like turning, milling, and grinding). All NC machines were connected to a network drive in which the NC codes are stored. Around 15 of the NC machines were also connected to CAD/CAM.

Almost all the CAM programmers had experience as an operator. They created and simulated the NC codes via CAD/CAM, while operators set up and monitored the NC machines to ensure the fulfillment of operations. They serviced the NC machines by changing the inserts and blowing off the chips. For some NC machines, operators also needed to manually measure the tools and enter those values to edit the NC codes (Interview, Nils, CAM programmer, 180524).

In sum, these roles navigated across a myriad of digital artifacts. Manufacturing engineers were avid users of ERP and CAM programmers were of CAD/CAM. Operators were familiar with their responsible NC machines and their operating systems. However, not all had experience in PLM, before the MBD project.

5.1.2 Current way of working in manufacturing

A manufacturing routine is directed at realizing design intents into physical parts. In this study, there are eight distinct steps involved, namely Design release, Manufacturing review, Manufacturing preparation, CAM preparation, Tool preparation, Post-processing, Production order creation and Part manufacturing. The current drawing-based ways of working relied on drawing as the leading document and ERP as the primary system.

Step 1: Design release
When an R&D engineer finalized the design work in CAD/CAM for the part to be manufactured, a workflow was created to release the product data to PLM, including the drawings and models. The part's internal structure was created in an E-BOM in PLM.

Step 2: Manufacturing review
A manufacturing engineer received the workflow to verify manufacturability of the design. Once the design was reviewed and approved, the E-BOM was transferred to ERP via a link.

Step 3: Manufacturing preparation
Triggered by the E-BOM in ERP, the manufacturing engineer planned the manufacturing work by detailing the materials and resources needed in an M-BOM in ERP, which would be purchased by the procurement department. Some calculations were made on cost and lead time. The manufacturing engineer allocated NC machines and planned the overall sequence of CAM operations in an M-BOP via ERP. Technical instructions were created to clarify, for example, safety information.

The manufacturing engineer consulted with other manufacturing engineers, the responsible CAM programmer, and the operators of the associated NC machines on the manufacturing sequence. If needed, the manufacturing engineer would change the M-BOM and the M-BOP, based on their feedback. Then they printed the drawings, technical instructions, M-BOM and M-BOP, and prepared them in a document binder.

Step 4: CAM preparation
The responsible CAM programmer collected the drawings and models of the part from PLM and imported the models to native CAD/CAM. Based on its completeness, the models were checked and supplied additional information from the drawings. The responsible programmer also created a new folder in the network drive, in which the NC codes would be stored. The folder was organized by the NC machines and the drawing numbers of the part.

Step 5: Tool preparation
For each CAM operation, the CAM programmer decided the tools and fixtures used in machining, such as turning machines, lathes, drilling machines, and milling machines.

To create a tool list, a separate 2D tool management system was used, which served as a repository for tools and fixtures. The CAM programmer first created the tools and fixtures in the 2D tool management system. Then, they were rendered in 3D in CAD/CAM. A tool list was generated and sent to the manufacturing engineer, who would update the M-BOM and M-BOP.

If the standard tools and fixtures were used, the CAM programmer could, in most cases, export the tool list and reuse the models created in previous jobs. If the existing tools and fixtures were not suitable, new tools and fixtures would be ordered.

Step 6: Post-processing
Based on the models of the part, tools, and fixtures in CAD/CAM, NC codes were created and stored in the folder created. NC codes provided a NC machine with specific machining instructions. The CAM programmer chose from the standardized templates of NC codes from the machines and edited the codes line by line and point by point. The machining process was then simulated to validate the tool paths, though the accuracy varied. Based on the CAM operations, the CAM programmer also created setup instructions for the NC machines.

Step 7: Production order creation
Triggered by a customer demand a production order was created in ERP. The manufacturing engineer updated all the documents and consolidated them in a binder for the operators, including the M-BOM, M-BOP, drawings, technical instructions, tool list, NC nodes, and setup instructions. Documentation of each CAM operation for the complicated parts could be as extensive as 500 pages.

Step 8: Part manufacturing
The operator conducted the preparation work for the NC machine accordingly. After the materials, tools, and fixtures arrived, the operator transferred the NC-codes from the network drive and ran them in the NC machine.

Minor changes would be done by the operator, and major changes and improvements would be reviewed by the CAM programmer in CAD/CAM. When manufacturing a new part, the operator was always extra attentive to check if there were any errors. If so, the operator would inform the CAM programmer and alter the codes, involving sometimes the responsible manufacturing engineer and the R&D engineer.

During machining, the operator measured and recorded the tolerances for quality control. Together with any changes in the NC codes, these were documented in the binder. The operator checked off the operations on the M-BOP and moved on to the next ones.

I summarize the current routines in manufacturing in Table 12. below.

Table 12. Current manufacturing routines at TurbineCo

Step		Drawing-based
1	Design release	R&D engineer created a workflow to release the design, including drawings and models to PLM. An E-BOM was created in PLM.
2	Manufacturing review	Manufacturing engineer reviewed and approved the design, and transferred the E-BOM to ERP.
3	Manufacturing preparation	Manufacturing engineer created an M-BOM, M-BOP and technical instructions in ERP, which were printed and consolidated in a document binder.
4	CAM preparation	CAM programmer retrieved the drawing and model from PLM and updated the model in CAD/CAM. A folder was created in the network drive.
5	Tool preparation	CAM programmer created tools and fixtures in the 2D tool management system to create a tool list to update the M-BOM and M-BOP. Tools and fixtures were recreated in CAD/CAM.
6	Post-processing	CAM programmer generated and simulated NC codes and stored them in the designated folder. The setup instructions were created for the NC machines.
7	Production order creation	Manufacturing engineer updated and handed over the binder of documents to the operator, following a production order in ERP.
8	Part manufacturing	Operator executed the NC codes and documented the tolerances in the binder.

5.1.3 Assembly

There were around 200 employees and contractors in the assembly workshop and the MBD project would affect the role of the production engineer and the assembly worker (see Table. 13 below). In general, many office roles had one shift and could start as early as 6 am, while the roles on the shop floor had three different shifts: morning, evening, and night. Many assembly workers were contractors, and some had been working with TurbineCo for a long time.

Table 13. The assembly roles affected by MBD

Role	Core responsibility	Headcount
Production engineer	Defining the assemblies and work instructions	10
Assembly worker	Assembling the parts and components	60 + 60 contractors

The assembly workshop was divided into workstations, where core, mechanical and electrical, and packaging subassemblies took place. The assembly workshop had limited access to stationary computers. Many workers were used to reading and searching for information in the binders with the paper documents.

Upon receiving a production order, production engineers planned and defined the subassemblies and composed detailed work instructions for the production workers. They would also oversee the logistics and ensured that the right materials and components were delivered to those workstations. The assembly team followed the work instructions and conducted the subassembly work. They also performed some tests before transporting the turbine to the next workstation.

In the assembly line, labels at the workstation would indicate its current subassemblies and the responsible team of assembly workers. The general workflow was to set up a base frame and a dummy for preparing auxiliary systems like piping. The core turbine and its adjacent mechanical parts were assembled first. Then, electrical wires would be installed, together with a control panel. Finally, the enclosure and casing were installed.

5.1.4 Current way of working in assembly

An assembly routine is directed at putting together parts into a functional machine and it involves four steps, namely Design release, Assembly preparation, Work plan preparation, and Part assembly. A drawing-based way of working relied on drawing in paper format as the leading document and ERP and Excel as the primary system.

Step 1: Design release
Similar to manufacturing, a workflow started when an R&D engineer created a workflow to release the design and product data to PLM, including the drawings, models, and E-BOM.

Step 2: Assembly preparation
Upon receiving a production order in ERP, a production engineer started planning the subassemblies (i.e., core, mechanical or electrical). From the drawings, the production engineer sketched out the materials and resources needed in the A-BOM in ERP. However, not all drawings were digitally linked to the A-BOM; instead, their IDs were referred to in the text. The production engineer also worked on a rough A-BOP in ERP, which listed a sequence of assembly, only including the amount of the materials and resources needed, without detailing how those assembly activities were conducted.

For the externally sourced materials, the procurement department would purchase and arrange the logistics. For the locally manufactured, the parts were transported from the manufacturing workshop.

Step 3: Work plan preparation
Based on the A-BOP, the production engineer created a detailed work plan in Excel. The production engineer clarified the entire sequence, and then coordinated and calculated the time needed for each subassembly activity.

As the cell structure in a spreadsheet only allowed for certain characters without being visually incomprehensive, the production engineer had to be concise and at times abstract with the instructions. Only for certain complicated activities, the production engineer provided the technical instructions and safety information in a separate document. Sometimes, the production engineer could reuse the technical instructions from previous orders. These instructions, along with the drawing IDs, were referred to in the work plan. All documents were stored in a network drive.

The production engineer printed the work plan and its associated drawings and work instructions and organized them in a document binder. Some reusable instructions were stored in physical drawers at the workshop.

Step 4: Part assembly
Assembly workers retrieved the binder of documents to commence the subassembly activities accordingly. Since the work plan did not always clarify the exact batches of materials, the assembly workers could proceed with the ones they found in the workshop.

During the assembly sequence, the assembly workers also measured and recorded the tolerances on paper, which was then enclosed in the binder.

I summarize the current routines in assembly in Table 14. below.

Table 14. Current assembly routines at TurbineCo

Step		**Drawing-based**
1	Design release	R&D engineer created a workflow to release the design, including drawings and models. An E-BOM was created in PLM.
2	Assembly preparation	Production engineer created an A-BOM and A-BOP in ERP, following a production order in ERP.
3	Work plan preparation	Production engineer created a work plan in Excel, including technical instructions when needed. The drawings and other documents were consolidated in a document binder.
4	Part assembly	Assembly workers received the binder to start the assembly sequence.

5.2 Preferred situation

PLM+ was dubbed "an enabler for real digitalization" at TurbineCo, serving as the backbone for design and production information, MBD, and digital thread. It offered new features to enable ways of working at a higher model maturity level, via the CAD-CAM chain suite (including Resource Application, Manufacturing Application, Instructions Application and NC Application) and the Digital Work Instructions (DWI) suite (including Manufacturing Application, Instructions Application and Animations Application). These were best practices (D'Adderio, 2011) inscribed by technology vendors from IndustryCo, corresponding to at least a model maturity level 3. In Table 15. below I detail what these assumptions would entail as a preferred situation for manufacturing and assembly.

Table 15. The situation and preferred situation after the MBD project

	Current situation	**Preferred situation**
Manufacturing	**Maturity level 2 (mainly)** Level 1 existed for older (legacy) components. The lead time between R&D and manufacturing was long. Models from R&D did not contain all the necessary information. CAM workers reworked models based on drawings and manually updated them.	**Maturity level 3 (mainly)** Technically afforded by CAD-CAM chain in PLM+. R&D and manufacturing would be more connected, so that manufacturing could happen at an early phase: concurrent engineering and lead time reduction. Models from R&D including PMI could be used for generating NC codes.
Assembly	**Maturity level 2 (mainly)** Level 1 existed for older (legacy) components. Hardcopies of drawings and technical documents were not always up to date. Not all assembly workers had the access to computers to look up the newest revisions by R&D.	**Maturity level 3 (mainly)** Technically afforded by DWI in PLM+ Drawings, 3D models, video animations, and other technical documents could be retrieved from mobile devices like tablets.

5.2.1 Envisioned way of working in manufacturing

The new CAD-CAM chain suite in PLM+ would set the PLM as the primary system and the possibility to reach at least a maturity level 3 with quality-assured models, i.e., model-based way of working. Some new features in PLM+ would replace many digital artifacts in the drawing-based ways of working. With CAD-CAM chain suite, users could create and reuse product data across R&D and manufacturing functions, so that NC codes could be generated from the models (see Table 16. below).

Table 16. The CAD-CAM Chain suite

CAD-CAM Chain	Description	Replacing
Resource Application	Creation and management of manufacturing-related resources, such as 3D models of tools, fixtures, and NC machines	2D tool management system
Manufacturing Application	Creation and management of M-BOMs and M-BOPs	ERP
Instructions Application	Creation, management, and visualization of text-based work instructions	Paper documents
NC Application	Management and transfer of NC codes, replacing network drive	Network drive

When models were quality assured, all product data could be linked to the originating models of the part. Therefore, the M-BOM, M-BOP, models of the tools and fixtures, NC codes, and all the associated technical documents could be traced and displayed in PLM+. The visual presentation in PLM+ was more intuitive, instead of the texts in ERP. More detailed envisioned changes would include (see also Table 17. for a summary):

Step 1: Design release
Similar to the current way of working, the R&D engineer would initiate a release workflow, but the iterations between the R&D and manufacturing could take place throughout the design process to ensure manufacturability.

Step 2: Manufacturing review
A manufacturing engineer could review and verify manufacturability in an earlier phase when the design work was underway, and subsequently would transfer the E-BOM to ERP.

Step 3: Manufacturing preparation
The manufacturing engineer would plan the manufacturing work and create the M-BOM and M-BOP via the Manufacturing Application in PLM+ and transfer them to ERP. ERP would still be needed for calculating the cost and the lead time. The technical instructions would be created and managed via the Instructions Application.

Step 4: CAM preparation
The CAM programmer would collect the model from PLM+. The folder in the network drive was no longer needed.

Step 5: Tool preparation
The CAM programmer would create models of the tools and fixtures in CAD/CAM and would manage them via the Resource Application in PLM+,

where the tool list was also generated and attached to the M-BOP via the Manufacturing Application in PLM+.

Step 6: Post-processing
The NC codes would be stored via the NC Application in PLM+. The setup instructions for the NC machines were created via the Instructions Application.

Step 7: Production order creation
A production order would be created in ERP as the current way of working; however, the manufacturing engineer no longer needed to prepare the document binders as all the information would be available via the Instructions Application. If there were no stationary computers close to the workstation, a tablet or laptop would be used to display the documents and instructions.

Step 8: Part manufacturing
NC codes could be retrieved from the NC Application, in which further communications and measurement also took place.

Table 17. Envisioned manufacturing routines at TurbineCo

Step		**Model-based**
1	Design release	R&D engineer would create a workflow to release the design, including the drawings and models to PLM+. An E-BOM was created in PLM+.
2	Manufacturing review	Manufacturing engineer could review and approve the design in an earlier phase and transferred the E-BOM to ERP.
3	Manufacturing preparation	Manufacturing engineer would create an M-BOM and M-BOP in PLM+ and transfer them to ERP, while the technical instructions were created in PLM+. Other manufacturing engineers could review and approve the M-BOM and M-BOP if needed.
4	CAM preparation	CAM programmer would retrieve the model from PLM+.
5	Tool preparation	CAM programmer would create tools and fixtures in the CAD/CAM and use PLM+ to manage and create the tool list.
6	Post-processing	CAM programmer would generate and simulate the NC codes and stores them in PLM+. Some setup instructions for the NC machines would be created in PLM+. Other CAM programmers could review and approve the NC codes if needed.
7	Production order creation	Manufacturing engineer would update and hand over the information to an operator via PLM+.
8	Part manufacturing	Operator would execute the NC codes and document the tolerances in PLM+. The operator could communicate with the CAM programmer via PLM+ if needed.

In addition, PLM+ would afford a new revision, and a review and approval process for the M-BOM and M-BOP in Step 3: Manufacturing preparation, and NC codes in Step 6: Post-processing. The creator would become the owner, their peer the reviewer, and their senior or line manager the approver. This also meant that for the operator, in Step 8: Part manufacturing, it was not possible to revise the NC codes by themself without a proper revision with the CAM programmer.

Envisioned way of working in assembly

The DWI suite would offer new functionalities to replace Excel and the use of paper binders in assembly. DWI was a suite to create and display the interactive and digital work instructions for the assembly. Apart from the access to drawings and models of the parts, the assembly workers could play animations of assembly sequences and read the work instructions via the same user interface (see Table 18. below).

Table 18. The Digital Work Instructions suite

DWI	Description	Replacing
Manufacturing Application	Creation and management of the A-BOMs and A-BOPs	Excel
Instructions Application	Creation, management, and visualization of text-based work instructions	Paper documents
Animations Application	Creation, management, and visualization of animations	Paper documents

Overall, after the introduction, an MBD maturity level of 3 would utilize quality-assured models instead of drawings as the main leading document in communication and PLM+ as the one-stop-shop for all information. In other words, the work plan and work instructions would be connected to the part model in PLM+. More specifically, the envisioned changes would be (see also Table 19 for a summary):

Step 1: Design release
Similar to the current way of working, R&D engineers initiated the workflow and created the E-BOM to PLM+.

Step 2: Assembly preparation
The production engineers would use the Manufacturing Application in PLM+ to create the A-BOM and A-BOP and send them to ERP.

Step 3: Work plan preparation
Based on the A-BOP in PLM+, the production engineers would create the detailed work plan and work instructions via the Instructions Application in

PLM+. If needed, animations of certain assemblies could be created via the Animations Application. A simplified work plan could also be exported to Excel to calculate the time and coordinate the assembly sequence.

Step 4: Part assembly
The assembly workers would access to the A-BOPs, instructions and animations, and other product data like drawings, models from the Animations Application. The materials and resources were visually linked to each assembly so that the assembly workers would know which one to retrieve at the workshop.

Similar to model-based in manufacturing, if there were no stationary computers close to the workstation, a tablet or laptop would be used to display the digital instructions. In addition, a new revision, and review and approval process would be afforded to manage the work plan. The assembly workers could even collect and report back the measures via PLM+.

Table 19. Envisioned assembly routines at TurbineCo

Step		**Model-based**
1	Design release	R&D engineer would create a workflow to release the design, including the drawings and models to PLM+. An E-BOM was created in PLM+.
2	Assembly preparation	Production engineer would create an A-BOM and A-BOP in PLM+ and transfer them to ERP, following a production order in ERP.
3	Work plan preparation	Production engineer would create a work plan in PLM+. Somme detailed technical instructions could be prepared, with animations if needed. Other production engineers could review and approve the work plan if needed.
4	Part assembly	Assembly workers would receive the work plan and its associated documents via PLM+ to start the assembly sequence.

5.3 Project setup

Despite the rush of time (see Chapter 6), Sven managed to form an interdisciplinary Business team by handpicking three more team members from manufacturing: Nils and Mats, CAM programmers, and Robin, Manufacturing engineer; and one more team member from assembly: Vincent, Production engineer, to represent the interests of the Business. Tomas, Design engineer, was released from his “day job” and worked full-time on the MBD project, while the rest of the team members were recruited to work 20% (see Table 20. for a summary of the Business team).

IndustryCo allocated an IT team with two IT architects, Kaveh and Vikram, supporting the team members from manufacturing and assembly, respectively. The Business and IT teams were based in different geographical locations. The IT architects were responsible for communicating with the Business team about the requirements. They also served as technical support and contact points with the overall PLM+ development team, which fulfilled, tested, and implemented the software requirements, whose members were scattered around the globe. Kaveh and Vikram's responsibilities were handed over to the onsite IT support, Bo, during Period II (see Table 21. for a summary of the IT team).

The funding for the MBD project was divided between these two teams. The IT team would oversee the system license, development, and maintenance, while the Business team would take care of business readiness activities and necessary technical equipment and infrastructure. The support organization was established to guide the project, in which the CEO and CFO of TurbineCo, and senior management of manufacturing and assembly, and the representative from the Swedish sites' IT service had recurring meetings with Sven. The direct line managers of the Business team Emma and Josefin, were also in the loop (Interview, Sven, Project manager, 190522) (see Table 22. for a summary of the support organization).

TurbineCo took the lead in making critical decisions while Sven informed other sibling sites regularly about the progress. In the beginning, the sibling sites took a rather passive role, and their main task was to review the use cases and requirements (Interview, Sven, Project manager, 171220). One site, Motorville, gradually took a bigger role after the Release 2 (Interview, Sven, Project manager, 180424). Since the establishment of the global digitalization group, Erik, Coordinator, was also involved.

Table 20. The Business team

Name	Role	Department	Work experience at TurbineCo	Involvement	Responsibility
Sven	Project Manager	R&D & Manufacturing	10+years	100%	Project Management Manufacturing Assembly
Tomas	Design Engineer	R&D	5+ years	20% until 2016, 100% since 2017	R&D Assembly
Nils	CAM Programmer	Manufacturing	10 years	20% Since 2017	Manufacturing
Mats	CAM Programmer	Manufacturing	20+ years	20% Since 2017	Manufacturing
Robin	Manufacturing Engineer	Manufacturing	15+ years	20% Since 2017	Manufacturing
Vincent	Production Engineer	Assembly	15+ years	20% 2017	Assembly

Table 21. The IT team

Name	Role	Work experience at TurbineCo	Involvement	Responsibility
Kaveh	IT architect	5+ years	50% between 2018 and 2019, 100% between 2019 and 2020	Manufacturing
Vikram	IT architect	5+ years	100% between 2017 and 2020	Assembly
Bo	Onsite IT support	5+ years	100% since 2020	Manufacturing and assembly
Development and implementation team supported by IndustryCo				

Table 22. The support organization

Name	Role	Work experience at TurbineCo	Involvement	Responsibility
Emma	Line Manager	5+ years	Since 2018	Line manager to Nils, Mats, and Robin
Josefin	Line Manager	15+ years	Since 2017	Line manager to Vincent
Erik	Coordinator	1+ years	Between 2018 and 2019	Sven's colleague in the digitali-zation group
Steering committee: **CEO and CFO from TurbineCo (Swedish sites: Rotorstad; Statorstad; North American site: Motorville)** **Swedish sites' senior management from manufacturing and assembly** **Swedish sites' IT service**				

5.3.1 Agile way of working

The PLM+ was developed according to agile methods. Many of the practices were inspired by a framework called Scrum, which allowed for iterative and incremental software development. The overall development and implementation were divided into eight releases, between 17Q4 and 20Q1. The time-boxed iterations, or sprints, were the key to stay agile. Each release was divided into two or three sprints (varying from three to five weeks), which took place back-to-back.

In a nutshell, there were four main steps in the agile development, including Scope management, System development, Acceptance testing, and Ad-hoc change management. Within each sprint, the Business team, acting as product owners, came up with a list of user requirements from the backlog. The user requirements were prioritized by the Business and the IT team into different sprints and releases, based on resources and urgency levels. Using the available features in PLM+ and its adjacent applications, the IT architects would translate the user requirements into software requirements and compose a scope document. Upon agreement, subsequently, the development and implementation team would develop those features. Should any changes occur, the Business team had to formally submit change requests. The Business team would then conduct a variety of tests to validate the functionalities.

Step 1: Scope management
Each release in the MBD project was directed by two sets of documentations. The first set was called *the MBD in PLM+: Scope outline*, which sketched out the planned releases within the current fiscal year. As an outline (see Table 23. for an example), this short document (around 20 pages) briefly walked through the planned features briefly. Sven, as the team lead, was in charge of creating and maintaining the document in conjunction when preparing the project renewal.

Table 23. Example of a scope outline

Chapter 1	General objectives	The overall goals for the releases planned
Chapter 2	Introduction	An overview of the previously accomplished releases
Chapter 3	In scope	Short descriptions of the planned features for each release
Chapter 4	Out of scope	The unaddressed features
Chapter 5	Abbreviations & terminology	Some short definitions

The in-scope items were not described in detail. For instance, an in-scope feature like "transfer data" would be described at a high level and was not specific enough to include the kind of data, nor the direction of the transfer.

Instead, the detailed descriptions of each release were recorded in a much longer document (100+ pages), called *User/Software Requirements Specification*, which would include and translate all business/user requirements into software requirements for development and implementation (see Table 24. for an example). A few weeks before each release, the IT team would initiate the drafting process. The content was created and managed from a project management system. In there, the MBD project was divided into releases and the corresponding two or three sprints, filling in with the following content.

Table 24. Example of a user/software requirements specification

Chapter 1	Changes	When deviations occurred, they would be documented with descriptions of the changes and the areas they were affecting.
Chapter 2	Use cases User requirements	The business/user requirements were transformed into one or more use cases, to exemplify the interactions between actors and systems, accompanied by some use case diagrams. Each use case had its assigned priority and perceived complexity.
Chapter 3	Software Requirements	For each use case, the software requirements explained what PLM+ and its applications needed to achieve. Each requirement had its assigned priority in its respective sprints and an ID to track and trace for later testing purposes.
Chapter 4	Features	For each software requirement, features defined how the implementation team could achieve the software requirements.
Chapter 5	Technical data models	For each use case, the data models, such as the data flow diagram, visualized how data traveled across the entities.

For example, for the Instructions Application, a use case would be "create textual operations by a manufacturing engineer". A software requirement would be "installation of Instructions Application on server and client", and a feature would be "installation for Instructions Application using PLM+ add-on manager".

For the Business team, based on their own experience and the experience of their colleagues, they put forth the business requirements. They would prioritize the remaining items from the project backlog. The IT architects would also fill in and define the requirements to their best knowledge when the Business team was short in time, as most of them worked only 20%.

For the IT team, the IT architects needed to create use cases, and filled in the software requirements for the implementation team. In some cases, one business/user requirement could lead to 200+ software requirements. Thus, they would need to estimate the velocity and distribute the software requirements into different sprints.

After the IT architects first drafted the specification, they would consult back and forth with the Business team to ensure its content was agreed upon between the Business and the IT team before the commencement of the release.

The *User/Software Requirements Specification* was regarded as the de facto contract between the Business and the IT team, as a customer and a supplier. Should some requirements be missing from the implementation, the Business could technically confront and demand fulfillment.

Step 2: System development
The development and implementation team, based on the *User/Software Requirements Specification*, would customize the features in PLM+ and its adjacent applications. The geographically dispersed team would change the codes in the source program to adjust to the specific business/user requirements. For example, certain user groups would have different levels of access to the functionalities. The user group *manufacturing engineer* would be authorized with "read and write" permission for the Manufacturing application, while the user group *operator* would have "read only".

When new functionalities that were not part of the PLM+ solution were requested, the development team would involve other programmers to develop and code those in due time. While developing the features, the development team and the IT architects would also conduct unit testing (each use case individually) and system testing (PLM+ as a whole) in their developer system. Then, they would release PLM+ to various testing environments.

Step 3: Acceptance testing
The implementation team, together with the IT architects, would transform the use cases into test cases and create a variety of acceptance testing, facilitated by an application lifecycle management system.

The IT architects would allocate the tests to specific Business team members, and their main task was to conduct the tests to determine if the designated user requirements were met or not. Test cases included dummy IT tests, meaning no actual components were produced. Those dummy tests were ordered according to the priority of use cases and supplied with the objectives, the role of the user group, and detailed steps to verify the intended functionalities.

Depending on the sprints, there could be as many as 100 test cases for the Business team to test. Some tests could take only five minutes to complete, while others could take hours. Tests would also be repeated in different testing environments, which might vary in terms of the version of PLM+, its connection to other applications, and the site.

When testing the use cases, it was common for the Business team to find some defects. They first conducted the tests step by step, and they would pass the steps until the step failed. They would describe the errors in detail.

For those failed tests, the Business team would submit tickets to contact the IT architects through emails and video conferencing tools. The IT architects would then investigate those defects. Sometimes, the defects perceived by the Business team might be quite the opposite, i.e., the functionalities could be as intended. The Business team would then receive instructions to retest those test cases according to the new procedure. In some cases, the defects were known to the implementation team, which might concern not only the MBD project but the overall PLM+ introduction. When defects were oversights from the implementation team, they could negotiate the new requirements with the Business team and put them in the backlog, if not fixable through hotfixes before the end of the sprint.

During the last few weeks of acceptance testing, the IT implementation team would conduct unit and system testing again to ensure technical functionality.

Step x: Ad-hoc change management
The setup of scrum allowed for ad-hoc changes. When the unexpected happened during a sprint, the Business team could request to change the requirements. For example, if the requirement "transfer data from PLM+ to ERP" was not fulfilled in the way the Business team was expected, they could write a change request with their suggestions to reach fulfillment.

The stakeholders in the Change Control Board would step in to determine how to implement the proposed changes. The Board consisted of system experts for PLM+ from the implementation team. Depending on the timing, they would also decide when to introduce those changes and document them accordingly. Certain changes would be at a higher cost for the Business, so the Business team would try to negotiate with the IT architects to seek alternative solutions.

The steps were not sequentially based, rather timing-based, as the Business and IT teams would at times concurrently work on two releases. More specifically, when testing the last sprint of an upcoming release, the Team had to start managing the scopes for the next release (i.e., Step 1: Scope managment).

I summarize the agile development routine in Table 25. below.

Table 25. The agile development routine in the MBD project

Step		Agile way of working
1	Scope management	The Business team and the IT team planned the sprints in the upcoming release.
2	System development	The IT team implemented the features.
3	Acceptance testing	The Business team accepted or failed the dummy tests.
x	Ad-hoc change management	The Business team and the IT team responded to ad-hoc changes.

5.3.2 Overview of the releases

The Business and IT teams worked toward creating and remedying functionalities in the CAD-CAM chain and DWI suites, which would enable connectivity across software interfaces. The main maturity level could reach a level 3 in manufacturing and assembly, instead of a level 2. Each release was about establishing different "links", between the applications of PLM+, between PLM+ and CAD/CAM, and between PLM+ and ERP.

In Period I, the first three biannual releases (Release 1 at 17Q4, Release 2 at 18Q1, Release 3 at 18Q3) followed a schedule of three ten-week sprints. For each sprint, the Business team had for each sprint an acceptance testing period of six weeks, and the IT team had around four weeks for developing and resolving minor defects. For the first two releases, PLM+ was installed in a separate server with no connection to any productive system, and thus design data migration took place incrementally. PLM+ replaced the preceding PLM system after Release 3.

In this period, the goal was to enable the functionalities within PLM+ and its connection to CAD/CAM. Many MBD-related features went live, however, the functionalities were rudimentary, and certain features had unsolved defects.

In Period II, PLM+ became the incumbent PLM, and the MBD project entered a new period for the next five quarterly releases (Release 3.1 at 18Q4, Release 3.2 at 19Q1, Release 3.3 at 19Q3, Release 3.4 at 19Q4, Release 3.5 at 20Q1). The project work in between each release was condensed to two six-week sprints, in which the Business team had four weeks of acceptance testing, and the IT team had two weeks of developing.

As the basic functionalities and connection to CAD/CAM were in place, the first two releases were aimed at resolving the remaining issues (i.e., stoppers) while improving some of the applications within PLM+. In the three following releases, the connection between PLM+ and ERP was incrementally established, and more defects were fixed.

There were recurring meetings during each sprint, to communicate the latest progress of the MBD project to a variety of stakeholders. The Business team would have a weekly Scrum meeting on Mondays to discuss the project backlog and current work. Sven, as the project manager, had more responsibilities in arranging meetings with the IT architects and the stakeholders within the Swedish sites Rotorstad and Statorstad, and with the North American site, Motorville. For example, he had weekly meetings with the managers in manufacturing and assembly to update about the progress of the project and decide the future directions. Meetings with the steering committee were also arranged, in which funding decisions were made.

In addition, the team members would have some ad-hoc meetings with the IT architects when defects were encountered and with their colleagues when working on pilots, especially in Period II.

Since Release 2, once a new release took place, the affected users would receive an information package of the overall PLM+ implementation, regarding the updates and patch notes, via email. In addition to the generic information package, Sven would also prepare more project-specific information on the MBD for a limited audience via email.

On the Intranet, there were news articles regarding the latest release and links to online support materials. Prepared by the IT implementation team, detailed instructions would be found for the overall PLM+ and MBD. For instance, there were user manuals on creating an M-BOM and creating an M-BOP, with written steps and screenshots for each step.

Apart from these formal channels, the team communicated their current project work to their colleagues during Fika.[17] The team members had small talks near the coffee machine. People were often curious about the MBD project, and the team members took the occasion to share their project work.

[17] The "Fika" culture is integral to a Swedish way of working. Coffee breaks are institutionalized in the morning and afternoon.

6 Period I

IndustryCo aimed to implement a single PLM solution, PLM+, for its power generation business across the globe, including TurbineCo's two sites Statorstad and Rotorstad in Sweden and their sibling site Motorville in North America. The MBD project team worked on the CAD-CAM chain and DWI suite from PLM+, which could afford respective envisioned ways of working in manufacturing and assembly, corresponding to a level 3 in the model maturity level.

In Period I, there were three biannual releases: Release 1 at 17Q4, Release 2 at 18Q1, and Release 3 at 18Q3. I first describe in first-order narratives of the happenings after the MBD project became official and in between the releases, including the project work in manufacturing, assembly, and project management. Period I ended when the stoppers were discovered. The team evaluated the situation and updated their visions of a preferred situation. Next, I detail in a second-order prehensive analysis how the team conversed with the unfolding situation to make live routines and how in some situations the stoppers emerged. I then summarize how the team addressed the puzzle of generativity in Period I.

6.1 Before Release 1

As Release 1 was planned a few months ahead, Sven had to rapidly draft the scope outline and already define the general ideas on the model-based ways of working and areas of tests and demonstrative pilots. From their previous project work and some reoccurring problems in the current ways of working, the team made some educated guesses in defining the business requirements for the CAD-CAM chain and DWI suite.

Manufacturing. Models were not foreign to manufacturing. They were needed to generate the NC codes. However, it was the link in the "CAD-CAM chain" that was missing at TurbineCo. The models created from R&D could not directly be applied by CAM programmers, instead, new models were created in Step 4: CAM preparation due to the lack of required information. This unnecessary step could be avoided by including more manufacturing information in models at R&D, facilitated by the CAD-CAM chain.

The team also planned some specific components to validate the envisioned ways of working after Release 1 went live. For manufacturing, they would focus on the turbine disks and turbine rings of IGT100. Those pilots would demonstrate how models with manufacturing information could be the only inputs needed for producing them once the feature CAD-CAM chain was implemented in PLM+.

Assembly. When dealing with constant engineering changes, the prevalence of paper documents in the assembly workshop could not always guarantee up-to-date information. Moreover, drawing-based work instructions lacked clarity due to the limitation of Excel. To retain the readability of the printed Excel sheets, only key information was included in each cell. DWI would circumvent this by facilitating work instructions in digital format.

Some core assemblies of IGT200 would be experimented with using the DWI suite, which afforded the digital link between A-BOMs and A-BOPs. The digital link would keep all the associated drawings, models, work instructions updated. As a result, production engineers could prepare all the assembly procedures in PLM+ and skip printing out documents from Excel, and assembly workers would receive an overview of the assembly and have access to up-to-date instructions and documents.

Project management. When the MBD project officially became a part of the PLM+ project, Sven, Project manager, realized that one priority was to recruit more team members. Sven pushed strongly for having TurbineCo's employees as part of the core project team. In the past, similar projects that relied heavily on external contractors and consultants ended in "presentations in the drawer", as they were outsiders and did not gain any trust from the inside. Being an insider entailed that someone had a longer tenure at the company, expertise in their work, or knew how to pull strings with internal sponsors. Identifying and selecting those insiders, however, took time. Sven (181017) mentioned that he *"spent several months pinpointing which persons, trying to convince their managers why those persons should be involved, to have their influences on board."*

The selected team members were sponsors of the MBD and were considered champions by the colleagues in their respective roles. While Tomas, Design engineer remained as a representative from R&D and assembly, Sven recruited more team members from manufacturing: Nils and Mats, CAM programmers; Robin, Manufacturing engineer; and from assembly: Vincent, Production engineer, to have all three departments represented in the project.

The project funding provided was sufficient to sustain full-time commitment from Tomas, while the other team members would work only 20% on the project, which was equal to one workday per week. Some concerns were raised about the quality of the project work. But Sven thought that as the team members could remain in their day jobs and responsibilities, they would be able to reflect *in* and *on* their ways of working with their colleagues and in parallel contemplate the new ways. According to Sven (180327), this situation would encourage a more bottom-up approach to handling change: *"[The team members] are working in the system and at least some of them are talking to colleagues about what they are doing. So that's part of the change management. Some people explain to the colleagues informally what they're doing rather than having a top-down approach say this is the new way of working."*

6.2 Release 1 at 17Q4

In Release 1, some design data, especially drawings, were migrated from the preceding PLM to PLM+. Returning to the project work, the IT team and the Business team discovered some technical issues when those data appeared in unintended places.

Manufacturing. MBD would unify and standardize many existing individual ways of working in manufacturing. During this phase, the team focused on the requirements concerning the following steps: Step 5: Tool preparation, Step 6: Post-processing, and Step 8: Part manufacturing (see Table 12. and Table 17. for a comparison between drawing-based and model-based ways of working in manufacturing).

For Step 5: Tool preparation, the 2D tool management system introduced in the 90s would be replaced by the Resource Application so that CAM programmers could skip switching to a different software and avoid double work. If design engineers would update the models, PLM+ would notify the CAM programmers.

Even though there was a naming convention for the NC codes in place, it was up to the individual to create the file name and file structure when releasing the NC codes in Step 6: Post-processing. With PLM+, the file name and structure for NC codes would be automatically generated.

Whenever operators encountered problems with the NC codes, they would often change the codes themselves in Step 8: Part manufacturing. The NC Application would offer a more rigid feedback loop for communication of errors between CAM programmers and operators.

The project team would use this opportunity to create new documentations. Currently, there were few descriptions of the overall ways of working in manufacturing. Many described them at a high level, only mentioning the inputs and outputs without detailing the specific steps. For example, the process description would take the creation of NC codes for granted. It would not reveal the problematic details such as storing the M-BOPs and NC codes on local computers natively, instead of having them connected in live systems. Sven (180523) was intrigued by the surprising absence of digital artifacts in TurbineCo's documentations: *"What in general is missing in paper documentation is all the connecting software. ERP system is never mentioned, even though every company has one."*

Even though the project work continued, the pilots planned for manufacturing were purposefully postponed until the next release to have the CAD-CAM chain suite available. Since not all the essential data was accessible in the test environments, pilots without any real data could not validate if the team managed to fulfill the requirements for manufacturing.

Assembly. The team worked on Step 2: Assembly preparation, Step 3: Work plan preparation, and Step 4: Part assembly (see Table 14. and Table 19. for a comparison between drawing-based and model-based ways of working in assembly). These steps would take advantage of Instructions Application and Animations Application in the DWI suite so that the engineering and assembly information in the work instructions could be displayed via models. Instructions would be created in PLM+ instead of Excel and delivered in a digital format to assembly workers, with the possibility of including animated instructions, interactive 3D models, and other documents via a tablet.

Work instructions in DWI would serve the purpose of training new employees and knowledge transfer across sibling sites, so that the ways of working would be standardized and conformed to the regulations. The perceived benefits from standardization, however, came at a cost of sacrificing potentially efficient workarounds, taking longer time, and losing the ownership and the freedom of work.

Tomas and Vincent worked closely with some colleagues from IGT200 assemblies and provided them an overview of the model-based way of working. They also contemplated the need for animations in the Step 3: Work plan preparation, regarding how detailed the information should be for each operation.

After postponing the pilots in manufacturing, the team agreed on prioritizing assembly. Those steps were tested in 17Q4 on two IGT200 assemblies with real data, and positive feedback was received. The communication department even made a reportage on MBD and the project at TurbineCo and IndustryCo (Document, Assembly happens with 3D models).

6.3 Release 2 at 18Q1

The overall objectives for Release 2 were achieved. PLM+ went live; however, the MBD-related features were still running in the sandbox environments, which were planned to go live after Release 3. On site, there were posters and printouts of PowerPoint slides to introduce PLM+ and its benefits and core values, apart from the newsletters and workshops (Personal observation notes). CAD/CAM was shut down shortly after the release so that design data, especially models, could be migrated to PLM+. The MBD project tested PLM+ in a new separate environment, which mirrored the productive system, with some real data. The connection between PLM+ and ERP was prepared for Release 3.

Manufacturing. Since the MBD-related features were scheduled to go live at Release 3, the project work consisted of fine-tuning the steps of new ways of working when "the devil lies in the details". The team found for example that there were unresolved interface-related problems between CAD/CAM and PLM+ after Release 2, when the NC codes could not be saved to PLM+ in the Step 6: Post-processing.

For Step 5: Tool preparation, Nils witnessed how timesaving it would be with MBD. In a current drawing-based way of working, he needed to build tools three times, which would take around 40 minutes, while using MBD, Nils did a test to create a simple milling and cutting operation, and it took fewer than five minutes. Also, PLM+ would introduce a new numbering system of tools, which would eliminate the need for CAM programmers to remember the ID numbers. Nils (180524) reflected on this change: *"We are used to remembering all these numbers because everything is connected by numbers. In PLM+ where we have quite long numbers, it is impossible to remember them. The drawing has nine digits, and the numbers are impossible to remember. But this is also a good thing. You need to connect everything. Everything needs to be connected."*

Using some productive data, the MBD project continued with dummy tests on the newly implemented features. Since the manufacturing workshops were busy with new turbine orders, the team members tried out some features in their own daily work. Nils, for example, tried to create NC codes.

Assembly. The team focused on the A-BOM and A-BOP-related steps. Tomas worked on alignment methods to create a one-to-one relationship. He tried out alternatives to create an A-BOM and A-BOP in PLM+ in the Step 2: Assembly preparation. PLM+'s feature *CAD-part alignment* would check accountability among the E-BOM, A-BOM, and A-BOP. Some alternatives could trigger errors, which Tomas needed to circumvent.

Tomas also created tests for Vincent, Production engineer. When migrating 3D models from the productive system to the sandbox environment, Tomas came across some problems with the nuclear compliance of some models, which had been left out when being filled in by other designer engineers. Therefore, he had to manually check and add the required information to the models.

Tomas also found some technical issues with PLM+. The videos embedded in the digital work instructions could not be displayed properly. He had to have constant contacts with the IT architects and implementation team behind DWI.

Project management. IndustryCo created global digitalization groups within the departments in the Business, such as R&D, sales, procurement, and manufacturing. These groups echoed the priorities of TurbineCo, i.e., "make digitalization work". In Sweden, apart from Sven, the group comprised Erik, Coordinator; a digitalization team consisting of five people; and a project manager. Sven would share his knowledge with his counterparts around the globe and then report back to the local management.

Up until now, Sven kept his role as a project manager in R&D. He received a new role as a project manager in the global digitalization group of manufacturing where he would be able to further explore MBD together with representatives from other sibling sites. MBD was regarded as one of the key areas. The group set up technology roadmaps, a planning tool to match strategic goals with specific digital solutions, which listed all initiatives in manufacturing conducted at TurbineCo and its sibling sites. They would help to identify projects that misused the label digitalization and to elevate "real" digital projects.

One of the sibling sites, Motorville, decided to partake in the MBD project. It was an assembly site, with less complicated requirements. Tomas provided training to his colleagues over the Atlantic and helped them to initiate some pilots to try out the features of DWI.

As the funding would terminate after Release 3, Sven aimed to renew the project for another year; otherwise, the future releases would not be managed by the project team. In other words, the Business had to come up with new strategies and potentially a new team to handle the development work. For Sven (180424), to sustain the project, he had to pitch more for resources so that the team members would dedicate more to the project work: *"We're struggling with resources in general, to have enough people, and the people in the team being able to put in the effort to work. It's one thing for management to say you have this person for 50% but the hard thing is to actually get the 50%, especially when the other 50% is part of the daily operations; and if you have a malfunction in the operations, then, of course, that needs to be resolved."*

6.4 Release 3 at 18Q3

Release 3 went live according to plan and PLM+ replaced the preceding PLM. A majority of features of the MBD were live in the productive environment. The team members encountered *stoppers***,** including severe issues caused by current drawing-based way of working in R&D, defects, and missing functionalities in PLM+. They also postponed the connection between PLM+ and other digital artifacts as there was simply not enough time to do all the testing. These stoppers hindered the introduction of model-based ways of working to the roles affected.

Stopper 1: R&D modeling practices. Sven and Tomas found occasions when models and parts were not aligned, meaning drawings had no connection to or did not match with the parts or components in the BOMs. For example, a CAD-part was not aligned when the standard components like screws were not represented in drawings but were required in the M/A-BOMs. Tomas was surprised to find out the time needed to align the standard parts, up to 5,000 hours! They had to address these issues to R&D and raised the awareness of the new requirements when creating the models.

Stopper 2: Defects and missing functionalities in PLM+. The team realized that due to the cultural differences between engineering and IT, they spoke different languages, and this hindered how requirements were dealt with, which led to more defects and missing functionalities than expected. Sven (180327) described a typical moment when the Business team and the IT team were in disagreement: *"From the Business, we need to be able to do this, and then from [the IT]: 'ok you mean this', 'yeah maybe'. And then you end up in some confusion and also it has been some discussions that 'yeah but the system works' 'yeah it works but it takes five times longer than the processes today'. So for the Business it doesn't work, even though the system-wise the functionality works but it's too slow or too many obstacles in the processes."*

Stopper 3: Connection between PLM+ and ERP. The connection between PLM+ and other digital artifacts took a longer time than expected to establish. Without proper connection to ERP, only certain steps in the model-based ways of working could be enacted.

Manufacturing. The planning for productive pilots resumed despite the stoppers. The team first chose the turbine rings, which were of strategic importance to the company, as the pioneer for the MBD productive pilots. The team identified their respective models and machines, engaging also operators for the first time. Since Robin, Manufacturing engineer was working on a specific turbine ring, the team would enact the available steps to test the envisioned ways of working. At the same time, together with Nils and Mats, CAM programmers, they would prepare the M-BOPS, tools, and NC programs for the components using MBD as much as they could despite the defects.

Assembly. Meanwhile in assembly, some assemblies, for example, electrical assembly of IGT100 and core assembly of IGT200, were selected as the focus. Tomas and Vincent planned on electrical assemblies of ladders and cable trays, and core assemblies of compressors, as they saw the potential in improving the work instructions.

Sven decided to arrange the MBD training with video tutorials. Tomas made some "how-to" videos from the testing environment, as a proof-of-concept, such as "how to create a BOM". Sven and the IT architects liked the videos and considered retouching them in the productive environment to be consistent with the latest user interface of PLM+ and using actual data of IGT200.

Some of the team members took advantage of those videos. For instance, Vincent, Production engineer, before this point, had only tried individual steps with the guidance from Tomas, and rarely had the chance to enact the model-based way of working in its entirety independently. Vincent (181114) reflected more on this challenging task: *"I have found that there are some online instructions, so I use that. And then, Tomas has made some videos. The plan is to learn as much as I can. Right now, I have to figure it out in my head how every step should work because it's a lot of information, and they're not connected yet."*

Project management. In his capacity as a project manager in the global digitalization group, Sven had a comprehensive overview of all the running projects across the various sites. He worked on local and global roadmaps of digital artifacts. In Sweden, MBD was juxtaposed to digital projects in CAD/CAM, ERP, PLM+, among others.

The renewal of the project funding started. The process was twofold: first, the project had to go through the global digitalization group, to align with the roadmaps. After their blessings, the decision needed to be made by the local CFO of TurbineCo. Sven went ahead with the project after receiving the green light from the global organization. However, due to the lack of final local approval, the project had to borrow resources from the global PLM+ project, which, in turn, limited resources available for the project, for instance, Kaveh, IT architect, worked only 50% for the project and partially increased the lead time for manufacturing-related features. Sven paused formal meetings with the steering committee.

Motorville committed some financial resources and set up their project team of five, mirroring the project setup. Together, they looked through the defect list and agreed upon the priorities for Release 3.1 to 3.3. They agreed that since ERP was integral to enable an end-to-end process in the CAD-CAM chain and DWI suites, the connection between PLM+ and ERP was considered as being of the highest priority for the upcoming releases.

6.5 The situation after three releases

The MBD project rode on the wave of TurbineCo's new strategy "make digitalization work", from talking about digitalization to working on digitalization. In Period I for a year and a half, many MBD-related features were developed and released in PLM+. Various IT tests and limited production pilots were done in the sandbox environment. More and more managers and coworkers were informed about the progress of the MBD project. But only a handful of them, aside from the project team, had participated in the tests. Some video training materials were prepared and were well received by the participants.

A global digitalization group was established to share insights on digitalization. Sven also received a new role overseeing the digital roadmap. Digitalization brought about more questions than answers, and the Swedish sites were far from being alone. With sibling site Motorville formally joining the MBD project, they would have a speaking partner to discuss the change that would come with a model-based way of working.

Due to the stoppers, the ways of working in manufacturing and assembly remained mainly at a maturity level 2. The team also realized that some older legacy product would remain at a level 1, Sven (180327) consciously excluded these turbines from the project: *"We have already seen that we have a workshop that is only focusing on old turbines where we don't even have 3D data. They will of course not be the first ones to implement this since it is depending on the 3D data. In many of those cases, we don't even have the 2D, we have scanned drawings which are more or less revised by tipping some pens because they are old*."

The team was hopeful, however, as the need for change persisted. Sven was aware of the risk of losing the sense of urgency for some, but as long as the existing problems and ways of working were unchanged, the intention to change would still remain the same. Tomas (181017) concurred with this insight: "*It's a big change for manufacturing because they haven't really worked with PLM before [...] But the way they've been working today, it's just ridiculous; the fact that it has been accepted is odd [...] I think they have been lucky as well probably that nothing major has happened."*

6.5.1 A new preferred situation

The team got firsthand experience of system implementation and had to adjust their expectations. PLM+ went live but not the MBD-related features due to the stoppers. It was a reality check for Sven (181115) to understand the time needed to work on PLM+: *"It took us two years to switch from one PLM to another. Of course, we have added some functionalities, but it takes quite some time. I'm sure that the ERP system or MES system in the workshop will take three to five years minimum until they are fully implemented. The software already exists in an out-of-the-box solution but [it takes time] to have everything aligned and so on."*

The team reaffirmed their proposition that MBD only marked the start of digitalization and would have a long way to go to achieve a digital thread. Sven concluded that model-based ways of working in manufacturing and assembly would bring about even more changes at TurbineCo. To facilitate higher maturity levels 4 or 5, or digital twin, there existed some loose ends in other functions like R&D and quality management, and the connectivity in digital landscape. The team was aware of the "boring work" and the costs involved in recreating models for all parts in the turbines as individual components.

Therefore, it became clear to the project team that both drawing-based and model-based ways of working would co-exist at TurbineCo, depending on the team and the components they worked on. A few teams would dedicate themselves to MBD with the newer components, while others would continue with their current ways of working to produce the older components, especially those without the best model quality. In other words, the new vision for the MBD project was still set to achieve a maturity level 3, but not for all workers at the manufacturing and assembly workshop.

In the event of new stoppers, Sven decided to limit or postpone MBD but would not stop the project. This is Sven's (181016) "non-existent" contingency plan: *"Everything won't work. There is a small thing called reality. Since this is a new way of working, Plan B is more or less to postpone the implementation until it works, or the intended implementation will be limited. If we had 10 things, 10 components, and or 10 teams involved, maybe we need* *to reduce it to five. But there is no real Plan B. The real Plan B is just to shift the date for the implementation in this case."*

I summarize the current and the new preferred situation in Table 26. below.

Table 26. The current and preferred situation after Period I

	Current situation	Preferred situation
Manufacturing	**Maturity level 2 (mainly)** The CAD-CAM chain suite was developed. Stoppers emerged. Productive pilots of turbine disks and turbine rings of IGT100 were scheduled. Training was planned.	**Maturity level 3 (mainly)** MBD for some components after the stoppers were removed.
Assembly	**Maturity level 2 (mainly)** The DWI suite was developed. Stoppers emerged. Some model-based steps were tested in the IGT200 assemblies. More productive pilots of electrical assemblies of IGT100 and core assemblies of IGT200 were planned. Training was planned.	**Maturity level 3 (mainly)** MBD for some components after the stoppers were removed

6.6 Prehensive analysis

In this second-order analysis, I dial back to before Period I started. I first detail the routine design process when the MBD team had envisioned a preferred situation to reach a maturity level 3 for manufacturing and assembly. Thereafter, I relate their design actions to address the puzzle of generativity.

Period I spanned over three releases. While the situation was unfolding, I observed how the team conversed with the unique situation and reflected in action to reach a preferred situation (Schön, 1983; Simon, 1996/2019) through prehension (Whitehead, 1929/1978). To put in a contextualized way, in order to reach model maturity level 3 (when models were quality-assured) in manufacturing and assembly, the team designed model-based ways of working and shaped the situation based on what had transpired in the past releases and what was about to come in the future releases.

6.6.1 Overview of the problem setting

With the design of model-based ways of working gaining traction, the team realized the need for *outreach*. As their colleagues were obscured by the changes, the team needed to inform their colleagues (current and future routine participants) about what was about to come at the same as they designed the changes, hence “a moving target”.

In each department, there were only a few experts who understood the ways of working in their entirety. Senior members of TurbineCo were consulted when designing the model-based. To ensure that the modeling practice was viable across R&D, manufacturing, and assembly, the team facilitated *interdisciplinarity.* Tomas, coming from R&D, had limited knowledge of assembly. Together with Vincent, they were in touch with key persons in assembly, who would help them with all kinds of information, to pinpoint what could be and what should be changed. Also, since the manufacturing and assembly routines would intersect with the R&D routines, Sven (180321) also invited senior engineers, engineering standard, and quality in the picture: *“I have two senior engineers from R&D who are speaking partners. I can pretty much ask them questions: how do you think would be the best way of solving this or doing this with our experience from engineering?”*

PLM+ was the key artifact of MBD. Two dedicated IT architects, Kaveh and Vikram, were assigned by IndustryCo as the contact persons from PLM+ development, responsible for the MBD features related to manufacturing and assembly, respectively. The Business and IT teams had a close collaboration, and their goal was *functionality*, i.e., to develop the CAD-CAM chain and DWI suites for TurbineCo. For each release, a document called *User and Software Requirements Specification* (see Chapter 5) was drafted, as a reference document overseeing the project work. Prior to their involvement, the project work during the “pet project” phase of the MBD was done without proper technical setup and support. With the formal MBD project approved, a separate sandbox environment was initiated, installing out-of-the-box CAD/CAM and PLM+. This sandbox testing environment had no connections to any other digital artifacts. Therefore, the team could explore the new features freely, test the use cases, and create demonstrative pilots. Nils (180126) elaborated on the role of the sandbox environment, like a playground: *“In the beginning, we have a test environment what we call a sandbox environment, in which we tested use cases. Tomas showed us what you can do in PLM+, just playing around with the system, but the system has zero connection to anything else.”*

MBD hinged on the interfaces of PLM+ and others to create *interoperability***.** In a digital landscape, the network effect lay in how digital and physical components work alongside each other. Despite the role of PLM+ and its applications to MBD, other digital artifacts like CAD/CAM and ERP would be integral to many of the steps in the model-based ways of working.

The current manufacturing and assembly ways of working from a bird's-eye view were deemed robust and the MBD project would potentially induce additional costs that could not be justified by any proven benefits. To sustain the project and project funding, the team sought after *managerial support***.**

Within IndustryCo, the sites were making progress at different levels in their digital journeys. With the creation of a digitalization group, Sven aimed to create *global alignment* with his peers and learn from other sites. Some sites were moving ahead of TurbineCo's Swedish sites in certain areas, according to Sven (181015): *"We are implementing end-to-end, and there are already solutions available for some parts of it. For instance, there are already sites working with much more automated NC codes creation than what we are doing, but they are not connected in the same way to PLM+. Other locations are much more upfront when it comes to track and trace, what kind of materials go into the workshop or leave the workshop, and so on. They are more advanced but like on separate islands, and we are trying to connect those islands altogether."*

In sum, I observe how the team members framed the situation in the following ways:

- Outreach: how to communicate a "moving target".
- Interdisciplinarity: how to have the other silos on board.
- Functionality: how to develop the MBD features.
- Interoperability: how to connect PLM+ with other systems.
- Managerial support: how to get buy-ins from management.
- Global alignment: how to coordinate projects across the sites.

In the next section, I narrate the design actions encapsulated in each framing to capture how the team members conversed with the situation and how they reacted when the situation talked back.

6.6.2 Outreach

Situation. Between manufacturing and assembly, there were different levels of exposure to digital technology. In manufacturing, many used computers in their daily work to do smaller programming tasks and enter inputs into ERP, but not in assembly. The negative connotation associated with digital technology was prevalent in the assembly workshop. Despite some assembly workers welcoming the presence of computers, many others were not fond of using computers, out of practical reasons like the inconvenience of stationary computers and out of personal reasons like the fear of being laid-off and being surveilled.

Organizing training and support. Sven prepared formal information packages to update the workers regularly on how MBD would provide the technical foundations for the Business, their external partners, and even the customers to collaborate using models, and model-based way of working itself was not an end goal. More visible measures could be seen in some Fika rooms. TVs were set up in various manufacturing offices and workshops, displaying internal news, weather forecast, and other useful information, in the hope of more exposure to more projects like MBD.

Sven was certain, however, that not everyone would be reachable through this means and there was an asymmetry of information. For roles like manufacturing engineers and CAM programmers, they were well in touch with the happenings. But for operators and assembly workers who worked in shifts, they had limited opportunities to meet the team.

Buzzwords like industrial digitalization, especially digital thread and digital twin, were misunderstood by many. Sven had to unwrap the buzzwords and inform the Business something concrete. Sven (171122) distinguished the terminology: *"Looking at TurbineCo as a whole, we are working on both digitization and digitalization. To scan a document, that's not digitalization, that is digitization. In this project, what we are focusing on is to actually using the 3D model as the data carrier in downstream processes. Today, we are limited to the downstream process of assembly and manufacturing, but of course, the intention is to use it throughout the lifetime of the turbine and service and also in contact with suppliers, sub-suppliers, and things like that. In this case, we try to remove this drawing-centric way of working."*

New features of the CAD-CAM chain and DWI suite were never seen before in TurbineCo, and only a few MBD enthusiasts understood what they would entail for manufacturing and assembly. Sven realized that the biggest misconception of MBD was the complete withdrawal of drawings, as the notion of *paper-less* was wrongly equated with *drawing-less*. Paper drawings caused conflicted emotions among the workers: many liked and disliked them at the same time. Sven had to reassure them in any communication effort that MBD was not about removing drawings. Even after the rollout of MBD, it would take more work to discard drawings completely.

Even though the MBD-related features were not yet rolled out, the project created some fuzz by team members talking to their colleagues about the progress and what to expect. They observed some mixed attitudes from the workers; despite the openness, some were rather indifferent toward the upcoming change. Tomas (180522) recalled some skeptical comments: *"The response I've gotten so far is 'Well, we're gonna get something like this soon, anyway! We might as well take it and work with this', but we haven't really shown them the end result yet."*

Sven worked on the training program by first narrowing down the participants and machines. The team identified a few more local champions in manufacturing and assembly who would be introduced to the MBD first. The selected few were based on their workload and the technical setups of machines that they were responsible for, to deem the ones with the shortest payoff time, involving around 20 people.

After Release 3, Sven connected a few colleagues and formed a support network for MBD. Those would act as the first line of contact when any problems were encountered by the workers, before escalating the issues further. In the same vein, when workers had suggestions, they would also propose them. In this support network, the owners of PLM+ at TurbineCo would also join. The team members would serve as the key users and local experts to help dispel the concerns and misgivings.

When the situation talked back. Through these efforts, Sven wanted to debunk the mysteries associated with MBD, and he made clear from the get-go that MBD was an enabler for digitalization and that it would not lead to layoffs. In assembly, those efforts to push MBD to the workers were transformed into a "pull", i.e., some assembly teams saw the values with MBD and DWI to solve their problem with the drawing-based, and they were eager to participate in the first pilots. Vincent was working with those requests. Sven (181015) gave an example of the pull from the assembly: *"We were focusing on the IGT200 turbines, but we got some information from the shop floor that they had some issues with a lack of information on the electrical installations on the turbines. [...] Since they pulled for a model-based way of working, we put that test number one, where we actually have a pull from the Business and from production engineers. There will be pilots to see what's working and what's not"*.

6.6.3 Interdisciplinarity

Situation Sven was aware of the implications of the project being located at the intersection of R&D, manufacturing, and assembly. MBD would create a new interface between R&D and manufacturing, between R&D and assembly, in which models would be the main information carrier, replacing drawings, to enable concurrent engineering. In turn, for R&D, there would be more requirements on the models they created, according to Tomas (180522): *"We have to educate them on why, because first of all, there might be more work* *for some, but you have to see the whole picture, including service in the end. I think people need to know why they're doing extra work [...] Because of how the company is structured; it's said that these people should do that; we are responsible for that part, and you are responsible for that part. And in a sense R&D and manufacturing have also been split up like this; but when this change arrives, we need to cooperate much better."*

What made the situation even more intricate was the internal politics when departments became silos. The MBD project explicated those silos, as Sven (181115) experienced: *"R&D is one silo. Manufacturing is another and why should R&D put their account of expense to help manufacturing? [...] Some people fully understand the fact that what I produce is the data that someone else uses, but others don't really want to see that, they just want to do as little changes as possible for their work."*

Recruiting experts. While Sven was recruiting more team members, he networked in different departments at the Business to seek team members and sponsors. Sven (171220) described that: *"One reason why Nils and Mats are involved in the project is because at least I believe they are good sponsors for that project in their own programming community. Mats is a senior programmer, and if he is working on this and tell the others that this is something good. Nils and Mats are structured. Then you know most of them will have a positive attitude toward doing it, just by hearing him saying that, rather than me, from engineering, or some managers coming along and saying 'use this, you know it will be better for you', then we will get resistance from the organization".*

When the situation talked back. After Release 3, the team identified a stopper: the way in which the R&D engineer created the models. This again exposed drawbacks of a drawing-based way of working when R&D did not supply quality-assured models. Sven (181015) elaborated on this further: *"[MBD] really puts hard requirements on the fact that the model needs to be correct. In general, we have had that demand for 15 years but since it's only the drawing that matters, as long as the drawing is correct, no one has really cared about the models behind them. But in this first step, we really see that we have a drawing, but the model is incorrect, so we can't use this in the way intended. We have a hard demand that the models need to be correct compared to the drawing."*

The CAD-part alignment feature in PLM+ would be a potential remedy. This feature enabled the downstream usage of models. Drawings and models would be checked with their M/A-BOMs to see if there were any misalignments. Without the alignment, models could only be viewed as one component; its internal structure and parts were not visible. CAD-part alignment, was considered an important prerequisite to the DWI suite. Engineers would have to ensure the alignment between the models and the actual parts. Sven (181015) discovered how this CAD-part alignment would be an opportunity for improving the models: *"They need to connect the CAD data with the actual parts, with the M/A-BOMs in a new way which we have not done before at all. That's a completely new requirement in engineering, where the first initial steps are already done and effective in the PLM system already. But there are some processes and ways of working that still need to be defined in parallel with the MBD project."*

The CAD-part alignment feature, however, had some defects as well. It was possible before to have two variants, marked with A and B, sharing the same drawing, in other words, one CAD model aligned with two M/A-BOMs. But now, it was not possible with CAD-part alignment. Tomas had to reach out to the IT architects for this initiative to discuss what the implications of this were on MBD.

6.6.4 Functionality

Situation. When developing the CAD-CAM suite and DWI suite, the Business and the IT team realized rather quickly that they had different expectations on the requirements and how the requirements could be fulfilled, which resulted in a growing backlog and missing functionalities after each release. The engineering and IT mindsets were rather distinct, which could be seen from the project setup, i.e., scrum, and the teams experienced cultural differences and spoke different languages.

Exposing differences. Sven sharply pointed out that this agile way of working with partial delivery and a backlog in the software industry, which contrasted with the logic of delivery in full in the manufacturing industry. In other words, PLM+ could be delivered with incompletion and defects fixed and enhancements added later on, while a gas turbine would be expected to work perfectly upon delivery. Sven (180327) noted that: *"For software, you can deliver 90 percent and say it's working and in the next upgrade in a few weeks you will get additional functionality it's missing today. But for a turbine or a car, you can't deliver the car without the steering wheel. You need to have everything in place."*

Secondly, the turbine business itself differed from other standardized production methods like mass production, as gas turbines were comparably complicated and low volume. For the IT team and their previous experience with mass production, they might not always be able to spot the subtle nuances in those requirements, and what the requirements meant.

And lastly, how the requirements were fulfilled was not the only obstacle that stood between the Business and the IT team. As PLM+ was not in place, it was challenging for the IT team to implement the MBD-related features in a system that was yet to exist. This added complexity was also the culprit to some technical issues. Sven (171220) explained this: *"We are not including new functionalities into the existing PLM. We are introducing new functionalities into the new systems which we don't have yet. We are shooting at moving targets. [...] It is adding a lot of extra effort and a lot of extra issues on the IT side, of course, since they are struggling with the normal PLM functionality as well."*

When the situation talked back. After working with Vikram during Period I, Tomas (181015) noticed some improvements in their work relationship, and they were more empathetic and upfront toward each other's requests, especially after he realized that Vikram was busy with the never-ending backlog items: *"We kind of talk the same language most of the time, but sometimes he floats away, but he does the changes and then he tries them out: 'I think this could work if you do it like this', and then he asks me: 'is it okay if we do it like this', and I say: 'no it's not; let's do it like this'. I'm really trying to avoid too many clicks and too many back-and-forths."*

When Release 3 went live, the team discovered that the remaining defects and missing functionalities stopped the rollout of MBD. The team members contacted Vikram and Kaveh, IT architects, for support. A few of those issues concerning the MBD-related features were patched by hotfixes before release 3.1 and more scheduled for the next releases. While waiting for them, it was not shocking to find out that project team was "*somewhere between anger and frustration at the moment with the defects*", according to Sven (181016).

6.6.5 Interoperability

Situation. MBD foregrounded the need for interoperability across the digital artifacts. The challenge, as the team understood it, was to set the systems up in the right way so they could talk to each other and transfer the data in between the systems.

Detecting interfaces. All digital artifacts would work standalone. But in pursuit of the connectivity between digital artifacts, the team detected interface problems between PLM+ and CAD/CAM, between PLM+ and ERP. To make the matter worse, almost all digital artifacts were often customized to the specific business requirements, just as the development of PLM+ to MBD. They were not always compatible with PLM+ and caused many unexpected technical issues. When attempting to connect between CAD/CAM and PLM+, the team ended up with errors and bugs. It would not be the case if the connection was made between CAD/CAM out-of-the-box and PLM+ out-of-the-box.

Another interface was physical machinery, like NC machines. With machines that ran their own software as old as 20 years old, PLM+ would not be able to cover the last mile of the CAD-CAM chain. In such cases, model-based would only be enacted to the steps before Step 6: Post-processing in manufacturing.

In addition, the team foresaw some difficulties associated with the access to digital technology on the shop floor. Josefin (170126), Line manager, had a realistic understanding of the practical issues with mobile devices: *"If we come to the workshop, even though it is a modern industry, the workers are still standing in a booth with big gloves and it's warm and dusty, and then they have to stand there and poke on the small iPad. It's difficult for them. They may sit with a computer for a maximum of an hour a day, so it becomes such a contrast with paper. If it breaks just print a new one. I think we have to learn how to handle this conflict."*

When the situation talked back. During the planning of Release 3, the project team discovered that the sprints coincided with the vacation period, and the IT team would only have two and a half months to work on the software requirements on PLM+ alone and implementing a connection to other digital artifacts was not a realistic ask.

For example, to recall the envisioned PLM-ERP relationship and rationale behind PLM+ as detailed in Chapter 4, despite the role of PLM+ as the primary system, ERP would still be crucial for triggering the workflow of E-BOM, M/A-BOM and M/A-BOP. Even if the applications, especially the Manufacturing Application, would be rolled out, M/A-BOM and M/A-BOP could not be transferred to and from ERP.

Different from the other two stoppers discovered after Release 3, the team made a conscious choice to postpone the connection between PLM+ and ERP. Practically, this meant the development of PLM+ would become longer to establish the interfaces to other digital artifacts. Sven (181115) estimated that: *"It will take almost 2 months of testing to see how [PLM+] interacts with ERP, MES, Office, and all different kinds of software it has to support and to work together, including the postprocessors in the NC machines and everything."*

6.6.6 Managerial support

Situation. For the middle and especially top management who were not familiar with different ways of working, MBD involved a lot of PLM terminologies, alongside the CAD/CAM and ERP terms. Not all managers worked with PLM or CAD/CAM, which made it more difficult to get the understanding. The business case was rather weak and ambiguous to them. At TurbineCo, an example of a business case could be a reduction of non-conformance costs and lead time. The project manager would emphasize the time saved after the project, which would equal a saving of X Swedish crowns in X amount of time.[18]

Sven (180126) had a difficult time pinpointing a fixed value of MBD as it would affect how the product information was delivered, and that would be a change without affecting non-conformance costs and lead time: *"Coming to digitalization and new stuff, of course, I have some business cases but it's hard to show actual figures. You can show we will reduce* non-conformance costs *by 10% and get questions 'why not 5%or 15%'? From a management perspective, that has been a challenge because they are used to having everything in a project plan with a fixed business case, and especially a project like this; having a model-based way of working itself is an enabler for future digitalization rather than the solution for all the issues. From that perspective, it's a 'boring fixing your data' project, and, in general, that just costs a lot of money. You don't see real benefits on a short term basis, you need to see 'ok with this given data, oh, wait a minute then I can do all these things, and actually have a new business model for customers or having more efficient workflows, that's also something of a higher quality, what does that mean in terms of euros', so that has been a challenge in the mid-management level."*

Communicating progress. Many middle managers were in the dark and they found it difficult to know what they were going to make decisions about. During Period I, Sven had regular meetings with the steering committee, as well as the manufacturing and assembly middle management, to discuss what MBD entailed and what the project aimed to achieve, to get their buy-ins for conducting more pilots. Line managers like Josefin would invite Sven to monthly meetings with all managers at the assembly workshop, where he would present the MBD project and its progress. She underscored the importance of middle and top managers getting the information firsthand.

As PLM+ was developed in parallel while the team was selling MBD to the middle and top management, the team had to present something more concrete and concise with the benefits and scopes. There were some teething troubles with PLM+, and the MBD-related features were not always features. The team produced demonstrative pilots to get management on board (see Chapter 8). Tomas (180424) recounted this: *"I've done a few presentations and*

[18] It was also common for initiatives to underestimate the cost and overestimate the benefits to get the green light.

animations. […] Since the project just started, we needed to show something flashy for the management, to really get them hooked, but it's so much beneath the surface."

When the situation talked back. Some first line managers were supportive of MBD. In assembly, Josefin, Line manager, tried her best to demonstrate to her managers what MBD entailed in practice. Team members would chime in to push for features and relate to how MBD would be the means for other important digital projects, as Nils, (181112) in manufacturing, stated: *"[Digital Factory] is a really hot subject, and this is something I try to explain to my management that we need this system to take the next step. They just want to take the next step and see the benefit."*

Some of the efforts paid off in manufacturing. Sven continued his formal meetings with managers of different levels in manufacturing. Nils, Mats, and Robin also presented for management in manufacturing and showcased the model-based. They were surprised by how the top management positively responded to the new level of connectivity and their curiosity about the technicalities of MBD.

Sven (181017) was glad to see some changes taking place; in this case, moving CAD programmers to one physical location: *"They were scattered along in different workshops and departments. They were actually put together into one central team, and one reason was the MBD project. It was not the only reason, but it was one of the reasons why we put them together to be able to have a standardized way of working and being supported by one organization rather than different organizations as in the past. In that sense, we have already changed the organization to cope with this project, which I guess is a bit unique; in general, you start with the new way of working, and then you realize what you need to do in the Business. In this case, we have already started."*

6.6.7 Global alignment

Situation. The MBD project was one of the many initiatives emerging at IndustryCo. During the past years, in the power generation business, TurbineCo and some sibling sites saw a surge in the number of initiatives in implementing new digital technology; some shared similar goals and some repeated similar mistakes that could have been avoided.

Consolidating efforts. The new digitalization group, created after Release 2, oversaw the ongoing digital projects across the various sites. Correspondents from each site would share their roadmaps of the digital projects. The group hosted knowledge exchange activities across the sites to coordinate and update their initiatives and to set up expert teams who worked in the same areas.

Erik, Coordinator, was responsible for the roadmaps at TurbineCo. Erik first had workshops with managers and workers from manufacturing to document their visions. He then prepared a roadmap and presented it to IndustryCo. Subsequently, even though each site had their budgets to design and prioritize their own projects, the group has the final say in approving which projects to run.

Furthermore, together with his colleagues worldwide, Sven worked on aspirations for other digitalization topics, ranging from the overall software infrastructure, quality management, and MES (Manufacturing Execution System) to envision what novelty those would bring to the Business. The group would then summarize and store those roadmaps of projects in a database across the sites. Together, a global roadmap was formed to align with the local ones and to avoid doing twice the work.

When working toward the goal of digital factory, the group would also decide collectively a few different systems in which they saw the most potential, wherein they made recommendations to each other. In total, there were ten focus areas, among which PLM+ and MBD took an integral role, according to Sven (181115): *"The project influences the global roadmap since, with this PLM+ and CAD/CAM, we are the ones in the lead; we are driving the development, and others are following us and looking into what we are doing to see, to do some cherry-picking later on."*

When situations talked back. PLM+ would be a global system and TurbineCo took the lead in the defining the functionalities. If some sibling sites would like to go to another PLM, the digitalization group could use the mandate to decline such requests. To accommodate different sites was a challenge. Nils (181112) experienced this issue first-hand to agree on common requirements that would work at different sites, including the user interface and ways of working.

The team, especially Tomas, was in close collaboration with Motorville and considered how the project work would affect Motorville, as an assembly site. Especially with the connection to ERP, Tomas (181015) tried to learn their Business and ways of working: *"I know where they are going and some of their limitations as well. They might need some backing to get them on their feet, but then my job would be the same as the IT architects have done for me. So, I could tell them: 'This is how we do stuff' and then I will need their help with how the Business is from their sites, because we use the same interfaces, but the Business is not the same."*

6.7 Addressing the puzzle of generativity in Period I

I observe that while designing routines (model-based ways of working in manufacturing and assembly) and digital artifact (PLM+) in tandem, in order to reach the envisioned preferred situation, the team framed the situation and tackled design problems in the following design actions (see Table 27. below for a summary).

Table 27. Design actions in Period I

Problem setting	Design action	Conversing with unfolding situation
Outreach: how to communicate a "moving target".	Organizing training and support	There were misconceptions on MBD and digitalization at large. The team prepared different means to reach out to the roles that would be affected by MBD. They recognized a pull from some assembly teams.
Interdisciplinarity: how to have the other silos on board.	Recruiting experts	MBD demanded an interdisciplinary effort from R&D, manufacturing, and assembly. A stopper was identified when the team realized the models made by R&D were not quality assured.
Functionality: how to develop the MBD features.	Exposing differences	The Business and the IT team had limited work experience in each other's expertise, which caused some conflicts. After Release 3, some remaining defects were not resolved, which became a stopper.
Interoperability: how to connect PLM+ with other systems.	Detecting interfaces	The development of the CAD-CAM chain and DWI suites was fundamental to MBD, and so was the connection between PLM+ and ERP, CAD/CAM and others. Before Release 3, the team deliberately postponed the connection between PLM+ and ERP, which was another stopper.
Managerial support: how to get buy-ins from management.	Communicating progress	Sven and the team publicized MBD and its progress to the line, middle and top managements. Many line managers and top managers responded positively.
Global alignment: how to coordinate projects across the sites.	Consolidating efforts	Many sites worldwide had different projects to "make digitalization work". To align those efforts, a global digitalization group was established. TurbineCo would take the lead in designing model-based ways of working for other sites.

To recall the puzzle of generativity: *how are generative systems of routines and digital technology created from without?*

When seeing sociomaterial assemblage as the agential unit in routines (D'Adderio & Pollock, 2020), these design actions hold keys to (re)configuring the sociomaterial assemblage (such as actors, artifacts, theories and practices, see

Glaser, 2017). In other words, the generativity of routines and digital technology relies on the how digital artifact's ability to form envisioned sociomaterial assemblages.

In the design action of organizing training and support, the MBD team had reflective discussions (Dittrich et al., 2016) with the actors regarding what digitalization entailed in their own work. The efforts to prepare information packages and support network were directed at creating a joint understanding (Dionysiou & Touskas, 2013) of the envisioned ways of working.

Knowing that model-based ways of working were situated across R&D, manufacturing, and assembly, Sven recruited experts to form a cross-functional team that would cover all steps. However, as the starting point of both manufacturing and assembly routines were the design release from R&D, the team encountered a stopper when they realized that models were not sufficient enough to be used, which, in turn, identified potential conflicts among the roles (Gupta et al., 2015). In other words, the pre-negotiated truce ceased to exist, and the team had to renegotiate a truce (Nelson & Winter, 1982).

To inscribe intentions in PLM+ and to ensure that their intentions were understood by the IT team, the Business team exposed differences in how an agile way of working in the software industry clashed with the ways of working in the manufacturing industry. Despite their efforts to reconcile conflicting goals, the team discovered that envisioned functionalities failed to be delivered and the digital artifact itself became a second stopper.

MBD assumed the interoperability among (digital) artifacts to benefit from a system of artifacts (Cacciatori, 2012). The team attempted to connect PLM+ and ERP, PLM and NC machines and improve the digital environment on the shop floor. But they detected incompatibility of the connection between PLM+ and ERP, which was a stopper that prompted preemptive decisions to be pushed to future releases.

Within TurbineCo, some managers were more engaged than others (Grand, 2021). Sven's role as a project manager of the MBD project was to pitch and report on the progress in different meetings. Sven had to ensure that managers at different levels would support the MBD project and the model-based ways of working: for first line managers to agree on organizing training and pilots, for middle managers to understand what MBD entailed in practice, and for top managers to realize the benefits of MBD might not be measurable through non-conformance costs and lead time.

In the global digitalization group, Sven oversaw the digital projects across the various sites and took the lead in aligning interests in MBD, which added complexity of the project to consider practices from different sites.

All in all, the design actions (re)configurated different relationships within sociomaterial assemblages and when the situation talked back, three identified stoppers (R&D modeling practices, defects in PLM+, and interface between PLM+ and ERP) indicated the breakdowns in the (re)configurations of socio-material assemblages, which would, in turn, indicate breakdown in a chain of materializations.

In the next chapter, I narrate how these stoppers were managed.

7 Period II

With the stoppers identified, the MBD project had a new preferred situation to reach a main model maturity of level 3 for selected components. In Period II, the team continued with the project work for five quarterly releases: Release 3.1 at 18Q4, Release 3.2 at 19Q1, Release 3.3 at 19Q3, Release 3.4 at 19Q4, and Release 3.5 at 20Q1.

Similar to the preceding chapter, I first present the happenings in between the releases in first-order narratives, including the project work in manufacturing, assembly, and project management. The team then evaluated the situation when the MBD project ended and updated their visions of a preferred situation. Next, I detail in a second-order prehensive analysis how the team conversed with the unfolding situation to make live routines and how the team dealt with the stoppers emerged in Period I. Finally, I conclude the chapter with how the team addressed to the puzzle of generativity in Period II.

7.1 Release 3.1 at 18Q4

The official PLM+ project ended after Release 3.1 went live. The MBD project had yet to receive its formal approval from TurbineCo, but it continued with some reduced IT support from the PLM implementation team. As the focus for the upcoming releases was to resolve the connectivity issues with ERP, Sven invited the local ERP team to the project. With their involvement, the team hoped that the connections between PLM+ and ERP would be established so that double work with M/A-BOM and M/A-BOP would be avoided.

Manufacturing. The preparation work for a productive pilot in turbine rings continued. To bypass the stoppers, the team planned on dividing the manufacturing steps into two groups: group 1 for preparing the M-BOM and M-BOP, including Step 3: Manufacturing preparation, Step 4: CAM preparation, and Step 5: Tool preparation. Group 2 for generating and sending the NC codes, including Step 6: Post-processing and Step 7: Production order creation and Step 8: Part manufacturing (see Table 12. and Table 17. for a comparison between drawing-based and model-based ways of working in manufacturing).

Group 1 utilized the Manufacturing Application and the Instructions Application in the CAD-CAM chain suite. Robin worked on technical instructions, referring to the video tutorials Tomas made. He also tried digital mapping of the manufacturing workshop and prepared the M-BOP for a turbine ring using PLM+ instead of ERP, despite the variable time not properly displaying. While Group 2 concerned the NC application. Nils created and saved the NC codes on the NC application, which was only available in the testing environment.

The team discovered a few more defects in the Resource Application, especially when creating and managing the tools. IT architects made some hot fixes, and Nils tested them in the sandbox environments.

The team had some networking meetings with manufacturing engineers and middle management, where they presented Step 3: Manufacturing preparation to use a model-based way of working to create an M-BOP. They also discussed how the interface with ERP was dealt with. They acknowledged that the workload would increase but would decrease in the long run.

Meanwhile, the team received the news that a new version of CAD/CAM would be released. This entailed that the local installations, or the native version of CAD/CAM would be phased out. The Business decided not to immediately switch to the new version until a year later to allow time for transition. Sven (190131) welcomed the decision to upgrade the CAD/CAM to the new version: *"For the Business that's a huge benefit to actually get rid of all the local installations. All the local work that is disconnected from pretty much everything. And to have the management on board, making the decision and informing the organization that this is the case is really good, because then we have all the buy-ins we need in the CAM area to actually resolve all the issues. Because everyone in the Business wants to move into the integrated system [...] So that was a really good push for the project."*

Assembly. A planned productive pilot was conducted of the electrical assembly of the ladders of IGT100. Due to the stoppers, Tomas had to retouch the models created by his previous colleagues in R&D. Vincent prepared the work instructions using the Instructions Application. The assembly workers tried out how the work instructions could be retrieved from the different tablets instead of paper binders. However, as a part of the backup, paper documents were still prepared, for the assembly workers to "sleep well". In total, some five people participated in this pilot over a week. The results were overwhelmingly positive. They saw the benefits of working with tablets when their work required mobility, and they also had access to other drawings and documents through PLM+.

Since it was the first productive pilot the entire process of a model-based way of working took longer than the drawing-based, and some technical hiccups were also noted. The workers were aware of the steep learning curve for some but were confident that eventually they would pick up the speed over time. To keep the momentum, more productive pilots were planned on the core assembly of the IGT200 compressor. At the same time, Sven (190131) was stressed about how the development of PLM+ could delay the progress: *"More and more people buy into the project and want to start working productively in the system. In that sense, it's picking up speed actually. We have had quite a lot of demo sessions, and we have had some productive pilots on the shop floor. We are falling behind in terms of delivering the system, to get all the functionality in the system"*

Project management. The digitalization group organized a digital fair in Rotorstad to showcase some ongoing digital projects for the entire workshop. Erik, Coordinator, was responsible for the fair, and he was content with the turnout. Apart from MBD, a few other change initiatives were also present, like mobile work (such as rugged tablets) and visualization (such as VR). Their presentations attracted many curious eyes. Over a hundred colleagues took some time off to attend the fair. The projects were hands-on with what their initiatives entailed in the day-to-day manufacturing work. Sven established himself as the first point of contact for digitalization-related change initiatives in manufacturing, and he hoped that the workers in the manufacturing workshop would be able to understand the buzzword of industrial digitalization and digital thread.

7.2 Release 3.2 at 19Q1

Release 3.2 went live but with reduced scope and minor improvements on functionalities, as the project had yet to receive its formal renewal approval. As a result, some suggestions discovered in the assembly pilot could not be put forth. The team divided the connection between PLM+ and ERP in the upcoming three releases (see Table 28. below).

Table 28. Planned connections between PLM+ and ERP

Release 3.3	**Release 3.4**	**Release 3.5**
Transfer new M/A-BOM	Transfer new M/A-BOP	Transfer revised M/A-BOM & M/A-BOP

The news had it that TurbineCo, together with its sibling sites in the power generation business, would form a new global company in 2020. For the MBD project, it might imply having things on hold until the new management cleared the air. Also, the licensing agreement of PLM+ and CAD/CAM supplied by IndustryCo might be affected. But until the major reorganization happened, it would be business as usual.

Manufacturing. Site Motorville, whose main product line was aeroderivative gas turbines, started to order from Site Rotorstad. The manufacturing workshop worked on the new AGT100 orders. The production of aeroderivative gas turbines was more restrictive with protocols and regulations, which put some pressure on the workshop to adapt. Subsequently, they could not work on the planned productive pilots for the turbine rings.

Meanwhile, some defects in the Resource Application were fixed. Nils and Mats worked on adjusting the NC machine templates in the Resource Application and imported them into the live environment.

Despite the delayed productive pilots, some team members enacted certain model-based steps in their daily work. For example, Robin taught one of his manufacturing engineering colleagues to create M-BOPs for an upcoming order, with the help of the video tutorials. The team also made some work instructions for operators. Tomas and Robin investigated libraries for textual instructions, in which they could make standardized texts like "don't stand in front of…" with the symbol "warning sign" in the library. Some demonstrative pilots for the NC Application were also initiated. The component was not produced, rather Nils and Mats sent the NC codes to folders named as machines.

Assembly. New productive pilots for the core assembly were planned for a new variant of the IGT200 turbine compressor. It was suggested that model-based could be enacted for all incoming orders of electrical ladders of IGT100. After communicating with the R&D engineers, Tomas received models in compliance with the CAD-part alignment. Tomas also attended seminars organized by the CAD-part alignment initiative, informing the R&D engineers of different alignment options, as well as which alignment should be used for which occasion.

Tomas taught more production engineers and assembly workers about the model-based ways of working. Some more feedback was flowing in, ranging from small visual changes in the user interface to a full-blown IT landscape with MES (Manufacturing Execution System), some of which were not in the scope of the MBD. Sven (190423) saw this as a positive indication of the project: *"There are some defects and enhancements required in the system but in general most of the feedback was what is the next step, which is out of the model-based scope. It shows their will to change, and they see a potential with working in the new ways and processes, so that's a really good response. At* *the moment the plan is to increase that pilot into some more assemblies, some more information to show what's going on and how to handle it."*

Project management. Sven went to IndustryCo and met with his colleagues from the global digitalization group, with whom he had weekly online meetings. Apart from keeping up with their ongoing initiatives, they shared and exchanged project management experiences. Sven's colleagues were particularly interested in the progress of the MBD project, as MBD was the only infrastructural project where the features in PLM+ were developed from the ground up.

Another digital fair was successfully conducted in Statorstad in 18Q2, where Sven and Tomas did some live demonstrative pilots for the MBD. Sven and Erik contemplated if the fairs should occur on a more regular basis, as it was out of their official responsibilities.

Tomas became the advanced key user of Manufacturing Application and led the support network for MBD. Tomas continued with making the video tutorials. He recorded the screen and supplied the footage with text, in which he navigated the applications in PLM+, to make the CAD-part alignment, M/A-BOM, and M/A-BOP. In addition, he offered some tips and tricks on making the animations. He received some more feedback from the project team, as a template for future videos. The team thought it was difficult at times to keep up with both the video and the text. Another challenging aspect was to make it convenient for the users to look for specific steps within the video tutorials, as they were around 30 minutes long.

7.3 Release 3.3 at 19Q3

Release 3.3 went live with the planned defect fixing and feature improvement, including "Transfer new M/A-BOM". The project received a renewal of funding from TurbineCo's CFO after a long approval process and would last until Release 3.5. The meetings with the steering committee were resumed to discuss the planning and budgeting of the Release 3.4 and 3.5 in the upcoming fiscal year. The project work was directed at identifying as many defects as possible, as Release 3.5 would be the last formal release. For Release 3.4 more specifically, some remaining MBD-related features were tested and finalized.

Manufacturing. The workshop was still busy with the AGT100 orders, and the planned pilots were delayed. The team worked instead on the connection between PLM+ and ERP. Tomas and Robin detected some issues with the planned feature "Transfer new M/A-BOP" from PLM+ to ERP, which failed to transfer all the necessary data. For example, the attached documents stayed in PLM+ without transferring to ERP. To make matters worse, the M-BOP transferred to ERP followed another numbering sequence of the operations than the manufacturing engineers were used to. Tomas had to communicate with the local ERP team and Motorville, and together they had to decide on a common solution.

Nils continued working on the NC Application. He created the folders called machines on the testing server and sent the NC codes to them. However, he encountered problems in the server which triggered network security issues, which, delayed the productive tests for the NC Application.

Assembly. The team succeeded in conducting more productive pilots in various assembly workshops. In Sweden, there were more productive pilots running in Rotorstad, and new demonstrative pilots started in Statorstad. The Motorville site also started a first demonstrative pilots of the model-based way of working in assembly. It was reassuring for Sven to see how their visions of MBD were realized in the assembly. He was reassured that PLM+ was working, and MBD was also working.

Project management. IT architects Kaveh and Vikram started to terminate their responsibilities for the MBD project. Bo, IT support, joined the project, and would officially provide onsite support from 20Q1. With Kaveh leaving the project at 19Q3 and Vikram leaving at 20Q1, the manufacturing part of the responsibilities was first transferred to Bo. Bo worked previously with CAD/CAM and PLM+ and understood the business requirements better than Kaveh and Vikram. They organized handover sessions and recorded them. They managed to work through the overview of the MBD-related features, and Bo asked for more clarification on the digital landscape to have an overview of how everything was connected.

7.4 Release 3.4 at 19Q4

Release 3.4 was postponed to resolve the major defects detected previously (like the numbering of M/A-BOP). The time of completing certain steps was shortened. For the final release, the main task was to implement the remaining items on the backlog and to fix bugs accumulated during previous releases.

Manufacturing. As the MBD project started to conclude, Tomas received a new role in manufacturing, in which he would support tool designs, while remaining as a key user of MBD.

The workshop was still predominately occupied with AGT100 and was planning for the updates of IGT200. With the extra requirements imposed by the aeroderivative gas turbines, manufacturing had limited possibilities to be flexible. The so-called "lock-in" way of working had stricter demand on how technical instructions were documented, how the same models and machining processes were used to generate the same NC codes, and so on. In other words, new ways of working in manufacturing started to emerge especially among CAM programmers and operators.

Assembly. The team worked on the planned features to connect PLM+ and ERP and found some new issues. In the recent release of "Transfer new M/A-BOM", Tomas discovered that the A-BOMs created at the Statorstad site could not be transferred to ERP. Some of the issues were partially due to an oversight from the Business to agree on and define the requirements across the sites.

When testing the new features for "Transfer revised M/A-BOM and M/A-BOP", the team found that after transferring the revised processes and operations, the M/A-BOPs were not, in fact, revised in ERP, and only the documents attached were. Bo was contacted to fix these issues, and together with IT implementation, he was involved in solving the problem.

And after recognizing some site-specific properties, Tomas made some more training videos on M/A-BOP creation for the Rotorstad and Motorville sites. Motorville also continued with their demonstrative pilots in their workshop, in which they found a necessary property missing in the features.

The model-based was enacted in some orders of electrical assembly of IGT100, with fewer than ten people affected. Some hands-on training on A-BOPs was done by Vincent for his colleagues. Most participants reacted in a positive way and again suggested other areas for functionalities, such as quality data, automatic report, which may exist in the system but required modification from the software development team. The problems experienced were related to infrastructures, such as Wi-Fi and hardware. Some separate projects from the IT department would improve the Internet connection.

Project management. The early outbreak of Covid-19 disrupted the supply chain, and uncertainty remained in terms of what kind of materials were available and when they would arrive. Some engineers started to work from home, but not the operators and assembly workers. Sven (200206) contemplated how the MBD project would be continued: "*We have a lot of people working from home. It is not as efficient as being in the office, and we have a lot of related issues: we need to ensure that we have materials, we have something to manufacture, and deliver, and so on. It's a lot of small task forces forming up here and there to cope with the situation [...] Then a project like this is not prioritized. We try to move forward, but it is a slow process at the moment.*"

Bo had some more handovers with Vikram to learn more about the assembly side of the project, so that the local IT service team could take over the maintenance of the MBD project. They would be responsible for maintaining and updating the system after Release 3.5.

7.5 Release 3.5 at 20Q1

Release 3.5 went live with more defects resolved and features in PLM+ improved. The MBD project was partially on hold when the first wave of Covid-19 hit Sweden and thus paused the planning of pilots.

The scheduled major reorganization would happen later in 2020 and new licensing agreements with IndustryCo were done. As a result, CAD/CAM and PLM+ would be updated in late 2020, to make sure the same versions were used across the sibling sites. Bo would be responsible for leading this update and implementing a new version of PLM+ and CAD/CAM.

7.6 The situation after five releases

After five more releases, MBD-related features were fine-tuned and updated in PLM+. To this end, the MBD project was much like a software project to stitch and improve applications in PLM+ and the connection between ERP and PLM+. It was also time-consuming to navigate amongst the interest of different sites for a global system like PLM+.

To "make digitalization work", the development work focused on removing the existing stoppers and emerging defects. None of the team members were key users of ERP, so the local ERP team was summoned to provide business requirements. Some infrastructure-related issues emerged.

Unlike some other projects which ended with proof-of-concepts, MBD was practiced in the workshop, with uneven progress in the manufacturing and assembly. The manufacturing workshop was busy with the aeroderivative gas turbine AGT100, which changed their way of working by imposing stricter compliance with the M-BOMs, M-BOPs, NC codes, and work instructions. The workers understood the urgency of introducing MBD and how it could aid the work with industrial gas turbines. For example, Nils (191030) saw how his ways of working were changed and a fully-fledged MBD would entail even more than what the project achieved: *"I have changed maybe a little bit. I think I see the possibilities with [the NC Application] to do a lot more things, and this will only be the first step. I'm not sure if MBD at the moment is the right name for it, because this is only the start for MBD. The more you work* *with it, the more you talk to other people, you see there is a lot of open areas where you can improve and use the data from the model, from different kind of models, to have a more model-based working.”*

In assembly, model-based ways of working were enacted for orders of electrical ladders of IGT100. A few more productive pilots were conducted in Rotorstad, and some demonstrative pilots were done in the Statorstad and Motorville sites. The pilots particularly brought about new requirements on R&D, using CAD-part alignment. The team was satisfied with what they achieved and paved the way for future improvements. Sven (191030) kept a cool head with this progress: *“With actually testing and seeing that we can connect PLM+ with ERP, I feel more confident this will be a new way of working. Then there are still some remaining issues, defects in the system, that need to be resolved before we can work on a large scale. [...] We have delivered something that works. Like any other system, you can get a car running, but it's not until it's comfortable to ride it that you actually buy that car. This is more or less the same; we have developed an operational system, but it needs to go from okay to good”.*

The introduction of MBD gave rise to more training. Apart from the online guides of PLM+ prepared by the PLM+ implementation team, Tomas offered video tutorials; moreover, hands-on face-to-face training would be done individually within the support network. It was also decided to keep the MBD project team structure, and the members became the owners of some new ways of working. Practically, this ownership granted the respective team members’ right to change the features and the ways of working in the future.

But due to Covid-19, the MBD project and the roll-out of model-based ways of working were put on hold. Sven, together with the steering committee, decided to pause all planned pilots. In sum, during Period II, the MBD maturity level at manufacturing remained at mainly a level 2. At assembly, some electrical assemblies of IGT100 and core assemblies of IGT200 reached a level 3, but it remained at mainly a level 2 due to Covid-19.

7.6.1 A new preferred situation

The journey toward a digital thread continued. The MBD team would resume its project work in some shape and form toward a main MBD maturity level of 3 for some selected few components, as the team was convinced that drawing-based and model-based ways of working would co-exist. When working on those components with legacy data, a level 1 would be enacted; however, when working on the new components and new turbine models, it would be the model-based. Therefore, manufacturing and assembly would see two processes existing in parallel based on the components and the management. Sven

(191029) shared his insight regarding this co-existence: *"To be honest I doubt that we will have MBD 100% before 2030 because now we have old machines and if we sell two machines a year, the business case is to update from R&D first and then for manufacturing or assembly. And I doubt that there will be a business case. I think there will be two ways of working, the old one and the new one. And over time, old products will be kicked out and replaced by new ones. And by that, we will also change the way of working. I think both ways will work in parallel for quite some time."*

MBD brought about more initiatives in enabling a digital thread, like the CAD-part alignment initiative. Sven hoped for more digital projects to introduce relevant software and hardware to further digitalize manufacturing and assembly. Since the pilots in manufacturing were delayed, the team hoped to experiment more in the connection between PLM + and CAD/CAM. After negotiating the licensing and updating PLM+ and CAD/CAM, native CAD/CAM would be ideally replaced, and PMI could be reintroduced. With an integrated PLM+ and CAD/CAM, a next step would be including Direct Numerical Control, and Coordinate Measuring Machine so that "everything will be in the same system from R&D to the manufacturing shop floor".

I summarize the current and the new preferred situation in Table 29. below.

Table 29. The current and preferred situation after Period II

	Current situation	**Preferred situation**
Manufacturing	**Maturity level 2 (mainly)** CAD-CAM chain suite was fine-tuned. Stoppers were removed. Many realized the need for MBD due to AGT100. Productive pilots of turbine rings of IGT100 were planned but put on hold due to Covid-19.	**Maturity level 2 (mainly)** **Maturity level 3 in some newer components.** More initiatives would be involved to enhance connectivity between R&D and manufacturing.
Assembly	**Maturity level 2 (mainly)** **Maturity level 3 in some orders but on hold due to Covid-19.** DWI was fine-tuned. Stoppers were removed. Productive pilots were conducted of electrical assemblies of IGT100 and core assemblies of IGT200. More pilots were done in other locations, but new ones were on hold due to Covid-19.	**Maturity level 2 (mainly)** **Maturity level 3 in more assemblies.** More initiatives would be involved to enhance PLM+.

7.7 Prehensive analysis

I now turn to the process of routine design. Similar to the preceding prehensive analysis, I first explore the routine design process when the MBD team picked up project work from the aftermath of the stoppers. Next, to address the puzzle of generativity, I document how their design actions vis-à-vis the (re)configuration of sociomaterial assemblage, and especially the stoppers, were removed to create the conditions for a chain of materializations.

In this incarnation of the MBD project, there were five releases. The team continued with conversing with the situation to reach a newly envisioned preferred situation of model maturity level 3 (in which they lowered their expectation to enact the model-based ways of working in some selected components). They prehended (Whitehead, 1929/1978) what led to the stoppers and framed the problematic situation (Schön, 1983). They also recognized how the situation was developing in their favor when the manufacturing and assembly roles recognized the need for MBD, and not in their favor when Covid-19 hit.

7.7.1 Overview of the problem setting

To pick up the situation where three stoppers were identified: the first relating to how R&D created the models. Some defects in the MBD-related features remained unsolved. Lastly, the connections between PLM+ and other digital artifacts were purposely postponed. The team adjusted their visions, and the new preferred situation was to enable an MBD maturity level of 3 for some components after the stoppers were removed.

In Period II, more workers tried out the new features in PLM+, and there was more demand on the team for *outreach*. When communicating to the workers, the team framed MBD as something that could have a long-lasting impact on the ways of working, instead of being a flash in the pan. At the same time, Erik, for example, was mindful of how MBD would be integrated with the Business without overthrowing the progress in the manufacturing and the assembly throughout the years.

The workarounds in R&D were brought to light. R&D engineers who created the models must develop new ways of changing models, which, if not properly done, would have consequences on the downstream. MBD partnered up with the CAD-part alignment initiative from R&D at TurbineCo to facilitate *interdisciplinarity***.** In hindsight, this was essentially a data issue, which was not prioritized in Period I. Sven (190523) deemed it would take a longer time to remedy all the data: *"If you take the journey to update all the data with new requirements, first you will lose a lot of valuable time in the end. I think to have any progress, you need to be aware of the missing information or using* *requirements and start closing the gap in parallel; otherwise, I mean if we would have taken care of the data first, we would not even have started with PLM+."*

Another identified stopper concerned the defects and how defects were handled. After more than one year of working on the MBD project, the Business and the IT team gained a deeper understanding of their collaboration and how they would ensure the *functionality* of PLM+. While the Business team got used to the agile way of working, the IT team also understood the business requirements better and would try to accommodate as much as possible.

To cope with the stopper in the framing of *interoperability* discovered in Period I, after Release 3.2, the Manufacturing Application and the Instructions Application sufficed to create M/A-BOPs and work instructions. The focus was switched to establish the connection between PLM+ and ERP, so that the transfers of M/A-BOM and M/A-BOP would be available. Especially when A-BOPs would be able to transfer to ERP, a full digital thread would be available in the assembly, if hardware-related interoperability issues were solved. Sven (191030) explained: *"When an A-BOP is transferred to ERP, it generates a production order, and it ends up being executed on the shop floor. And without this final transfer, it would have been a manual step or a glitch in the overall process. By having this interface removed, we can actually create the data and ensure that the data ends up where it needs to be, which is the ERP system."*

The progress of MBD was considered more observable when there were digital fairs in manufacturing and productive pilots in assembly. Sven observed changes when conversing with some managers, namely that the MBD project moved into an "approval situation". However, there was still a lack of *managerial support* and understanding of digitalization. Erik (190130) wanted more involvement from the management: *"The main challenge is getting management's involvement, not attention but involvement in understanding what [digitalization] is and what we want to achieve with it. They just want projects, and they want them to be implemented. They want the results, but they don't want to be involved…they don't have an end goal or vision with digitalization; that's something we have in the group. They have seen it presented, but they haven't absorbed it."*

The involvement of Motorville increased the uncertainty regarding if the standardized way of working would work across the sibling sites and how it would entail for the other routines at the Motorville site. In Period II, the team had to ensure the *global alignment* among the sites. As Sven (190522) sharply pointed out it was a "one solution for all" situation: *"For instance, we define how we transfer from PLM+ to ERP since we use the same PLM+ and the* *same ERP. And if we define what kind of data should be transferred and where it should be transferred to, then we are stuck with that process; then we need to change the [way of working] accordingly. With the same system, maybe it's not possible technically to have two different solutions, so that we are forced into the same process, which can be, of course, both good and bad. Hopefully, we can fulfill all the requirements by doing so."*

Because of the implications, the team had to investigate different scenarios and options to have the full picture, so that the new ways of working would capture different business requirements from engineering, assembly, and service to examine the pros and cons for all the different options and how each site should keep or improve their ways of working based on others.

To summarize, the team members updated their understandings of the situation and changed the framing in the following ways:

- Outreach: how to communicate a "long-lasting impact".
- Interdisciplinarity: how to have R&D and other silos on board.
- Functionality: how to develop the MBD features.
- Interoperability: how to connect PLM+ with other systems.
- Managerial support: how to get buy-ins from management.
- Global alignment: how to balance the requirements for MBD from different sites.

Now I turn to the design actions, some of which are similar to Period I, to understand how the team members conversed with the situation, and how they removed the stoppers in some of the problematic ones. I also detail how they reacted when the situation talked back.

7.7.2 Outreach

Situation. In manufacturing, even though there were limited opportunities to enact the new ways of working, some team members like Nils (191030) showed the colleagues what he was working on in formal and informal settings. The reactions were positive when they could see how MBD could remedy the problems they encountered now. But model-based would bring about changes outside Nils' and other team members' immediate network.

Organizing training and support network. The support network of key users was important. Those affected could consult with the team members in case of the unexpected. Some might trigger new bugs and defects, and some might misunderstand the new features and MBD. Bo stressed the importance of having key users in the Business so that for each role there was at least one contact person who could investigate and report the bugs and defects.

Those who participated in the pilots also referred to the video tutorials created by Tomas. Sven provided a PowerPoint slide displaying the different steps in the model-based way of working, and Tomas linked them to some timestamps in the video tutorials. When talking about the video on making an M-BOP, Sven (191031) recounted how the benefits of MBD could also be visualized: *"This is the M-BOP with the text, and Tomas added some text to a picture, and some more information. You can see how this looks in the operator's view. You see that they get the same information as the manufacturing engineer. I think that is the beauty of it."*

In addition to the video tutorials, more training sessions were planned to explain the long-lasting impact from MBD to the adjacent roles. The team was optimistic with the trend that more people were curious and would reach out for more information.

When the situation talked back. Sven realized a much bigger pull than a push from the Business, after Release 3.2. More people showed an interest in testing MBD and those involved saw the potential.

Video training also had its limits. Nils (191030) realized some would prefer a proper guide with detailed step-by-step instructions, for some experienced operators: *"They want to have it on paper step-by-step on how you should do it, and then follow it. And for me, I love videos; and I think videos are the best way to have instructions on and then I can do it, see all the icons and everything is in color."*

7.7.3 Interdisciplinarity

Situation. To address the stopper for the modeling practices in R&D, Tomas participated in the CAD-part alignment initiative, in which he acted as a spokesperson for manufacturing and assembly to explicate their demands. CAD-part alignment would ensure the quality of the models, containing enough information for manufacturing and assembly. To complete a CAD-part alignment would increase the workload in engineering, and in the long-term, when achieving a higher degree of MBD, more work needed to be done.

Combining forces. The increasing requirements from the CAD-part alignment initiative suggested new standards for the R&D engineers and models. The MBD team arranged training sessions to inform the R&D engineers in the hope of increasing the model reuse. Sven also organized meetings with the R&D management to present the requirements from a manufacturing and assembly point of view, hoping to incorporate those into the engineering standards, the guidelines, and rules for R&D.

According to Sven (191031), it would be a win-win situation for R&D, manufacturing, and assembly: *"People start to realize why are we doing this, and there are actually benefits across the board; it's not just in the manufacturing[...] Even in engineering; working with models, you want to have quality where you don't have to get non-conformance report from manufacturing or angry phone calls saying 'what the hell have you done; we don't understand a bit of your drawing'. Of course, you want to have something that's accepted and work also downstream."*

When the situation talked back. CAD-part alignment was only one important stepping stone for MBD. The project was dependent on and complemented by other initiatives in ERP, additive manufacturing, and MES, to overcome the silo thinking and workarounds. These compatible initiatives would promote an even more integrated end-to-end manufacturing and assembly.

The project worked with other initiatives like MES. MES would be able to close the gap between the execution and the production orders in PLM+, which would, otherwise, be a manual step, even with MBD. Sven (191030) explained further: *"MES can transfer the production order from ERP to a shop floor worker and at the same time gather the feedback in terms of measurement, protocol, stampings into the MES. Even with MBD, those things will still be a manual step. You still need to have the measuring protocol on paper because we don't have any other way at the moment to handle them, for instance. We still need to log into ERP manually to say that this operation is completed."*

7.7.4 Functionality

Situation. When backtracking on why MBD-related features did not function as they should, the team realized that agile at times was not "agile". Comparing to engineering releases that would happen within a day, agile development for the MBD project entailed a much longer turnaround. Sven (190522) was critical about this discrepancy: *"Personally, I think this project shows that an agile project approach is not agile. Because in an agile project, you should be able to change the requirements, change the scope at least a minimum by each sprint. But in many of these projects, in general, they are approached as a waterfall, meaning we have all the requirements from the start. They are divided into sprints, and then something is delivered. In that sense, it's not an agile approach but all the theories behind with the sprints, the ideology is having an agile project, but, in the end, it is not."*

Exposing differences. The development of MBD-related features was expensive, paid for by the Business. Due to the resource constraints, the team had to estimate the lead time of features and prioritize them. Those lowly prioritized would have to wait or were not attended to at all, which led to frustrations when the defects persisted. To make sure that the defects were accurately recorded, Tomas tape-recorded some occasions when errors occurred, which would otherwise be difficult to articulate via text or screenshot alone.

Some team members also discovered how they would improve the user requirements after learning more about PLM+. Nils realized that some earlier user requirements were not well thought through. But at the same time, it was difficult to shoot at moving targets when PLM+ was ever developing. As he (190524) reflected, they needed to know about a system that they did not have yet: *"We need to put all the requirements. We need to think how the system will work and what the problems could be, and if you find some problems when we do the testing and we put as a defect, then it's a longer task to do that and it's quite hard to predict."*

Reflecting on the releases, Sven also stressed the importance of mutual understandings and acknowledged that there are things overlooked by both from the Business and from IT: "*some of them could probably have been avoided if we had spent some more effort in testing or if the architects from the IT side would have gained more experience and knowledge about the Business."*

The timing of testing often collided with scoping. In other words, when the Business was doing the acceptance testing, they had to already define new requirements for the upcoming sprints in releases. According to the MBD team, the IT architects, and the implementation team could have done more tests for minor functionalities, like "naming a part", so that the team would devote more time to testing. Tomas (191029) found it hectic in the testing setup: *"There's not enough time really for the regular users to test the system in their pace and create bugs and get them fixed before the release. [...] We found bugs and hopefully they got fixed but they never got fixed in that release, so it's always the next one. There's always this backlog for each new bug."*

With the involvement of Motorville, the MBD project also did not have enough time to get all the business requirements for each sprint. Sven (190524) found it stressful: *"Now we are dealing with us and Motorville. When we start transferring things to the ERP system, meaning that we need to align the processes and agree on the processes, then it's the next level of issues. It has been really hard for us to put down requirements, the business requirements, so that we can send them to the IT development team, and especially with the timeframe we have had."*

When the situation talked back. The team could not manage to do all the tests and fix all the defects as they would have wished. They had reduced the MBD scope by removing PMI, which they realized was considered a big project in terms of the new features required. It was seen as a R&D endeavor to investigate how PLM+ would handle PMI.

The handover to the local IT support Bo was rushed. Even though Bo had relevant experience in IT and Business, he did not have the time to absorb all the new responsibilities, which slowed down the testing process.

Release 3.4 was originally scheduled for 19Q3 but was postponed. The Business submitted formal change requests to the IT implementation concerning the features planned to be delivered. It was the first time for the Business to be proactive, which in Sven's (191029) opinion, was "three years too late". Due to this postponement, Release 3.5 was pushed from 19Q4 to 20Q1: *"The Business was not too pleased with the project's agile approach, but in this case, there were some parts that the IT planned to put as backlogs. But the Business said 'no that is not acceptable, then we rather change the go-live date to ensure that these things are included in the release than having them as backlogs for later' [...] Today, it's not that much about developing a new functionality. It's smaller topics like enhancements, improvements, and some new functionalities that are included in the system from the start. And the earlier releases were to get a system up and running to be able to work with and you just had to accept the fact that some things were not delivered as they could have been developed. For this release 3.4, everything in scope is quite small things, and it's harder to argue that we miss these small things that we can't deliver it in time."*

7.7.5 Interoperability

Situation. The troublesome connection between PLM+ and ERP was one of the stoppers identified in Period I, which reflected how PLM+ and ERP were handled at TurbineCo. Workers obtained the status of key users in one system, as experts or owners of certain processes and applications. ERP, like PLM, was maintained in a specialized organization, with its owners and key users in charge of the features. They were, either PLM experts or ERP experts, not overall experts. Tomas initiated contacts with the local ERP team to deal with the ERP-related requirements. The ERP experts helped to propose the business requirements and verified the use cases.

The complexity emerged when the ERP team had to take consideration of the Motorville site's requirements. According to Tomas (190424): *"This* M/A-*BOM transfer is a big point. The managers have meetings with each other in the ERP forum. They need to decide themselves what they need among all the sites. I think it's been a huge discussion on what they need because I don't think the* M/A-*BOMs between Motorville and Rotorstad look the same, and*

I'm still a bit confused about how this will actually look in ERP. All I know is how it looks in PLM+."

Connecting interfaces. As discovered in Period I, when PLM and ERP offered similar features, the team had to make a choice of assigning the primary and secondary system and see how the choice would impact the Business. For example, Robin reported that for manufacturing planning, the time variable did not work in PLM+, so that after the transfer of M/A-BOP, he had to insert a value for time in ERP manually. Sven (191031) was cautious about not making too many changes: *"We would need to decide whether we need to change on the PLM side or the ERP side. Based on that, we will have different responsible organizations. […] We try to avoid making too many changes on the ERP side since that's the ERP system, and it can have quite big consequences if something happens."*

The team admitted that there was a lot of work connecting PLM+ with ERP and they needed to understand a lot of different processes and functionality in ERP. For example, concerning the creation and transfer of M/A-BOM and M/A-BOP, when replacing ERP with PLM+, the key users of PLM+, like Tomas, had to learn how things work in ERP. He trusted the colleagues in the ERP organization to provide feedback when establishing the connection between PLM+ and ERP. Because of the division of work, Tomas had some difficulties in learning ERP and was concerned if there would be an increasing divide between PLM+ and ERP at TurbineCo.

When the situation talked back. Eventually, many of the connection issues were solved incrementally during Period II, and a model-based way of working in assembly could be introduced in its entirety. Sven looked forward to productive pilots after Release 3.4, when the production order in ERP was connected.

The team was also aware of other hardware-related problems like the quality and availability of Wi-Fi. With tablets, it would take longer to open PDF files and animations via the DWI suite. These issues with the infrastructure and the hardware, if not solved, would become a stopper to MBD. Sven (191029) wanted to have the IT department involved: *"In this case, the IT department had to actually invest in something based on the fact that the office tablets were not good enough. So, of course, that could be a potential stopper in some areas. If it turns out that they don't cope with the dust or small particles, things like that in the workshop, then we are in a situation where we don't have an alternative at the moment, since we have just raised the question. But hopefully, that will be the kick start for them to actually get something else in place"*.

7.7.6 Managerial support

Situation. Sven was facing a catch-22 moment. On the one hand some managers misunderstood MBD and thought that it would be the panacea for all ends in a digital factory, which was far from the case. On the other hand, the resources for the MBD project were still scarce. It was at times difficult to convince the managers to allocate resources when those benefitted would be someone outside their organizations. The team apart from Tomas, was only working 20%, and the funding renewal process took a longer time than expected.

Resourcing. Sven found it difficult to navigate in the overall budgeting and planning process for the company when it was done almost a year ahead. This approval structure made it almost impossible to ask for resources during the fiscal year. The team members needed to make time for the project work and oftentimes exceeded their assigned 20% workload. In most cases, their line managers were supportive and would allocate some of their regular work to their colleague. But Emma (190129), Line manager in manufacturing, had this dilemma when trying to balance the demand from production and the demand from project: *"We don't understand how much it costs in resources, efforts it takes to do this step changes. We want the step changed but we're not willing to give what it actually costs. And, as long as we are not willing to give what they need, we will never do the step changes and then it will be another project that we didn't go"*

When the situation talked back. The team had to set realistic expectations for the management and Sven (190524) found it difficult to communicate that model-based would not be *the* solution and would not resolve everything; rather, it would be *a* solution to enable other features needed for a digital factory. Sven (190131) tried to be more concrete to the Business: "*What does it actually mean in the day-to-day work? And by that, I think it's easier to get a buy-in. Because 'Internet of Things, what's that? How am I affected by that in my day-to-day work?' I think by having more information on a detailed level in this area we want to do this, as a means of, and it's not just I get rid of all the papers."*

When getting managerial attention, Sven and Erik discovered discrepancies in how much the managers at different levels knew about MBD and digitalization at large. Erik (190130) reflected on this issue: *"I report to top management, and in some cases, the middle managements get bypassed. If something is implemented on the shop floor, there are two managers that have been passed, and it is the top management that makes the decision. So, it's the middle managers that get bypassed, when we talk about digitalization."*

7.7.7 Global alignment

Situation. As the Motorville site took on a bigger role from Period II, the MBD project prioritized the requirements in consideration of both sites. At times, the team was inspired by their differences. For instance, Sven (191031) reflected on how the Swedish sites can learn from Motorville's engineering change management: *"We have some kind of cherry-picking based on Motorville and what we can actually use for our turbines as well. I think more and more people realize that we can't have a situation where we change our own NC codes between the two blades. Maybe, we need to have the same kind of regulations, but we don't have the same legal aspect. Internally, we can for sure have the same processes, as long as it doesn't cost too much, of course."*

Converging requirements. The inclusion of Motorville introduced some more constraints to the team. It was considered challenging to gather local requirements from different sites and work out how those would be accommodated under the scope of MBD. Especially, Motorville had different ways of defining A-BOMs compared to Rotorstad and Statorstad. In short, the Swedish sites used a form-fit based structure for A-BOM; when change occurred that would affect the form-fit, then a new A-BOM would be created. In Motorville, a date-based structure was used, e.g., there was one generic A-BOM per day, regardless of the component. Both ways of working would have implications for service and maintenance, and the option was not as simple as choosing one over another. With a form-fit based A-BOM, each unique structure could "live" on their own, while for date-based, it needed to have a separate system documenting the differences in each component for service and maintenance purposes.

To explicate the differences, the teams in both sites started to construct and compare their process charts (i.e., SOPs), to map out the ways of working and how they differed across sites. Sven stressed the importance of visualizing ways of working and the specific requirements from the different businesses were. For example, what an operator would do in the Swedish sites, and what the equivalent would be in other locations; what the impact would be if a standardized solution was introduced in different locations.

When the situation talked back. While working on AGT100 orders, the manufacturing workshop experienced changes in their ways of working when creating the M-BOMs, M-BOPs, and other materials to comply with stricter standards of the aeroderivative turbines. For certain steps, the team developed a mix of local and global ways of working. For manufacturing, in Step 5: Tool preparation, for instance, the numbering convention of tool ID was different for each site. Tool ID was a serial number that identified the actual tools in the machine. Since the various sites had different numbering conventions, the

MBD project envisioned two sets of numbering. Nils (190524) illustrated this example in detail: *"If I create a tool, I will send the [tool ID] to the workshop and they also need it to build the tool. We use this locally, but the requirement from the project is that [...] We need to have a global library. If I create a tool in PLM+, somebody else from a different site can access it and use it and for me, that's ok if they use the same number, but if they have a different serial number or logic behind the numbering on their sites, they need to follow us. They maybe want to change the numbers, and I cannot allow someone else to change my number. [...] To handle this problem between the different sites, they have created a global numbering."*

The new ways of working would entail changes for all sites. Despite some limited demonstrative pilots on the shop floor, Sven (191030) was skeptical about business readiness at Motorville since their engagement in the project was notably shorter than the Swedish sites: *"To them, this was unknown until a year ago, when they decided to join the project. So, for an operator and a vast minority of the Business, they were not aware that this was ongoing. Whereas here, this has been on the radar for last three years when we have had the project".*

7.8 Addressing the puzzle of generativity in Period II

When dedicated to removing the stoppers (R&D modeling practices, features in PLM+, and connection between PLM+ and ERP), the team framed the situation and tackled design problems in the following design actions (see Table 30. below for a summary).

Table 30. Design actions in Period II

Problem setting	Design action	Conversing with unfolding situation
Outreach: how to communicate a "long-lasting impact".	Organizing training and support network	As MBD was not accessible to all affected roles, the team tailored some video training materials and maintained the support network. The team experienced a bigger pull from the Business.
Interdisciplinarity: how to have R&D and other silos on board.	Combining forces	The team realized the stopper related to how R&D created models. The team worked with the CAD-part alignment initiative to investigate the solution, while the team participated in training session with R&D engineers. The team worked with the MES initiative to include more shop floor workers.
Functionality: how to develop the MBD features.	Exposing differences	The Business was not satisfied with how defects were handled, which led to the identified stopper. With the addition of Motorville and the task handover, the Business decided to postpone a release to fix some remaining defects.
Interoperability: how to connect PLM+ with other systems.	Connecting interfaces	The stopper regarding the connection between PLM+ and ERP was resolved in three successive releases, and the team contacted local ERP group and other initiatives to prevent future stoppers of infrastructural and hardware-related problem.
Managerial support: how to get buy-ins from management.	Resourcing	While the progress of MBD was misconstrued as a panacea to some, Sven still had some difficulties with the funding. With some delay the project was renewed. Sven tried to make sense of the budgeting process and how to communicate with different levels of managers.
Global alignment: how to balance the requirements for MBD from different sites.	Converging requirements	With Motorville on board, the project became more complex to accommodate the differences. Both sides compared and converged their requirements. In manufacturing stricter standards were imposed. The new ways of working had inspirations from both sites, but they also had some standardized steps.

To recall the puzzle of generativity: *how are generative systems of routines and digital technology created from without?*

In the routine design process of Period II, I record a balance between problem solving (Simon, 1996/2019) and reflection in action (Schön, 1983). The presence of stoppers indicated breakdowns in the (re)configurations of sociomaterial assemblages, and the team had to rationalize and determine the sources of the problem and worked out some plausible solutions to provide conditions for digital artifact's chain of materializations.

With the video tutorials and team members' engagement in the support network, the vision and MBD practices became more recognizable for the routine participants. These video tutorials facilitated "learning by experience" in a knowing community or an autonomous learning group of individuals (Cohendet & Llerena, 2008, p.258).

R&D modeling practices concerned the interdependences of routines and breakdown emerged in routines connections, or ecology of routines (Sele & Grand, 2016). In such sense, the models were mediators, but instead of their generative effects in Sele and Grand (2016), I observed their negative effects and the team's efforts to repair them (Feldman, 2000). In addition, the breakdown also presented opportunities for renegotiating a truce (Nelson & Winter, 1982) between R&D and manufacturing, and R&D and assembly.

Another stopper was the functionality of PLM+. Some contentious moments were caused by information problems (Gupta et al., 2015) when both the Business and IT teams lacked understanding of each other's ways of working. During Period II, both teams were more aware and tolerate of their differences, however, the Business pulled the trigger to postpone Release 3.4 to ensure that the digital artifact would technically afford the envisioned ways of working.

In a similar vein, after detecting the stopper in the interfaces between systems of artifacts (Cacciatori, 2012), the project team worked to progressively connect PLM+ and ERP. Here the team's design actions resembled Glaser's (2017) design performances: the team contacted local ERP experts to abstract grammars of action in ERP, to expose assumptions of different types of BOM and BOP transfer between PLM+ and ERP, to distribute agencies between PLM+ and ERP correspondingly and to appraise outcomes of the connections. The team also identified that some other infrastructure and hardware issues like Wi-Fi and tablets, if not dealt with, would become stoppers.

The conflicting goals from different levels of the managers revealed different or even competing interests among organizational actors. This tug-of-war of competing goals emerged from managers located at different levels of organizational structure.

And lastly, the team saw how endogenous routine changes took place in manufacturing after intensive collaborations with the Motorville site, when stricter ways of working could limit the freedom of individual work. This, in turn, called for MBD and model-based ways of working. In addition, the team deliberated and reflected (Dittrich et al., 2016) on the differences in the ways of working between sites and contemplated whether to replicate or to innovate (D'Adderio, 2014).

To summarize, the design actions continued at (re)configuring sociomaterial assemblages and repairing the three identified stoppers (R&D modeling practices, defects in PLM+, and interface between PLM+ and ERP). When these breakdowns were remedied, the envisioned sociomaterial assemblages were able to take form, and the conditions for digital artifact (PLM+) to exert its influence on routines were met.

Such materializing or a progressive/instantaneous chain of materializations is the focus of the next chapter.

8 Reconstructive analysis

The second-order prehensive analyses (in-the-flow) in the preceding two chapters detail how the MBD project conversed with the unfolding situation (Schön 1983) to create a preferred situation (Simon 1996/2019). I observe how the team members framed the problem setting and record their design actions to address the puzzle of generativity by (re)configuring sociomaterial assemblages and how the conditions for materializing were created.

In this chapter, I conduct another second-order reconstructive analysis (after-the-fact) to turn to two parts of the puzzle of recursiveness to make routines alive. I first unveil where intentional variations were sourced. The team created a category of design artifacts that I call routine prototypes. I use these to illustrate how a chain of materializations could be unfolded. The second part of the puzzle concerns selective retention, and I explore a new type of qualitative multiplicity (D'Adderio & Pollock, 2020; Feldman et al., 2021; Pentland et al., 2020) which I call spatiotemporal multiplicity to illustrate how patterns become.

8.1 Intentional variation

In the first-order narratives in Chapters 6 and 7, I hinted the role of design artifacts like demonstrative pilots and productive pilots. These design artifacts are variations that are intentionally generated from without the routine dynamics, corresponding to the first half of the puzzle of recursiveness: *how are variations generated from without?*

In the next section, returning to the routine design process, I detail the sources of these variations, their types, and which steps of materializations they represent in materializing the model-based ways of working.

8.1.1 Sources of variation

User requirements (see Chapter 5) represented the team members' expectations of the MBD and PLM+. When working in parallel with the project, the team members enacted the drawing-based ways of working, reflected upon them, and documented the perceived problems and inspirations in the form of user requirements. The Business team had all encountered specific problems in some steps of their manufacturing or assembly routines. For instance, the CAM programmers had problems with finding drawings and models, as they were scattered over different digital artifacts, to the point that it was more time consuming to gather information than to create the NC codes.

Not all problems would be resolved with the MBD project. The team had to demarcate what the project would be able to address. For instance, the manufacturing and assembly of some older turbine models, which predominately used drawings, would be considered on a case-by-case basis to remain at a level 1 or not.

Some inspirations were based on new features and best practices afforded by PLM+. Sven, Project manager, believed that those possibilities were worth looking into (180126): *"When it comes to CAM programming, there is Feature-based Machining, for instance, that's something we will have a look at and see if this will be something suitable for our business or not. So, there are some areas where we see if there is a possibility or not."*

On the other hand, when working on the requirements, the new features of PLM+ also prompted an unexpected paradox. There were aspirations for both model-based and drawing-based ways of working. It was tempting to propose requirements to tailor drawing-based, instead of model-based way of working. Also, those features of the applications constrained user requirements. As Sven (190523) explained: *"In many cases, you get new possibilities with new software or new machines, but you tend to think 'how can I use this in my existing process', instead of seeing what this new tool or machine allows me in terms of new ways of working.*"

The team found out that individual ways of working discouraged cooperation among routine participants. When observing the assembly routines, Tomas realized that each instantiation of a routine had different degrees of variation. Especially when using work instructions, there was a discrepancy between what routine participants did and what they were supposed to do. In manufacturing, this notion was echoed by the CAM programmers and operators. It was even surprising for the team members how the current routines sustained themselves, despite the problems. For example, Nils (180126) underscored the need for standardizing: *"When we talk to other CAM programmers and operators, they see the problem that everybody is doing in different ways. And in the end, everybody wants to have a standard way of working."*

Through his network in the Swedish industry, Sven had collaborations with other Swedish industrial firms regarding MBD. The project established contacts with those that had progressed further than TurbineCo to exchange lessons learned and their best practices. Consolidating the requirements from users in different sites, and experts in and outside the TurbineCo was not an easy feat. Sven (191031) had to balance different opinions and choose the ones the team deemed would suffice: *"[...] If the argument is simply: 'we have always done it like this'. Maybe that's not set in stone and then we can actually do it in a slightly different way. I think that has been the approach where we haven't been able to come to an agreement or haven't received correct or enough information. From the Business and the experts, we have the most requirements, but in cases where we haven't, then we have just done something we think is good enough and hope for the best, that's the only way you can't be too Swedish and have 25 meetings to agree that we should have a 26th."*

Apart from coming up with the user requirements for the IT team, the team informally put forward some "user requirements" to the Business, among which were the documentations of the routines. SOPs were not actively maintained, and the team suggested that many of the outdated SOPs would be revamped by describing the new model-based ways of working. The standard or quality group in each department would be contacted to update the documentation. Sven (181016) described the situation: *"There is a quality department handling this kind of instructions so we will use the existing channels, not creating something new, but we need to provide them with the information. In theory and what I will aim for is that they will do all the updates based on our information so that we don't create anything, and it should be updated in the already existing guidelines as far as possible."*

After some familiarization with PLM+, the team realized that the opportunities with model-based ways of working would entail much more than just the routines. In fact, the current roles and responsibilities within manufacturing and assembly would not suffice. For example, Nils considered how MBD would change the relationship between the CAM programmer and the operator, when the operator would have access to the models of the tools in PLM. Sven (180327) was convinced that the routine change would bring about new roles in some departments: *"This is such a big change. Without going into details, I can foresee that it's a new system we are working in, it will be new roles within the manufacturing, so the old defined roles for different persons will be changed, and responsibilities will be changed between different roles, and most likely even new roles will be created."*

In addition, there would be new roles, such as colleagues as a reviewer and line manager as an approver to the NC codes, M/A-BOPs, and work instructions. For example, Sven (191031) shared some discussions the team had regarding the review and approval process in manufacturing and discovered some deviations from the engineering review and approval process: *"If you* *look at an NC program, that's more or less like reviewing a software code and you could probably do every step in ten different ways, so what's the correct way? What can you review?[...] The same goes for* M/A-*BOP, some steps might be quite clear, but if you have one milling operation and one drilling operation, it may not be obvious which one is the best to start with; it could be any of them and then you can't say you have put the milling before drilling. You could do it the other way around because both are correct, maybe; so, it's harder to do this. You can't review everything, but you need to somehow ensure that the data itself is correct."*

In Period II, some new user requirements emerged from the ongoing changes in manufacturing and assembly, especially the production work involving the aeroderivative gas turbines became a source of inspiration. In manufacturing for instance, with the production of AGT100, the routines for producing components for aeroderivative also generated some new user requirements for MBD, concerning the way of technical instructions, NC codes, for instance. At Rotorstad, engineering changes happened rather frequently; even the production for the same component would entail subtle alterations in the drawings, models, and manufacturing methods, for instance. This loosely controlled engineering change was not allowed for AGT100 in aircraft engines; if any incidents were to happen, there would be investigations on the suppliers.

Sven (191031) understood when working with aeroderivative gas turbines, there would be different sets of regulations for operators to follow: *"[AGT100] has put demands on the Business for those components and in some cases [operators] are quite fond of the model-based. For instance, we should have a review on the NC code [...] Because, in general, working with the aeroderivative once you have approved the component and the way of working, you're not allowed to change it, or you can change it but then that's a completely new review and approval. In our case we need people from Motorville approving the engineering changes we are doing [...] So we need to ensure if we do all the blades, they all need to be exactly the same, using the same NC codes and so on. We can't change the NC codes between the two of them, even though it's a change that we might think it's not important, but we still can't do it. So that does put another set of requirements for sure in our business."*

8.1.2 Routine prototypes

These user requirements would serve the foundation for routine prototypes, including use cases, IT tests, demonstrative pilots, and productive pilots, which progressively became more alive and resembled routines. These were created to reach a preferred situation where a maturity level 3 would be achieved.

Use cases represented an initial form of a routine prototype in which the Business was able to explore its visions and intentions with MBD and define some ideal scenarios (see Chapter 5). Each use case described some generic and ideal *configurations* between the users and artifacts, with some visualized in the Unified Modeling Language (UML) diagrams.

Guided by those insights, IT architects transformed the user requirements into software requirements for PLM+. The IT team implemented the use cases corresponding to the features described in the software requirements. The Business team conducted IT tests to expose bugs and defects, on top of verifying if their requirements were implemented. Sometimes the team had to go the extra mile to explore use cases that were not documented, like how Nils (180126) illustrated in this case: *"What we are doing is trying to create CAM programs and all the steps I needed to do. I need to create the CAM operations at the right spot in PLM+. There are lots of small tasks that I need to do, and we have support from the PLM+ implementation team, and I have Kaveh there who gives me tasks that I need to do: 'test this and test this'."*

These *IT tests* were another form of routine prototypes. The tests usually concerned one step of the model-based, and at times, each step would be partitioned into even smaller ones. These granular tests were meant for both parties to test not only how the Business team understood PLM+ but also how the IT team implemented the requirements.

The team was reliant on testing in the sandbox environments to understand what the new requirements would be. There were multiple test environments set up for the project and many of them, however, were not an accurate representation of the digital landscape. For example, certain connections between PLM+ and ERP, between PLM+ and CAD/CAM, were missing, in addition to a lack of productive data. Even after Period I, the team could not conduct the IT tests in the live PLM+; instead, they repeated the tests in various testing environments, and not all tests would pass in all testing environments. Nils (190129) described this testing procedure in detail: *"Before [Period II], we were in a sandbox or test environment, and now we are in the real system, but you have a few test environments to test everything first, and then sent to another environment where it needs to be tested, and then also send to I think it's another environment as well, and then import to the real system."*

The team members spent a majority of their project working on those tests under Step 3: Acceptance testing (see Chapter 5). Tomas could do the tests "in his sleep". All the tests were done repetitively to explore the most available alternatives so that the one that satisficed would be selected (Simon, 1996/2019), as reflected by Sven (180424): *"To figure out the way of working, you need to do a number of different tests. In this case, M-BOP, to figure out* *this was probably not the best way; if I do it like this, maybe that's better. So then, we can define this as the suggested way of working."*

For Nils, testing was an opportunity to learn PLM+ and MBD, since he was using PLM differently and almost all features implemented were new to him (180126): *"This would be our training when we do all the testing and create the parts…we need to do first and see how we use the system."*

In Period II, some of IT tests were conducted through team members' daily work. When they imported tool models and work instructions, some more issues were exposed. The team was able to experiment with the features to trigger the potential defects. Nils (190129) made the IT tests "as real as possible" and found some more benefits with MBD: *"We don't need to export the models; we will have them in PLM+. When Robin is done with the M-BOP, I create my CAM operations in the M-BOP directly. So, I can see which CAM operations are in the M-BOP; I make it in the same system. I can see a real benefit in having everything connected, and if Robin wants to see which tools I am going to use for some reason, he can see it in the same system as well. You just need to do a few more clicks to open everything, and all the fixture and everything."*

A "more alive" routine prototype was a *demonstrative pilot*. These proof-of-concepts were prepared in the test environments and for different sites, displaying certain steps of model-based ways of working, utilizing the CAD-CAM chain for envisioned manufacturing routines and DWI for envisioned assembly routines. However, these demonstrative pilots oftentimes lacked productive data.

The team created the demonstrative pilots with two purposes in mind. Firstly, they served as a validation of how well the user and software requirements came together in the individual steps of routines. Demonstrative pilots were often video recorded. According to Sven (191031): *"It has been much more real when we can show a demo in the system and show it on a tablet that this is actually how it works. This recording is from our system, then, no one can think it's a sales video from somewhere else; it is done by us."*

Secondly, these videos were also used as communication materials to get attention from routine participants and managers, especially in Period I when MBD was less known at TurbineCo. In Period II, such videos were also seen at digital fairs and edited as video tutorials by Tomas. Sven (180327) adapted to a "model-based way" in communicating MBD as well: *"I would rather have some interactive videos or things like that to communicate, not the documentation-based way of working because, in the end, no one reads them anyway. I also think that for education, we need to adapt to the way of working* *we have in private life. If you want to learn how to do something, you search on YouTube; simple as that. And then, we should do it as far as possible in the same way. You can't have a model-based way of working and then create a lot of documents; it does not make any sense. Maybe, I need to convince some other process quality guys but, at least, the intention is to also change the way of teaching and communicating the change."*

The uncertainty of MBD nevertheless remained, despite IT tests and demonstrative pilots. According to Sven (180327), it was only through productive pilots that they could tell if the envisioned routines would work or not: *"We have already defined what we believe is the best way to do things, but we are in the test phase now. We have a system that we actually can try to work according to our own defined processes, and then we will see if that's the best way forward, or if we need to change something. The devil lies in the details. When you look at the details: should this data really be present in this area or should it be on a higher level or lower level?"*

As narrated in the preceding Chapters 6 and 7, the productive pilots in manufacturing were planned but put on hold due to the workload of AGT100 orders from Motorville. In assembly workshops, on the other hand, the team managed to conduct productive pilots of electrical ladders of IGT100 and core assemblies of IGT200 compressor.

These *productive pilots* were another type of routine prototypes, in which the model-based ways were enacted in the productive environment. In other words, PLM+ was not in its various test environments but had connections to other digital artifacts like ERP and CAD/CAM. Equally important were the quality-assured models. The team reached out to the corresponding R&D team to update the models, and Tomas retouched some of them, so that it would comply with the new requirements from the CAD-part alignment.

During these productive pilots, the actual routine participants (assembly workers) were involved. The team supplied them with tablets, from which they could retrieve the information needed for their assemblies. The piloted parts, in this case, electrical ladders and compressors, were assembled under the course of a work week.

The productive pilots were deemed important to gain the blessings and should be done in alignment with MBD as much as possible, according to Vincent's (181114) reflection on the planning: *"When we do the pilot, the first ones are important to get it right, so you get the blessing from the assembly people. Because I think everything depends on if they think it's any use to them or not. The buy-in from the assembly people is really important because if they don't see the advantages of MBD, then it is hard to implement."*

When selecting the areas for productive pilots in assembly, the team proactively looked for early adopters and skillful users who would connect the MBD to their daily work and even seek other opportunities. While there were ongoing pilots in electrical assemblies of IGT100 and core assemblies of IGT200, the team also explored packaging assembly. Sven (190129) decided not to pursue it due to the increased complexity. *"We have the assembly with all the auxiliary systems, process-wise is a hard thing because we depend on supplier information for instance. We don't have all the models ourselves, and we need to get them from the suppliers…There are a lot of process-related questions which makes it harder before we are in full-scale operations in assembly."*

These productive pilots of electrical assemblies of IGT100 and core assemblies of IGT200 showcased that a maturity level 3 was possible in assembly. A model-based way of working was enacted in some orders of the electrical assemblies of IGT100 during Period II (i.e., they came alive!). However, when Covid-19 disrupted the supply chain in early 2020, the MBD team and the steering committee decided to put all productive pilots on hold.

8.1.3 Chain of materializations

The four design artifacts (use cases, IT tests, demonstrative pilots, and productive pilots) are what I coin as routine prototypes.

To recall the processual turn in routine dynamics, the material aspects become materializing or chain of materializations (Latour, 1986; D'Adderio & Pollock, 2020; Glaser et al., 2021). In this sense, each routine prototype represented and enacted successively instantiations in this chain of materializations to translate ideas of MBD (like user requirements) into live routines. I have identified the following four materializations: converging ideas, negotiating collective intentions, aligning collective actions, and being embedded in sociomaterial context. The perceived "aliveness" of a routine was related to the steps completed in the chain of materializations: the more steps the routine prototypes instantiated, the more relationships were established in sociomaterial assemblages, as well as the more routine-like the routine prototypes were.

Step 1: Converging ideas

This first materialization concerns the very idea of how a digital artifact could and should exert its influence on routines. The routine designers *translate* ideas for the envisioned routines from, for example, what a digital artifact could afford, and the knowledge, the learning, and the lived experiences from current routines (D'Adderio, 2011).

At TurbineCo, the routine design team appropriated MBD practices and adjusted them to their current practices in manufacturing and assembly. They also learned from affordances from PLM+. Best practices of MBD were inscribed in the CAD-CAM chain and DWI suites by the technology vendor IndustryCo (To recall, TurbineCo and IndustryCo, in this setting, were considered as a client and a supplier). As a result, the team generated use cases to represent what MBD could entail for a model-based practice.

Step 2: Negotiating collective intentions
When ideas are converted into forms, a second materialization is how intentions in the plural can be converged and inscribed. Intentions may come from technology vendors and routine designers. Especially when the scripts are embedded in the digital artifact (D'Adderio, 2011), such scripts may or may not align with the routine designers' own intentions.

The team had certain expectations of how MBD in use would be and by conducting IT tests, they could confirm if their intentions were shared by the technology vendors or not. When IT tests failed, or in other words, when an envisioned sociomaterial assemblage was not formed, the team members came up with alternative solutions, which could be related to how the team understood the MBD or how they communicated their user requirements with the IT architects. But to find a solution, Nils (181112) found it challenging and time-consuming: *"The issue is to find a solution for the test that failed and then retest it. If I just put my head down and do, I can do half of all these tests today or tomorrow."*

Step 3: Aligning collective actions
When the collective intentions from technology vendors and routine designers are made aware to the future routine participants (and other organizational actors), a third materialization takes place.

Demonstrative pilots were a means of demonstrating what collective actions should be, for the routine participants involved in those pilots and for those who received training. For example, Robin (190130) hoped that by participating in demonstrative pilots, the manufacturing engineers would agree on the order of "clicking" in PLM+ to create an M-BOP, for example: "*I want it to be as close as this as possible for everyone to understand and recognize, so this order I have set. That's why I want to meet all the manufacturing engineers so we can say this order is how we want it, and make it a default, so everyone understands it."*

Also, the MBD team, for example, used demonstrative pilots in their video format in meetings, and at fairs to communicate with the affected routine participants and to continuously collect their feedback on the embedded intentions.

Step 4: Being embedded in sociomaterial context
Routines are nested in a broader sociomaterial structures (Howard-Grenville & Lodge, 2021), and a final materialization observed was how ideas, intentions, and actions would be embedded in a larger sociomaterial context.

For the MBD projects, demonstrative pilots were conducted in test environments and oftentimes without real productive data and lacked context. Through productive pilots, the model-based ways of working were embedded in the sociomaterial context. Sven (191029) hoped to capture any remaining loose threads: *"we can connect it into the existing processes in ERP so that's when we also can have the real-life tests to see what's working and what isn't. So, that will be the real test, if we have missed anything or not"*.

In sum, from ideas in use cases, to collective intentions in IT tests, to collective actions in demonstrative pilots and to sociomaterial context, each routine prototype successively instantiated steps in a chain of materializations (see Table 31. below). Productive pilots were most routine like, but were not live routines, in the sense that they were not repetitive.

Table 31. Chain of materializations

Routine prototype	**Elaboration**	**Chain of materializations**
Use cases	Interaction scenarios that visualize the user and software requirements in UML diagrams.	Converging ideas
IT tests	Test cases that focus on the functionality of one or more steps of interactions in the use cases.	Converging ideas Negotiating collective intentions
Demonstrative pilots	Simulations in the test environments that include some of the steps; some were recorded in video format.	Converging ideas Negotiating collective intentions Aligning collective actions
Productive pilots	Productions in the productive environments that include most of the steps; some were one-off, but some became live routine.	Converging ideas Negotiating collective intentions Aligning collective actions Being embedded in sociomaterial context

8.2 Selective retention

I now arrive at the second half of the puzzle of recursiveness: *how are variations selectively retained in the multiplicity of routines from within*?

Routines are equifinal, and the same goals can be achieved by different means, as Sven (191031) reflected: "*To simplify this project or remove all the complexity, a production order and all the processes surrounding it are the same, the only thing is we present the information in another way. This neglects the project a bit but on the high level that's what we are doing.*".

The observed emic (insider) manufacturing and assembly routines are a duality of one and many. They are all singular routines directed at manufacturing or assembly but, at the same time, they can be unfolded in different maturity levels (see Chapter 4). In other words, the same component of turbine can be manufactured or assembled through using different ways of workings with constellations of data sets of drawings and/or models (many), while it is still the same manufacturing or assembly routine (one).

The exploration of multiplicity of process (D'Adderio & Pollock, 2020; Feldman et al., 2021; Pentland et al., 2020) is a qualitative one in this monograph. To reiterate, a quantitative lens would focus on the multiplicity of roles, drawings, models, and components while a qualitative one focuses on how these multiplicities "relate to form a distinctive whole" (Pentland et al., 2020, p.3) of manufacturing and assembly.

Different from multiplicity of routines in terms of versions (D'Adderio & Pollock, 2020) or sequences (Pentland et al., 2020), I focus on a multiplicity of patterns (i.e., regularities, Becker, 2004). These patterns were manifested in manufacturing and assembly routines at TurbineCo as the five model maturity levels of constellation of data sets of drawings and models. To theoretically describe this multiplicity, I borrow Latour's (1986) distinction between in potentia and in actu and appropriate this distinction as the following: when a pattern of action is in use, it is in actu. When a pattern of action is possible but not in use, it is in potentia. I add a spatial dimension of ex situ to signify the "without-ness" of some patterns of action, i.e., when a pattern of actions is possible at without but not observed at within, it is ex situ.

I call this a spatiotemporal multiplicity. To empirically illustrate the working mechanisms (see Pentland et al., 2020) of spatiotemporal multiplicity, I describe in the following how the team spatially retained the patterns from without to within the routine dynamics (from ex situ to in potentia), and how they temporally retained the patterns (from in potentia to in actu) to make designed routines alive.

8.2.1 Spatial retention

Before the MBD project commenced, a higher model maturity was possible at manufacturing and assembly (close to a level 3, see the IGT100 development project in Chapter 4), and in the aerospace and defense industry (levels 4 and 5, see Chapter 4). In addition, the routine designer envisioned a higher level for manufacturing and assembly routines (a level 3, See Chapter 5) and created various routine prototypes (a level 3). Such inspirations, aspirations, and routine prototypes were patterns of action ex situ, situating without the current enacted routine dynamics that were in actu (mainly a level 2, a level 1 for legacy models).

Returning to the routine design process, at the end of Period I when the team discovered three stoppers: R&D modeling practices, functionality of PLM+, and connect between PLM+ and ERP. These stoppers were reminiscent of the "blockages" in Bucher and Langley (2016), in which the enactment of reflective spaces and experimental spaces was switched to cope with the puzzle of recursiveness. In the case of the MBD project, I record how these stoppers were removed to spatially retain patterns of action from ex situ to in potentia.

In the prehensive analysis of Period I, I indicated how the team set the problems, and some stoppers emerged as backtalks from the situation. These stoppers were breakdowns in the (re)configurations of sociomaterial assemblages. Subsequently in Period II, I detailed in the prehensive analysis how the team continued with their design actions to resolve the breakdowns. Each stopper hinted at different breakdowns in how sociomaterial assemblage was configured and the team's design actions to remove stoppers in turn provided conditions for PLM+'s chain of materializations.

The first stopper concerns the role of R&D engineers and how they created models in their model-based way of working. In fact, this so-called model-based way was relational. Indeed, the models might suffice in R&D, but they were not considered as quality assured in manufacturing and assembly. Since both the focal manufacturing and assembly routines started with Step 1: Design release (see Chapter 5), should the models fail to CAD-part align, the model-based way would also fail. In other words, a breakdown occurred when actors did not have a shared understanding of the practice, and in turn their practices were not supported by collective intentions embedded in PLM+.

In Period II, the team had to remedy some models themselves to facilitate the productive pilots at the same time; they combined forces with the CAD-part alignment at R&D to inform and train the R&D engineers in the requirements from manufacturing and assembly.

Another pivotal point in Period I was when the Business team discovered how the IT team failed to inscribe the collective intentions. There were remaining defects in core applications that prevented some steps. This breakdown was related to the fact that the model-based practices were not fully inscribed in PLM+ and subsequently, actors could not enact the model-based ways of working apart from partitioning the steps, like the team did after Release 3.1. In addition, the team had to delay Release 3.4 in order to ensure the functionality of PLM+.

While working toward a digital thread, the MBD team experienced the characteristics of digital technology (Yoo et al., 2010; Yoo et al., 2012) firsthand, among which the self-referentiality was critical to MBD. PLM+'s connection to other digital artifacts like CAD/CAM and ERP, for instance, laid the foundation of MBD.

The connection to CAD/CAM was established after Release 2, but not to ERP. That is to say, the last stopper and the breakdown concerned the systems of (digital) artifacts (Cacciatori, 2012). In Period II, the connection to ERP was considered a major task that required external involvement of ERP experts, and the team divided the connection points among Releases 3.3, 3.4, and 3.5.

On a similar note, in Period II, the team also identified a potential stopper, i.e., the Wi-fi and handheld devices, in other words, the network and device layers in a layered modular structure of PLM (Yoo et al., 2010) also constituted systems of (digital) artifacts and could potentially cause new breakdowns.

At TurbineCo, before the MBD project the maturity levels at manufacturing and assembly were both at levels 1 and 2; thus, they were in actu, meaning these routines were in use.

The stoppers were removed in Period II when there were quality-assured models, training videos on MBD, tailored information materials, support networks led by close colleagues, functional digital artifacts and managerial support, which provided conditions for ideas of MBD to materialize in a sociomaterial process. In turn, patterns of action ex situ (level 3), embodied by routine prototypes, were introduced to the internal routine dynamics, and became patterns of action in potentia, while levels 4 and 5 remained as patterns of action ex situ.

In the next session, I explain how patterns of action in potentia became in actu in assembly and became in potentia again after Period II concluded.

8.2.2 Temporal retention

I return to Latour (1986, p.265):

> What makes the difference between power 'in potentia' and power 'in actu'? The actions of others. […] The amount of power exercised varies not according to the power someone has, but to the number of other people who enter into the composition.

In the context of the MBD project, I liken this composition to a sociomaterial assemblage and the entanglement (see Glaser et al., 2021) of MBD in the sociomaterial assemblage through materializing. Ideas, intentions, and actions were progressively codified in routines and digital technology. The experience and learning by the routine designers were embedded in sociomaterial context. Through this chain of materializations, the idea of MBD transformed and became entangled within the heterogenous ensembles to exert its influence on routines. Especially during Period II, the team saw more connections (Feldman & Rafaeli, 2002), and MBD established more relationships within the sociomaterial assemblage, i.e., "what is held together" (Latour, 1986, p.276). The temporal retention concerns how potentiality (in potentia) becomes actualized (in actu) through "the actions of others." (Latour, 1986, p.265). Yoo (2012, p.136) echoes this point: "A designer transforms raw materials into a particular form in order to endow a certain potential function. I use the word *potential* deliberately to be sensitive to the shifting power from designers to users" (emphasis in the original).

These actions of others were experienced as a "pull" toward MBD in both manufacturing and assembly, while the team members were removing the stoppers during Period II. As manufacturing started to produce for Motorville, the workers were busy with orders for aeroderivative gas turbines (AGT100), which imposed a higher standard on how models were used and how NC codes were applied. They realized the need for MBD to handle the M-BOP and NC codes based on stricter requirements. Sven (190423) reflected on this: "*We need MBD in order to fulfill the aeroderivative requirements. […] We need to resolve this and have this up and running, so that we can be approved as a supplier for aeroderivative.*"

While in manufacturing the new understanding of MBD did not actualize a level 3, a new level 2 pattern emerged as Sven recounted: (200603): "*We manufacture completely new components according to the new process and new requirements. […] Engineers, operators, everyone ensure that they will work, and everyone is on board in terms of requirements and what needs to be done*."

It was more apparent in assembly and a level 3 was achieved in electrical assemblies of IGT100 and core assemblies of IGT200. When the stoppers were removed (or bypassed in preparations for the routine prototypes) and when the video tutorials were commonplace, Sven (190131) sensed there was a stronger pull: *"There are more questions more people asking for information, wanting me to attend their department meetings, to explain what we are doing, support them if we are to do something like that, where do we start, what do we need to do? I think from an employee perspective, it is a more of a pull today than some three months ago…"*

Coinciding with the concluding phase of the MBD project, TurbineCo had to deal with the contingencies with the early outbreak of Covid-19. The management decided to concentrate its work on safeguarding the production (enacting level 1 and level 2) and dealing with the supply chain related issues. The workload in the workshop was high, and almost all projects, including level 3 model-based ways of working in assembly, and the planned productive pilots, were "in quarantine". Sven (200603) proposed an agile approach with the planning: *"The planning is quite tricky. Some of the pilots have been on hold. We have prepared everything from the office, so the M/A-BOPs and everything. We have reviewed internally, made some adjustments and fine-tuned bit. We managed to get some slight improvements of the Wi-Fi on the shop floor as well, which is essential if we use mobile devices. […] I have some new 55-inch screens at my desk, just waiting to be installed in the workshop. It has been much less progress than I hoped for."*

Therefore, at the end of Period II, a level 3 at assembly was not enacted and became in potentia again.

8.3 Addressing the puzzle of recursiveness

Similar to Bucher and Langley (2016), when understanding routines as a multiplicity, the puzzle of recursiveness can be addressed in an evolutionary routine change, concerning firstly intentional variations of patterns, and spatial and temporal retentions of patterns.

Pattern variations can be sourced from perceived anomalies (see Nelson & Winter, 1982), best practices in the industry (D'Adderio, 2011), and transfer from other contexts (D'Adderio & Pollock, 2020). At TurbineCo, user requirements (see Chapter 5) were examples of the sources, which later became four different types of routine prototypes: use cases, IT tests, demonstrative pilots, and productive pilots. These routine prototypes provided an ample opportunity to dissect otherwise progressive and instantaneous chain of materializations. From successive instantiations of converging ideas, negotiating collective intentions, aligning collective actions, and being embedded in sociomaterial context, these routine prototypes became more routine-like but still lacked repetitiveness.

Variations recorded in routine prototypes were located outside the focal routine dynamics; hence, the Latin suffix ex situ. I observed another type of qualitative multiplicity called spatiotemporal multiplicity, focusing on the multiplicity of patterns. This multiplicity resembles what routines scholars theorize as “grammar of actions” (Pentland & Rueter, 1994), “prototypical (central) core of patterns of action” (Dionysiou & Tsoukas, 2013), “reservoir of routines” (Cohendet & Simon, 2016), and “space of possible paths” (Pentland et al., 2020).

In the beginning of the project, the lower levels of model maturity (levels 1 and 2) at TurbineCo encapsulates the lived experience, the knowledge, and the learning of the routine participants (Cohen, 2007; Pentland & Feldman, 2008; D’Adderio, 2011). These patterns were in actu. The higher levels (levels 3, 4 and 5) represent the experience, the knowledge, and learning of the routine designers, technology vendors, industrial experience (D’Adderio, 2011), which were ex situ. I illustrate this in Table 32. below.

I concluded that the MBD team experienced two types of selective retentions to make design routines alive. A first temporal retention was completed through resolving the breakdowns to provide conditions for materializing to introduce the patterns from ex situ to in potentia. A second spatial retention was completed through materializing. When more relationships within a heterogenous sociomaterial assemblage were established, a digital artifact (PLM+) was able to exert its influence on routines and there was a pull toward actualizing those patterns of action. The designed routines came alive (in actu).

Table 32. Model maturity level in manufacturing and assembly

Patterns		Example at TurbineCo	Manufacturing/Assembly		
			Before the stoppers were removed	After the stoppers were removed	After Period II ended
Drawing-based	Level 1 Drawing with an optional data set	A drawing only	In actu	In actu	In actu
	Level 2 Data set with drawing and simplified model	A drawing and a complementary model			
Model-base	Level 3 Data set with model and drawing	A drawing and a quality-assured model	Ex situ	In potentia/ In actu*	In potentia
	Level 4 Data set with model and simplified drawing	An interchangeable drawing and model		Ex situ	Ex situ
	Level 5 Data set with model only	A model with PMI only			

*In assembly a level 3 was achieved in some core assemblies of IGT100 and electrical assemblies of IGT200.

9 Discussion and Conclusion

For the focal change initiative, the MBD project, it was not until approximately one year later that some assembly routines came alive (patterns in actu). For TurbineCo, this routine design just marked the beginning of their digitalization journey toward a digital thread where PLM+ and MBD were enablers for industrial digitalization.

Returning to the research question: *how do organizational actors design live routines?* In the preceding chapters, I have provided first-order narrative accounts on the happenings during Period I and Period II. I address to the puzzles of generativity and recursiveness by zooming in and zooming out to conduct second-order prehensive and reconstructive analyses concerning how the team designed live routines. I find that the routines at TurbineCo are a multiplicity (see Pentland et al., 2020), and this qualitative multiplicity of patterns concerns a duality of one (one routine) and many (different ways of working).

In this final chapter, I consolidate the theorization efforts from the prehensive and reconstructive analyses to discuss the empirical phenomenon of industrial digitalization and the theoretical phenomenon of routine design. Next, I wrap up my empirical and theoretical observations. I relate them to discussions in the routines literature and propose avenues for future research. I also revisit Pentland and Feldman's (2008, p.247) *Guidelines for designing live routine*s for leading digital projects (see Sun & Tell, 2020).

9.1 Industrial digitalization

At TurbineCo, many practitioners (including managers) were baffled by the concepts like digital twin, digital thread, and even industrial digitalization. Against this backdrop, TurbineCo' own digital imperative "make digitalization work" could be also interpreted as an attempt to make sense of the buzzwords while applying them in the Business. And to "make digitalization work", I studied how one specific change initiative introduced MBD to manufacturing and assembly, through PLM+, heralded as "an enabler for real digitalization". To weave the product and production data in a digital thread, the team developed the CAD-CAM chain and DWI suites in tandem with the model-based ways of working.

The excursion on digital materiality in Chapter 2 provides some sensemaking of industrial digitalization and what they entail in theoretical terms. The hallmark of a digital thread is its potential for ontological reversal (Baskerville et al., 2020), where digital reality is created first and can be more real than physical reality. Despite digital technology's ability to digitalize (Iivari, 2007), this theoretical phenomenon ontological reversal observed at TurbineCo is rather an *ontological oscillation.* That is to say, a digital thread exists to some extent, though limited in certain lifecycle stages. There are instead islands of digital and physical realities, in which either digital or physical reality prevails, and in turn, reality is oscillated between them.

At TurbineCo, R&D, arguably, was the place where digital reality prevailed, but some downstream stages still resorted to physical reality. In manufacturing and assembly at TurbineCo, for example, there was still a reliance on paper drawings. In digital reality, models and associated data sets would be the main information carrier. But for a discrete manufacturer like TurbineCo where each product was made-to-order, the amount of (the revisions of) models and their data sets was astronomical. In this sense, the problems set by the team members under a routine design process were also associated with different aspects of data (or digital objects a la Hui, 2016) and the team's design actions aimed at connecting the islands of realities.

Firstly, due to semiotic binding (Nambisan et al., 2020), the interpretation of heterogenous data was socially mediated. At TurbineCo, the models created by R&D were sufficient for their internal purposes, but these were not quality-assured in the eye of manufacturing and assembly. The CAD-part alignment initiative illuminated the "openness" of interpretations, which in turn redefined the assumptions of roles, responsibilities, and tasks associated certain occupational and professional groups (see Kho & Spee, 2021), and shaped professional identity (see Karali, 2021).

Secondly, when navigating the sociomaterial infrastructure for data, the concept of "technical debt" could also be expanded to a sociomaterial one. The conflicts between the Business and the IT team during the MBD project were indicative of how debts were managed, due to competing assumptions, goals and interest in software development and business management.

And lastly, to establish the interfaces to create network effects of digital artifacts (Yoo et al., 2010; Yoo et al., 2012), especially in the context of a digital thread, the situation with burgeoning initiatives could also present a coordination challenge. At TurbineCo, digital projects were governed under a global digitalization group, and the MBD project partnered with other change initiatives, such as the CAD-part alignment and the MES initiatives.

As the team discovered along the way, digitalization was here to stay in the manufacturing industry, and the MBD project was one of the first digital projects to enable model-based ways of working and to accentuate the marriage between the physical and the digital. Digital thread would remain as a goal for many change initiatives to achieve collectively.

9.2 Designing routines

The routines literature unpacks the dynamics of routines. The internal dynamics, under a practice turn is understood as ostensive, performative and material aspects (Feldman & Pentland, 2003, D'Adderio, 2011) and under a processual turn, as patterning, performing and materializing (Feldman 2016, Feldman et al., 2016, Feldman et al., 2021).

When designing routines from outside (i.e., from without), their internal dynamics present a puzzling situation. The live-dead distinction of routines is useful here, based on Pentland and Feldman's (2008) and D'Adderio's (2011) extension of Cohen's (2007) reading of Dewey (1922). On the one hand, routine designers, when confusing routines with things, create dead routines, which do not involve contributions of actors and do not involve their experience and facilitate their learning. On the other hand, envisioned routines can also be rejected by the routine participants as routine dynamics are capable of endogenous change. Hence, I ask the research question: *how do organizational actors design live routines?*

Against this backdrop, I partition the situation into two interrelated puzzles. The puzzle of generativity to make live routines, concerning how the generativity of both routines (Feldman & Pentland, 2003) and digital technology (Yoo et al., 2012; Zittrain, 2006) are created and maintained: *how are generative systems of routines and digital technology created from without*? And the puzzle of recursiveness (Bucher & Langley, 2016) to make routines alive, concerning how the designed routines are reoriented to the current routine dynamics, while they are concurrently reproduced: *how are variations generated from without and how are variations selectively retained in the multiplicity of routines from within*?

My prehensive and reconstructive analyses were intended to address to the two puzzles respectively. From the two prehensive analyses of making live routines, I found that the team (re)configured sociomaterial assemblages (including artifacts, actors, theories, practices, see Glaser, 2017) to engage the experiences of routine participants. These design actions, in turn, provided the conditions for a digital artifact's materializing. From the reconstructive analysis of making routines alive, the team created variations in the form of routine prototypes from the inscribed best practices (D'Adderio, 2011), previous breakdowns (or anomaly, Nelson & Winter, 1982) and transfers from other sites (D'Adderio & Pollock, 2020). Routine prototypes were not routines. In the making of routine prototypes, the number of relationships increased in the sociomaterial assemblages. When the breakdowns in the sociomaterial assemblages were remedied, the designed routines from without became a potentiality from within (spatial retention) and when more and more elements came together, digital artifact achieved more instantiations in the chain of materializations, and, in turn, the designed routines came alive (temporal retention).

9.2.1 Live/dead routines

The live-dead distinction of routines is helpful to maintain that routines are not things, and live routines involve people and are capable of learning from experience (Pentland & Feldman, 2008). The design actions observed at the MBD project were directed at involving current and future routine participants, by, for example, engaging them in different types of training and participating in demonstrative and product pilots.

However, live routines do not necessarily mean all aspects of routines are open-ended and dead routines do not necessarily denote all aspects of routines are mechanical. In the context of industrial digitalization, there is "life" in dead routines and there is control in live routines.

My findings echo with D'Adderio (2011) that some elements of routines come from the routine designers' and technology vendors' learning (e.g., best practices). Such routines, as dead as they seem (in other words, controlled by the routine designers and technology vendors), can be transferred and replicated (D'Adderio & Pollock, 2020) through digital artifact's chain of materializations and come alive.

On the other hand, as elaborated in Chapter 2, because of the "power of default" (see Koch, 1998 in D'Adderio, 2003, p.344), even though in theory it is possible for routine participants to bypass the influence of digital artifacts, in practice, it is difficult to ignore the control of embedded scripts. For example, some MBD project work involved inscribing certain steps in PLM+, like the order of "clicking" in PLM+ to create an M-BOP. Similarly, the model-based ways of working were defined by TurbineCo for all the sibling sites. However, such intentions were collectively deliberated and reflected (Dittrich et al., 2016) among the routine participants across the various sites.

I also observe how standards and standardization (see Brunsson et al., 2012) pressure the routine participants to limit their individual ways of working. At the manufacturing workshop, for example, when working on the aeroderivative gas turbines, the manufacturing workers prioritized activities that would lock-step performances (Danner-Schröder & Geiger, 2016). And counterintuitively, such control gave rise to learning and a "pull" toward MBD.

9.2.2 Spatiotemporal multiplicity

In addressing the second puzzle, I discover a new type of multiplicity of patterns that I call a spatiotemporal multiplicity. Other forms of multiplicity can be seen in the routines literature. In D'Adderio & Pollock (2020) and D'Adderio (2021), this is called ontological multiplicity in which one singular routine can be constituted of different versions of the routine. In Pentland et al. (2020), they find how a process multiplicity is manifested in one single sequence of actions and many possible paths (of performing a routine).

Different from multiplicity of routines in terms of versions (D'Adderio & Pollock, 2020) or sequences (Pentland et al., 2020), the spatiotemporal multiplicity concerns patterns, or regularities (Becker, 2004). It is observed from routine participants' perspective, or emic (insider). This qualitative duality of one and many consists of many patterns (i.e., ways of working) and one process. There are three types of patterns: patterns in actu are in use, patterns in potentia are possible but not currently in use and lastly patterns ex situ are possible but not at within.

Then, when applying this multiplicity of patterns to understand the dynamics of routines, performing concern enacting patterns in actu, and patterning concerns creating and maintaining patterns in potentia. Designing concerns creating and introducing patterns from ex situ to in potentia, and materializing concerns realizing patterns from in potentia to in actu.

In other words, designing concerns creating and introducing new potentiality to the routines' internal dynamics, and materializing is to actualize routines' potential when a (digital) artifact exerts its influence successively.

Extending Tsoukas' (2021, p.42) processual theorizing: "Specifically, a performance is a particular actualization of virtuality; what *is* is a manifestation of what can potentially be (Colebrook, 2005, p.10)" (emphasis in the original), with spatiotemporal multiplicity, I add a spatial dimension to the potentiality (virtuality).

The spatiotemporal multiplicity of one and many also allows for a nuanced view on routine design, in terms of a macroscopic process in which a new “many” is introduced through designing and a microscopic process on a “one” is actualized through materializing (cf. Whitehead, 1929/1978, [PR 327-328]). That is to say, designing concerns the range of the many; subsequently materializing is a process of thrusting many to one.

9.2.3 Routine design as designing

I return to the definition of routine design, which is a change initiative understood as “intentional efforts to change one or more aspects of a routine to create a preferred situation.” (Simon, 1996/2019, p.111; Wegener & Glaser, 2021, p.301). With the focal change initiative, the MBD project at TurbineCo, through introducing a technology backbone PLM+, the team intended to change manufacturing and assembly routines from drawing-based to model-based ways of working, to pursue a digital thread.

When studying a routine design process, design actions are directed at “patterning a routine” (Wegener & Glaser, 2021, p.309) from without, which involves the configuration and reconfiguration of sociomaterial assemblages (D’Adderio & Pollock, 2020; D’Adderio, 2021; Glaser et al., 2021). Design actions, in turn, provide conditions for a digital artifact’s materializing or chain of materializations.

Wegener and Glaser (2021) outline a pragmatist research agenda to invite further theorizing on routine design. In line with their take on combining a scientific (Simon, 1996/2019) and a reflective (Schön, 1983) view on design, I suggest the following key insights:

- A routine design process is bounded in the form of a project and project alike.
- Organizational actors, or routine designers, have (evolving) visions of a preferred situation (Simon, 1996/2019), attaining certain values (Dorst, 2011).
- When conversing with the situation, routine designers create frames to tackle design problems and to reflect-in-action (Schön, 1983).
- A routine designer finds or generates one alternative of many routines (Simon, 1996/2019), encapsulated in the form of routine prototypes.
- These alternatives of routines are representations of the future and do not define future action (Suchman, 2007), in other words, the designed routines may or may not come alive.

I understand routine design as a planned and time-limited endeavor, with a vision of a preferred situation that is also evolving. Such exploration of envisioned routines can be encapsulated in a project separated from the ongoing routine performances, meaning these are nonroutine interactions. The project then could be considered as a space for controlled search process (Simon, 1996/2019), or reflective and experimental spaces (Bucher & Langley, 2016). At the same time, such nonroutine projects go beyond Obstfeld's (2012) "creative projects" and look at "getting thing done" in new ways, in addition to "getting new things done". I suggest when routine designers converse with the situational uniqueness, certain backtalks (Schön, 1983) may indicate breakdowns within the envisioned sociomaterial assemblages.

The design actions observed in the MBD project are different from what Glaser (2017) coined as design performances. Apart from creating a digital artifact, the team was devoted to informing routine participants, facilitating interdisciplinarity and interoperability, getting managerial support and aligning goals at the different sites. In this sense, the design actions were related to how organizational actors (re)configured sociomaterial assemblages.

Empirically, the breakdowns were referred to as stoppers (cf. blockage in Bucher & Langley, 2016). I put particular focus on three stoppers and how some of the design actions were direct at removing the stopper of "R&D modeling practices" that broke a truce and interdependence between R&D and manufacturing/assembly; removing the stopper of "defects in PLM+" that exposed the conflicting goals and intentions between the Business and IT teams; and removing the stopper of "connections between PLM+ and ERP" that hindered the creation of systems of artifacts (Cacciatori, 2012).

Collectively, these nonroutine actions share similarities with routines that change routines, like the change response of expanding in Feldman (2000), flexing and stretching work in Deken et al. (2016), and repairing and distributing in D'Adderio and Pollock (2020).

I coin the term routine prototype as the main design artifact to represent alternatives of routines. In line with Simon (1996/2019, p.xx): "Engineering, medicine, business, architecture, and painting are concerned not with the necessary but with the contingent—not with how things are but with how they might be—in short, with design", such routine prototypes are what routines might be. In the context of industrial digitalization, the origin of routine prototype can be best practices that "originate from assumptions that come from sectoral and industrial experience." (D'Adderio, 2011, p.207). These represent "knowledge, learning, and experience of software users and producers" (D'Adderio, 2011, p.207). In this sense, a routine prototype is an interface (Simon, 1996/2019) between current and envisioned routines, or between what routines can be and what routines should be.

9.2.4 Routine design as materializing

The internal dynamics of routines in the latest processual turn (Feldman, 2016; Feldman et al., 2021) are conceptualized as patterning, performing, and materializing. When materiality comes into play, digital or not, materializing can be understood as a chain of materializations (Latour 1986; D'Adderio & Pollock, 2020; Glaser et al., 2021). Latour's (1986) model of translation is *generative* in the routines literature; in the 2000s, it gave birth to the ostensive-performative distinction, and in the 2020s, it inspired routines scholars to unpack the translation process. In other words, a sociomaterial process across a chain of "translators" in which a digital artifact's influence on routines is exerted and transformed. As Glaser et al. (2021) indicate, these materializations may be progressive and/or simultaneous. In this dissertation, this chain of materializations was explicated through the routine prototypes, which successively came more alive through converging ideas, negotiating collective intentions, aligning collective actions and being embedded in sociomaterial context.

In this way, I also unpack how shared understandings could be created from without the internal routine dynamics (cf. Dionysiou & Tsoukas, 2013). My findings are also compatible with Feldman and Rafaeli's (2002, p.312) notion of connections (or interactions between people that enable them to transfer information) and routine prototypes can be seen as a means to make connections. More specifically, the interactions in sociomaterial assemblages are strengthened, when more steps in a chain of materializations are instantiated so that the digital artifact involves "the contribution of actors, their experience and learning" (D'Adderio, 2011, p.206). In other words, routine participants develop successively a shared understanding about why, how, what and when the actions are taken place.

Understanding the influence of digital artifact through a chain of materializations also complements Bailey and Barley's (2020) unified approach and Glaser et al.'s (2021) biographical approaches to uncover the trajectory of digital technology before inception and beyond use.

9.2.5 A dark side

The dynamics of routines and digital technology have a dark side. Both can be designed to reinforce oppression and exploitation, and conceal backstage behaviors (see Goffman, 1959).

Deceit, for example, is documented in the routines literature. Eberhard et al. (2019) in their case study of Romeo pimp routines unpack the relationship among deceit and routine dynamics, when such routines are designed to exploit routine participants. One of their key findings is (p.117):

> One actor can use deceit to intentionally create the illusion of a shared understanding, while personally maintaining a hidden agenda and a very different understanding of the two parties' roles and the purpose of their shared interactions.

Vulnerability is the other side of generativity of digital technology (Zittrain, 2006). The novelty and openness engendered entice also breaches. Cybersecurity risks like computer viruses, phishing attacks and hacking activities may reprogram digital artifacts to fulfil malicious intents.

Brynjolfsson and McAfee (2014) on the other hand caution about the adverse effects of technology in the form of spread, i.e., "large and growing differences among people in income, wealth, and other important circumstances of life when inequality is created" (p.127). This prompts a twofold reallocation of human agency in the human-technology relationship. At one end of the spectrum, digital technology is associated with the decrease of demand in certain job categories. In other words, these jobs are eliminated and are replaced by digital technology, and hence no need for human agencies. At the other end, generativity provides a comeback for Taylorism, and this time in the form of digital Taylorism (Swedish Trade Union Confederation, 2011) or Hyper-Taylorism (Andersson et al., 2021), which promotes standardization and precision meanwhile having the risk of exacerbating working conditions. Human agency in this sense is prescribed by digital technology.

In a similar vein, Zuboff (2019) warns about the emergence of surveillance capitalism, which harnesses human experience as a behavior surplus. Digital technology is not the culprit; however, it becomes an expression of some particular social and economic logics, diverting from "automating information flows about you to automate you" (p.339).

At TurbineCo, I touch upon in the problem setting "outreach" where the MBD team reflected their design rationales as to help routine participants and make their work easier. Sven (171220) was mindful of the dark side but deemed that MBD project would not render human agency obsolete: *"If you look at the publications down in manufacturing and digitalization, you are focusing on fully automated processes and you have robots, you have self-driving forklifts and whatever. Looking at that side I understand people: 'look I will be replaced by a robot or whatever'. That's something we need to explain, that it is not the case. It will take a lot of years before we have robots that can assemble a turbine. Today 95 percent of the work is still done by humans since it's not like the automotive industry where they have the fixed process. We have made-*

to-order on everything. Every project is unique. How do robots handle that? That's something we need to work on constantly to show that this is not a project to lay off people. This is a way to help the existing people in their daily business."

Nevertheless, when discussing business and the ethics of digital technology (see also Carlile et al., 2013), I concur with Martin et al.'s (2019) call for a greater corporate responsibility of design. Designers, be it routine designers or technology vendors, introduce their values (Dorst, 2011) in the making of routines. These values-laden routines should be attended to during and beyond routine design (see Bailey & Barley, 2020).

9.3 Participating in the routines literature

The research setting is *generative*, and I have *materialized* some of its *potentiality* in this dissertation to create novel understandings on live routines (Cohen, 2007; Pentland & Feldman, 2008, D'Adderio, 2011), routine emergence (Feldman et al., 2016), intentional routine change (Bucher & Langley, 2016; Glaser, 2017) and routine design (Wegener & Glaser, 2021). Methodologically, I combine two analytical modes (Langley & Tsoukas, 2016) to capture a routine design process.

In this dissertation, to design live routines is to address the puzzle of generativity and recursiveness. I extend Bucher and Langley (2016) and Glaser (2017) to examine a routine design process in which both design actions and routine actions take place, in which I center a team of routine designers, who are also routine participants, not managers (cf. Pentland & Feldman, 2008; Grand, 2021). In addition, these design actions are encapsulated in projects (cf. Bucher and Langley's (2016) loci of bounded social settings). I respond to Wegener and Glaser (2021) by applying both Simon's (1996/2019) scientific perspective and Schön's (1983) reflection-in-action. I also extend Feldman et al. (2021) and D'Adderio (2021) by bringing materializing to the center of routines. Finally, I propose a spatiotemporal way to categorize routines' multiplicity of patterns (e.g., D'Adderio & Pollock, 2020; Pentland et al., 2020).

The research setting is *generative*, and I have decided to delimit some of its *potentiality*, due to methodological choices and complexity.

Ethnographical research occupies an essential role in the routines literature (Feldman et al., 2016; Dittrich, 2021). Despite deploying similar techniques as fieldwork, headwork and textwork in ethnography (van Maanen, 2011), I have refrained from labeling this study as such. In order to be qualified as an ethnography, my mode of participation would have been expanded. For example, I would need to shadow (Czarniawska, 2007) and observe even more extensively situated actions (both design and routine) conducted by the MBD project members and the roles they represented. However, due to secrecy concerns, I was not authorized to engage with the informants outside of the pre-agreed interview slots, and I also limited my interactions with people outside of the MBD project. Even though I captured glimpses of current and envisioned routine performances during interviews and impromptu observations, I relied on the informants' own identification of *pattern*s. In turn, I delimited my analytic focus primarily on design actions in a routine design process.

The research site, TurbineCo, arguably deploys a variety of technology-general (Arthur, 2009), since gas turbines after all are classified as Complex Products and Systems (CoPS, see Magnusson et al., 2005). This dissertation concerns a small set of digital technology, and the focal digital materiality is about the 3D models in manufacturing and assembly routines and its (digital) representational role of the physical parts and components. In this sense, industrial digitalization does not digitalize actors; rather it digitalizes non-digital artifacts. In my study, I have intentionally backgrounded the actual physical parts of turbines to reduce complexity.

To advance the discussions about routine design, I suggest the following avenues for future research.

One of the foundational themes of industrial digitalization is the use of scrum and other agile frameworks. Agility provides an important empirical setting in which work is organized in an interdisciplinary team and is time-boxed in an iterative manner. There are at least two ways to further explore what agility entails in the context of routine design, concerning the tensions between routines and temporal nature of agile organizing.

I explored the tensions when the Business and IT teams worked on the PLM+. Especially, I highlighted how agility (and its iterative and incremental nature) was at odds with a discrete manufacturing mindset. Future research could focus on challenges associated with different forms of organizing (see also Kremser & Xiao, 2021). Another direction is to explore the temporality in agility when actors are perpetually and incrementally envisioning a future state of routines in a temporary project while having implications on the permanent organization. This is empirically known as a moving target that has a long-lasting impact.

An alternative way to unpack a routine design process is to focus on routine replication and transformation (see Feldman et al., 2019). I hinted the role of replication when describing routine emergence in manufacturing in Period II, and similarly there is room to explore how replication can also address the puzzles.

To complement fieldwork, I concur with BPM colleagues (see Wurm et al., 2021) that digital trace data could discover other patterns that might not be apparent to the researcher (and even to the routine participants).

In my dissertation, I rarely scratch the surface of the design literature. Following Wegener and Glaser's (2021) call, I also suggest bringing in more insights from design studies, concerning emerging intentionality (Dittrich & Seidl, 2018), emotions (see Baldessarelli, 2021), etc. Prototyping has also occupied an important role in this dissertation. I indicate how routine prototyping may be relevant for digital artifact's materializing and future research could focus on the role of routine prototypes in design actions.

On a similar note, my findings add to a transdisciplinary perspective of IS discourse on digital X. In addition to my efforts to unpack the dynamics of digital technology, more can be done to relate to the emerging discussions about the sociomaterial aspects of digitalization and their organizational consequences (Baskerville et al., 2020; Nambisan et al., 2020). For example, to better understand ontological oscillation/reversal, I suggest that future research could focus on the interplay between the digital and the physical artifactual representations of a physical artifact.

And lastly, the ethics of routine design is another important issue, where business ethics and technology ethics intersect (see Martin et al., 2019), and values are introduced to the way of working. As I outline above, deceit (Eberhard et al., 2019), power imbalance, and injustice can also be inscribed in routines and I encourage researchers to have a critical lens when investigating routine design.

9.4 Updated guidelines for designing live routines

Routine design, in the context of industrial digitalization, is sometimes organized in a form called digital project. In a Swedish popular science article, Sun and Tell (2020) put a normative spin on the story and advise on ways to manage such projects when routines are designed in tandem with digital technology. With these normative insights, I return to Pentland and Feldman's (2008, p.247–248) foundational piece on routine design:

> First, invest in the ostensive. […] Second, consider the point of view of each other. […] Third, think about the relationship between specific actions and abstract patterns. […] Fourth, attempt to create 'ruts in the road'. […] Fifth, think

> about design points in the process, rather than decision points. […] Sixth, try to lock in the events you really care about. […] Seven, be prepared for continued engagement.

Below, I revise their guidelines for designing live routines for project managers and team members leading change initiatives. With these suggestions, I hope to provide some answers to the questions that occupy them.

First, invest in the patterns. For a live routine, just knowing one pattern (i.e., one best way) is not enough. At TurbineCo, both drawing-based and model-based entailed multiple ways of working. They may be present in documents like SOPs, training materials, step-by-step guides, etc. Through exploring the multiplicity, there are multiple desired ways of working to achieve the same end.

Second, consider the relationality. What are actors, artifacts, theories and practices involved in the ways of working? Where are the ways of working nested? Not only are routines interdependent in relation to other routines (see Rosa et al., 2021), (digital) artifacts are in a network as well (Yoo et al., 2010; Yoo et al., 2012; Cacciatori, 2012). Sun and Tell (2020) detail how the modularity of digital technology is a double-edged sword and creates information islands, especially when data is stored natively within each digital artifact, with no connections among the digital artifacts.

Third, think about the generativity. Routines and digital technology are not things, rather they are both generative systems. What are the internal dynamics among performing, patterning, and materializing as well as what will the routines become? More specially, how will the artifact exert its influence when there is ongoing performing and patterning?

Fourth, aim to create conditions for actions. Be it performing, patterning or materializing, all involve interdependent actions. At TurbineCo, such conditions were created during the team's routine design process when the routine designers informed routine participants, involved domain experts, customized and connected digital artifacts, lobbied management, and consolidated global efforts.

Fifth, think in the shoes of routine participants. It is, after all, routine participants who enact designed routines, not (necessarily) routine designers. In a design process, routine designers may refer to design methodologies like the evolved Double Diamond model (Design Council, 2019) to "design the right routines" and "design the routines right", guided by design principles like "put people first".

Sixth, try to demarcate actions. In other words, routine designers need to think about whom/what performs which actions. This echoes with one of the key design performances from Glaser's (2017) distributing agency. Within the MBD project, the goal was to replace paper drawings with 3D models. That is, to put it crudely, some aspects of routines are dead (some actions are controlled) to make other aspects come alive.

Seven, be prepared for continued engagement. Routines are effortful and emergent accomplishments (Feldman et al., 2016; Feldman et al., 2021), and routine design, despite its time-limited nature, is aimed to have a lasting impact. At TurbineCo, the MBD project created a support network to provide information and capture anomalies. I also record the importance of managerial support, which echoes with Grand's (2021, p.399–400) suggestions on how managers should "engage in routine dynamics from within".

9.5 Long story short

Returning to the research question one last time: *how do organizational actors design live routines?*

This question is crafted so that it does not question the possibility. Despite some failed attempts documented in the routines literature, there are almost as many successful ones to design live routines, including mine, when model-based ways of working come to exist in potentiality.

Routine dynamics is an oxymoron. It implies that routines are both potential and actual. Though actuality is more coveted when designing live routines, I have come to believe that potentiality is equally important as routines become.

Epilogue

When I examined the way of development of those persons who, quietly, and as if unconsciously, grew beyond themselves, I saw that their fates had something in common. Whether arising from without or within, the new thing came to all those persons from a dark field of possibilities; they accepted it and developed further by means of it. It seemed to me typical that, in some cases, the new thing was found outside themselves, and in others within; or rather, that it grew into some persons from without, and into others from within. But it was never something that came exclusively either from within or from without. If it came from outside the individual, it became an inner experience; if it came from within, it was changed into an outer event. But in no case was it conjured into existence through purpose and conscious willing, but rather seemed to flow out of the stream of time.

Carl Jung, 1932, in *Commentary to The Secret of the Golden Flower* (p.89)

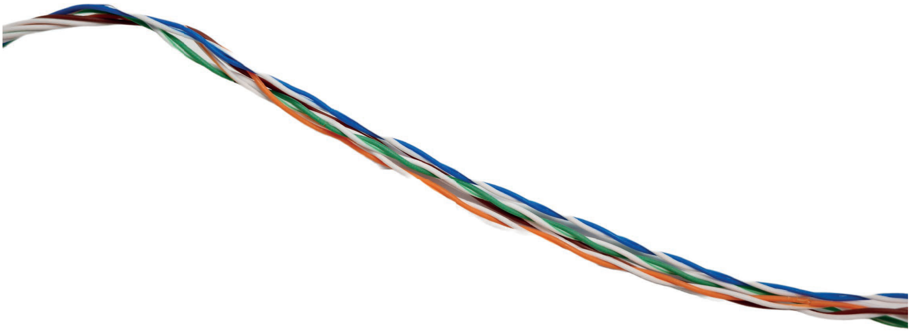

Photo (color in the digital version): © Yajuan Zhu

At-one-ment

After the attempt to narrate a routine change process, now it is my turn to introspect about a change process of my own. Instead of calling this text acknowledgements, I believe a more fitting title would be at-one-ment: when I am at one with my past self, when I am at one with those who have imprinted on my present self, and when I am at one with my future self.

But this is an atonement after all.

I have to first confess that the pursuit of a Ph.D. is not intentional.
It is *fatefully coincidental* (缘分). This Chinese oxymoron explains how meaningful connections are made from both chance and necessity. This perspective made me appreciate experiences, good and bad, beyond their apparent forms, especially the emotional turmoil that came with this pursuit.

I was eating bitterness (吃苦), another Chinese idiom that I never thought I would manage to experience in its true meaning. It was bitter because I came to the realization that I was not only becoming a researcher, but also, I was becoming me.

Hats off to my past self who endured various trials and tribulations.

I also have to confess that the Ph.D. journey is not individualistic.
It is *collective*. My present personhood was shaped by a composite of moments when my past self was at one with some of the best people I have ever known. I would like to express my enormous gratitude…

To Sven and members of the MBD project:
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Appendix 1: List of sources

List of interviews and observations

Visit No.	Date YYMMDD	Type	Duration	Informant
1	161208*	Interview	1h 7min	Sven, Project manager
2	170126*	Interview	1h	Sven, Project manager
		Interview	1h	Bengt, Project manager
		Interview	37min	Josefin, Line manager
3	170601*	Interview	1h 10min	Bengt, Project manager
		Interview	45min	Axel, Lead engineer
		Interview	20min	Sven, Project manager
		Release 1 at 17Q4		
4	171122	Interview	2h 55min	Sven, Project manager
5	171220	Interview	1h 28min	Sven, Project manager
		Interview	1h 8min	Nils, CAM programmer
6	180126	Interview	1h 44min	Sven, Project manager
		Interview	1h 6min	Nils, CAM programmer
		Release 2 at 18Q1		
7	180327	Interview	2h 35min	Sven, Project manager
		Interview	47min	Sven, Project manager
8	180424	Interview	1h 23min	Sven, Project manager
		Interview	1h 5min	Tomas, Design engineer
9	180521	Observation	5min	Project meeting
		Observation	1h	Sven, Project manager
	180522	Interview	1h	Tomas, Design engineer
		Interview	1h	Tomas, Design engineer
		Interview	1h 6min	Tomas, Design engineer
		Observation	2h	Tomas, Design engineer
	180523	Interview	1h 29min	Sven, Project manager
	180524	Interview	1h 9min	Nils, CAM programmer
		Observation	30min	Nils, CAM programmer
		Release 3 at 18Q3		
10	181015	Observation	40min	Project meeting

		Interview	1h 8min	Sven, Project manager
		Interview	53min	Tomas, Design engineer
	181016	Interview	31min	Sven, Project manager
		Interview	1h	Sven, Project manager
	181017	Interview	1h 16min	Sven, Project manager
		Observation	30min	Tomas, Design engineer
		Interview	16min	Tomas, Design engineer
11	181112	Observation	45min	Project meeting
		Interview	55min	Nils, CAM programmer
	181113	Interview	58min	Robin, Manufacturing engineer
		Interview	1h 19min	Tomas, Design engineer
	181114	Interview	52min	Vincent, Production engineer
		Interview	1h 10min	Josefin, Line manager
	181115	Interview	1h 37min	Sven, Project manager
Release 3.1 at 18Q4				
12	190128	Observation	1h	Project meeting
		Interview	51min	Mats, CAM Programmer
		Interview	22min	Nils, CAM programmer
	190129	Interview	43min	Sven, Project manager
		Interview	1h 6min	Sven, Project manager
		Interview	1h 1min	Emma, Line manager
		Observation	1h	Sven, Project manager
	190130	Interview	52min	Robin, Manufacturing engineer
		Interview	55min	Erik, Coordinator
		Observation	1h	Sven, Project manager
	190131	Interview	1h 28min	Sven, Project manager
Release 3.2 at 19Q1				
13	190423	Observation	30min	Sven, Project manager
		Interview	2h 7min	Sven, Project manager
		Interview	50min	Sven, Project manager
		Interview	6min	Sven, Project manager
	190424	Observation	30min	Tomas, Design engineer
		Interview	1h 55min	Tomas, Design engineer
		Interview	26min	Sven, Project manager
14	190522	Observation	45min	Sven, Project manager
		Interview	1h 20min	Sven, Project manager
		Interview	1h 3min	Sven, Project manager
	190523	Interview	55min	Sven, Project manager

		Interview	21min	Sven, Project manager
	190524	Interview	46min	Nils, CAM programmer
		Interview	16min	Robin, Manufacturing engineer
		Interview	17min	Sven, Project manager
		Release 3.3 at 19Q3		
15	191029	Observation	30min	Tomas, Design engineer
		Interview	50min	Sven, Project manager
		Interview	57min	Tomas, Design engineer
		Interview	29min	Tomas, Design engineer
	191030	Interview	57min	Sven, Project manager
		Interview	58min	Nils, CAM programmer
		Interview	27min	Sven, Project manager
	191031	Interview	48min	Bo, IT support
		Interview	1h 43min	Sven, Project manager
		Release 3.4 at 19Q4		
16	191218	Interview	47min	Tomas, Design engineer
17	200206	Interview (virtual)	31min	Sven, Project manager
		Release 3.5 at 20Q1		
18	200324	Interview (virtual)	1h 35min	Sven, Project manager
19	200603	Interview (virtual)	1h 35min	Sven, Project manager
20	220413	Interview	1h 38min	Sven, Project manager

* Conducted by the research project members prior to my Ph.D. project.

Statistics of interviews and observations

Title	**Interviews**		**Observations**	
	Hours	Times	Hours	Times
	Project management			
Bengt, Project manager	2h 10min	2	-	-
Sven, Project manager	15h 54min	34	4h 15min	5
Erik, Coordinator	55 min	1	-	-
	R&D			
Axel, Lead engineer	45min	1	-	-
Tomas, Design engineer	10h 50min	11	3h 30min	4

Manufacturing				
Nils, CAM programmer	6h 28min	7	30 min	1
Mats, CAM programmer	52 min	1	-	-
Robin, Manufacturing engineer	2h 6min	3	-	-
Emma, Line manager	1h 1min	1	-	-
Assembly				
Vincent, Production engineer	52min	1	-	-
Josefin, Line manager	1h 10min	2	-	-
IT				
Bo, IT support	48min	1	-	-
Scrum meetings	-	-	2h 30 min	4

	Interviews		**Observations**	
	Hours	Times	Hours	Times
Total	67h 57 min	65	10h 45 min	14

List of documents

Title	**Type**	**Release year**
History of TurbineCo*	Book	Early 2010s*
3D CAD and Model-centric Design	Article	2008
3D Model-based Value Definition	Consultancy report	2012
The Manufacturing Way at TurbineCo*	SOP	2012
CAD and PLM crucial to Enabling MBE Initiatives	Consultancy report	2015
PLM+ Scope Outline	Project document	2017
Assembly Happens with 3D Models	Internal news	2017
User/Software Requirements Specification for Release B	Project document	2019
MBD in PLM+: Scope Outline FY19	Project document	2019
TurbineCo’s Annual Reports (11 years)	Annual report	2010-2020
IndustryCo’s Annual Reports (11 years)	Annual report	2010-2020

*Anonymized

Appendix 2: Synopses of Periods I and II

Timeline		Happening
		Sven established the team and initiated the sandbox environment for routine design work. At short notice, he only had a few weeks to rush the project scope document of MBD-related features for Release 1. The team managed to produce video demonstrations on the envisioned manufacturing and assembly routines, hinging on the perceived shortcomings and what the new PLM features of CAD-CAM chain and DWI could afford.
17Q4	Release 1	Design data migration proceeded from the preceding to PLM+, starting with drawings
		When preparing for the second release, the project team continued with dummy testing in the sandbox environments. The team also detected some technical incompatibility between PLM+ and other digital artifacts and anticipated even more interface problems. Sven pitched to more communities in manufacturing and assembly to gain buy-ins. The Business team and the IT team discovered their language barriers when carrying on the project work. The live pilots in manufacturing were postponed due to issues with the testing environment, while for assembly, some productive pilots for IGT200 received positive feedback.
18Q1	Release 2	PLM+ went live, and the preceding PLM was running in parallel as a backup. No MBD-related features went live. Design data migration (3D models) started from the preceding to PLM+. The overall connection between PLM+ and CAD/CAM was established.
		Sven applied for funding for the MBD project for another year. One sister site (Motorville) joined the project. A new organization overseeing digital projects was established. The team made some progress on designing routines; however, technical issues prevented testing of the routines in their entirety. The team also started to prepare training materials for MBD.
18Q3	Release 3	The preceding PLM was shut down. The connection between PLM+ and ERP was delayed. Basic MBD-related features were implemented.
		The team discovered some stoppers that delayed pilots. Motorville formally joined the project, while Sven started the process of renewing the project. The team established a support network for MBD and started making videos for training. Some preparations were made for the pilots in manufacturing and assembly, despite the stoppers.

18Q4	Release 3.1	Many MBD-related features in the Instructions Application were released. CAD/CAM was upgraded, but the native installations were in use.
		The official PLM+ project was terminated. PLM+ and ERP were yet to be connected and the local ERP team was invited to assist in the MBD project. A digital fair was organized in Rotorstad. Live productions were planned for the manufacturing. In the assembly, participants praised the electrical assembly pilots, and MBD was suggested for all incoming orders, while pilots for core assembly were planned.
19Q1	Release 3.2	Many MBD-related features in the Animations Application were released.
		The project renewal was approved, despite some delays. A major reorganization of the turbine business was announced. Sven drew some interest from his colleagues in the digitalization group about MBD. Another digital fair was arranged in Statorstad. More video tutorials were produced by Tomas. The work to establish the connection between PLM+ and ERP was divided into the subsequent three releases. Motorville ordered some AGT100 components from Rotorstad. Stricter rules were introduced, and the workers understood more the benefits of MBD. Due to their workload, the pilots were delayed. Core assemblies commenced, and Tomas collaborated with the initiative CAD-part alignment to rework the models required. Assembly workers provided their feedback on the ongoing pilots.
19Q3	Release 3.3	An MBD related feature: Transfer new M/A-BOM was released
		The local IT support, Bo, began the first phase of IT handover, transferring the responsibilities of the manufacturing. The team increased their contact at R&D regarding the models. The manufacturing workshop was occupied with the AGT100 orders. Some more defects were found regarding the feature "Transfer new M/A-BOP" and the NC Application. Meanwhile, more assembly pilots were arranged for the Rotorstad, Statorstad, and Motorville sites. Release 3.4 was postponed, to ensure the delivery of all the planned features.
19Q4	Release 3.4	An MBD-related feature: Transfer new M/A-BOP was released. A majority of the stoppers were resolved.
		After working on the AGT100 orders, new ways of working emerged in the manufacturing workshop. Some more issues were found in the connection between PLM+ and ERP. The ongoing pilots in assembly pointed out the remaining defects and improvement areas in the infrastructure. Due to the outbreak of Covid-19, the supply chain was disrupted. Bo had his second phase of the IT handover, with the responsibilities from the assembly. The Business prepared for the major reorganization and its effects on the licensing of all software supplied by IndustryCo.
20Q1	Release 3.5	An MBD-related feature: Transfer revised M/A-BOM & M/A-BOP was released. A majority of the defects were resolved.

DOCTORAL THESES

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