vom Brocke, J., Braccini, A., Sonnenberg, C., & Spagnoletti, P. (2014). Living IT Infrastructures - An Ontology-based Approach to Aligning IT Infrastructure Capacity and Business Needs.*International Journal of Accounting Information Systems (IJAIS), 15 (forthcoming)*

Living IT Infrastructures – An Ontology-based Approach to Aligning IT Infrastructure Capacity and Business Needs

Abstract. Changes in organizational processes often interact with changes in the IT infrastructure. Accounting for the structural and economic consequences of changes to the modern IT infrastructure remains a challenge, as their complexity can affect more than one business process, and the need to share a common understanding between the IT and the business management challenges current IT governance practices. An integrative perspective of business processes and IT resources would help meet these challenges, but despite some progress such a perspective remains to be developed. This paper proposes a domain ontology - an Ontology for Linking Processes and IT infrastructure (OLPIT) – to model the relationship between IT resources and business processes for the purpose of measuring the business value of IT. The ontology was developed and evaluated in the context of a design research project conducted in the Hilti Corporation, an international manufacturing company, with the aim of defining how IT impacts the business and calculating the cost of IT services used.

Keywords: Process-based IT Value Assessment, Organizational Impact on IT, Ontology, IT Service Cost

1 Introduction

The operations of many organizations are driven or facilitated by their information technology (IT) infrastructures. Some organizations even rely on innovative IT infrastructures to help them create new business models and gain competitive advantage. To stay competitive, organizations must manage and control their IT, whether it is internal or based on cloud services, to ensure that the business strategy and the IT strategy are aligned to respond to changes in the environment from competitors' actions and technology (Henderson & Venkatraman, 1993). Developing and maintaining an IT infrastructure requires significant investments that, if not managed properly, may impair rather than enhance the organization's competitive position (Bowen, Cheung, & Rohde, 2007). Many organizations adopt IT governance methods, practices, and techniques to ensure that their investments in IT generate business value and to mitigate the risks associated with IT implementations (Van Grembergen, 2004). When successfully implemented, IT governance processes enable organizations to integrate business and IT decisions, implement IT solutions, and monitor IT effectiveness by fostering a constructive relationship between business and IT managers (Johnson & Lederer, 2005).

The rising complexity of modern IT infrastructures presents a number of issues for the successful implementation of IT governance practices. From the holistic, socio-technical, and evolutionary perspectives, IT infrastructures are dynamic systems whose growing complexity originates from the local, persistent, and limitless shaping of IT capabilities that results from the emergence of diverse communities with new learning and technical opportunities (Ciborra, 2000), giving rise to the notion of living IT infrastructures. In light of this complexity, measuring the impacts on the IT infrastructure of changes applied to business processes (and vice versa) is challenging. New methods and tools are needed to map the complexity of IT infrastructure resources and business processes in order to adapt business needs and IT infrastructure capacity dynamically. Although emerging organizational models and business strategies can be driven by digital platforms and IT infrastructures (Resca et al., 2013), in this paper we refer to the more traditional view of IT strategic alignment that applies to organizations whose business processes are vertically integrated in a hierarchical structure.

In this context the information systems manager and the audit community can benefit from the availability of new methods, practices, and tools that support the shift of IT governance processes toward transparent IT decision making, clear accountability, and acceptable and actionable IT measurements. Since IT infrastructures can easily affect more than one business process (Scheepers & Scheepers, 2008; Tallon, 2007), an integrative perspective would be useful in which business-related entities (such as activities) and IT infrastructure-related entities (such as IT resources) are systematically linked. Such a solution could enable companies to trace and measure effects in both directions: changes in business that affect the IT infrastructure and changes in IT infrastructure that affect the business.

This paper contributes to this measurement problem by presenting the results of a design research project that developed a domain ontology for linking IT infrastructure and business elements and instantiated it into a software tool. The prototype was then evaluated during a three-year period in the context of the Finance Control Department of the IT branch of the Hilti Corporation, an international manufacturing company. The project, which adopted a design science research (DSR) approach, reports on the evidence collected from the iterative design and evaluation process of the ontology. The artefact is grounded in a body of knowledge that spans IT value measurement (Davern & Wilkin, 2010), enterprise ontologies (O'Leary, 2010), and IT governance frameworks (Bowen et al., 2007). The expository instantiation of the artefact into the empirical settings of the Hilti case provides insights on the effectiveness of the approach in terms of IT planning and cost analysis activities and on the design principles of an ontology that is focused on IT value. The DSR approach adopted is described in the next section.

2 The Design Science Research (DSR) Framework and Methodology

DSR focuses on the creation of purposeful artefacts to change existing situations into preferred ones (Simon, 1996). Following the seminal work of Walls et al. (1992), March and Smith (1995), and Hevner et al. (2004), DSR has captured growing attention in the information systems literature (Fischer et al., 2010). According to Hevner et al. (2004), the main outcome of DSR research is prescriptive knowledge embodied in IT artefacts that solve business problems. Therefore, DSR is considered inherently a problem *solving* paradigm [rather than a] problem *understanding* paradigm (Hevner et al., 2004). IT artefacts can be constructs, models, methods, or instantiations, but they are concrete prescriptions that enable IT researchers and practitioners to understand and address problems in their fields.

Hevner et al. (2004) provide a concise conceptual framework for understanding, executing, and evaluating research in the design science paradigm. This framework design is an iterative search process in which the “environment” and the “knowledge base” are accessed in order to generate solutions that are tested against requirements and constraints, so they are both relevant and rigorous. In addition to such general guidelines and definitions, several methodologies for conducting DSR in information systems have been proposed. In this work we adopt the design science research method (DSRM) (Peffers et al., 2008), which is a synthesis of prior DSR methodologies. Geerts (2011) discussed the use of the DSRM within the accounting information systems domain. The DSRM separates the DSR process into six activities: problem identification and motivation (I/M), definition of the objectives of a solution (O), design and development (DES), demonstration (DEM), evaluation (EVAL), and communication (COM). However, since a sequential view of the DSR process does not accommodate the emerging nature of IT artefacts, more fine-grained patterns, especially in the evaluation phase, have been proposed (Sonnenberg & vom Brocke, 2012).

In our DSR process we iterated the demonstration and evaluation activities several times in order to strengthen the relevance and rigour of our artefact. Figure 1 shows the compound results of individual design activities as they are documented in two publications (vom Brocke et al., 2009, and this paper). The environment includes requirements and constraints taken from the application domain, and field-testing activities performed during the project (relevance cycle). The knowledge base includes foundational elements like scientific theories and methods; expertise, used as grounding for the different phases of the DSR process; and additions to the knowledge base itself as a product of the research (rigor cycle) (Hevner, 2007). White boxes represent activities reported in this paper; grey boxes represent activities reported in previous work

A first draft of the artefact was presented at an information systems conference (see vom Brocke et al., 2009) with a demonstration of the artefact as kind of an “artificial” evaluation (cf. Pries-Heje et al., 2008). The present paper reports on the complete set of design science research activities that have been conducted in order to build and evaluate our artefact. The evaluations presented in this paper comprise both artificial as well as naturalistic evaluations (cf. Pries-Heje et al., 2008). The design activities comprise of grounding the solution objectives in measurement theory (O) revising the initial OLPIT (DES), and evaluating the resulting OLPIT specification regarding its formal correctness as well as its usefulness for practice (EVAL). The evaluations required the development of a software prototype for IT value assessments, its application in a test case (DEM), and the application of the domain ontology in a real organizational context (“naturalistic” evaluation) (EVAL).

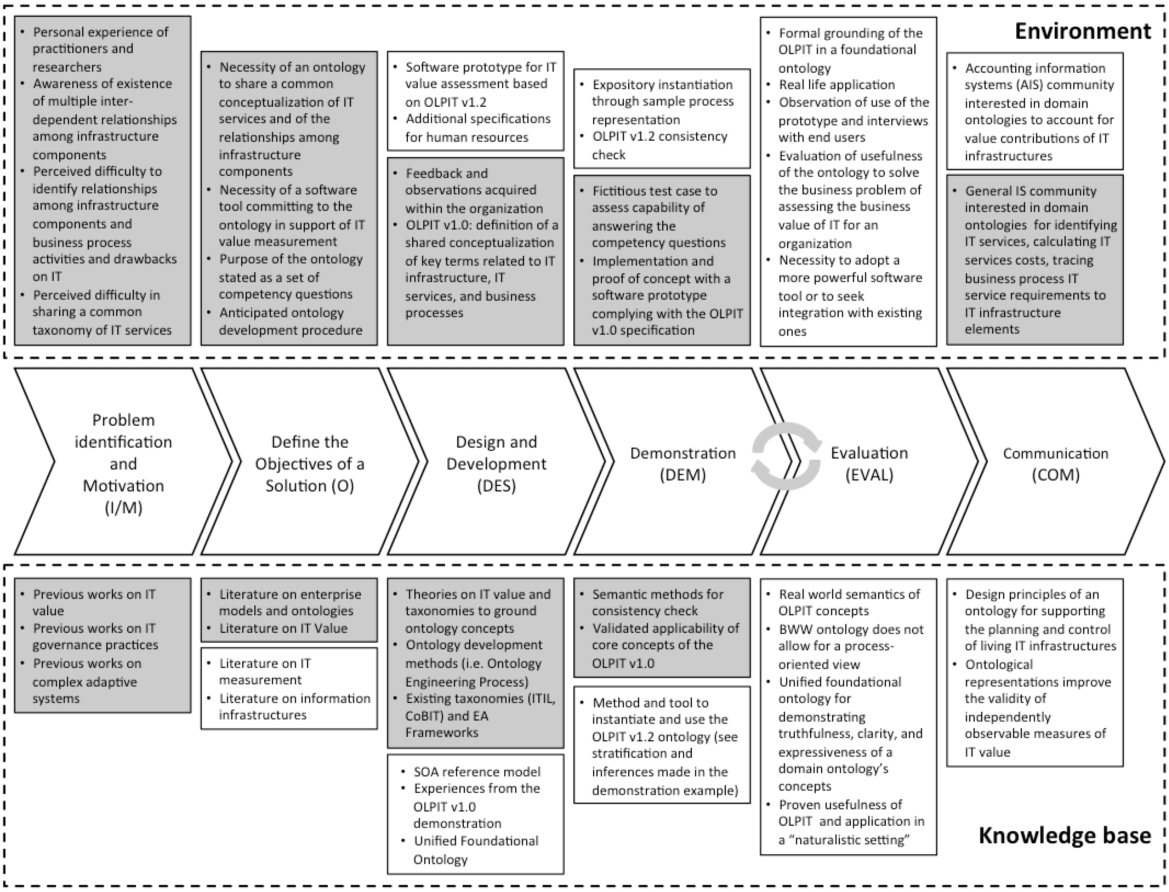


Figure 1. The DSR process (adapted from Hevner, 2007, and Peffers et al., 2008)

Since the I/M and O phases make clear the need for an artefact for sharing a common conceptualization of IT services and of the relationships among infrastructural components, the subsequent phases of our DSR process focus on the design and evaluation of a domain ontology. To ensure a rigorous development of the ontology, we referred to the ontology engineering process proposed by Sure et al. (2004) as a specialization of the first four phases of DSRM. The need to resort to a specific ontology engineering process in the DSR effort is motivated by the peculiarities of ontology engineering processes as DSR processes that are the result of the nature of the type of artefact created. An ontology is a model (a shared conceptualization) (Gruber, 1993; Grüninger, 2003) that is comprised of constructs (another DSR artefact type), so ontologies are composite artefacts that require an integrated evaluation of models and constructs. In this regard, ontology evaluations focus on proving correctness; that is, an ontology specification is correct if the constructs and the relationships between them are consistent and do not produce contradictory conclusions. Ontology engineering processes provide specific guidance for the design and evaluation of this kind of artefact.

Another consideration regarding the ontology development process concerns the difference between ontology engineering and data engineering, as this difference is important when researchers engage in DSR in either of these domains. Since ontologies are formal, shared conceptualizations of a domain, including domain rules, they represent artefacts that are generic and, by design, abstract from the ways things actually operate. Data models are also shared conceptualizations of a domain, but they are not generic—that is, they are not necessarily true and useful in many (unanticipated) circumstances. Data models often emerge from the specific requirements of an organization or a particular problem domain (cf. Spyns et al., 2002) and have to be adapted when they are applied in other domains. In contrast, ontologies are stable, and their conceptualizations anticipate unforeseen uses of that ontology (cf. Spyns et al., 2002).

Our ontology is designed to inform the development of tools for assessing the business value of IT for an organization. It structures the universe of discourse that holds true independent of a particular conceptual data model that might underlie such assessment tools. Thus, our ontology is designed to foster a common understanding and conceptualization of relevant terms and their relationships in the domain of IT value assessment. While engineering processes for ontologies and data models might be similar in the conceptualization and design phases, they differ with regard to the evaluation phases because of differences in the natures of ontologies and data models: Evaluations of data models concern the integrity of data sets, while evaluations of ontologies address not only the integrity of the domain rules defined but also that of the domain conceptualization (cf. Spyns et al., 2002). Since we intend to provide a stable conceptualization of the business value of IT that informs not yet fully anticipated designs of assessment methods, we adopted an ontology engineering process.

The evaluation criteria applied to our ontology are effectiveness (applicability), feasibility, suitability, truthfulness, clarity, expressiveness, and usefulness. While the first five criteria are related to a formal evaluation of the ontology, usefulness requires means to observe artefact uses in a naturalistic setting (Sonnenberg & vom Brocke, 2012). Case study research (Yin, 2009), expert interviews, and surveys can serve to evaluate the usefulness of an artefact (Sonnenberg & vom Brocke, 2012).

The exploratory nature of the case study investigation is justified since we want to infer from it the usefulness of our artefact to solve a business problem, rather than a causal relationship in the form of *“if ontology-based treatment X, then increase of some variable Y.”* In particular, we deemed a case-study-oriented evaluation appropriate, as we expected new aspects of the IT artefact to emerge continuously throughout the evaluation and design process, as is typical for DSR projects. (See Sonnenberg & vom Brocke, 2012, on how to deal with the emerging nature of IT artefacts.) In this regard, the external validity of the evaluation is limited to contexts that are similar (in size, IT infrastructure scope, and assessment problems) to our unit of analysis, although the field problems our study addresses also apply to smaller organizations that undertake IT value assessments.

The remainder of the paper is structured to follow the DSR process shown in Figure 1. Section 3 discusses the related works that are pertinent to the domain problem this paper addresses (I/M); section 4 describes the objectives of the solution sought (O); section 5 introduces the ontology design and development (DES) process and demonstrates the usefulness of the ontology to model real-world situations (DEM); section 6 presents results of a formal evaluation of the ontology by describing its grounding in a foundational ontology (EVAL); section 7 extends the evaluation of the ontology by presenting evidence of its usefulness for practice gained in applications of the ontology in a real production environment (EVAL); section 8 formulates considerations regarding the usefulness of the artefact proposed and regarding its application, along with implications for research and practice (COM); and section 9 concludes the paper with some suggestions for future research.

3 Related Work (I/M)

Our work is framed in the field problem of assessing the business value of IT investments. The business value of IT has been widely discussed in the management literature, but after more than two decades of research, organizations continue to seek ways to increase the value gained from their IT investments (Grover & Kohli, 2012). Therefore, the assessment, quantification, or measure of the value produced by IT remains difficult and subject to diverse opinions (Nevo & Wade, 2010).

The value of IT has been studied using a wide range of approaches (Melville et al., 2004) and theoretical perspectives (Oh & Pinsonneault, 2007). The IT value literature distinguishes among a macro level of assessing value, a firm level, a process level, and an individual IT-resource level (cf. Melville et al., 2004). We advance the knowledge on IT value measurement by linking an organization’s process level to its IT-resources level.

Earlier studies that have analysed the value of IT investments have highlighted the significance of processes-level analysis (Ray et al., 2007; Tallon, 2007; vom Brocke et al., 2009; Tallon & Pinsonneault, 2011). In particular, Ray et al. (2007) emphasize that IT applications tend to be process-specific, that is, that their effects produced during a specific process do not transfer to other processes. Davamanirajan et al. (2006) hold that process-level analysis enables the effects of IT on specific processes and tasks to be traced and that evaluation at the process level is important because investment decisions are made at this level. Other authors, however, contend that separating IT value into processes is difficult since during the process the IT asset interacts with other organizational resources (Melville et al., 2004; Nevo & Wade, 2010), which have their own value (Tillquist & Rogers, 2005). In addition, modern IT infrastructures are sufficiently complex and intertwined that a single IT resource can easily impact more than one business process (Scheepers & Scheepers, 2008), making identification of the IT resource that impacts a specific business process or activity more challenging.

The studies of IT value contribute *descriptive knowledge* in the form of theories about value generation through IT, but the literature lacks contributions to *prescriptive knowledge* in the form of DSR artefacts that provide practical guidance for assessing or measuring the economic value created by IT. Designing and evaluating such measurement artefacts is a “crucial aspect of accounting information systems (AIS) research” (David et al., 2002, p. 2).

In this paper we propose an ontology for measuring the impacts of IT infrastructure changes on business processes, and vice versa. The ontology establishes an integrative perspective of IT and business processes that allows the relationships between the IT infrastructure and the activities of a business process to be identified. To our knowledge neither the IT value research nor AIS research proposes a similar ontology to support IT value measurement activities. As such, our ontology is a novel contribution that addresses problems that occur frequently in IT value-measurement practices. The ontology proposed in this paper can serve as a starting point from which measurement tools can be derived and applied in practice.

The ontology development was conducted in the context of a DSR project over three years. The details of the DSR approach with reference to the objectives of the solution sought are described in section 4.

4 Objectives of the Solution (O)

The definition of the solution objectives lies in three bodies of knowledge: the problem of measuring IT value in complex organizational environments, enterprise models and enterprise ontologies as tools for mapping the IT infrastructure resources and business processes, and IT governance frameworks.

4.1 Independently observable measures of IT value

From an accounting perspective, measurement refers to a representation of some aspects of an underlying economic reality. Two representational approaches can be distinguished in measurement: independently observable measures and perceptual (subjective) measures. In their analysis of IT value measurement, Davern and Wilkin (2010) refer to measurement theory to characterize the quality of measures and to motivate the need for perceptual measures in IT value measurement. We follow their line of reasoning in justifying the requirements of the proposed solution to our IT infrastructure-business process problem.

Measures are prone to errors in terms of reliability and validity. A highly reliable measure consistently yields the same outcome in repeated use across identical settings, but its validity may be compromised if it measures the wrong reality. Independently observable measures are potentially more reliable than perceptual measures are, but in practice they face greater challenges with validity. In fact, since independently observable measures are not designed to represent underlying economic reality, they can be causally or temporally too distant from the timing and locus of the measured attribute to be sufficiently diagnostic. Perceptual measures have been introduced to overcome these limitations, but they introduce reliability issues because of the subjective nature of their approach.

In addition to the objective/subjective dimension, the nature of the operations undertaken in describing and classifying an economic reality can differ. The representational theory of measurement defines measurement as the mapping (homomorphism) of an empirical relational system into a numerical relational system that preserves all the relationships and operations observed in the empirical one (Finkelstein, 2003). Measurement systems must be based on scales that are consistent with the empirical reality; therefore, as opposed to “evaluation” and “preference” operations, measurement operations set the empirical relationships that must be represented without ambiguity by means of a measurement system that realizes internal consistency (Cecconi et al., 2007).

Because of the nature of our research problem, we refer only to the validity issues of independently observable measures and do not consider perceptual measures or evaluation and preference operations. We make this choice because independently observable measures can be quantified easily and can be used in formal contracts, such as outsourcing and Software as a Service, so they are tailored to the needs of the information systems accounting and control community. Therefore, the ideal scenario is to achieve a clear and complete mapping in which a given attribute of the underlying economic reality (IT infrastructure and business processes) maps directly to an observable measure and is the only attribute to map to that measure.

When applied to IT value, independently observable measures refer to elements of IT infrastructure like hardware devices, IT services, IT applications, and business processes as underlying economic realities. These elements inhabit, are components of, and engage interactions with entities at a variety of levels, resulting in a complex system that continuously adapts to the organization (Spagnoletti & Federici, 2011). An appropriate measurement system for mapping relationships between the numerical and the empirical system must be consistent with the structural nature and the evolutionary dynamics of such IT infrastructures.

IT infrastructures are complex systems that are structured as inclusion hierarchies, where entities interact at each level and the dynamics induced are nearly decomposable (Simon, 1996, p. 204); that is, they are characterized by loose coupling both vertically, where processes at different levels have different temporal scales, and horizontally, where entities cluster into weakly interacting subsystems that interact on an input-output basis. IT infrastructures are continuously adapted to both their inner components and the enterprise architecture (Hanseth & Lyytinen, 2010), so they evolve dynamically with the implementation of new elements and the dismissal of old ones, giving rise to a “living” IT infrastructure that requires a continuous mapping process (D’Urso et al., 2012).

Therefore, the representational mapping between the economic reality and IT value measures must be consistent with the layered modular architecture of an IT infrastructure (Yoo et al., 2010) and with its evolutionary nature. Our general objective of mapping the value of IT infrastructure resources with business process elements is an attempt to provide an ontology that extends the capabilities of current enterprise ontologies with regard to the dynamic mapping of business processes with components of IT infrastructure.

4.2 Enterprise models and ontologies

Generally, enterprise architectures (EAs) provide the means for a common (model-based) understanding of an enterprise, and they address the problem of integrating the IT and business perspectives (Lankhorst, 2003; Winter & Fischer, 2007). In addition to IT-related artefacts, EAs consider business-related artefacts like organizational goals, business units, products, and services (Winter & Fischer, 2007; Harmon, 2007).

An enterprise model, a fundamental constituent of any EA, captures the entities and their relationships from multiple perspectives. A hierarchical approach to modelling an "enterprise" is usually applied by distinguishing several architectural layers, starting with a strategy or organizational layer and then establishing a hierarchy of subordinate layers (e.g., an application layer, an infrastructure layer). There are several such frameworks in the field of EA— including TOGAF (The Open Group, 2012), Zachman (Zachman, 1987) and IBM's SOA reference model (Arsanjani et al., 2007)—that propose a layered architecture for the structure of an information system. These frameworks are architectures that are divided between technology entities (i.e., data, application, platforms, and components, as in TOGAF; a physical technology model and logical models in Zachman's framework; or consumer interface, business processes and services, service components, and operational systems in IBM's SOA reference model) and organization-related entities (i.e., organization, motivation, and function in TOGAF, and business functions and business process models in Zachman's framework). These frameworks do not always specifically describe how the entities relate to each other and sometimes leave the representation of phenomena in different layers to tools that are not easily interoperable (e.g., business process diagrams for business processes and asset lists for IT assets).

Furthermore, depending on the modelling concept applied, the models may differ in their degree of formality. In particular, three generic modelling concepts can be distinguished: glossary, metamodels, and ontological theories (Winter & Fischer, 2007). Among these modelling concepts, ontological theories have the highest degree of formalization.

In addition to the model concepts and their relationships (meta-model approach), ontological theories are used to specify rules and constraints comprehensively from the domain of interest (IFIF-IFAC, 2003; Grüninger, 2003). An ontology is commonly described as an explicit specification of a shared conceptualization (Gruber, 1993; Grüninger, 2003), so it can be a suitable tool with which to create a mutual understanding among related actors. In particular, ontological theories facilitate the formal analysis, execution, and validation of enterprise models and the drawing of inferences about them. Ontological theories are best suited to describing the most generic enterprise-related concepts and to defining the semantics of modelling languages to be employed (IFIF-IFAC, 2003). Because of their high degree of formalization and their ability to define semantics, ontological theories are ideal means by which to ensure consistency in enterprise models and, because of the formulation of axioms and rules, to reduce the number of facts to be modelled. Enterprise models that are based on an ontological theory are capable of not only answering queries about what is explicitly represented in the enterprise model (as in the traditional meta-model based approach) but also answering queries about what that representation implies (Fox et al., 1998).

Despite a considerable variety of ontologies for individual enterprise-related phenomena, only three have been constructed explicitly for the purpose of enterprise modelling: Edinburgh Enterprise Ontology (EEO) (Uschold et al., 1997), TOronto Virtual Enterprise (TOVE) (Grüninger, 2003), and Design and Engineering Methodology for Organizations (DEMO) (Dietz & Hoogervoorst, 2008). These approaches considerably overlap in their sets of concepts, as they all define classes related to organizational aspects, strategy, activities, and time, but they differ in the number of domains they capture (O'Leary, 2010). They also all define, on a high level, key terms for enterprise modelling, but while their definitions of the same term (like Activity) are concise and axiomatized, they differ to some extent. Therefore, current enterprise ontologies do not promote a shared understanding, as depending on what ontology is used to describe an enterprise, the meaning of key terms may differ (although only slightly). The reason for these differences is that the ontologies are not grounded in a formal, domain-independent ontology that would facilitate the reuse and extension of these ontologies with new ontologies that conceptualize more specific domains of an enterprise. Moreover, while the enterprise ontologies conceptualize processes, resource usage, and costs, none specifically addresses IT infrastructures, the problem of assessing IT value, or concepts related to IT service. EA frameworks, on the other hand, conceptualize the presence of layers of organizational and technological entities but do not always clarify the relationships between the two.

The literature has also applied to enterprise modelling other, more specific domain ontologies than EEO, TOVE, and DEMO. These ontologies were designed to describe particular aspects of enterprises, such as the resource-agent-event (REA) enterprise ontology, which was proposed to model an enterprise's accounting phenomena (Geerts & McCarthy, 2002). The business model ontology (BMO) (Osterwalder, Pigneur, & Tucci, 2005), and the e3-value ontology (Gordijn, 2001) also aim to conceptualize economic phenomena within and across enterprises: the BMO describes economic phenomena from the perspective of a single enterprise, and the e3-value ontology models economic phenomena within a network of enterprises. The SUPER approach was also proposed (www.ip-super.org) to model and analyse business processes (e.g., cf. Pedrinaci et al., 2008) to enable semantic web-based services. Initiatives have been undertaken to ground these specific domain ontologies' key concepts within a foundational ontology (as is the case with REA and SUPER), but to our knowledge no specific domain ontology has been proposed for the problem domain of assessing the business value of IT in organizations.

With respect to our general objective of mapping the value of IT infrastructure resources with business process elements, the enterprise models and ontologies mentioned here represent the knowledge base to which we contribute by developing a new domain ontology for IT value measurement.

4.3 IT governance frameworks

A third element of the body of knowledge on which our artefact is grounded concerns IT governance frameworks (Bowen et al., 2007). The input for the ontology engineering process made use of existing taxonomies grounded in widely accepted IT governance frameworks (ITIL v3 and CoBIT v4.1) as a foundation for the ontology design. These frameworks are a collection of best practices or international standards that encompass a wide body of knowledge on IT management.

Our research project uses IT governance frameworks, which describe taxonomies of key terms used in the IT governance domain, as starting points from which to identify the essential constructs of the ontology to be discussed, refined, and adapted during the design process. The terms in these taxonomies that are relevant for the domain of our ontology are *process*, *business process*, *IT service*, *application*, *component*, and *infrastructure*. Taken from the ITIL and CoBIT frameworks, these terms served as an input for discussions among the researchers and practitioners involved in the project and as a starting point for the definition of the ontology's constructs. The definitions provided by the two frameworks were not always convergent, and for some of the relevant constructs, there was no description at all (as in the case of CoBIT). Some terms, such as those related to activities and business processes, presented no ambiguities, while others required further discussion. The largest effort was expended on the definition and specification of the IT service concept, which was further detailed in the structure of the ontology.

The availability of IT governance frameworks that are widely accepted by the practitioner community provides us with a means to assess the correctness, applicability, and usefulness of the IT value methods and, thus, a way to ensure the relevance of the proposed solution. In fact, the contribution to existing IT governance practices can be considered an additional objective of our design effort.

The next section presents the outcome of the design and development phase of our DSR process, which was driven by three main objectives: to improve the validity of independently observable measures of IT value, to identify the design principles of a domain ontology that can support the governance of living IT infrastructures, and to ensure the relevance of the proposed solution as an effective approach to supporting managerial practices in the IT governance domain.

5 OLPIT’s Development and Demonstration (DES/DEV & DEM)

5.1 Ontology specification for linking processes and IT

Ontologies that are developed to solve practical problems are shared conceptualizations that are useful when they help users to reach consensus and to answer relevant questions. The ontology engineering process we followed addresses this aspect of ontologies by guiding developers in the specification of ontological competencies (Sure et al., 2004). For this reason, the following competency questions were formulated at the beginning of the ontology development process:

- What services does IT offer to fulfil business requirements?
- What does IT offer to the business side (service catalogue)?
- What are the most critical infrastructure services?
- What happens if a piece of hardware fails?
- What are the potential single points of failure in a given situation?
- When does the IT infrastructure run into a bottleneck?
- What investments are required to resolve bottlenecks?
- What are the costs of providing the IT infrastructure internally?
- To what extent are individual services underemployed/overburdened?
- Is our IT infrastructure capable of fulfilling business requests?

An OWL reasoner was used during the development process of the ontology to avoid inconsistencies in the specification of ontology classes and properties. The reasoner was used during the development process to verify that neither the inferred class hierarchy nor the members list produced inconsistent results compared to the originally stated class hierarchy and members list (Figure 2). The absence of inconsistencies was a necessary formal condition for the completion of the ontology development process. The other formal condition was that the ontology specification is truthful, clear, and expressive (see section 6).

Figure 2 depicts the structure of the Ontology for Linking Processes and IT infrastructure (OLPIT v2.0) and indicates the ontology’s classes and their relationships. As the OLPIT development was triggered by a problem encountered in practice, the initial ontology specification (see vom Brocke et al. 2009) incorporated concepts suggested by the ITIL v3 and COBiT v4.1 frameworks in order to consider best practices in IT management. The corresponding definitions of the key terms relevant to the domain addressed by OLPIT are listed in Table 2 in Appendix 1.

While the initial OLPIT specification provided a common understanding of the problem domain among the business and IT staff at the Hilti Corporation, it lacked a rigorous formal evaluation. Although derived from frameworks intensively used in practice, the ontology concepts lacked a semantic foundation. In particular, concept definitions that the frameworks provided were ambiguous and lacked clarity. Consequently, further iterations of the OLPIT development focused on rigorously developing a domain ontology that is grounded in a formal ontology in order to satisfy formal evaluation criteria (see section 6). Figure 2 shows the result of the OLPIT development. The corresponding OLPIT implementation was created using Protégé (http://protege.stanford.edu) and the OWL v. 2.0 language. (The OWL specification can be accessed at http://www.cersi.it/olpit/index.html.). Subsequent sections justify the proposed ontology specification by means of a formal evaluation and the experiences gained during its practical application.

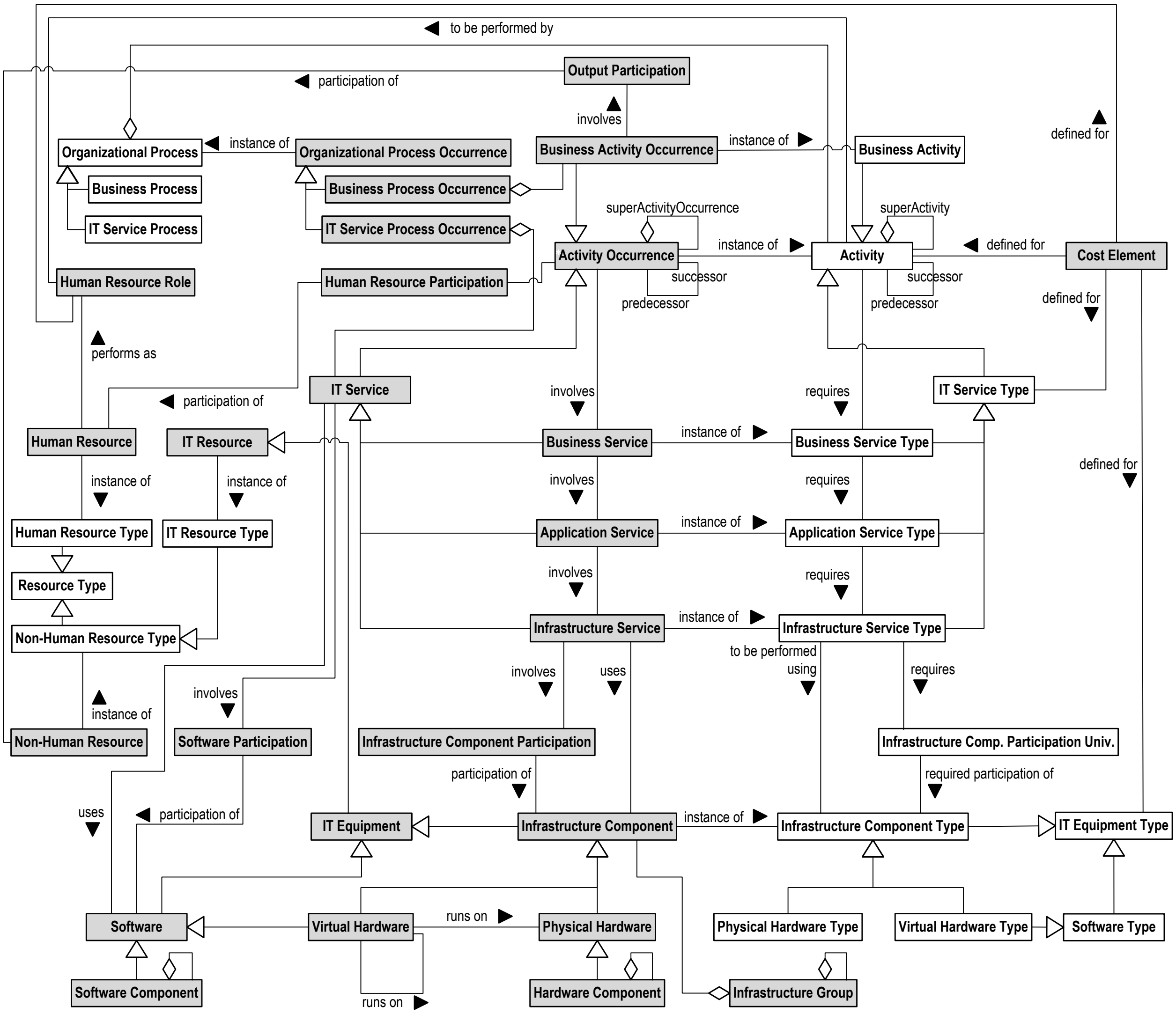


Figure 2. The OLPIT ontology schema (v2.0)

The OLPIT ontology, which reflects the layering suggested by the ITIL and CoBit frameworks, can be read from top to bottom, starting on the process level, followed by a service level, and concluding at the infrastructure level. The OLPIT also distinguishes between type-level constructs and instance-level constructs. The following description focuses on describing the instance-level constructs. Because of space limitations the complete set of relationships between OLPIT constructs is shown only for instance-level constructs in Figure 2. However, these instance-level relationships have corresponding relationships on the type level.

OLPIT defines the concept of `Organizational Processes` and `Organizational Process Occurrences,` which are comprised of `Activities` and `Activity Occurrences`. On the highest level, `Organizational Processes` represent the activities that are conducted in an organization. These processes can be further specialized into processes that are essential for doing business and that directly contribute to an organization’s welfare and identity (i.e., `Business Processes`). An organization creates value to internal/external customers through a `Business Process`, which is comprised of `Business Activities`, which create an output that can be either sold on a market or used internally as inputs to other `Organizational Processes`. Output instances are of a `Non-Human Resource type` and are associated with `Business Activity Occurrences` through the concept of an `Output Participation.` (For a clarification of the participation concept, see section 6.)

Inputs of business processes are modelled implicitly as resource participations or via the `IT Service` classes. For example, a process `Activity`, which can be either a `Business Activity` or an `IT Service`, may involve the participation of a `Human Resource`. `IT Resources` participate in the context of IT service activities. In order to model participations of `Non-Human Resources`, which are not `IT Resources`, the OLPIT ontology can be extended by modelling additional participations for more specific types of resources.

Another specialization of `Organizational Processes` addresses the activities that support `Business Processes`. OLPIT defines `IT Service Processes` as the specialized support processes that manage the IT infrastructure and the availability of IT services. In particular, IT service processes are comprised of IT service activities, which can themselves be specialized into IT services. (An IT service in OLPIT is understood as an activity.) This view is based on the work of Alter (2008) and Grönroos (2000), the latter of whom defines a service as “a process consisting of a series of more or less intangible activities that normally, but not necessarily always, take place in interactions between the customer and service employees and/or physical resources or goods and/or systems of the service provider, which are provided as solutions to customer problems” (p. 46).

A `Business Process` is defined as a collection of `Activities` that manipulates inputs and produces outputs. Input and outputs may come from or be directed to other `Business Process(es).` An `Activity` may demand the execution of one (or more) `IT Service(s)` to deliver value. `Activities` are linked, so they may have predecessors and/or successors.

`Business Processes` often `require` IT support or may even be fully coordinated and executed through IT. This view is consistent with the IT value theoretical framework proposed by Melville et al. (2004), which suggests that the execution of a business process may require a complex set of IT services. Therefore, OLPIT holds that the execution of business processes can involve `IT Services` to deliver IT infrastructure capabilities to the activities of a business process. An `IT Service` is a particular `Activity`, that is, an `IT Service Activity` that involves the participation of `IT Resources` in the form of `Human Resources` or `IT Equipment`, which can be either software or hardware. Conceiving of an IT service as an activity rather than a resource, as is sometimes proposed in the literature, is justified, as IT services exhibit the characteristics of complex events. These events are also termed perdurants, which are the concepts of an upper ontology in which the OLPIT has been grounded (see section 6). The distinct characteristic of perdurants is that only parts of them, not their entirety, can be observed or perceived at any one time. Perdurants, especially services, happen in time and accumulate their temporal parts over time, rather than all at once. For example, only parts of a room-cleaning service instance, not its entirety, can be perceived at a given point in time. Such a service might require the cleaning of windows, floors, and trash bins, each of which represent activities that contribute to the provision of the overall service, but not all activities occur at the same moment. Committing to provide such a service implies a commitment to execute all activities that are required to accumulate the temporal parts of the overall service activity.

OLPIT stratifies IT services into three categories that are hierarchically dependent: `IT Infrastructure Service(s), IT Application Service(s),` and `IT Business Service(s).` IT services are particular `Activities` that use IT Resources (`Human Resources` and `IT Equipment`). For example, an employee who wants to perform a purchase request from a workstation (a PC) requires a specific feature, or module, of an ERP system, which is provided via an IT service. To be used, this module might require additional lower-level IT services, such as the functionalities of a data base or an application server, as well as network services to allow the client PC and the application servers to communicate. The example becomes more complex if backup and disaster recovery functionalities are brought into play. Ultimately, IT services depend on a physical IT infrastructure (network hardware and server hardware) in order to work properly.

In this complex interplay of IT services, an IT Business Service directly supports the execution of a Business Process via Activities, so an IT Business Service has a business value from the business side. In the purchase request example, an IT Business Service is the specific functionality of an ERP software module that is required to perform a purchase request.

IT Business Services require one or more IT Application Service(s). An IT Application Service provides the functions of specific Software Components. If the functions of legacy systems or operating systems are to be provided, then IT application services require complex activities that may involve many (automated) interactions—so-called Software Participations—between software components. For example, an operating system, although it is Software, is not considered an IT application service in OLPIT, as it offers multiple IT application services, with each application service bundling a set of the operating system software components' functions. In order to be delivered, an IT Application Service requires one or more IT Infrastructure Service(s). In the purchase request example, a whole ERP software module can be considered an IT Application Service.

An IT Infrastructure Service delivers the capabilities of the IT Infrastructure Components to Application Services. In the purchase request example, the network, the application server, and the database server are all components that are responsible for delivering infrastructure capabilities to the ERP system.

IT Infrastructure Components form the IT infrastructure of an organization. An IT Infrastructure Component is a part (such as an individual computer system) of something more complex (the IT infrastructure itself) that participates in the delivery of an IT Infrastructure Service (see Infrastructure Component Participation). IT infrastructures are formed of several kinds of components that can be either individual hardware entities (in the case of servers, storage systems, printers, hubs, switches, routers, and others) or Infrastructure Groups that are composed of infrastructure components (as in the case of a cluster of servers). Therefore, IT Infrastructure Components are divided in the OLPIT into Physical Hardware, Virtual Hardware, and Infrastructure Groups.

The largest part of the hardware in IT infrastructures is usually physical, so Physical Hardware is a component of the IT infrastructure that is physically located somewhere in the world (e.g., in a data centre in central Europe) and that is tangible (as in the case of hardware devices, physical storage systems, or physical network components whose physical locations are on a rack in a data centre). Virtualization technologies allow for the presence of intangible, virtual hardware (as in the case of virtual machines and virtual disks) in IT infrastructures. Therefore, a Virtual Hardware is a component of the IT infrastructure that is located somewhere in the world but is not physically tangible; for example, a virtual server does not exist in reality but only inside a virtualization. The existence of Virtual Hardware is ultimately bound to the existence of some Physical Hardware that has the capability to run a virtual hardware (see runs on relationship). Virtual Hardware can also run on another Virtual Hardware. Since it is not physical, virtual hardware is considered software. In OLPIT a virtual hardware is treated as an object rather than as an activity, so virtual hardware is a special kind of IT infrastructure service. This distinction of virtual hardware as an object reflects the practical experiences that suggest that virtual hardware is used in the same way as physical hardware entities; that is, it is perceived and treated like a component of physical infrastructure. The functions of virtual hardware (e.g., remote access, storage, computation tasks) are then provided via IT infrastructure services.

Components of an IT infrastructure can be logically interrelated such that it is sometimes convenient to treat them as a single component (as in the case of a cluster). An Infrastructure Group is a set of interrelated individual components, either Physical Hardware or Virtual

`Hardware`. `Infrastructure Groups` can be organized hierarchically (see the recursive relationship in Figure 2)

Finally, in order to assess and investigate the costs related to IT infrastructure components, IT services, human resources, activities, and business processes, the OLPIT ontology contains a `Cost Element` class. A `Cost Element` registers costs (planned or realized) for internal (management) accounting purposes, so they can be defined for `Activities`, `IT Infrastructure Component Types`, `IT Service Types`, and `Human Resource Roles`.

The next subsection presents an example of how IT infrastructures can be represented in terms of OLPIT.

5.2 Representing part of an IT infrastructure with the ontology (DEM)

This section demonstrates how the ontology can be applied to represent the relationships among business process activities, IT services, and infrastructure components. Figure 3, a direct output of the ontology development software used in the project, shows an instantiation of the ontology with data from a real IT infrastructure. The output shows the relationships among individuals (instances of ontology classes), representing some activities of a sample process called `P01_Order_Entry`. To improve readability only a part of the instances of the example process are shown in the figure (the complete figure is available online at http://www.cersi.it/olpit/index.html). For reasons of confidentiality and space, the figure shows only a simplified representation of the process and a reduced number of IT resources.

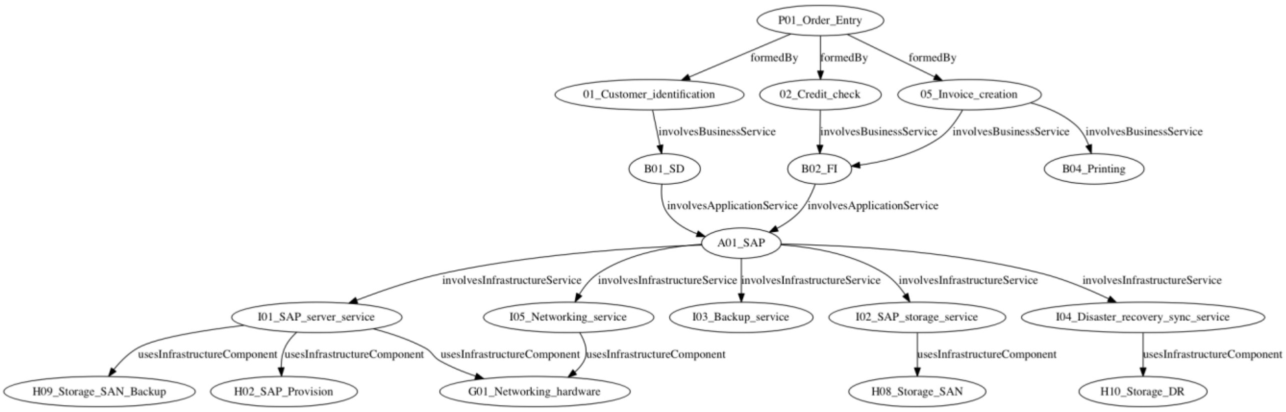


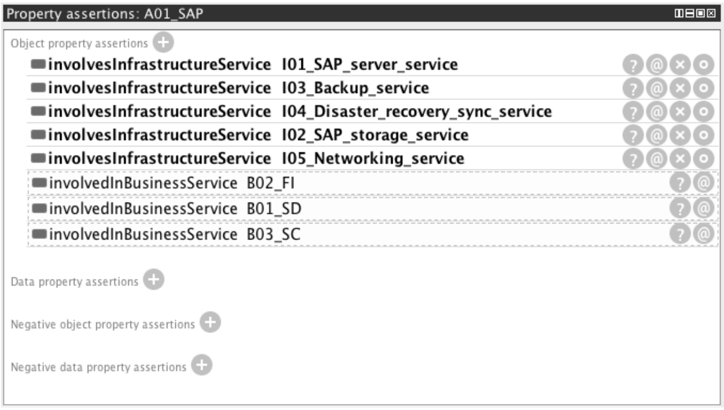
Figure 3. A sample output of the ontology development software for a process with activities, IT services, and infrastructure components, modeled with the OLPIT ontology

The software output shown in figure 3 decomposes the process into seven activities, some of which are supported by IT services and some of which are not. The output also shows the relationships between IT resources (physical hardware and groups) and IT infrastructure service, so which piece of hardware is involved in the delivery of which IT infrastructure service can be determined easily. The output also shows the fraction of the IT infrastructure component that supports the specific business process.

The instances represented in the output are automatically layered by a plug-in of the Protégé software based on our intended layering of constructs in OLPIT. OLPIT stratifies the IT infrastructure “reality” into business processes and business activities (first level), which use business services (second layer). Business services use application services (third layer), which themselves rely on infrastructure services (fourth layer). Infrastructure services provide the capabilities brought about by the IT infrastructure (components) (fifth layer). In the software output shown in Figure 3, this layering materializes as business process (`P01_Order_Entry`), activities

(`01_Customer_identification`, `02_Credit_check`, and so on), IT business services (`B01_SD`, `B04_ printing`, and so on), IT application services (to improve readability just one application service, `A01_SAP`, is shown in the figure), IT infrastructure services (`I05_Networking_service`, `I03_Backup_service`, and so on), physical hardware (`H01_SAP_Support`, `H10_Storage_DR`, and so on), and infrastructure groups (`G01_Networking_hardware`, `G02_SAP_Cluster`). The company found the layered representation of instances produced by the ontology specification software to be useful for interpreting and communicating the relationships among the ontology concepts and in the communication activities with the employees of the company. (See section 7 for the evaluation of the usefulness of the OLPIT.)

Useful information can be obtained also by querying the instantiated ontology structure. As an example, Figure 4 shows the software output for the properties of a specific instance of an IT application service. Thanks to the capabilities of a reasoner tool (which would be the optimal solution to benefit from the use of the ontology), the output shows the specified properties of an application service `A01_SAP` (in bold), and the properties that were inferred by the reasoned (in plain). In this example, the reasoner inferred that the specific application service is involved in three business services. Referring to the competency questions stated in section 5.1, this inference helped to identify the business services that depend on the execution of the application service and identified some services that the IT offers to the business side. The inferred information also helped in identifying which IT business services could fail in the case of a failure in the specific application service.



involvesInfrastructureService I01_SAP_server_service
involvesInfrastructureService I03_Backup_service
involvesInfrastructureService I04_Disaster_recovery_sync_service
involvesInfrastructureService I02_SAP_storage_service
involvesInfrastructureService I05_Networking_service
involvedInBusinessService B02_FI
involvedInBusinessService B01_SD
involvedInBusinessService B03_SC

Figure 4. Output for the stated and inferred properties of an IT application service as computed by Protégé

Having demonstrated how the OLPIT can be applied, we subsequently report on its evaluation. The evaluation phase of a DSR consists in rigorously proving the correctness of the artefact specification and in observing and measuring how well an artefact supports a solution to the problem. We formally evaluated the domain ontology and inferred the usefulness of our domain ontology by applying it in a real context. Sections 6 and 7 report the results of this evaluation.

6 Formal Evaluation – Grounding the OLPIT in a Foundational Ontology (EVAL)

This section presents the results of a formal evaluation of the OLPIT ontology that were achieved by grounding the OLPIT in a foundational ontology. This formal evaluation does not necessarily contribute to proving the relevance and usefulness of the OLPIT, but a formal evaluation contributes to a rigorous design. In this regard, we adhere to the design science evaluation pattern in Sonnenberg and vom Brocke (2012), who proposed that DSR evaluations must first ensure that the artefact is “technically” sound, that is, that an artefact’s design specification is free from formal errors. Therefore, the formal evaluation conducted in our work corresponds to the second evaluation phase (EVAL2 in Sonnenberg & vom Brocke, 2012).

We did not intend primarily to build a computational domain ontology, so we did not focus on defining axioms[1] . Our aim was to define a domain ontology that informs the design of tools for measuring the value of IT infrastructures in support of an organization's processes. Therefore, the evaluation criteria that we applied in the formal evaluation of our ontology design were *truthfulness*, *conceptual clarity*, and *expressiveness* in representing the subject domain (following Bringuente et al., 2011).

In order to show that the OLPIT satisfies these criteria, we grounded our ontology in an upper ontology, a "foundational ontology." (A similar evaluation is reported in Bringuente et al., 2011.) Foundational ontologies provide general concepts of types of things (e.g., space, time, matter, object, event, action) and relationships between these concepts, independent of any domain (cf. Guarino, 1998). They characterize explicitly a viewpoint of "reality" (cf. Borgo & Leitão, 2004), and the concepts and relationships they define can be used to equip a domain ontology with "real-world" semantics that can be shared among computer applications and, in particular, among humans.

A domain ontology is *truthful* if all of its concepts can be consistently interpreted in terms of the worldview adopted; that is, all domain concepts have exactly one corresponding concept in a foundational ontology. If a domain concept does not correspond to any concept in a foundational ontology, the concept has no real-world meaning, so it cannot be assumed to exist in the real world. The advantage of using foundational ontologies to achieve truthfulness is the semantic interoperability of two distinct conceptualizations (or domain ontologies) (cf. Guizzardi, 2005). If each domain ontology commits to the same foundational ontology (worldview), then whether two concepts that have the same name also refer to the same thing in the assumed reality can be determined easily.

Conceptual clarity results from enabling unambiguous interpretations of domain concepts in terms of the foundational ontology to which a particular domain ontology has committed. Since a concept in a domain ontology is unambiguously mapped to a concept of an upper ontology—that is, the domain ontology is truthful—each domain concept inherits the meaning of its upper concept in the foundational ontology. (How ontological clarity can be achieved through grounding in a foundational ontology is discussed by means of an example in Appendix 2.)

A domain ontology is *expressive* if its underlying conceptualization of the real word can be shared among human and/or software agents. Therefore, it is important to provide both semi-formal descriptions (Figure 2) to be interpreted by humans and corresponding formal specifications (our OWL OLPIT specification) that can be interpreted by computers. Our primary intent is to provide a semi-formal ontology specification that represents the subject domain of IT-value measurement with truthfulness, clarity, and expressiveness.

While the expressiveness of OLPIT was demonstrated in section 5.2, the current discussion presents the results from evaluating the OLPIT's truthfulness and clarity. In particular, we show how the OLPIT is grounded in a particular foundational ontology, the Unified Foundational Ontology (UFO) (cf. Guizzardi, 2005; Bringuente et al., 2011). We could have chosen the Bunge-Wand-Weber ontology (BWW) (Wand & Weber, 1993; Weber, 1997), which has a long track record in the information systems discipline, but there are several reasons for our decision not to do so.

The most important argument against the BWW ontology is its realist position (Wyssusek, 2006) that assumes a world of matters that exist independent of observers (Recker & Niehaves, 2008). This world is made up of things that exist (Weber, 1997) and that anyone can perceived in their entirety at any point in time. The implication of this realist position is that the BWW does not consider institutional realities like business processes, activities, actions, or costs. In essence, the

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[1] However, we provided a computational OWL ontology specification that can be downloaded from the website www.cersi.it/olpit.

BWW does not allow for a process-oriented view on either information systems or organizations. Therefore, the use of the BWW as a foundational ontology for our purpose of proposing an ontology for a process-oriented measurement of IT value is neither justified nor possible. Studies that have tried to evaluate conceptual modelling grammars for business process modelling based on BWW (e.g., Green & Rosemann, 2000, 2004; Recker & Indulska, 2007) and a study that used the BWW to characterize the “goodness” of process decompositions (Johannesen & Leist, 2012) express discontent with BWW because of the absence of a close match between BWW concepts and the constructs frequently used in process modelling. To our knowledge, no study that refers to the BWW ontology in the context of process modelling reflects that the realist position implied by BWW is usable with process-modelling tasks. (For a detailed argument, see Appendix 2.)

UFO as a foundational ontology, on the other hand, allows for conceptual representations of processes, activities, services, cost elements, and other institutional realities. We did not refer to all concepts specified by UFO but to a fragment of it. A discussion about the UFO fragments used is out of scope of this paper. The interested reader might want to refer to the publications of Bringuente et al. (2011) and Santos et al. (2013). Figure 5 illustrates the grounding of the instance-level part of OLPIT; the type-level grounding can be done in an analogous manner. Concepts of the UFO ontology are in grey, OLPIT concepts are in white.

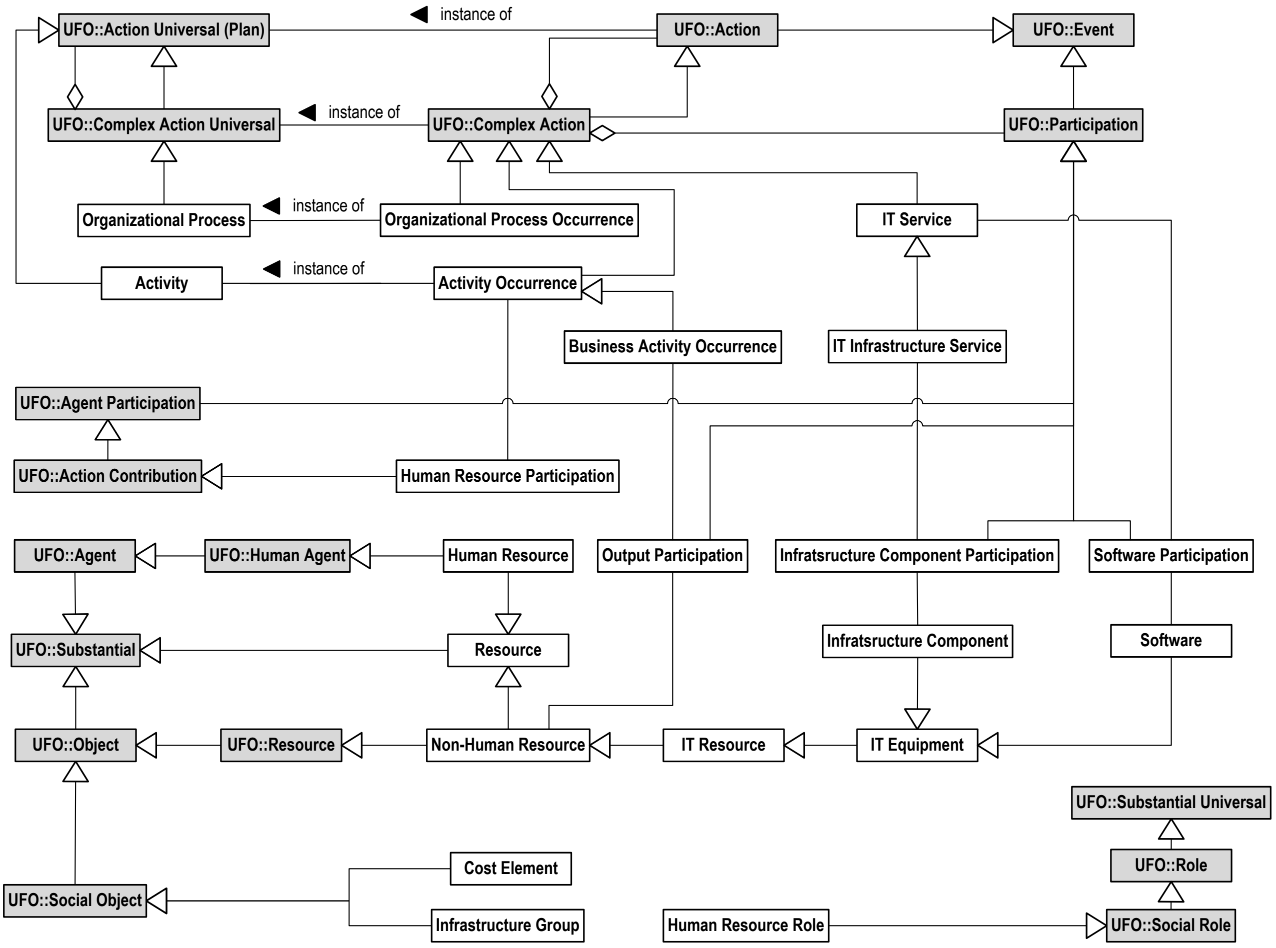

Figure 5. Mapping of OLPIT concepts to concepts of the Unified Foundational Ontology (UFO)

As a first result, we confirmed that the distinction between a type level and an instance level made in OLPIT is warranted by UFO and that it directly corresponds to the UFO distinction between `Universals` and `Particulars` (Bringuente et al., 2011). The concepts of `Organizational`

`Processes` (together with their specializations `Business Process` and `IT Service Process`) and the `Activity` concept (with its specialization) correspond to `Complex Actions` and `Actions` in UFO, respectively. This correspondence and the meaning of OLPIT concepts implied by the UFO concepts is consistent with what we intended to express. Organizational processes and activities are the intentional participations (see Bringuente et al., 2011) of agents that pursue goals. Moreover, organizational process and activities denote specific `Events` that can be perceived by social agents (see Bringuente et al., 2011). Therefore, it is possible to account for such events and to make process/activity occurrences "visible." Organizational processes are assumed to represent the apex of the composition lattice of complex actions and are not part of any other complex action or event.

`IT Services` are `Complex Actions` that involve the `Participations` of `Human Resources` and `IT Resources` in the form of `IT Equipment`. Participations denote `Events` in which agents or objects (`Substantials)` participate in a complex action (e.g., a printer, a piece of paper, and a human all "participate" in a printing action).

The distinction of `Resource` into `Non-Human Resources` and `Human Resources` was not made in the initial OLPIT v1.0 version (vom Brocke et al., 2009). The absence of such a distinction (i.e., treating human beings and objects as things of the same kind) would cause ambiguities since a human resource refers to human agents while a non-human resource refers to objects that are incapable of having mental states. OLPIT v2.0 now holds that `Human Resources` are `Social Agents`—`Substantials` that have mental states—and `Non-Human Resources` (like `IT Equipment`) are considered `Objects` (non-agentive and substantial) that are incapable of having mental states. The participation of a human resource (`Human Resource Participation`) is an `Action Contribution`, which is a special kind of event since it denotes the commitment of a human agent to perform part of an activity. A `Human Resource Role` is considered a `Social Role` in UFO terms. `Cost Elements` and `Infrastructure Groups` are `Social Objects`, as they are the results of the social constructions of human agents.

Grounding OLPIT concepts in UFO helped to refine and improve the formal quality of our domain ontology. By referring to UFO, we could equip OLPIT with semantics that also account for representing institutional realities in the IT-value measurement domain. The magnitude of the refinements through this grounding is visible in a comparison of the OLPIT v1.0 specification (see vom Brocke et al., 2009) with the current OLPIT v2.0 specification.

In addition to a formal evaluation of the OLPIT specification, it is important to prove its relevance and usefulness in solving practical problems. Since statements of truth in DSR ultimately refer to proofs of usefulness (cf. Sonnenberg & vom Brocke, 2012), we evaluated the OLPIT by applying it in practice. The next section presents the application context and the results that were achieved.

7 Evaluation of the Applicability and Usefulness of OLPIT (EVAL)

The Hilti Corporation, which develops, manufactures, and sells products for the construction industry, is primarily targeted to professional end-users in more than 120 countries. Its IT branch, called Hilti Global IT, delivers standardized IT solutions to the entire Hilti Corporation. This research was carried out as part of an internal project called Infrastructure Measurement System (IMS), which is owned by the Finance Controlling department of the IT branch of the Hilti Corporation.

When engaging the IMS project, the project management illustrated the problem to be solved with the following example: A few years ago, the purchase department decided to increase the frequency of the orders registration process from weekly to daily, estimating an annual cost savings of €266,000 from economies of scale. However, the new level of frequency resulted in an unanticipated increase in the workload of the servers that support this process. An extension of the IT infrastructure was needed, resulting in investment of €300,000 that had not been planned, and the expected €266,000 savings turned into a €34,000 loss in the first year. At the time the decision was made to increase the frequency of the orders registration process, neither the IT department nor the purchase department predicted the effects that changes in the process would have on the IT infrastructure or how these effects would impact the financial performance of the process-improvement initiative.

7.1 Context of application

The purpose of the IMS project was to resolve the problems that resulted from the misalignment of technical and financial information regarding the assets of Hilti's IT infrastructure. The most pressing issue was the unavailability of accurate information to support investment decisions into the IT infrastructure.

Technical information on Hilti's IT infrastructure was fragmented among three teams that were responsible for the Unix systems, the Microsoft systems, and the storage systems, respectively. These teams autonomously maintained the information in lists contained in simple spreadsheets or in other customized reports. These lists were not updated regularly, nor was consistency of updates enforced among the teams. Consistent maintenance of the spreadsheets was also impeded because the teams did not share a common understanding of the structure of their lists (e.g., the lists contained different attributes). As a result, there were often deviations between the actual situation of the IT infrastructure and the one represented by the data obtained from these lists.

The financial information regarding the IT infrastructure was maintained in the financial module of Hilti's ERP system and was not linked to the technical information stored in the spreadsheets. Moreover, each time an investment related to the IT infrastructure was made, new asset numbers were created in the ERP system. Sometimes these numbers referred to specific IT components, but in other cases an asset number corresponded to more than one IT component. Consequently, financial and technical information was not linked—in fact, was not linkable—because of the differing granularity levels employed for IT asset management.

As a result, considerable effort was necessary to keep all the independent sources of information updated and aligned. Moreover, some managerial activities, such as IT investment planning, execution, and decommission, were hardened and sometimes hampered because of the absence of coherent data on (mainly) the depreciation and maintenance costs of the IT infrastructure components. Under these conditions, there was no way to calculate IT service costs, so neither internal nor external benchmarking activities regarding IT costs were possible. In short, the precise contribution of the IT division to the company's performance was, and would remain, unclear.

Therefore, the main drivers behind the IMS project were the need:

- to improve the picture of all the IT assets and their costs;
- to have a lean and easy-to-use process to support investments and lifecycle decisions;
- to clarify the relationships and the interdependencies of all the IT components that were required for business services;
- to be able to communicate to the business side which services IT offered to support the company's value-adding activities (i.e., the business processes); and
- to be able to benchmark these services internally and externally.

Expected benefits of the project were:

- improved support of IT investment decisions and facilitation of internal and external benchmarking;
- increased transparency of IT costs, with the possibility of empowering IT performance-monitoring by means of KPIs; and
- improved ability to explain IT's contribution to the company's value generation by showing the relationship between IT infrastructure components and the business processes they support.

7.2 Application of the ontology

Considering the complexity of the IT infrastructure in the given organizational context (about 1000 IT assets at Hilti's headquarters), a stepwise approach to applying the OLPIT was chosen in the IMS project. First, a test case was analysed, taking into account all concepts contained in the OLPIT (demonstration and applicability check of OLPIT). Then the OLPIT was used to design an application prototype that was then applied in daily operations. The company decided at this point to reduce the complexity of the project and at the same time to increase the likelihood of its success by focusing the implementation of the prototype to only the most challenging and relevant part of the overall IT infrastructure, considering that they could easily extend the implementation to the rest of the IT infrastructure later. Therefore, the prototype committed to only part of the OLPIT.

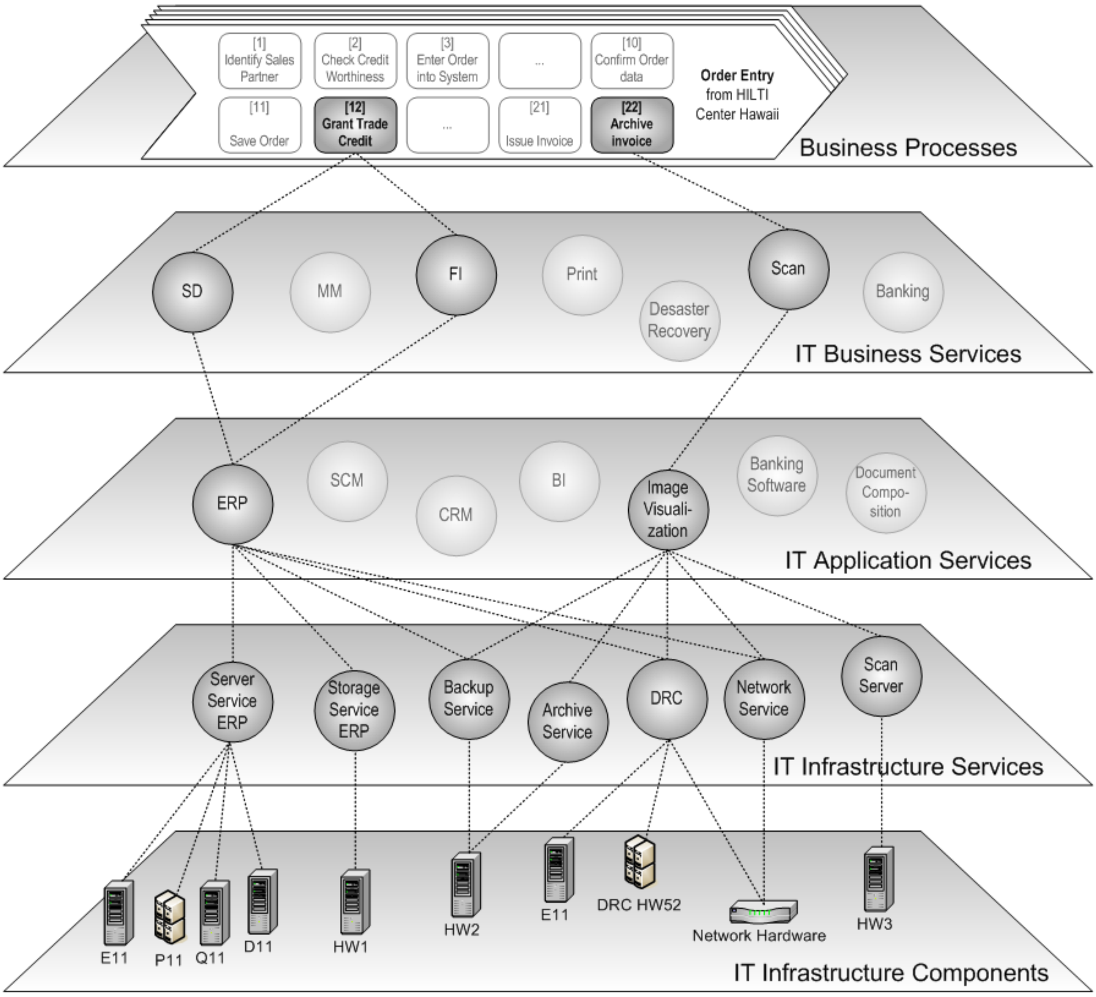

Figure 6. Application of OLPIT to conceptualize IT infrastructure demand caused by a sample business process

The test case on the integral structure of the OLPIT ontology was undertaken to ensure that the approach would achieve all the expected benefits by modelling a single process of the Hilti Corporation and identifying all the IT services and IT resources that were necessary to support the process's execution. Information regarding the IT resources necessary to execute this process was collected manually. A graphic representation of the relationships between each activity in the process and the IT services and infrastructure components required to execute it was used to discuss the results with IT managers and finance. For more clarity, the OLPIT classes used in the example were organized into five layers. Figure 6 shows the part of the IT infrastructure used by just two activities from the sample process. For example, the execution of the activity `Grant Trade Credit` requires the availability of the `SD` and `FI` business services, which are provided by the Hilti `ERP` application service. This application service requires the infrastructure services `Server Service ERP`, `Storage Service ERP`, `Backup Service`, and `Network Service`, which themselves require some hardware components or groups of hardware components. Building on the test case, the practitioners confirmed that the structure of the OLPIT ontology was suitable for representing the relationships among the activities in a business process and the IT resources required to execute them. Therefore, it was decided to implement an integrated spreadsheet-based solution informed by the OLPIT and to put this solution into operational use.

In applying and implementing the OLPIT ontology in daily operations, we initially focused on the IT component and the IT infrastructure service layers only because of the complexity of capturing every relationship and corresponding structural information in the application domain. This complexity also meant that a manual approach to capturing structural information like the approach used for the test case was not suitable for daily operations. For this reason, we implemented a prototype using Microsoft Excel to support the application of the OLPIT. The choice of Excel was also made to respect the company's desire to invest in a more advanced tool only after a prototypal implementation had proven to be feasible and useful.

Using the prototype, four organizational units (the financial control team and three IT infrastructure teams) collected and managed financial and technical information pertinent to IT components and IT infrastructure services. In order to ensure data quality, we made using the prototype mandatory in the four IT management processes that affected the IT infrastructure (planning, investment, change—of location, function, and application, and upgrades, downgrades, and replacements—and decommissioning) and to have the prototype generate a unique identifier (`UID`) each time an item was added to the prototype. This unique identifier had to be used in all four of the processes, and the management did not authorize requests related to these processes if the UID of the affected IT assets was not specified. In addition to the `UID`, the prototype was used to manage data that was pertinent to IT infrastructure components: asset data, financial data (investment cost, depreciation, maintenance, energy costs, software costs, other indirect costs, activation date, decommission date), technical data (hostname, power consumption, technology type, size), location data, infrastructure service data, and application data.

Thus, the initial prototype was extensively used in IT operations to capture all information relevant to the IT infrastructure service and IT component. The integrated spreadsheets were used to query the competency questions, and the information stored in the spreadsheets was used to balance IT infrastructure capabilities with the IT business demand and to determine potential and actual bottlenecks in the IT infrastructure. The data collected was used to determine the cost of providing individual IT services in order to support sourcing decisions (e.g., whether to use cloud computing). As to the calculation and querying of relevant performance measures from an OLPIT representation, we refer to vom Brocke et al. (2009).

The next section focuses on how we evaluated the usefulness of the OLPIT based on its application in practice.

7.3 Results of the evaluation

The prototype was used at Hilti for almost three years after the end of the IMS project and is still used today on a weekly basis.

We evaluated the usefulness of the OLPIT artefact by means of interviews with the former head of the IT Controlling Department, who is now responsible for IT procurements (HITCD) in the Procurement Department; an IT controller (ITCD); and the head of the Enterprise Server Team (HEST), one of three teams that manage the IT infrastructure at Hilti. The semi-structured interviews, which lasted about one hour each, were conducted during November and December 2010.

All three interviewees said that using the OLPIT, as implemented in the prototype was beneficial. HITCD observed, “Our expectations are met. In some respects, I feel the solution is even above expectations. I am still surprised to see how easy and effective the tool is.”

As a field of application, the main benefits were achieved in the investment-planning process and in the cost-calculation activities. As ITCD reported, “We can now plan the server capacities much better because it is the first time we actually have an operationalized approach to it.” HITCD explained that, in the past, when the IT Controlling Department asked the engineering teams how many servers Hilti needed for the next year, the answer was always that they did not know and did not know how to find out. Now answering such a question is easier because the system can show all the items that are running out of depreciation in the next two years. There is more clarity about future investments because Hilti can “know exactly what it has to replace during the next year or the year after that. We know we have, for example, 100 servers that will be at the ends of their lives in four years, so we can put them into our planning so we know how much we will spend on that. Before, it was just guessing” (ITCD). HEST reported additional positive impacts on the budgeting activities, which Hilti performs three times each year: “It is much easier to plan the investments and answer the IT controlling requests regarding the costs that have to be sustained in future periods” (HEST).

The second main advantage regards cost calculations for the applications and services of the IT infrastructure. According to HITCD, “it is now possible to calculate the TCO for some of the IT infrastructure services, such as the backup service, the server service, and the storage service, including both direct and indirect costs” (HITCD). Moreover, the company could “calculate the costs for different systems or applications in use; previously it was impossible. Also clear cost tracking to different services is now easier” (ITCD). The employees valued the positive effect on data integration that the OLPIT ontology facilitated, as “everyone has basically the same information” (ITCD). The prototype, which incorporates the concepts according to the OLPIT specification, now serves as a shared repository of information, to which the teams and departments all have access. Having a shared repository based on a shared conceptualization also improves transparency regarding the maintenance of data since there is no need “to maintain several sources of data, and there is one source. It is much better. It is also good that it is a centralized *solution where someone else can collect information on his or her own*. If they need some information, they could just check the prototype” (HEST, emphasis added).

Other advantages were also reported. The three teams that manage the IT infrastructure aligned the information on the location of the IT assets in the data centres: “We put together the data centre maps because, before, more or less every team had some maps. We put all of them together because, when another tool becomes available, it will be easy to migrate the data from one source to the new one” (HEST).

The interviews also showed that the improved transparency in the planning process contributed to improvements in other activities that are outside those originally targeted. According to HITCD, the procurement office can use the information on IT costs from the prototype to negotiate with vendors “when we talk about green IT, for example” (HITCD). In addition, uses in evaluating the adoption of cloud services were envisioned, as “we are now looking into options of buying cloud servers outside. Since now it is easier for me to know my overhead costs, it is much easier to negotiate with vendors” (HICTD).

The interviews also elicited information about the limitations of the prototype ontology-based implementation. Limitations were primarily related to the Excel application, which was based on a set of interlinked spreadsheets with formulas and macros. While the tool was perceived as helpful in understanding the concept, the interviewees raised concerns about its usability in daily business. However, we see as a limitation of the Excel-based applications, not as a limitation of OLPIT, as the Excel-based prototype was simply an expedient choice. HICTD summarized this choice: “We explicitly chose Excel, and it is called a prototype because it could be a more advanced tool, but there were constraints about starting it as a dedicated tool. We once planned a project that adopted a tool-oriented approach, and the tool was a very expensive piece of software that could, of course, do much more, but there was little trust that the tool would solve our problems. So the idea here was to implement a handmade Excel tool based on the OLPIT and to develop this solution incrementally based on particular information needs. We wanted to make sure and to demonstrate that it could work in Excel." HEST added, "Now that we know *it is useful*, we have to implement a database soon. This Excel is really overbooked with functions" (HEST, emphasis added).

The switch to a more powerful tool is also seen as a source of future benefits. HEST observed, "I also have some more technical information that I would like to have in it, but maybe not in this. If we build a database, … we could also *integrate it with other systems* like the ticketing system. They need to know that a specific service is populated with specific pieces of hardware, so if there is a hardware failure, and a ticket is opened, it is easy to go into the database to see which service is affected by the failing hardware" (HEST, emphasis added). Apart from these technical issues of implementation, no other problems were reported that relate to the OLPIT specification.

In summary, the results produced by using the OLPIT in the Hilti Corporation indicate two positive effects. First, there is a direct effect on decision-making capabilities, as all interviewees reported significant advancements in investment planning and budgeting processes and that improved information quality about infrastructure capacities and cost structures was helping support colleagues and negotiations with business partners. Second, interviewees reported indirect effects on people's behaviour as it relates to information, such as their attitudes about sharing data and information among teams and organizational units. In addition, using an ontology that defines and relates relevant concepts like resources, activities, and services, strongly contributed to the evolution of shared mental models, which evolution has a positive influence on the efficiency and effectiveness of management processes. In particular, the interviewees reported that this shared understanding improved the alignment of views, such as those of IT and business. In this way, we see support in decision-making processes that are related to the IT infrastructure.

All interviewees agreed that the OLPIT's structure (domain concepts and the relationships among them), on the basis of which the prototype was designed, is appropriate and useful and does not need further changes. However, as the OLPIT is in practical use, our ontology is likely to be subject to refinements that increase its usefulness by integrating OLPIT with other enterprise ontologies, particularly REA (Geerts & McCarthy, 2002). The aim is to incorporate information on the IT infrastructure into the extant accounting information systems at Hilti consistently. The OLPIT version described in this paper is a mature and stable core on which such future refinements can build.

8 Final Considerations (COM)

8.1 Implications for practice

The approach we propose can support a number of practical IT management needs. It fosters a representation of the IT infrastructure that goes beyond the technical or accounting perspective of IT management problems to include the IT customer's side by referring to business processes that are supported by the IT infrastructure. The proposed approach considers the IT infrastructure not as just a set of technological components but as a living part of the organization that can articulate its contribution to the execution of business processes. The Hilti case shows how the approach can support managerial decisions regarding investments in IT infrastructure, including those related to the choice between the internal infrastructure and cloud computing. Moreover, by grouping all of the IT infrastructure components that are required to deliver services, the approach can help in estimating the total cost of ownership for the execution of specific IT services.

Moving from an accountancy perspective to a management perspective, the approach facilitates the identification and communication of the kind of support that the IT infrastructure is capable of offering to the execution of actual and potential business activities. Because of the approach's ability to identify the IT resources that support the execution of business process activities, risk management and continuity management are also supported. Using the ontology, managers can identify which activities of which business processes will be affected when part of the IT infrastructure is unable to deliver its services. By following the network of relationships that are established among IT infrastructure components and IT services, managers can identify which services cannot be executed after a failure in the hardware that supports their execution and, as a consequence, which activities cannot be executed. On the basis of the strategic relevance of the activities that the IT infrastructure supports, it is possible to identify strategic IT assets that require special treatment for the sake of business continuity.

Following up on this idea, we see that a general assessment of resource utilisation becomes possible. By relating groups of IT resources to business process activities that use IT services, the approach allows the part of the IT infrastructure that is actually exploited to be identified. Detailed measurements can then be conducted to reveal which services are delivered to what specific business activities and in what frequencies and quantities. This capability offers new potential for actively managing living IT infrastructures according to business needs.

In approaching the design of the OLPIT ontology following the ontology design process described in section 3, we formulated a set of competency questions on the basis of the company's information needs, but the questions also represent generic IT management problems that are applicable to other organizations. If the ontology is instantiated with the data of a full IT infrastructure, it can be queried to answer all of these competency questions, as specified in Table 1. Table 1 also indicates whether the specific competency question was targeted in the application in this paper or in our previous work (vom Brocke et al., 2009), or was left for future revisions.

Competency question	Query	Application
What services does IT have to offer to fulfil business requirements?	All the instances of IT infrastructure, application, and business service classes	Here
What does IT offer to the business side (service catalogue)?	All the instances of IT business services (The business processes that make use of these services are the customers of the IT services.)	Here
What are the most critical infrastructure services?	The infrastructure service that is most frequently used by application services	Here
What happens if a piece of hardware fails?	All the infrastructure services that demand the capability of the specific infrastructure component (When this component fails, the returned services will not be available.)	Here
What are the potential single points of failure in a given situation?	-	Future
When does the IT infrastructure run into a bottleneck?	Predict the point in time of when the IT infrastructure will run into a bottleneck (requires relating infrastructure component capabilities with IT services demands at different time points).	vom Brocke et al. (2009)
What investments are required to resolve bottlenecks?	-	Future
What are the costs of providing the IT infrastructure internally?	All the instances of the cost element class related to a specific infrastructure component/IT service	Here and vom Brocke et al. (2009)
To what extent are individual services underemployed/ overburdened?	Determine employment ration (requires relating infrastructure component capabilities with IT services demands at different time points).	vom Brocke et al. (2009)
Is our IT infrastructure capable of fulfilling business requests?	Determine demand for IT infrastructure caused by IT Business services (requires relating IT Infrastructure capability with IT Business Service demands at different time points).	vom Brocke et al. (2009)

Table 1. Answering competency questions

Given that an Excel file was used in the application described in this paper, the application's ability to answer the competency questions is limited. In any case, the software tool allows the user to obtain the information necessary to answer the competency question if he or she interacts with certain Excel features (i.e., filters, search functionality, and some specific macros). A more powerful software tool that can use the ontology directly might improve the application's ability to answer the competency questions. For example, if the software tool contained a semantic reasoner, the reasoner could be used to perform the queries—and perhaps others as well—since ontologies allow the reasoner to reason about what is specified by the model and what is implied by it.

8.2 Implications for research

The specification of the OLPIT informs research in two ways. First, to our knowledge, the OLPIT is the first attempt to define and evaluate in ontological terms relevant concepts with which to assess the business value of IT. Therefore, it contributes to both the IT value research field and to the AIS research domain. The OLPIT also advances the process-level perspective in IT value research by defining the relationships between organizational processes and IT infrastructure components. In addition, we evaluated the usefulness of OLPIT by applying it in a real organization over three years. The evaluation confirmed the usefulness of our domain ontology, so it can be assumed that our artefact is truthful with regard to its usefulness and its formal correctness. (For truth statements in DSR, see Sonnenberg & vom Brocke, 2012). Therefore, researchers can build upon our ontology to extend or integrate it into other ontologies.

The second way in which specification of the OLPIT informs research is that researchers can benefit from our formal ontology evaluation, as it demonstrates the usefulness of a formal evaluation with respect to the truthfulness, clarity, and expressiveness of ontology specifications. Our evaluation also provides an exemplary instance of grounding a domain ontology in a formal ontology. Such instances are rare in the IT value and AIS research fields.

We are also aware of two primary limitations in our approach. First, although IT service management (ITSM) covers a wide variety of services, our proposal addresses only operational and automated services. Even though the ontology includes a class with which to model human resources, it has not been thoroughly tested with services that are based primarily on or even include human effort. Second, the value-based perspective we adopt is only partial, since we addressed only the passive side (costs) of the financial cycle. Nevertheless, since we decided to adopt an ontology-based approach because of the possibility of easy integration with other ontologies, future work can integrate our domain ontology with other domain ontologies that refer to the positive side of the financial cycle or integrate economic duality relationships, as suggested by the REA ontology (cf. Geerts & McCarthy, 2002). An extension of this research could also integrate skill and capability profiles, thereby extending the concept of human resources. In this case, the OLPIT would be useful in building a competency map for human resources on IT services and would help in evaluating an IT infrastructure's readiness to fulfil business processes' needs from a competency point of view.

9 Conclusion and Outlook

This paper addresses the problem of aligning IT capacity to changing business needs. Our DSR project presents an ontology that enables the relationships between IT resources and activities in business processes to be modelled and that allows cost analyses based on a consistent set of relationships between IT infrastructure and business process elements to be conducted. Our report on the outcome of the longitudinal study is based on interviews conducted with managers at the Hilti Corporation, who used the ontology in their daily activity for three years. The evaluation showed that the OLPIT was perceived as useful when used to model the relationships between the IT infrastructure and the business process activities by means of IT services.

The results of our interviews also suggest that the OLPIT was useful in conducting cost analyses based on a consistent set of relationships between IT infrastructure and business process elements. The integration of information related to infrastructure components, IT services, and their costs that was fostered by the use of the ontology was a relevant and crucial step toward achieving the benefits described. While the evaluation showed the value of the conceptual structure of the ontology, it also revealed limitations in regard to the prototype used. From these limitations we learn that an efficient, professional use of the OLPIT in daily business processes requires more a user-friendly implementation and more powerful supporting tools. The integrative use of the OLPIT appears to be favourable in integrating the ontology into extant accounting information systems rather than programming a stand-alone solution. Considering heterogeneous IT environments, our observations show that the implementation of an OLPIT service that interacts with systems that are relevant to an organizational context may be a promising way forward.

The longitudinal study on the application of the OLPIT at the Hilti Corporation shows that professional software support can increase efficiency by applying the OLPIT to daily business. The adoption of an Excel base prototype was useful in letting the team start to work together, but it had its limitations, and users involved in the project acknowledge the need for a more powerful (potentially database-based) supporting tool. Research on extending Configuration Management Data Bases (CMDB) appears promising, considering the opportunity to integrate such tools with accounting information systems. CMDBs provide repositories of information related to all components of the IT infrastructure and offer means by which to integrate data sources, a process that would be a useful functionality in implementing the OLPIT ontology. In any case, the full advantages of the OLPIT ontology can be achieved only through the use of a software tool that allows reasoning. These aspects of the ontology will be targeted in future studies.

For researchers, the OLPIT can serve as a starting point from which to engage in building methods and tools for assessing the business value of IT. As a generalized result of our findings, we demonstrated the applicability of an ontological representation of the economic reality—in this case a living IT infrastructure—for increasing the validity of independently observable measures of IT value. Researchers interested in designing ontology artefacts to solve real-life problems that are related to the domain of the OLPIT can integrate our ontology and can refer to our mapping of OLPIT concepts to the concepts of the UFO foundational ontology to make other ontologies interoperable with the OLPIT. Since design-oriented research is inherently iterative, our future studies will test and revise the OLPIT ontology by targeting the competency questions that cannot yet be answered.

Acknowledgements

This work was conducted using the Protégé resource, which is supported by grant GM10331601 from the National Institute of General Medical Sciences of the United States National Institutes of Health.

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Appendix 1 – Definitions of key terms in ITIL and COBIT used for the ontology development process

	ITIL	COBIT
Business Process	A Process that is owned and carried out by the Business. A Business Process contributes to the delivery of a product or Service to a Business Customer. For example, a retailer may have a purchasing Process, which helps to deliver Services to their Business Customers. Many Business Processes rely on IT Services.	A Process is generally, a collection of procedures influenced by the organization's policies and standards that takes inputs from a number of sources, including other processes, manipulates the inputs, and produces outputs, including other processes, for process customers. Processes have clear business reasons for existing, accountable owners, clear roles and responsibilities around the execution of the process, and the means to measure performance.
Process	A structured set of Activities designed to accomplish a specific Objective. A Process takes one or more defined inputs and turns them into defined outputs. A Process may include any of the Roles, responsibilities, tools and management Controls required to reliably deliver the outputs. A Process may define Policies, Standards, Guidelines, Activities, and Work Instructions if they are needed. See Business Process	
IT Service	A Service provided to one or more Customers by an IT Service Provider. An IT Service is based on the use of Information Technology and supports the Customer's Business Processes. An IT Service is made up from a combination of people, Processes and technology and should be defined in a Service Level Agreement.	
Application	Software that provides Functions that are required by an IT Service. Each Application may be part of more than one IT Service. An Application runs on one or more Servers or Clients. See Application Management, Application Portfolio.	A set of controls embedded within automated solutions (applications) A program that processes business data through activities such as data entry, update or query. It contrasts with systems programs, such as an operating system or network control program, and with utility programs, such as copy or sort.
Component	A general term that is used to mean one part of something more complex. For example, a computer System may be a component of an IT Service, an Application may be a Component of a Release Unit. Components that need to be managed should be Configuration Items.	
Infrastructure		Technology, human resources and facilities that enable the processing of applications

Table 2. List of relevant terms from the ITIL and COBIT glossaries

Appendix 2 – Grounding of OLPIT in the Unified Foundational Ontology (UFO)

A2.1 Meaning of “clarity” in the context of ontology evaluations

Conceptual clarity results from enabling unambiguous interpretations of domain concepts in terms of the foundational ontology to which a particular domain ontology has committed. Since a concept in a domain ontology is unambiguously mapped to a concept of an upper ontology (i.e., a domain ontology is truthful), each domain concept inherits the meaning of its upper concept in the foundational ontology.

For example, assume a *foundational ontology* defines a concept `Event`, which denotes an occurrence in time. Assume further that the foundational ontology defines a concept `Complex Action,` which denotes an accumulation of related events (cf. Bringuente et al., 2011).

Let a *domain ontology* (like OLPIT) be grounded in this foundational ontology, and let such a domain ontology have defined the concept of an `Activity`. Let the domain ontology contain an additional concept, `IT Service Type,` which denotes a special type of `Activity`. Furthermore, the domain ontology contains the concept of a `Process,` which denotes a set of related activities. What are an activity, a service, and a process all about in terms of real-world things? To clarify the meaning of these concepts, the domain ontology is equipped with real-world semantics; that is, the domain ontology is grounded in the foundational ontology.

To realize the grounding, each domain concept is linked to one and only one concept of the foundational ontology. For example, the domain concept `Activity` is classified as a `Complex Action` in terms of the foundational ontology. Therefore, without further specification an activity in OLPIT can be understood as a composite of two or more events. An activity can be perceived in its entirety only after all related events have occurred. If an activity has not been fully executed, then only parts of the activity occurrence can be perceived at a given point in time based on the events that have already occurred. An activity occurrence can be said to exist if at least one event pertinent to that activity has already occurred. Since a service is a specialized activity, it is also a complex action. Thus, a service can be perceived in its entirety only after all events that contribute to it have occurred. Finally, a process occurrence is a collection of complex actions. Again, a process occurrence can be perceived in its entirety only after all activity occurrences (complex actions) have occurred. A process occurrence exists only if at least one event that pertains to an activity occurrence of that process has already occurred. Thus, the grounding of domain concepts in the semantics of a foundational ontology makes it possible to reason about the conditions for when a domain concept can be said to exist and what the domain concept is all about.

Now consider another domain ontology that defines the concept of an `Economic Event` (like the REA ontology, see McCarthy, 1982). This domain ontology is not grounded in the foundational ontology assumed above and so it remains unclear what is meant by an economic event here? Does it correspond to a self-contained `Event` in terms of a foundational ontology, is it an `Activity` as described by the OLPIT domain ontology, or does it denote a `Process`? According to McCarthy’s (1982) textual descriptions, all three interpretations are possible. However, in ontological terms this ambiguity leads to conceptualizations that have little clarity (as vom Brocke et al., 2011, and Sonnenberg & vom Brocke (2014) discussed for the domain of process-oriented accounting.

Guizzardi and Wagner (2005) conducted an ex-post grounding of the REA ontology in an upper ontology that resulted in REA `Economic Events'` being considered `Complex Actions` and, therefore, corresponding to `Activities` in OLPIT. As this simplified example shows, grounding a domain ontology in a foundational ontology (i.e., grounding a domain view in a more general worldview) provides “real-world” semantics to the underlying domain concepts and further contributes to the semantic interoperability of different domain ontologies.

A2.2 Rationale for choosing UFO over the Bunge-Wand-Weber (BWW) ontology

UFO is hardly the only foundational ontology we could have chosen for grounding our domain ontology. As one example, the Bunge-Wand-Weber ontology (BWW) (Wand & Weber, 1993; Weber, 1997), another foundational ontology for grounding the OLPIT, has a long track record regarding its use in the information systems (IS) discipline for purposes of IS modeling and representational analysis of conceptual modeling techniques (e.g., Green & Rosemann, 2004; Recker 2007). Judging from the number of BWW-related publications in leading IS journals, this ontology is the most widely used foundational reference ontology in the IS discipline (Guan et al., 2012). However, the BWW ontology is less suitable than UFO for equipping OLPIT concepts with real-world semantics. Here we present our arguments for our decision not to use the BWW ontology. (We do not provide an in-depth discussion of ontologies and ontological commitments in IS but simply highlight some central shortcomings of the BWW as it relates to a process-oriented view of information systems.)

General argument: BWW does not allow institutional realities or institutional facts to be conceptualized. This shortcoming means that business processes, activities, actions, costs, and cost elements cannot exist in a BWW reality.

The realist position the BWW takes (Wyssusek, 2006) in presuming a world of matters that *exists independently of observers* (Recker and Niehaves, 2008) explains how the BWW neglects institutional realities. According to the BWW, the world is made up of things that “really exist in the world” (Weber, 1997, p. 34), and only these things can be described by the constructs of a scientific language. In this regard, Bunge (1977) holds that “Unless a construct is assigned a definite mathematical status […,] it is not exact and may be a fake […]” (Bunge, 1977, pp. 8-9). In this sense, constructs like “business process” and “activity” have no substance and cannot by themselves acquire a mathematical status, so they cannot be assumed to exist. This conclusion is made clear by looking at how a process is defined in BWW.

In BWW a process is defined as a sequence of status changes (i.e., a sequence of mathematical status changes that are called “events,” in BWW terminology) in the properties of things (that participate in a process). In BWW the existence of a process can be inferred ex-post only by means of an event history. However, while a process is “active”, by definition in the BWW ontology it cannot be said to exist as a process and can never acquire a mathematical status itself. All status changes in a process relate to a “real” thing in the world (a thing of substance). The event history discloses only what has happened to a thing or how properties of a thing emerged to a particular point in time. However, an event history, as the name implies, is backward looking and does not explain what a current process. At best, event histories are evidence for processes that already ceased to exist. By now means are BWW events or event histories suitable to refer to a current or actual existence of a bears no means of actual existence of a meta-physical thing like a process. Moreover, an event history is observer-dependent, as what event does or does not belong to an event history cannot be objectively or independently observed. (This issue relates to the questions concerning when a process starts and when it ends.) Therefore, processes themselves can never be observed in their entirety while they are “in progress,” and processes cannot be said to exist independently of observers, so processes, as such, never exist at all in BWW. The same argument holds for activities or actions. In the same way, the existence of costs or cost elements associated with a process is also observer-dependent, as the multitude of cost management approaches, each of which implies a different “form” and interpretation of costs, demonstrates.)

However, we hold that business processes, activities, and cost elements, as institutional facts, do exist. Such an assumption is justified since business language frequently refers to processes, activities, and costs. To what are these linguistic expressions referring if not to things that exist in the world? The existence of such linguistic expressions also indicates that there must be at least an implicit consensus regarding the existence of institutional facts and that these institutional facts are meaningful.

Essentially, then, the realist position implied by the BWW should be put under scrutiny regarding its implications for the conceptual modeling of information systems. Although Wand and Weber (1993) claimed that the BWW provides a universal representation system in conceptualizing information systems, why the BWW does not allow institutional facts observed and brought to existence by social agents to be conceptualized remains in question. Information systems are not only a technical phenomenon (a view that supports a realist ontology) but also a socio-technical one. Conceptualizations in the context of a process-oriented perspective on information systems must consider institutional facts, which are non-existent in a realist ontology. Therefore, a realist ontology might be inappropriate for conceptual representations of information systems.

Specific argument: The BWW does not allow for conceptual representations of a genuine process-oriented view on either information systems or organizations since:

- BWW-based conceptualizations do not allow process artifacts like activities or events to be modeled as (ontological) classes since, according to BWW, classes are allowed only for things that are real (substantial things) (Guizzardi, 2005).
- BWW conceptualizations of a process as series of state changes do not allow process decompositions to be modeled. According to BWW, part-whole relationships are allowed only for things that have substance (cf. Guizzardi, 2005).
- Since they do not allow for the existence of processes or activities, BWW conceptualizations cannot reflect process decompositions. (One study used the BWW to describe good process decompositions but had to make some critical assumptions to do so; see Johannesen and Leist, 2012.)
- Green and Rosemann (2000) hypothesized that the concepts of BWW are inadequate to reflect information requirements in the context of process modeling. (This inadequacy might be due to BWW's lacking a foundation in ontological theories that reflect linguistics and cognitive sciences; cf. Guizzardi, 2005.)

The BWW would allow things in the world to be represented as classes only if they have substance, that is, only if they exist independently of observers. As Guizzardi (2005, p. 244) pointed out, "*The proponents of the BWW approach claim that classes in a conceptual model of the domain should only be used to represent substantial universals.*" Regarding the task of modeling process-aware information systems or even process-aware ontologies like the OLPIT, the BWW would not allow classes to be defined for things that have no substance but are institutional facts instead (like processes, activities, events, or cost elements). However, only allowing for things that have substance to exist appears to be somewhat counterintuitive and does not correspond to the common practice of modeling process-aware information systems by making reference to classes like processes, events, and activities.

Moreover, the BWW holds that properties of (substantial) things can have no other properties; that is, the BWW does not allow for higher-order properties. As Guizzardi (2005, p. 266) concluded, "Since Bunge denies the existence of *particularized properties*, one could simply state that properties should not be represented as classes because they should not be allowed to have instances." In other words, the BWW ontology does not support the common practice in software engineering and information system design of allowing classes (like the class "Customer") to have properties that themselves represent things that exist in the world (e.g., a customer's property "Current Account," which is represented through a class "Bank Account").

According to BWW, processes and events (even if they can be assumed to be real things) cannot be decomposed. In this regard, Guizzardi (2005, p. 196) stated that BWW "defines parthood only between *things*, i.e., substantial individuals." Although BWW does not account for the existence of processes and, in particular, process decompositions, many studies have used the BWW to evaluate process-modeling grammars or to derive “good” process-modeling practices in terms of the BWW ontology. For example, Johannesen and Leist (2012) used the BWW to derive criteria that describe a good process decomposition but, in order to accomplish their study objectives, had to make critical and contradictory assumptions. First, in order to retain compatibility with the BWW systems view, they assumed that a process was a system consisting of subsystems. Second (and contradictory to the first assumption), they related a representation of a process to the BWW concept “transformation” and “transfer function,” although a transformation in BWW does not denote a system that can be decomposed but a state change, and state changes cannot have a hierarchical relationship to each other. A transfer function assigns all inputs of a system to a system’s output (cf. Weber, 1997), but again, such a function cannot be hierarchically decomposed. These fundamentally contradictory assumptions led to the study’s mixed results. The study concluded that direct mapping of the BWW decomposition rules onto a process-modeling grammar are not possible using the event-driven process chain (EPC) because of an assumed ontological deficit of the EPC. We would argue instead that the BWW’s realist position and inability to account for institutional realities may have caused this result.

Johannesen and Leist (2012), like other related studies that have evaluated process-modeling grammars (e.g., Recker and Indulska, 2007), frequently justified the choice of BWW with the observation that BWW has already been widely used in similar contexts and that it has a wide range of applicability that covers all essential aspects of systems modeling. However, this justification is not convincing, as these studies assume that process modeling is a specific instance of systems modeling and that a realist ontology is appropriate for process modeling. We hold that the opposite is true: process modeling is essentially concerned with representing institutional realities, which are alien to BWW.

In particular, the BWW lacks a notion of (social) agency. One cannot express through BWW a situation in which a thing intentionally or unintentionally participates (in an activity) in order to put another thing into existence or to change a state of affairs. UFO accounts for the intentional and social entities that provide a foundation for agent-modeling concepts (cf. Guizzardi and Wagner, 2005).

The BWW’s realist position in its implications about conceptual representations in the information systems domain has been subject to some fundamental criticism (see Wyssusek, 2006). As Lyytinen (2006, p. 82) remarked, “*The Wand and Weber ontology is amazingly close to the original ideas of logical positivists. These rebels of philosophy claimed that the main challenge for philosophy was to devise a universal scientific language in which ‘all relevant scientific phenomena’ and their explanations could be formulated and solved. […] We now know that this program failed, though it produced many important findings including incompleteness theorems, decidability problems, the failure of induction, and so on.*”

Lyytinen’s (2006) remark suggests that the BWW, with its realist position, might fail to prove its universal applicability in support of information systems modeling and motivates the consideration of alternative foundational ontologies for conceptual representations of information systems. Such an ontology should support the notion of social agency and intentionality, that is, institutional facts which can be assumed to exist but are not independently observable. The unified foundational ontology (UFO) Guizzardi (2005) and Guizzardi and Wagner (2005) proposed accounts not only for “real things” but also for institutional realities. Therefore, we opted for UFO in order to equip OLPIT concepts with real-world semantics.