Towards an Ontology-Driven Approach for Digital Twin Enabled Governed IT Management

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Abstract. The Digital Transformation of our society requires IT infrastructures to be more agile, more adaptive, and more connected than ever. At the same time, the owners of such infrastructures are confronted with an increase in regulatory pressure (e.g., the GDPR). These developments put a lot of stress on IT management and governance. To enable IT management and governance to better deal with these challenges, we propose to digitally transform IT governance and management itself by using a Digital Twin based approach. In line with this, we aim to create on ontology-driven Digital Twin for Governed IT Management (DT4GITM) framework. The goal of this framework is to act as a reference architecture for a Digital Twin based infrastructure that connects three interrelated systems: the IT governance processes, the governed IT management processes, and the managed organizational IT assets. The core of the framework involves a generic Governed IT Management (GITM) Domain Ontology, which is planned to be operationalized by a Knowledge Graph based approach that realizes an integrated view on the heterogenous data streams originating from the IT governance and management processes, and the managed IT assets. In this paper, we start by outlining the planned DT4GITM framework and the pivotal role of the GITM Domain Ontology within this. We then elaborate our incremental, and scenario-/case-driven strategy towards the development of the framework as a whole, and the GITM Domain Ontology in particular. This is followed by the elaboration of a specific DT4GITM scenario which serves as a first proof of principle.

1 Introduction

The Digital Transformation of our society puts extreme pressure on IT infrastructures (i.e., the *system of organizational IT assets*) and their associated *management processes*. As a result, IT infrastructures need to be more agile, more adaptive, and more connected than ever. At the same time, the owners of these infrastructures find themselves confronted with an increase in regulatory pressure (e.g., the GDPR).

We conceptualize the *IT governance and management system* as being the whole of interrelated organizational governance assets (i.e., organizational structures, processes, and relational mechanisms [3]) that purposefully combines and integrates three systems: (1) the *organizational IT assets*, (2) the associated *management processes*, and (3) the *IT governance processes*, in order to ensure strategic alignment, risk management, and compliance [4].

To enable IT governance and management to better deal with these challenges, we propose to digitally transform IT governance and management itself by using a Digital Twin approach. We posit that such digitalization and the related cultural/organizational change, make IT governance and management more apt to address the challenges that come with digital transformation and the corresponding changes to the organizational IT assets (e.g., IT staff, applications, data, infrastructure, processes, projects) and their management processes. To this end, we are working towards the creation of an ontology-driven *Digital Twin for Governed IT Management (DT4GITM) framework*, with a *Governed IT Management (GITM) Domain Ontology* at its core.

The goal of the resulting DT4GITM framework is to serve as a reference architecture for a Digital Twin based infrastructure that connects the earlier mentioned interrelated systems, involving the organizational IT assets, the associated management processes, and the IT governance processes. When applying this framework in a specific organizational context, the framework, and the generic GITM Domain Ontology in particular, will need to be specialized to the organization-specific context and priorities.

In developing the GITM Domain Ontology, we will mainly draw on ITIL 4 [1] and COBIT 2019 [4, 12]. Where needed, this will be complemented with concepts from other relevant standards. We found that the performance indicators as provided by COBIT, and even ITIL, are defined rather 'loosely' and/or at a highly aggregated level. This makes it difficult to directly relate them to data streams that can be used to 'feed' the IT governance Digital Twin. This means that, for the purposes of the DT4GITM framework, these indicators need to be operationalized further, both in terms of concepts in the GITM Domain Ontology, as well as in terms of how these indicators can be qualified/quantified (which ultimately defines the Digital Twin parameters, i.e., the data to be gathered to materialize the Digital Twin). As will be elaborated in Section 5, we therefore, plan to follow an incremental and scenario-/case-driven strategy to develop the DT4GITM framework (and associated reference implementation toolset).

As mentioned before, the GITM Domain Ontology forms the core of the DT4GITM framework. To operationalize this domain ontology, we plan to use Knowledge Graphs [6, 7]. The use of Knowledge Graphs enables an integrated view on the heterogenous data streams originating from the IT governance and management processes, as well as the managed IT assets.

In the remainder of this paper, we will start by outlining the proposed DT4GITM framework in Section 2. In Section 3 we then zoom in on first steps towards the development of the GITM Domain Ontology, in particular in terms of concept maps for the COBIT 2019 and ITIL 4 frameworks. Section 4 then discusses in more detail the planned operationalization of the GITM Domain Ontology in terms of a Knowledge Graph based approach. This is followed, in Section 5, by a discussion on the incremental, and scenario-/case-driven strategy we will follow towards the overall development (and validation) of the DT4GITM framework in general, and the GITM Domain Ontology in particular. Before concluding, Section 6 presents a first example scenario of the use of a Digital Twin in the context of Governed IT Management.

2 Outline of the DT4GITM framework

To guide the development of Digital Twins as data-driven and smart IT governance systems, we propose the DT4GITM framework (see Fig. 1). An earlier, and more COBIT-specific, version of this framework was included in [16]. The DT4GITM framework aims at providing a reference architecture for an IT governance Digital Twin based infrastructure. DT4GITM defines the different components of such infrastructures in terms of their purpose, function, and relationships with other components or the system's environment. The detailed design and implementation of the components is subject of future research.

To provide the *mirroring function* (also called *twinning function*), the Digital Twin should be able to represent (i.e., to model) the organizational IT assets, as well as their management and governance processes. A first key question here is "*what*" needs to be represented (i.e., what should be the model's contents). At the core, this question is answered by an organization-specific ontology for IT governance, for which the DT4GITM framework provides a domain ontology (i.e., *GITM Domain Ontology* in Fig. 1). This domain ontology is envisioned to cover the entire governance system, as well as its evolution over time (within the organization). As discussed above, the governance system includes: (1) the system of organizational IT assets, (2) the associated management processes, and (3) the governance processes,

A second key question is "*how*" the relevant data and knowledge about organizational IT assets and their management and governance processes (i.e., the twinning parameters) needs to be represented. Here, we propose the use of Knowledge Graphs as they have the ability to integrate and uniformly represent heterogeneous data. The *GITM Knowledge Graph* (see Fig. 1) provides a reference how to consistently and uniformly represent all relevant data for IT governance, including particularly data streams from *IT Governance Processes*, *IT Management Processes* and *Organizational IT Assets*, which can be further related to *Other Data*.

The basis for the *virtual processing* function is the Digital Twin based infrastructure that synchronizes the organization-specific ontology and the modeled organizational IT assets and their management and governance processes (i.e., virtual processing is driven by the data captured in the Digital Twin's Knowledge Graph). The operation of this function follows the *Sense-Think-Act*

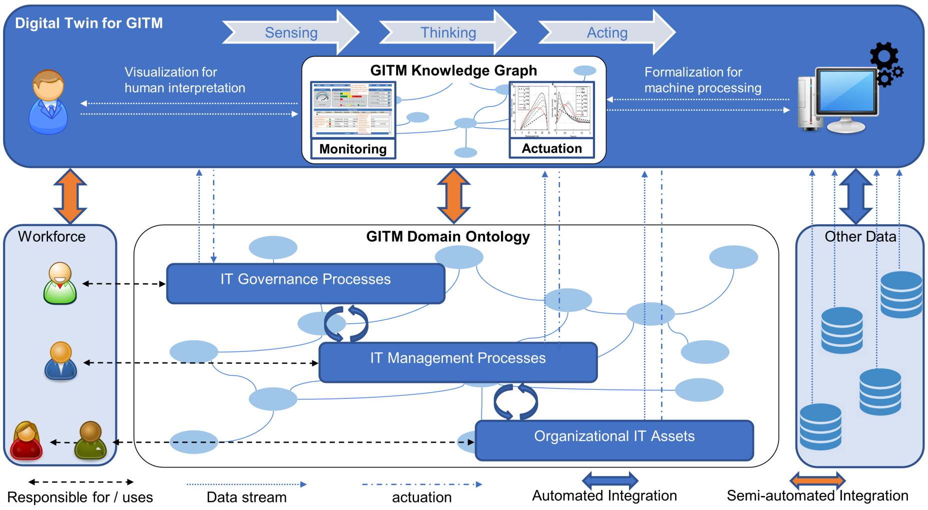

Fig. 1. The Digital Twin for Governed IT Management (DT4GITM) Framework

paradigm of Control Theory [17] and requires apart from analytical/simulation capabilities for monitoring and actuation, also visualization capabilities for human interpretation (i.e., *Workforce* in Fig. 1). Knowledge Graph technologies provide formalization capabilities for the machine processing of the twinning parameters and other internal and external data, to realize these virtual processing capabilities. The *Digital Twin for GITM* component provides a reference architecture for developing Digital Twin based infrastructures that offer the necessary functionalities for our envisioned solution.

3 Towards the GITM Domain Ontology

A foundational element in the realization of an IT governance Digital Twin is the GITM Domain Ontology, as it defines more precisely what the virtual entity will be concerned with, in terms of the concepts in the domain, their relationships and properties, as well as possible constraints. In general, within the field of Applied Ontology, a domain ontology enables one to define what (can) exist(s) in a given domain [10]. As such, the GITM Domain Ontology defines not only what the IT governance Digital Twin will be concerned with, but also the data that needs to be gathered to monitor the status and performance and to track the evolution of the organizational IT assets and their management and governance processes (i.e., the IT governance twinning parameters).

The DT4GITM framework thus offers a domain ontology as a conceptual basis for developing organization-specific ontologies for GITM. When developing an IT governance Digital Twin in the context of a specific organization, the generic domain ontology will need to be situated to the specific concerns of that organization (e.g., privacy, security, costs). A design process that is driven by the GITM Domain Ontology, ensures that relevant IT governance concepts, and their properties, relationships and constraints, are accurately represented in the organization-specific ontology. This design process also involves defining which twinning parameters are relevant given the specific IT governance concerns of an organization.

To operationalize our vision of DT4GITM as a reference architecture for developing IT governance Digital Twins, the GITM Domain Ontology should at least cover the concepts of the COBIT 2019 and ITIL 4 frameworks. This can later be complemented with more specific concepts from relevant other standards.

In moving towards a first version of such a GITM Domain Ontology, we already produced concept maps of the COBIT 2019 (see Section 3.1) and ITIL 4 (see Section 3.2) frameworks. First considerations of relating these two concept maps are also presented in Section 3.3 whereas a formal integration is on our agenda for future research. The concept maps use an informal way to graphically distinguish concepts (blue rectangles with rounded corners), concept properties (yellow circles), and concept instances (green squares).

3.1 COBIT 2019 Concept Map

There have been some proposals for describing the ontology underlying previous versions of COBIT [2, 8, 13, 14]. However, to the best of our knowledge, an IT governance domain ontology that includes the concepts of COBIT 2019 has not been defined yet. Since the conceptual model underlying COBIT 2019 has been purposefully designed [18], this conceptual model can be used as a starting point for the development of the governance aspects of the GITM Domain Ontology.

Fig. 2 shows a concept map containing the concepts of COBIT's main guidance towards IT governance practitioners. Key concepts include:

Governance Components – Factors that, individually or collectively, contribute to the good operations of the enterprise's governance system over Information Technology (IT).

Governance and Management Objective – An objective that should be achieved for IT to contribute positively to enterprise goals. The objective is either a governance objective or a management objective. There are five governance objectives and 35 management objectives described in the COBIT 2019 Core Model (i.e., the main focus area of the COBIT 2019 framework). Such an objective always relates to one process and a collection of governance components of other types to help achieve the objective.

Governance and Management Domain – Grouping of governance and management objectives for areas of governance or management activity. There is one governance domain and there are four management domains.

Focus Area – A governance topic, domain or issue that can be addressed by a collection of governance and management objectives and their components (e.g., COBIT 2019 Core Model, cybersecurity, privacy, SMEs, and DevOps).

Processes – Describe an organized set of practices and activities to achieve certain objectives and produce a set of outputs that support achievement of overall IT-related goals.

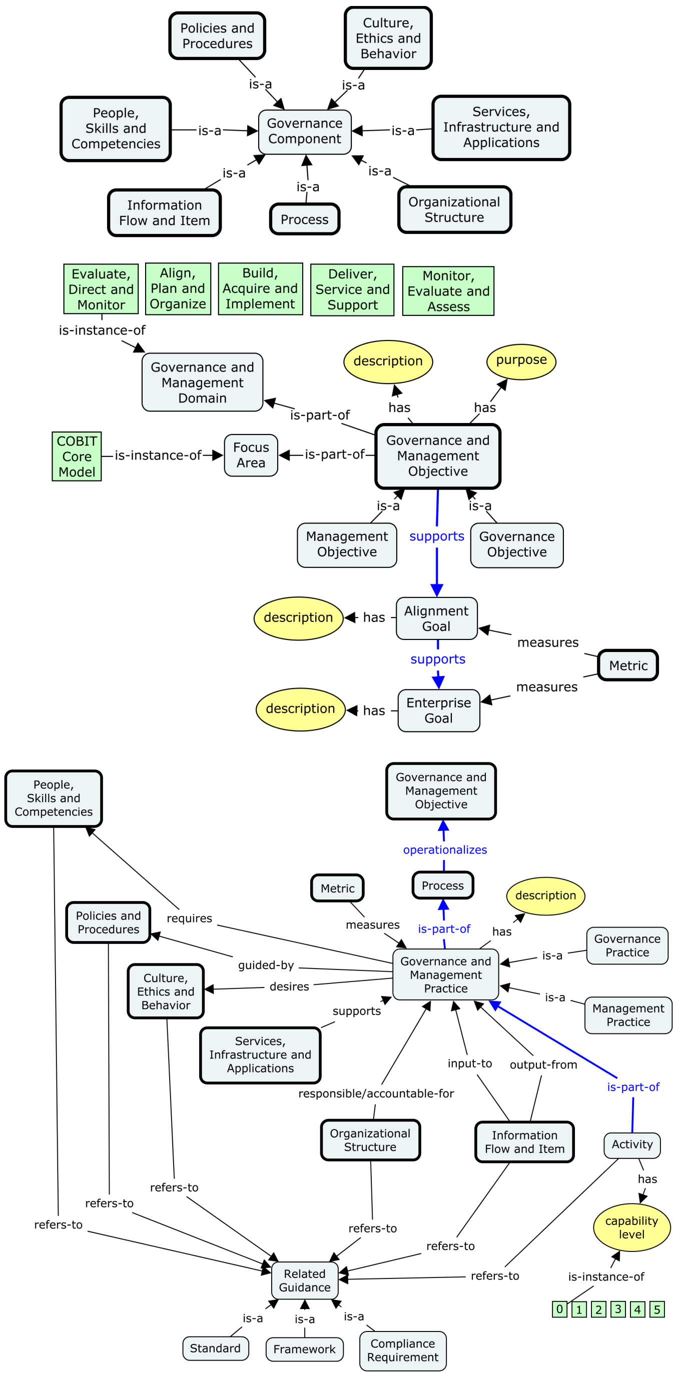

Fig. 2. Concept Map of the COBIT 2019 Core Model
Legend: Concepts with a thick border occur multiple times in the diagram.

Governance and Management Practice – Grouping of activities, as part of a particular process, with metrics to measure achievement of the practice.
Activity – Work to be performed, as part of a governance or management practice, at a certain capability level.

3.2 ITIL 4 Concept Map

To obtain a more complete description of organizational IT assets and their management processes we will (as already hinted at in the introduction) primarily draw on concepts from the ITIL 4 framework for IT service management [1].

Fig. 3 shows a concept map for the key concepts as identified in the ITIL 4 framework [1]. This concept map will be used in the further development of the IT management related aspects of the GITM Domain Ontology. The main identified concepts are:

IT Service Management (ITSM) Practice – A set of organizational resources designed for performing work or accomplishing an objective. There are 34 ITSM practices in the ITIL 4 framework: 14 general management practices, 17 service management practices, and three technical management practices.
Generic Value Chain Activity – Steps that an organization takes in the creation of value. There are six generic value chain activities in ITIL 4: plan, improve, engage, design and transition, obtain/build, deliver and support.
Guiding Principle – A recommendation that guides an organization in all circumstances, regardless of changes in its goals, strategies, types of work, or management structure.
Value Stream – A specific combination of value chain activities and practices, designed for a specific scenario, that describes a series of steps an organization undertakes to create and deliver products and services to consumers. Provides a complete guide to the activities, practices, and roles involved to realize an intended outcome.

As we will discuss in Section 5, we will follow a (real world) case-driven approach in the development of the DT4GITM framework in general, and the GITM Domain Ontology in particular. In doing so, we also plan to include (relevant parts of) existing ontologies for ITIL (see e.g. [19, 5]).

3.3 Relating COBIT 2019 and ITIL 4

In developing the GITM Domain Ontology, it will be necessary to integrate/ align the concepts from ITIL 4 and COBIT 2019.

When comparing the concept maps of COBIT 2019 and ITIL 4, we already see that the guidance provided in an ITIL 4 *Value Stream* is comparable in terms of purpose and granularity to the guidance provided in a COBIT 2019 *Governance and Management Practice*, making ITIL 4 Value Stream *steps* similar to COBIT 2019 *activities*. The guidance provided in ITIL 4 is, however, more detailed and more situation-specific. For instance, ITIL 4 describes responsible

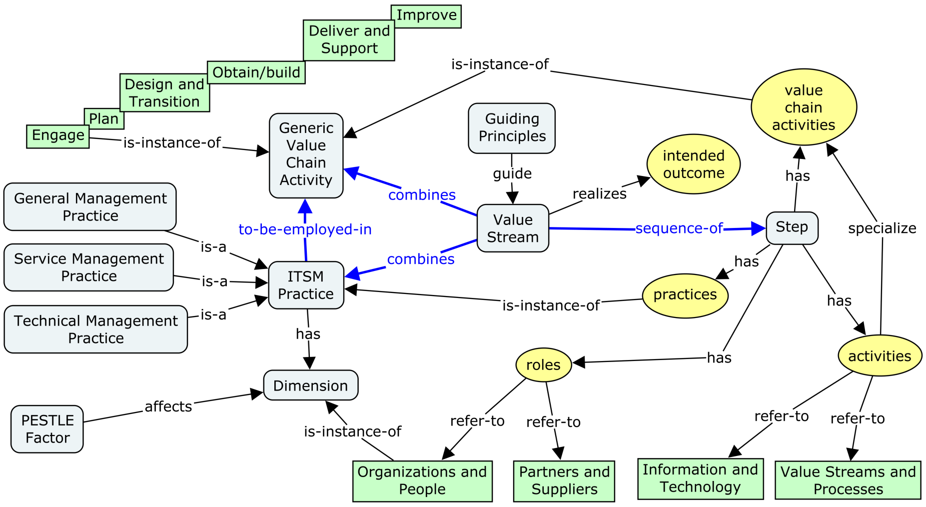

Fig. 3. Concept Map of the ITIL 4 Framework

roles, inputs/outputs, resources and operations to be performed at the level of individual value stream steps, whereas COBIT 2019 describes responsible/accountable roles and information items flowing in and out at the more aggregate level of practices. Further differences are that ITIL 4 does not cover IT governance responsibilities and activities, while COBIT 2019 also has a broader view of IT management, extending beyond developing and improving the IT service management capability. For instance, processes such as budget management, innovation management, and data management are not covered in ITIL 4. On the other hand, an ITIL ITSM practice such as service catalogue management, is present in COBIT 2019, but only at the activity level, so with much less comprehensive guidance.

4 The Role of the GITM Knowledge Graph

The GITM Domain Ontology, and its organization specific refinement, also defines the twinning parameters (i.e., data about organizational IT assets and their management and governance processes) that are relevant to an organization and its specific IT governance concerns. As mentioned above, to represent these twinning parameters and to integrate them with other relevant data and knowledge representations, including data from external sources (see Fig. 1), we plan to use a Knowledge Graph based approach.

The GITM Knowledge Graph component of our framework provides a reference of how such Knowledge Graphs can be constructed. Furthermore, it describes the visualization and formalization capabilities that such Knowledge Graphs should offer to allow for human interpretation of the information and machine processing of the data, respectively. Operationally, the GITM Knowledge Graph component consists of a set of tools that realize interactive visualizations (e.g., Visual Analytics tools, Business Intelligence dashboards) and efficient querying of the vast amounts of IT governance related data in order to support decision making.

Metrics for IT governance and management performance indicators can be operationalized as predefined queries which can be easily parameterized and executed by business users. Moreover, powerful Knowledge Graph platforms like Stardog[1], fed with the data of the organization-specific IT governance Digital Twin's Knowledge Graph, enable the application of advanced AI algorithms to also proactively respond to environmental or internal changes of the organizational IT assets and their management processes.

Consequently, the realization of the GITM Knowledge Graph will have to cater for the fact that the Workforce (see Fig. 1) has diverse backgrounds and roles with regards to IT governance and management. The DT4GITM framework needs to make the data-driven and AI-enabled algorithms accessible and comprehensible in adequate graphical user interfaces to be applicable.

5 Strategy to Develop the GITM Domain Ontology

Since the DT4GITM framework, and the GITM Domain Ontology that is part of it, are artifacts designed as solutions for solving problems related to the challenges posed by the Digital Transformation to IT governance, we will use a Design Science Research methodology [9, 15]. The DT4GITM framework, as a reference architecture, also needs to be complemented with heuristics to apply (and refine) the reference architecture in specific situations. This is where we will use Situational Method Engineering [11] as a research method. Using example scenarios, and real-world cases, situational factors will be identified to differentiate the specificities of the cases, as well as guidelines and heuristics to tune the GITM Domain Ontology and/or DT4GITM reference architecture to the situation at hand.

As discussed before, the conceptual models of COBIT 2019 and ITIL 4 require more elaboration in terms of their performance indicators such that sensors and data streams can be defined. Specific concerns/qualities, such as security, performance, costs, etc, are also likely to lead to a need to refine the GITM Domain Ontology. This process will also be driven by the needs of example scenarios and real-world cases, which will also result in requirements on the actual GITM Domain Ontology.

For the GITM Domain Ontology, this leads to the situation as depicted in Fig. 4. The triangle represents the ontology, involving different levels of genericity. At the top, we find a foundational ontology (e.g., UFO [10]). Using conceptual models of the contributing frameworks and standards as a base, as exemplified by the concept maps discussed in Section 3, we will then define an *IT generic* GITM Domain Ontology expressed in terms of the foundational ontology. This part of the ontology is *IT generic* in the sense that it may refer to e.g., IT assets, but does not yet refer to specific information technologies, such as WiFi,

[1] `https://www.stardog.com/`, last visited: 09.07.2021

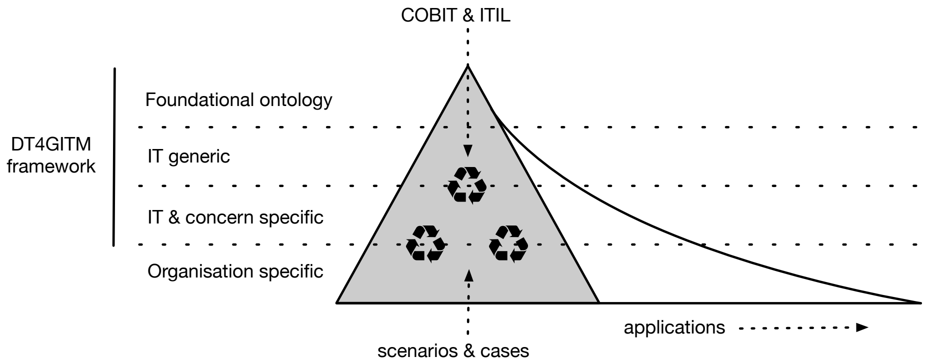

Fig. 4. Development and evolution of the GITM Domain Ontology

Blockchain, Cloud solutions, etc. Driven by concrete scenarios and cases, this IT generic ontology can then be refined further (and iteratively validated and improved) towards (1) considerations pertaining to specific information technologies, and (2) specific concerns/qualities. This *IT & concern specific* part of the ontology is still organization agnostic. In other words, for a specific organization, with its priorities, technology choices, etc., further refinements will be necessary. For the DT4GITM framework, as a reference architecture, only the three higher levels of the (stratified) ontology will be included, where the DT4GITM framework is also foreseen to include guidelines (designed using a Situational Method Engineering approach) for specializing the generic core to an organization specific ontology.

What is also hinted at in Fig. 4 is the further evolution of the ontology when applying it in different organizations. Here, it is expected to see the strongest evolution for the lower layers while the upper layers – especially the foundational ontology – should remain stable.

6 A Hardware Incident Management Scenario

Fig. 5 shows the ITIL 4 *value stream* for hardware incident management as applied to the failure of a wireless access point in a warehouse [1]. Each row is a value stream *step* that refers to one or more *generic value chain activities* and zero or more *ITSM practices*. Also the *roles* involved in the incident management procedure and the *activities* to be performed, are detailed. It is intended that all these concepts (see Fig. 3) are included in the GITM Domain Ontology of the organization.

Returning to the example, as a result of the failure, the warehouse forklift driver cannot receive instructions quickly enough. Before the incident can be resolved, it needs to be noticed. Next, the appropriate procedures need to be triggered to fix the problem and learn from it.

It is clear that technology can considerably speed up this *sense-think-act* process described in the value stream. In our envisioned Digital Twin solution, the

Value chain activity/ input/outcomes	Practices	Roles	Activities
Demand		Warehouse manager, forklift driver	It is discovered that there is no WiFi coverage in one area of the warehouse. This means that the forklift driver needs to drive across the warehouse to pick up their instructions, causing delays and risking missed business deadlines.
Engage	Service desk, incident management	Warehouse manager, service desk agent	The warehouse manager phones the service desk and describes the issue. It is agreed that this is a Priority 2 incident, and the manager is notified of the expected resolution time. Information about this incident is logged by the service desk agent.
Deliver and support	Service desk, incident management	Service desk agent, network support engineer	The incident is rapidly escalated to the network support team.
Deliver and support, improve	Incident management, change enablement, service configuration management, IT asset management, continual improvement	Network support engineer	The network support engineer identifies that the wireless access point has failed and replaces it with a spare from the store. This is a standard change, so the engineer needs no additional approval. Information required to configure the new access point is obtained from the CMS. IT asset information is updated to show that this spare part has been consumed. The network engineer updates the incident management system and marks the case as resolved. The network engineer thinks about what happened and whether they could have predicted this issue or resolved it more quickly.
Engage	Service desk, incident management	Service desk agent, warehouse manager	The service desk agent contacts the warehouse manager to check that everything is now working properly, then closes the incident.
Value		Warehouse manager, forklift driver	WiFi coverage is restored and the forklift driver can now work efficiently.
Engage, improve	Service desk, incident management, continual improvement	Warehouse manager, service desk manager	A brief satisfaction survey is emailed to the warehouse manager, which they complete and return. The scores are used to identify trends, and the comments are passed to the service desk manager for consideration.

Fig. 5. Example ITIL 4 value stream for hardware incident management [1]

wireless access point would be represented in the organization's GITM Knowledge Graph as an instance of an organization-specific IT asset concept in the GITM Domain Ontology (e.g., wireless communication device). The Knowledge Graph would relate it to other relevant information such as its location (i.e., the warehouse), its state, etc. Data streams from the access point logs and a sensor would be in place to automatically detect failures, and such failure signals would change the state of the device in the Knowledge Graph. A rule-based component would automatically qualify the incident as a Priority 2 incident which would directly trigger its resolution. The Knowledge Graph comprises information of the workforce and their roles. A network support engineer would be contacted who would then actuate the resolution procedure. Most likely, she would first replace the access point in order to immediately enable the forklift driver to resume the standard way of working. The Knowledge Graph incorporates data from the Configuration Management System (CMS) that describes the configuration of the warehouse access points to properly function within the organization's network. Moreover, the Knowledge Graph enables the network support engineer to execute a query that would help her identifying similar access points that are currently either not in use or dispensable.

The data about the failure would also be available for further analysis. For instance, accumulating failure data of wireless access points could be used for developing a predictive maintenance model, in the hope that next time a replacement is installed already before the device actually breaks. Moreover, feedback gained from all involved persons of this value stream will be collected and analyzed in the Knowledge Graph in order to learn about the quality of the implemented resolution in particular as well as on the incident management in general.

As the example scenario illustrates the connectedness of IT assets and governance/management processes realized through the Digital Twin based infrastructure, allows for directed and timely reactive and proactive responses of the IT governance/management system. But also, the ontology-driven approach induces a certain robustness in the system (as suggested in Fig. 4), making the system more adaptive and IT governance and management more agile. For instance, further warehouse automation would replace forklift drivers by robots that are actuated by the warehouse control system. The wireless access point would be replaced by built-in IoT devices. This would only affect the organization-specific GITM Domain Ontology, but not the IT & concern specific, IT generic, and foundational layers of the GITM Domain Ontology of the DT4GITM framework. In other words, it would be clear how to adapt the organization-specific Knowledge Graph to the new situation and to figure out the required changes to the rule-based component.

7 Conclusion

The Digital Transformation of our society requires IT infrastructures to be more agile, more adaptive, and more connected than ever. In the paper at hand we argue for a digital transformation of IT governance and management itself by proposing the Digital Twin for Governed IT Management (DT4GITM) framework that applies the concept of Digital Twins to IT governance. The conceptual backbone of DT4GITM is a domain ontology that aims to formally represent the concepts, properties, and relationships of COBIT 2019 and ITIL 4 frameworks, amongst other relevant standards and frameworks for IT governance and management.

The paper described the conceptual outline of the DT4GITM framework and elaborated on our strategy for developing the GITM Domain Ontology. The potential benefits of using the framework were exemplified by means of a hardware incident management scenario from ITIL 4. We believe this paper establishes a meaningful foundation for research in the direction of digital transformation of IT governance and management. Our plans for the near future are to apply and evolve the DT4GITM framework and the GITM Domain Ontology in real case studies.

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