The Project Management Ontology called ProjectCO: Architectural Aspects, Concepts, and Usefulness

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Abstract. *This paper presents the concepts, relationships, constraints, and verification issues of the project management ontology called ProjectCO. Its concepts represent key concerns of the conceived world for project management, embracing particular things (or entities) and their relations, as well as assertions that deal with them. ProjectCO is placed at the core level in the context of a five-tier ontological architecture, which considers foundational, core, top-domain, low-domain, and instance layers. A given ontology is located in this architecture according to the level of generality/specificity of its concepts, which in turn depend on the established development goal and scope. Therefore, since we aim for ProjectCO concepts to be cross-cutting, domain-independent concerns of any specific discipline, its scope is limited to core terms that need to be reused and specialized at lower domain levels. Note that many definitions and labels of ProjectCO terms were adopted or adapted from four well-known standard glossaries, as well as from a previous project management ontology. To showcase its usefulness, this work discusses enriched and harmonized concepts for a top-domain ontology for measurement and evaluation projects.*

1. Introduction

The ISO 704 (2022) standard establishes that the vocabulary or terminology of an area or field of science is not an arbitrary collection of concepts. The relevant concepts –designated by terms– constitute a coherent concept system based on the relations existing between them. Concept systems can be represented and formalized from lower to higher structural richness, from glossaries and taxonomies to ontologies. While a glossary includes terms that designate concepts and their definitions –and occasionally synonyms, acronyms, references, and additional notes–, an ontology is a concept system with a richer structure than a glossary since it represents not only defined terms for concepts in a given subject field or subfield but also taxonomic and non-taxonomic relationships and constraints. Glossaries are well-known knowledge/information resources used in academia and industry to support the human consultation, understanding, and learning of frequently used concepts in a given field. Ontologies also support human understanding and learning in addition to other benefits such as structuring and representing knowledge in a more reusable, extensible, and interoperable way, supporting tools with semantic processing capabilities, and semantic annotation of information resources, among other features.

For example, for the project area, several different initiatives have developed glossaries and ontologies for project management. On one hand, just to mention a couple of glossaries, most professionals in this field are familiar to some extent with

glossaries such as PMBOK (2021), which stands for Project Management Body of Knowledge, and APM (2021), which stands for Association for Project Management. According to Becker et al. (2023), the former has 350 primary terms while the latter has 753. This large number of terms can hinder the human understanding and learning process, mainly if the terms designate concepts at different levels of generality/specificity, e.g., at the core and domain levels. Furthermore, in a comparative analysis of four project management glossaries, these authors showed problems of syntactic and semantic consistency, as well as problems of semantic correctness, since, for instance, their definitions are rarely linked explicitly and correctly through the use of hypernym-hyponym relations, when necessary. On the other hand, just to mention a couple of ontologies, Rivera et al. (2016) built the first version of a project management ontology, which adopted and adapted some labels and/or definitions of terms from PMBOK (2013). This ontology was reduced in the number of included terms and therefore in its scope. Also, it does not represent the generality/specificity of terms considering domain and core levels in the framework of a multitier architecture. More recently, Bastos et al. (2018) developed SPMO, the Software Project Management Ontology, with the aim of establishing a common conceptualization of the software project management field, initially focusing on software project planning and monitoring. SPMO does consider core and domain terms, but its scope is limited to the software field and project planning and monitoring concepts in terms of scope, time, and cost. As the authors recognize, concepts related to techniques or methods, among others, applied to project management are left out of the conceptualization of the SPMO.

The main contribution of this work is the discussion of ProjectCO, which is a Project management Core Ontology built considering updated standard glossaries and an ontology in this area. D'Aquin and Gangemi (2011) establish a set of principles or characteristics that must be taken into account when building 'beautiful ontologies'. They claim that international terminological standards for a given domain should be considered as sources when building an ontology. Another principle is that the designed ontology elements should be grounded in a foundational ontology. Additionally, the designed ontology should be modular, extensible, and reuse already developed related ontologies, as suggested by the characteristic of beautiful ontologies of being modular or integrated into a modular framework or architecture.

Regarding the first principle, ProjectCO is based on definitions and labels of glossary terms coming from PMBOK, APM, IAPM (2021), which stands for International Association of Project Managers, and PRINCE2 (2017), which stands for PRojects IN Controlled Environments. To do this, ProjectCO takes into account the comparative analysis carried out by Becker et al. (2023), which recommends a set of lists of common terms to be adopted or adapted from these four glossaries that evidenced higher to lower levels of syntactic/semantic consistency. In addition, ProjectCO also considers some ontology terms and definitions made by Rivera et al. (2016).

Regarding the second principle, ProjectCO is based on the foundational ontology called ThingFO (Olsina, 2023), which represents the world with three generic concepts such as the particular thing (and instances), universal thing (or categories of things), and human assertions that deal with these two concepts and their relationships. Having ontologies for different application domains that inherit the same core and

foundational basis allows terms and relationships with similar semantics to have a common background or conceptual foundation. Lastly, ProjectCO, which is conceived as an ontological component at the core level that has domain-independent concepts and relationships for project management, reuses terms and relationships from developed ontologies at the same level such as ProcessCO (Becker et al., 2022) and can be extended at domain levels for different types of project management regarding development, evaluation, and testing, among others. All these ontologies are placed in the framework of an ontological architecture called FCD-OntoArch (Olsina, 2023), which stands for Foundational, Core, Domain, and instance Ontological Architecture.

As a result, the ProjectCO conceptualization includes 45 core terms –each semantically enriched with terms reused from other core ontologies, or with terms extended from ThingFO–, 10 properties, 20 taxonomic relationships, 33 defined non-taxonomic relationships, as well as constraints. Finally, as functional requirements, we defined 27 competency questions to be answered by ProjectCO. The ontology development approach followed was Methontology (Fernández-López et al., 1997).

The remaining sections are organized as follows: Section 2 provides an overview of FCD-OntoArch, in which ProjectCO and other ontologies are placed. Section 3 discusses the goal, scope, and additional requirements of the proposed project management core ontology and its conceptualization. Section 4 illustrates the usefulness of ProjectCO for enriching concepts and relationships of a domain ontology. Section 5 analyzes related work and Section 6 outlines the conclusions and future work.

2. Location of ProjectCO in a Multi-level Ontological Architecture

One motivation for this research lies in the updating of a previously developed project management ontology (Rivera et al., 2016) since it was limited in the number of represented concepts –and therefore in its scope– and there was no clear separation of concerns considering the domain and core levels when placing generic/specific project management terms into modules in the context of a multi-level architecture. Hence, keeping this goal in mind, the new ProjectCO module or component is placed at the core level in the context of FCD-OntoArch as shown in Fig. 1. It should be noted that this ontological architecture was conceived in 2019 after the development of the first version of the project management ontology which was in 2016. More details about guidelines and rules of this ontological architecture can be found in Olsina (2023).

To provide an identification of the ontological components in FCD-OntoArch, ontologies that belong to a certain level of generality/specificity have a designation associated with their location within it. For example, an ontology at the foundational level is called Foundational Ontology (FO for short); ontologies at the core level are called Core Ontologies (CO); ontologies at the top-domain level are called Top-Domain Ontologies (TDO), and so forth. On the left side of Fig. 1, the five levels of generality/specificity are depicted. It also shows the domain-independent and domain-dependent layers. The components located on the right side of the figure correspond to the ontologies already built in the architecture and harmonized with ThingFO.

At the foundational level, ThingFO is the only necessary ontology, which has the three generic concepts mentioned in the Introduction Section. It represents the world through particular Things, universal Things, and Assertions. These are the unique concepts (plus their related terms) that specialize in the lower components.

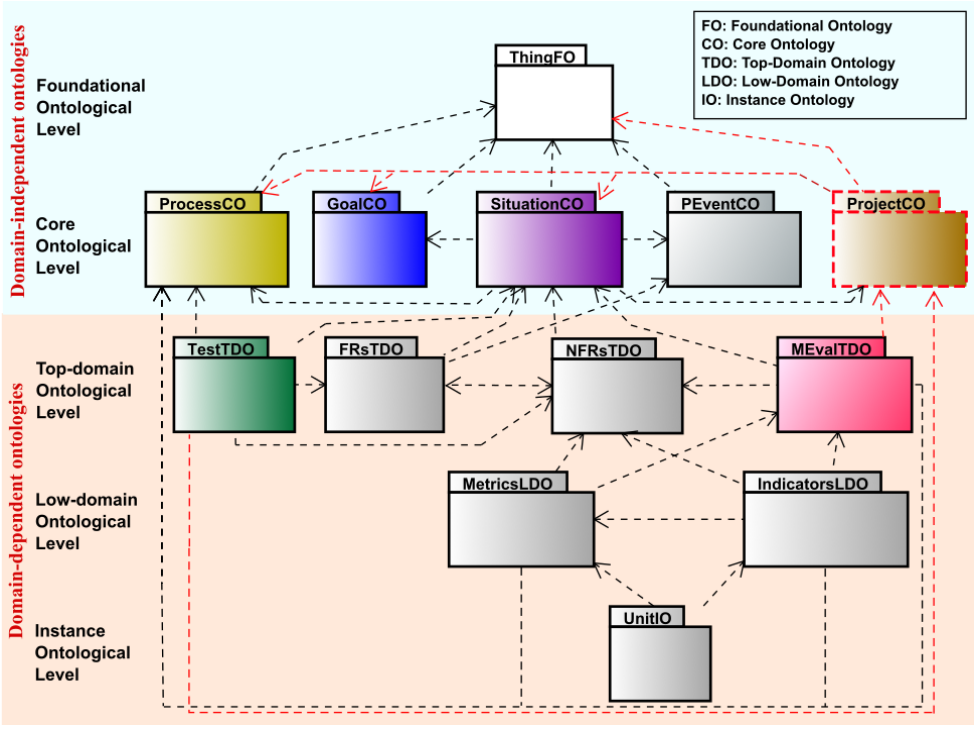

Figure 1. Allocating the new ProjectCO component in the context of the ontological architecture called FCD-OntoArch

At lower levels of the above architecture, the ontologies already updated are: i) at the core level: ProcessCO, GoalCO, SituationCO, and PEventCO (Particular Event); ii) at the top-domain level: TestTDO, FRsTDO (Functional Requirements), NFRsTDO (Non-Functional Requirements), and MEvalTDO (Measurement and Evaluation); and iii) at the low-domain level: MetricsLDO and IndicatorsLDO. Note also that Fig. 1 depicts components shaded in grey that will not be mentioned later in this paper.

As said, the former project management ontology should be updated and harmonized in light of other abovementioned foundational and core ontologies, resulting in ProjectCO. Fig. 1 shows with red dashed lines not only the location of the ProjectCO component to be updated but also the dependency relationships with other ontological components. Therefore, some ProjectCO terms should be semantically enriched with ThingFO terms and others should reuse the semantics of ProcessCO, GoalCO, and SituationCO terms. In turn, ontologies at the top-domain domain level, such as MEvalTDO and TestTDO (Tebes et al., 2021) specialize, for example, the term "Project", which is now a core term. Thus, in MEvalTDO the specialized term is "Evaluation Project" and in TestTDO it is "Test Project", which are specific to the measurement/evaluation and testing domains respectively.

Consequently, since the ProjectCO component is now finalized, the MEvalTDO and TestTDO ontologies must be revised to realign and harmonize them with the new or updated core terms of ProjectCO. In Section 4, we will discuss the usefulness of ProjectCO to semantically enrich and harmonize some terms and relationships from the previously developed MEvalTDO ontology.

3. Discussion of ProjectCO Scope, Concepts, and Relationships

As commented in the Introduction Section, the ProjectCO module includes 45 core terms –each semantically enriched with generic terms reused from other core ontologies, or with terms specialized from ThingFO. Therefore, at first glance, it is a more complete ontology than the previous project management ontology (Rivera et al., 2016) which included only 16 terms mixing top domain and core terms in the same component. Next, in subsection 3.1, we discuss the goal of ProjectCO, as well as its scope or functional requirements, defining a collection of 27 categorized competency questions (CQs). Then, in subsection 3.2, we depict the resulting ProjectCO conceptualization and analyze a set of concepts and relationships that will be used in Section 4. Finally, in subsection 3.3, we show an excerpt from the ProjectCO terms, relations, and properties verification matrix considering CQs.

3.1. Definition of Competency Questions

ProjectCO's development goal statement can be briefly formulated as "Build a project management ontology at the core level –primarily considering terms from recognized and up-to-date project management glossaries– where its domain-independent concepts can be specialized into domain levels for different disciplines and, as benefits, can be used as a reference vocabulary for understanding, learning, and communication for stakeholders in both academia and industry, as well as providing semantic processing capabilities". It should be noted that ProjectCO concepts can be specialized by different disciplines, not only for the field of software engineering but also for civil, mechanical, and biomedical engineering, among many others.

Before building ProjectCO, we conducted an exploratory study to perform a comparative analysis of the syntactic and semantic consistency of terms from four selected project management glossaries and then to provide recommendations for core terms. We did so by considering glossary terms that belong to categories related to the organizational entity, intentionality/goal, situation/event, work process, work product, and project resources such as strategy/approach, method/technique, and agent/role. These terminological-semantic categories turned out useful for identifying conceptual blocks or patterns and specifying the scope of the new project management ontology at the core level in the context of FCD-OntoArch, which was described in Section 2.

As a result, 5 CQs belong to the Organizational Entity category, 2 to the Project Goal, 3 to the Project Situation, 6 to the Project Work Process, 3 to the Project Work Product, and 8 CQs are included in the Project Resource category. For example, below, CQ2 is included in the Organizational Entity category, CQ9 is a CQ related to the Project Situation category, CQ13 is a CQ related to the Project Work Process, and CQ20 belongs to the Project Resource category.

- **CQ2**. What are the entities through which an organization organizes work and resources together?
- **CQ9**. Are a project's situation, objectives, and requirements related in any way?
- **CQ13**. What are the processes that are integrated into a project process?
- **CQ20**. What are the types of resources that a project has?

The reader can find the rest of the categorized CQs in Appendix B of the document at https://bit.ly/ProjectCO_Appendices.

As a final observation, Monfardini et al. (2023) reported on a survey that provides data on how CQs have been used in ontology engineering. This study shows that CQs have been considered useful and have mainly helped to define the scope of a given ontology and verify its conceptualization. We fully adhere to these perceptions of usefulness, both to help define the scope and to verify and validate the conceptualization.

3.2. ProjectCO's Conceptualization

As noted in the Introduction Section, the four project management glossaries selected and analyzed are PMBOK, APM, IAPM, and PRINCE2, which were the main glossary sources for recommending the core terms to be included in ProjectCO. For example, the term Project is a common term in all four glossaries, i.e., it has a frequency of occurrence of 4. This term label was then recommended and adopted, as well as the terminological-semantic category of Organizational Entity, which was common in the definitions of the four terms. At the same time, this term was also available in Rivera et al. (2016), so we adapted its definition as shown in Table 1, which is somewhat similar to the definitions given in all glossaries, now explicitly having the type of particular thing or entity. However, the term Program was not available in this cited ontology, while it has an occurrence frequency of 4 in the glossaries, so we adapted its definition from the PMBOK. The same goes for the term Project Management Office.

Fig. 2 depicts the resulting conceptualization of ProjectCO specified in UML. It shows 45 core terms, which are semantically enriched with stereotyped terms reused from other core ontologies, or with extended terms from ThingFO, among other elements. It is worth mentioning that the ontologies of this work use the stereotype as a mechanism to reuse, enrich, and align terms semantically. What does it mean that the concepts of an ontology at one level can be semantically enriched by other higher-level ontology concepts? It means that a given concept (usually designated by one or more terms) of an ontology at a certain level (e.g., core or top-domain) can inherit the semantics of the corresponding more general concept and then specialize it. The same procedure can be used to enrich a term from terms of other components at the same level. For example, in Fig. 2 we observe that the term Plan has the semantics of Artifact, which is a term defined in ProcessCO. In turn, the term Artifact inherits the semantics of the term Thing. In Becker et al. (2022), authors argued that stereotypes can reduce model complexity, also promoting understandability and communicability.

For the sake of brevity, looking at Fig. 2, we can see that an Organization establishes a Project Goal and arranges work by means of a Project. In turn, a Project operationalizes a Project Goal, which is derived in Project Requirements and implies a Project Situation.

The term (concept of) Project mandatorily has a Project Process and Project Resources. In turn, the Project Process necessarily has two work processes that are labeled Project Management Process and Engineering Process. These three terms for processes are enriched with the stereotype <<Work Process>>, which is a term defined in ProcessCO. Also, the Project Management Process produces a Project Management Plan, which is a Plan that has the semantics of <<Artifact>>. In ProcessCO, the term Artifact is a kind of Work Product and, in turn, the term Work Product has the semantics of a particular Thing, which is one of the three concepts included in ThingFO.

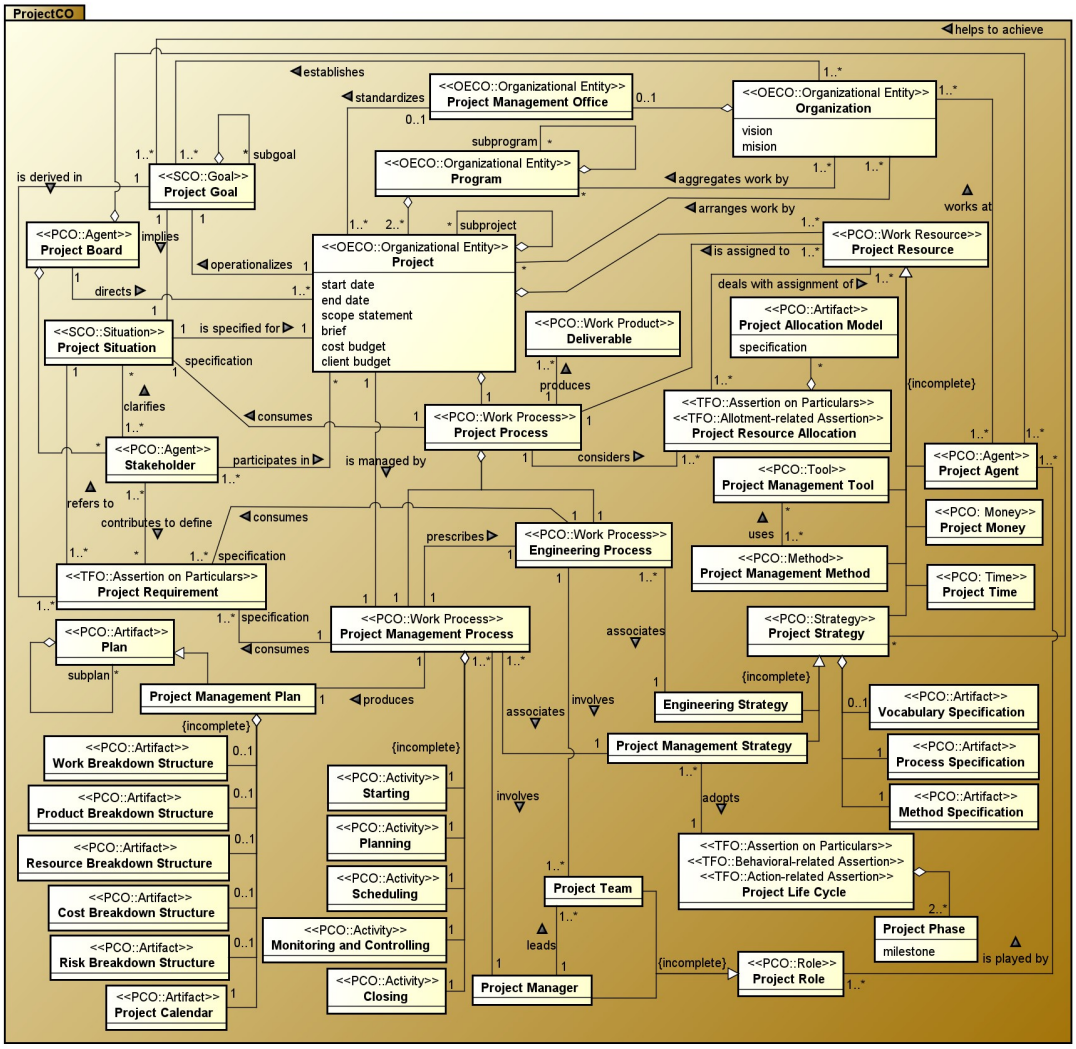

Figure 2. Project management ontology, which is located at the core level of FCD-OntoArch in Figure 1. Note that TFO stands for Thing Foundational Ontology, PCO for Process Core Ontology, SCO for Situation Core Ontology, and OECO for Organizational Entity Core Ontology (yet to be developed)

Table 1. Excerpt from ProjectCO v2.0's particular concepts

Term	Definition
Deliverable	It is a Work Product that can add other Work Products, which is produced by the Project Process and delivered as agreed to an internal or external involved Agent. Note 1: The internal and external involved Agents are Stakeholders and Project Agents. Note 2: A Deliverable can be an Artifact, a Service, or an Outcome. The term Work Product and its subtypes viz Artifact, Service, and Outcome are defined in ProcessCO.
Engineering Process	It is a Work Process including a set of technical Activities intended to produce the agreed Work Products to be delivered to certain Stakeholders.
Engineering Strategy	It is a Project Strategy that helps to achieve the engineering (technical) purpose of a Project Goal.
Organization	It is an Organizational Entity, generally under a defined legal form, comprising people and other resources that is structured and managed to establish and pursue

	organizational Goals and is affected by and affects its environment or context.
Organizational Entity	It is a Thing comprising Work Processes and human and non-human resources that are structured and managed to establish and pursue primary or subsidiary organizational Goals and purposes and is affected by and affects its environment or context.
Process Specification	It is an Artifact that represents a model which relates a set of process elements such as Activities, tasks, inputs and outputs, pre- and post-conditions, Artifacts, and Roles, amongst others. Note: A Process Specification can consider different process perspectives such as functional, behavioral, informational, and organizational.
Program	It is an Organizational Entity representing a strategic goal-oriented, temporary endeavor made up of related Projects, subsidiary programs, and program activities and resources that are managed in a coordinated manner to obtain benefits not available from managing them individually.
Project	It is an Organizational Entity representing a goal-oriented, temporary endeavor with defined *start* and *end dates*, which considers a managed set of interrelated Activities, tasks, and Project Resources aimed at producing, modifying, and delivering unique Work Products (i.e., Artifacts, Services, or Outcomes) to meet the needs of certain Stakeholders.
Project Goal (synonym: **Project Objective)**	It is a Goal that the Organization intends to achieve through a specific Project. Note: In SituationCO, the term Goal says, "It is an Intention-related Assertion, that is, the statement of the aim to be achieved by the Organization which considers the propositional content of a Goal's purpose in a given Situation and time frame".
Project Management Process	It is a Work Process including a set of managerial Activities intended to achieve the Project Goal operationalized by a Project. Note: The Project Management Process is usually composed of five interrelated Activities, namely: Starting (Initiating), Planning, Scheduling, Monitoring and Controlling, and Closing.
Project Process	It is a Work Process representing the entire process that is composed of two interrelated sub-processes, namely, the Project Management Process and the Engineering Process, which leads to the delivery of the project Work Products considering the Project Situation, Project Requirements, and Project Resources.
Project Requirement	It is an Assertion on Particulars that states managerial, engineering (technical), and contextual aspects of the Project and its Work Products to be delivered considering the needs of certain Stakeholders. Note: See the definition of the term Assertion on Particulars in ThingFO.
Project Situation	It is a Situation that the Stakeholders and ultimately the Project Board define for the Project. Note: In SituationCO, the term Situation says, "It is a Situation-related Assertion that explicitly states and specifies the combination of circumstances, episodes and relationships/events embracing particular entities and their surroundings, […], which is of interest and relevant to be represented by a Human Agent/Organization with an established Goal".
Project Strategy (synonym: **Project Approach)**	It is a Strategy as a Project Resource that includes principles and integrated properties such as a Vocabulary Specification, a Process Specification, and a Method Specification to help achieve the purpose of a Project Goal.
Stakeholder	It is an Agent, such as individuals or groups, that has an interest and participation in the Project or is impacted by it. Note: A Project Agent as an internal interested party may be a Stakeholder but not necessarily.

Lastly, the term Project Situation (see definition in Table 1) is not available in the four glossaries or in Rivera et al. (2016). The stereotyped term Situation is borrowed from SituationCO and has the semantics of <<Assertion>>, which is another concept included in ThingFO. Instead, Project Life Cycle –defined as "*It is an Assertion on Particulars, specifically, a Behavioral- and Action-related Assertion that defines the series of phases that a Project passes through from its inception to its closure*"– is a

semantically enriched term directly from ThingFO, as represented in Fig. 2. The reader can find the rest of the definitions for terms, properties, and non-taxonomic relationships in Appendix A at https://bit.ly/ProjectCO_Appendices.

As a final observation, we would like to point out again that the 45 ProjectCO terms are cross-cutting concerns and independent of the domain of any specific discipline. For this reason, the scope of ProjectCO is limited to core terms that must be reused and specialized at lower domain levels by any discipline, not only for the software engineering domain but also for fields such as civil, electrical, and biomedical engineering, among others. In contrast, SPMO (Bastos et al., 2018) is mainly intended for the software engineering field.

3.3. Verification Matrix for the ProjectCO's Conceptualization

Verification and Validation (V&V) are two key approaches to the artifact construction process. V&V entails activities, methods, tools, and ultimately strategies for ensuring quality when developing artifacts. An ontology as an artifact can be conceptualized and/or implemented. Tebes et al. (2021) have applied five V&V methods for the TestTDO conceptualization and implementation.

In the present paper, due to the current state of ProjectCO development, we only show the static verification of its conceptualization against the CQs, which represent the scope-related requirements, as commented in subsection 3.1. The goal purpose is to verify that all CQs were addressed by some of the terms, properties, and relationships. In this direction, we generated a verification matrix as shown in Table 2 using a specification-based (black-box) method. To design the verification matrix, we used as a test basis the 27 CQs and the elements that any ontology has such as terms, relationships, and/or properties. Thus, this matrix is a checklist that contains one row per CQ, in which we record what elements of the conceptualization help answer the CQ. After iterations, at the end of the ProjectCO conceptualization process, we ensured that each CQ passed.

Note that Table 2 represents an excerpt from the ProjectCO verification matrix. The entire verification matrix with all checked CQs can be accessed in Appendix C at https://bit.ly/ProjectCO_Appendices.

Just to highlight a few aspects, in the right column of Table 2, we see taxonomic and non-taxonomic relationships with underlined text. For example, for CQ2, the association between the terms Organization and Program is defined in Appendix A as "*An Organization aggregates work by means of none or more Programs*". Note that the UML cardinalities in Fig. 2 act as constraints, as well as the `{incomplete}` label for the subtypes of the term Project Resource. Even if we represent commonly used terms for project resources (see answers for CQ20), we could include, for example, the term Project Knowledge Base as a subtype.

Additionally, in the glossaries analyzed the term Project Objective is used more frequently than Project Goal. But the latter is the term adopted in our previously developed ontologies, which is why we indicate in CQ9 that Project Objective is synonymous with Project Goal. Besides, we use the non-taxonomic relationship has the semantics of to express the dependency between a given term and the term which enrich it, as is seen in the CQ13. Finally, we show the two well-known taxonomic relationships such as is part of and is a, for example, in CQ20.

Table 2. Excerpt from the ProjectCO verification matrix

Competency Question	Verification of Terms, relationships, and *properties*
CQ2. What are the entities through which an organization organizes work and resources together?	An Organization arranges work by Projects
	An Organization aggregates work by Programs
CQ9. Are a project's situation, objectives, and requirements related in any way?	Project Objective is a synonym of Project Goal
	A Project Goal implies a Project Situation
	A Project Goal is derived in Project Requirements
	A Project Requirement refers to a Project Situation
CQ13. What are the processes that are integrated into a project process?	A Project Management Process is a type of (has the semantics of) Work Process
	A Project Management Process is part of a Project Process
	An Engineering Process is a type of (has the semantics of) Work Process
	An Engineering Process is part of a Project Process
CQ20. What are the types of resources that a project has?	A Project Resource is part of a Project
	A Project Agent is a Project Resource
	Money is a Project Resource
	Time is a Project Resource
	A Project Management Tool is a Project Resource
	A Project Management Method is a Project Resource
	A Project Strategy is a Project Resource

4. ProjectCO's Usefulness

In the sequel, we highlight how some MEvalTDO terms are aligned and harmonized with the new ProjectCO ontology. It is important to note that this article will not discuss the content of the MEvalTDO ontology, but rather the resulting enrichment and reuse of terms, properties, and relationships. Fig. 3 shows a fragment of the updated MEvalTDO ontology with some elements semantically enriched or reused from ProjectCO. The complete updated conceptualization can be found at http://bit.ly/updatedMEvalTDO.

MEvalTDO is a top-domain ontology that addresses measurement and evaluation (ME) activities and methods in general, while MetricsLDO and IndicatorsLDO are ontologies at the low-domain level (see Fig. 1), which address, in particular, measurement and evaluation activities and methods based on metrics and indicators, respectively. Note that MEvalTDO can also be specialized by other low-domain ontologies such as QuestionsLDO, i.e., a Questionnaire-based Measurement Low-Domain Ontology to be developed. It is important to say that since MEvalTDO is for ME activities and methods, only the minimum and necessary ProjectCO terms have been considered. Thus, for example, terms related to the activities involved in the evaluation project management process are not explicitly included in this updated version of MEvalTDO.

In the previous version of MEvalTDO (which can be found at http://bit.ly/MEvalTDO) there was the term called Evaluation with the stereotype <<Work Process>> (from ProcessCO) to designate the concept of the evaluation process and the term called Evaluation Management with the stereotype <<Project Management>> (from the Rivera et al. (2016) ontology) to designate the evaluation project management process. However, the term Project Management in the old version of the project ontology was not enriched with any stereotypes. Thanks to the new ProjectCO, in the updated MEvalTDO the term Evaluation is now renamed Evaluation

Process (see Fig. 3) and is stereotyped as <<Engineering Process>> (from ProjectCO, which in Fig. 2 is enriched with <<Work Process>> from ProcessCO). Also, the old term Evaluation Management is now renamed as Evaluation Project Management Process and stereotyped as <<Project Management Process>> (also enriched with <<Work Process>> in Fig. 2). Consequently, it is now clearer that an Evaluation Project has an Evaluation Project Process composed of engineering and management processes.

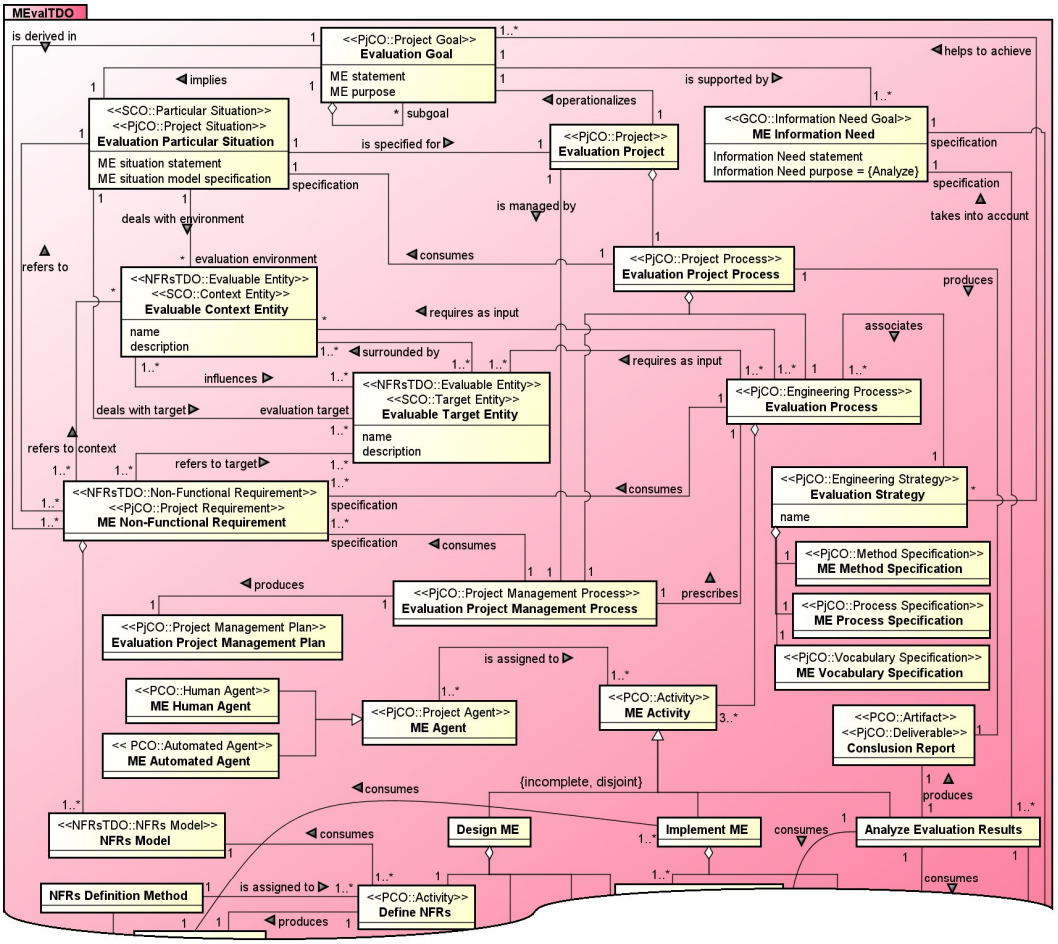

Figure 3. Excerpt from the conceptualization of the Measurement and Evaluation Top-Domain Ontology (MEvalTDO), which is aligned and harmonized with the new ProjectCO. Note that ME stands for Measurement and Evaluation, PjCO for Project management Core Ontology, PCO for Process Core Ontology, SCO for Situation Core Ontology, GCO for Goal Core Ontology, and NFRsTDO stands for Non-Functional Requirements Top-Domain Ontology

Furthermore, in ProjectCO, an Engineering Process associates an Engineering Strategy that helps to achieve a Project Goal. MEvalTDO is now aligned with this conceptual pattern since an Evaluation Process associates an Evaluation Strategy (stereotyped <<Engineering Strategy>>) that helps to achieve an Evaluation Goal (stereotyped <<Project Goal>>). The concept of Evaluation Strategy in the previous MEvalTDO was enriched with the concept of Strategy (from the Rivera et al. (2016) ontology) and was defined as "*It is a work resource that encompasses principles and integrated capabilities such as domain conceptual bases, the specification of ME*

process perspectives, and methods for helping to achieve an Evaluation Project's goal purpose". As the reader can surmise, the stereotype and this definition do not allow us to distinguish whether an Evaluation Strategy is an Engineering Strategy or a Project Management Strategy.

Fig. 3 shows that an Evaluation Strategy has an ME Method Specification, an ME Process Specification, and an ME Vocabulary Specification (which are new terms in MEvalTDO and specialized from ProjectCO). An example of ME process specification for the evaluation strategy called GOCAME (*Goal-Oriented Context-Aware Measurement and Evaluation*) (Olsina and Becker, 2017) is shown in Fig. 4. This process specification takes advantage of the MEvalTDO terminology represented by the ME Vocabulary Specification domain concept. Thus, the activity names in Fig. 4 are taken from terms of the updated MEvalTDO. Note that the specification in Fig. 4 shows only the process behavioral perspective, but other process perspectives are possible.

Besides, in the fragment shown in Fig. 3, Analyze Evaluation Results produces a Conclusion Report, which is stereotyped as <<Artifact>> (a type of Work Product in ProcessCO) and <<Deliverable>> (from ProjectCO). Originally, the term Conclusion Report was defined as "*It is an Artifact that documents the analysis of all Measurement and Evaluation Values*", but thanks to the double enrichment it is now defined as "*It is an Artifact that documents the analysis of all Measurement and Evaluation Values and is delivered as agreed to an internal or external involved Agent*". Hence, this new Conclusion Report definition considers the idea of Deliverable (see this term definition in Table 1).

Previously, in MEvalTDO there was no direct relationship between the terms Evaluation Process (originally called Evaluation) and ME Non-Functional Requirement. But thanks to the new ProjectCO, there is now a relationship named consumes between both concepts since an Evaluation Process consumes the ME Non-Functional Requirements specification. Note that this conceptual pattern is modeled in ProjectCO by the more general Engineering Process and Project Requirement concepts. Finally, some properties are specialized considering ProjectCO. For example, the 'statement' and 'purpose' properties of the Evaluation Goal term have been renamed to 'ME statement' and 'ME purpose' to be more specific.

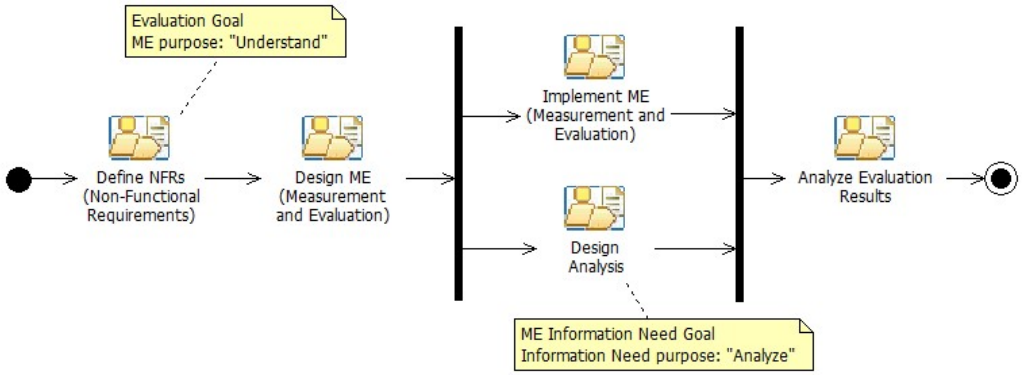

Figure 4. Measurement and Evaluation (ME) Process Specification for the Evaluation Strategy named GOCAME: A behavioral perspective

5. Related Work

In this Section, we discuss related work that simultaneously considers the three principles stated in the Introduction Section. They should be taken into account when building an ontology and are: i) the use of international terminological standards such as glossaries; ii) the use of the elements of a foundational ontology to specialize and align the newly developed elements; and iii) the designed ontology must be modular, extensible, and integrated into a multi-level ontological architecture or network.

Recently, Iatrellis et al. (2021) conducted a systematic literature review on software project management ontologies. Most of the reported ontologies do not satisfy the above three principles simultaneously. For example, we can mention the project management ontology called PMO (Ruiz Bertol and Dolado, 2008) and the one proposed by Aramo-Immonen (2009) that are based on previous versions of the PMBOK glossary. Moreover, the latter ontology, for its development, was also based on the knowledge of other standard terminologies. However, both do not satisfy the criterion of being aligned with the elements of a foundational ontology. It is important to note that PMO represents core terms (in the PM-Core component) that are expanded with the components called PM-Process, PM-Organization, PM-Cost, and PM-Planning.

The ontology that does meet the three principles is SPMO (Bastos et al., 2018). Regarding the principle i), the authors nourish SPMO from PMBOK (2013). Regarding principle ii), the authors align SPMO with the Unified Foundational Ontology (Guizzardi, 2005), which is made up of three foundational ontologies, namely: UFO-A (endurants), UFO-B (perdurants or events), and UFO-C (social entities, built on top of UFO-A and B). And taking into account principle iii), SPMO is in the context of an ontological architecture called SEON (Ruy et al. 2016), which locates ontologies organized in layers of generality/specificity.

Ultimately, ProjectCO also satisfies the three principles. Unlike SPMO, ProjectCO has a broader scope and nourishes most of its core concepts by making a comparative analysis of the syntactic and semantic consistency and recommending terms from the four project management glossaries mentioned in subsection 3.2. In addition, FCD-OntoArch includes only a foundational ontology instead of the three of UFO. ThingFO has only three foundational concepts, which facilitate specialization in lower-level ontologies. Finally, the project management ontology of Rivera et al. (2016) does not meet the three principles, as emphasized at the beginning of this paper.

6. Conclusions and Future Work

This paper has primarily discussed the goal, scope, and conceptualization of ProjectCO, which is a domain-independent ontology for project management concepts placed at the core level in the context of a five-tier ontological architecture. This architecture promotes a clear separation of concerns by considering ontological levels that allow for proper mapping of conceptual components (ontologies) and encourages modularity and consistent reuse and extension of ontological elements at all lower levels.

Since ProjectCO is at the core level, some ontologies at lower levels benefit from specializations of its core project management concepts. For example, to show the usefulness of ProjectCO, this paper has illustrated the semantically enriched terms of the MEvalTDO ontology at the top-domain level, as well as the reuse of its terminology

in the process specification of the measurement and evaluation strategy called GOCAME.

As commented throughout the paper, many definitions and labels of ProjectCO terms were adopted or adapted from the PMBOK, APM, IAPM, and PRINCE2 glossaries, as well as from a previous project management ontology. Since these glossaries are well-known knowledge/information resources used in academia and industry to support the human consultation, understanding, and learning of frequently used concepts in this field, ProjectCO with 45 core terms can benefit the structuring of these glossaries that range from 197 to 753 intermixed core and domain terms. One can envision having a glossary section for core terms, including domain-independent terms that designate cross-cutting concepts. Then, we can design other related sections for specific domains such as agile project management and quality project management, among others. As an additional benefit, the terminologist can express hypernym-hyponym relationships between core and domain terms in their definitions. Rarely are the definitions of terms in the cited glossaries structured using the hypernym-hyponym relationship, which implies a lack of semantic correctness. Instead, we do this explicitly with the use of the expression 'is_a' in all definitions, as can be seen in Table 1.

In future work, we will discuss the updated MEvalTDO with ProjectCO in detail to showcase how its concepts impact the design and application of real-world evaluation strategies.

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