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Collaborative Ontology Development Approach for Multidisciplinary Knowledge: A Scenario-Based Knowledge Construction System in Life Cycle Assessment

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SUMMARY Creating an ontology from multidisciplinary knowledge is a challenge because it needs a number of various domain experts to collaborate in knowledge construction and verify the semantic meanings of the cross-domain concepts. Confusions and misinterpretations of concepts during knowledge creation are usually caused by having different perspectives and different business goals from different domain experts. In this paper, we propose a community-driven ontology-based application management (CD-OAM) framework that provides a collaborative environment with supporting features to enable collaborative knowledge creation. It can also reduce confusions and misinterpretations among domain stakeholders during knowledge construction process. We selected one of the multidisciplinary domains, which is Life Cycle Assessment (LCA) for our scenario-based knowledge construction. Constructing the LCA knowledge requires many concepts from various fields including environment protection, economic development, social development, etc. The output of this collaborative knowledge construction is called MLCA (multidisciplinary LCA) ontology. Based on our scenario-based experiment, it shows that CD-OAM framework can support the collaborative activities for MLCA knowledge construction and also reduce confusions and misinterpretations of cross-domain concepts that usually presents in general approach.

key words: *sematic web, ontology-based knowledge management, collaborative framework, multidisciplinary ontology development, life cycle assessment*

1. Introduction

Consuming more products not only have an effect in the environmental resource reductions but also cause many environmental impacts, such as the increase of carbon dioxide from industrialization can lead to having more greenhouse effect and global warming. To preserve and organize the resources, *Sustainable Development (SD)* [1] paradigm is proposed as a current trend in improving the sustainability of natural systems for meeting demand, both of economy and society. SD paradigm focuses on many aspects (domains), but three most essential aspects that SD has been discussed in many contexts are the aspects of economic development, social development, and environmental protection.

Life Cycle Assessment (*LCA*) [2] is one of the essential topics in SD paradigm, and it is used for identifying and quantifying levels of energy and materials used and released to the environment. LCA is also used for indicating carbon footprints through product life cycle. Although LCA knowledge is considered as an environmental protection domain of the SD paradigm, the knowledge has been adopted and used for other purposes, such as promoting environmentally friendly products. For the LCA in marketing and business domains, essential knowledge, called *Life Cycle Costing (LCC)*, is analyzing total cost of production's investment and promoting environmentally friendly products in a marketing plan. LCA and LCC domains are considered for achieving a business goal that concerns costing and environmental protection. The business owner and relevant stakeholders have to understand appropriately in multiple domains collaboration, which is related to LCA knowledge. Many stakeholders (e.g., a researcher) attempt to construct LCA knowledge for sharing their understanding, but the knowledge is represented from one perspective based on only environmental protection domain.

In this paper, we introduce a collaborative framework for facilitating stakeholders in knowledge construction of multiple domains. A framework provides a collaborative environment for supporting knowledge co-creation of different domain stakeholders (e.g., domain experts and knowledge engineers). Our integrated approach is introducing knowledge acquisition based on a combination of a collaborative scenario in knowledge management, which is learning from sources of knowledge, such as reference documents as ISO standard guideline, and shared ontologies [3].

Ontology development in the LCA domain has been constructed for performing different research or business purposes. F. Cappellaro et al. [4] and M. Braescher et al. [5] designed LCA ontology to represent ISO standard guidelines [6], [7]. B. Bertin et al. [8] designed another LCA ontology to represent a mathematical technique for presenting an application of electricity production processes, and E. Muñoz et al. [10] designed LCA ontology for business management. B. Sayan [9] attempted presented LCA domain in an open framework. For the LCA domain in our re-

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search approach, we published two LCA ontologies, namely Ontology-Enhanced Life Cycle Assessment (O-LCA) ontology [10] and Data Qualification for LCA (DQ-LCA) ontology [11]. O-LCA was our first ontology designing based on Description Logic language [12] that has the purpose to recommend alternative resources for cleaner technology. DQ-LCA is the second ontology that we improve the LCA knowledge for qualifying environmental data.

In order to employ domain ontologies for serving business applications, we can create a new ontology or modify/extend/reuse the existing domain ontologies. Notwithstanding the LCA ontologies, the difficulty of creating ontology or modifying/extending/reusing the existing ontology comes from the misinterpretations and confusions of semantic meanings of some terms (concepts) and their relationships from a different domain perspective. Selecting relevant ontologies and understanding the ontological structures are major challenges for domain stakeholders, especially for those who are inexperienced in working with domain ontology. For this reason, our research aim is to resolve those issues by introducing a framework supporting collaborative environment and features for both highly experienced and inexperienced stakeholders to create/modify/extend/reuse ontology.

To design our collaborative framework, the following challenges are taken into account including: (1) what is an approach supporting domain stakeholders to work with LCA ontologies, (2) how to understand ontological structure and discover an interrelation from LCA domain to other domains, and (3) how to encourage different domain stakeholders in participating and making agreements in different perspectives. Therefore, this paper presents a community-driven ontology-based application management (CD-OAM) framework that uses a collaborative approach to overcoming the research challenges.

Our approach seeks to overcome the challenges and thereby the rest of this paper is organized as follows. Section 2 defines a characteristic of multidisciplinary with an issue under the LCA domain. Section 3 next introduces a collaborative framework supporting knowledge construction, and describes a methodology of adaptive ontology development. Section 4 then explicates a collaborative use case scenario with roles and activities of stakeholders. Obstacles to traditional collaboration are discussed, and then we exploit our collaborative framework encouraging different stakeholders to work with a domain ontology. Last, Sect. 5 discusses and conclude by highlighting the contributions in each research challenge and providing with the future research directions.

2. Background and Related Work

2.1 Multidisciplinarity in Life Cycle Assessment

Based on the SD paradigm, *Life Cycle Assessment (LCA) [2]* is a branch of knowledge in an environmental protection aspect that is used to indicate an environmental impact. The LCA aspect could be crossed to other aspects, and it can overcome limitations of different stakeholder perspectives. For instance, crossing from an economic development aspect, the LCA knowledge could be used to explain the economic domain, such as *Life Cycle Costing (LCC)* that LCA to determine the most cost-effective among different competing alternatives in decision making through production life cycle.

However, only the LCA domain is a single discipline that could not cover clearly explanations to address a gap among different stakeholder perspectives. To understand the different domain perspective, we are taken a characteristic of *a multidisciplinary approach* [13], [14] into consideration in knowledge sharing. The approach involves drawing appropriately from multiple-disciplinary thinking to redefine problems outside normal boundaries and solve a complicated situation with solutions based on an understanding of different domain perspectives. Multiple perspectives are acquired for breakthrough their blind spots. Therefore, the multidisciplinary approach is selected to manipulate in multiple domains in different viewpoints of stakeholders.

Table 1 A comparison of LCA ontology development considering two criteria: sources of knowledge and cross-disciplinary domains.

Related Work	Resources of Knowledge	Cross-disciplinary Domain
F. Cappellaro et al. [4]	ISO14018	Industrial standards
M. Braescher et al. [5]	ISO14040, 14048	Follow-up of LCA
B. Bertin et al. [8]	ISO14040	Mathematic
E. Muñoz et al. [15]	ISO14040	Business management
B. Sayan [9]	ISO14040	Software development
A. Takhom et al. [10]	ISO14040, 14048	Cleaning technology
A. Takhom et al. [11]	ISO14040, 14048	Data qualification
S. El Kadiri [16], [17]	ISO14040, 14044	Life Cycle Costs

2.2 Previous Works on LCA Ontology Development

As illustrated in Table 1, many LCA ontologies based on Semantic Web approach [4] have been developed for explicating different domain perspectives. We summarize their characteristics by considering two criteria: resources of knowledge, and cross-disciplinary domains. First, LCA standard guidelines [6], [7] is the primary sources of knowledge that standardize principle, framework, and data document format through a family of best-practice procedures. Next, a cross-disciplinary domain is other domains that are applied to the LCA domain for achieving research plans.

The CASCADE [4] was the first LCA ontology designed by interpreting standard guidelines [7]. The ontology focused on data format aiming at accommodating standard development in design and manufacturing. A cross-disciplinary domain is representing industrial standards in an application of data conversion. The second ontology is LCAO [5] designed according to standard guideline [17] and considering the Follow-up of Life Cycle Assessment (FLCA) approach as a cross-disciplinary domain. Next, Bertin et al. [8] ontology was semantically ontology based on a case study of data management, and applied mathematical technique as a cross-disciplinary domain for data manipulation. Afterward, Muñoz et al. [15] designed the LCA ontology by considering enterprise resource management as a cross-disciplinary domain. The last one is an open source software (OSS) by B. Sayan [9] that presented LCA in linked data.

We have further examined LCA ontologies development and published elsewhere. Ontology-Enhanced Life Cycle Assessment (O-LCA) [10] was our first ontology based Description Logic (DL) [12]. The ontology was formalized by taking standard guidelines [6], [7], [18] into account in *Life Cycle Inventory (LCI)* and impact method (LCIA). As a cross-disciplinary domain, a recommender system was utilized an inferential ability for reducing environmental impact regarding a Cleaner Technology [19] approach. Lastly, we attempted to drawn across the LCA domain to data qualification and Data Qualification for LCA (DQ-LCA) ontology [11] represented in our second generation.

As aforementioned, this paper intends to overcome the challenge in elaborating collaboration of multidisciplinary knowledge and encourage different domain stakeholders to work with LCA ontologies. In the following section, we describe the development of an adaptive LCA ontology supporting multidisciplinarity knowledge.

3. Community-Driven Ontology-Based Application Management (CD-OAM)

3.1 A Collaborative Framework

With a rationale to support a collaboration of different stakeholders, *a community-driven ontology-based application management framework*, called *CD-OAM* [20], has been designed for willing every stakeholder to participate in the knowledge sharing and maintenance. The framework extends the canonical OAM Framework† [21] that we intend to simplify collaborative activities and support stakeholder's collaboration. Stakeholders can contribute their expertise in knowledge construction.

As depicted in Fig. 1, a system architecture represents five essential components designed for supporting collaborative activities consisting of a proposed framework, domain stakeholders, a knowledge base, database, and a web-based application. The framework provides two facilitating system features for knowledge acquisition and expansion, and details of each are as follows.

- **Knowledge Base** is a feature built from analyzed sources of knowledge (e.g. existing ontologies, guideline documents), as depicted in Fig. 2, and designed by domain experts. The feature consists of a visualization tool for representing a knowledge structure of a domain ontology and a discussion space for stakeholder collaboration.
- **Collaborative Knowledge Construction** facilitates processes of creating or updating concepts. Stakeholders can propose their understanding and make an agreement with other through this feature.

†OAM: An Ontology Application Management Framework (http://text.hlt.nectec.or.th/ontology).

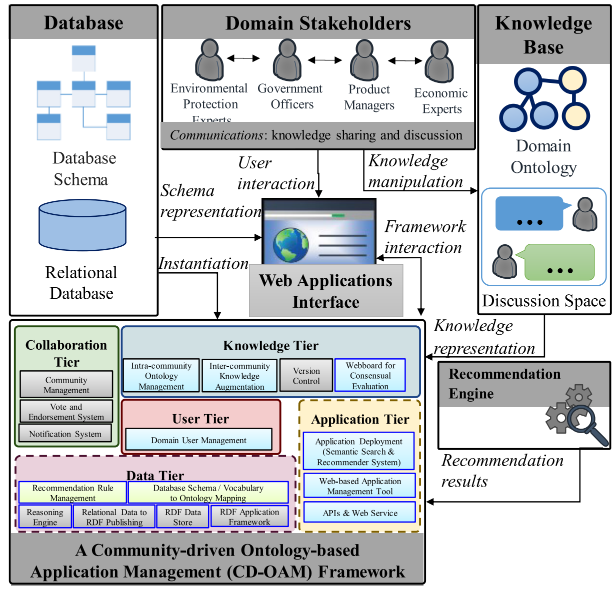


Fig. 1 A system architecture ofa community-driven ontology-based application management (CD-OAM) framework [20], [21].

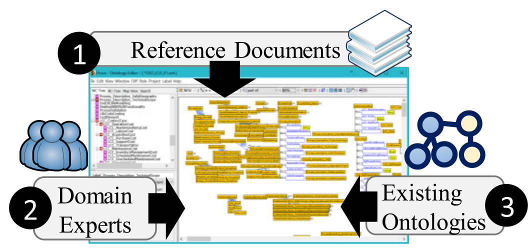


Fig. 2 Three sources of knowledge for ontology development.

3.2 Adaptive Ontology Development

Designing an adaptive ontology is a research challenge that we attempt to encourage domain stakeholders to work multidisciplinary knowledge. We carry on improving our LCA ontologies and appropriately designing for extending knowledge in particular domains.

In ontological engineering processes, Hozo [22] is the ontology editor that we choose to explicate and visualizes the ontological structure of the existing LCA ontologies, as mentioned in Sect. 2.2. Necessary concepts in different domains are distinguishably defined by related domain context, and we identify the relation the LCA concepts with other corresponding concepts.

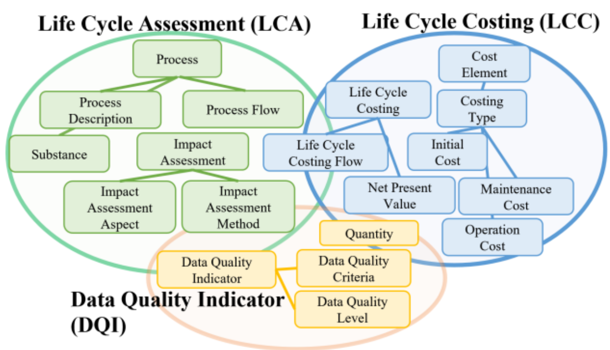


Fig. 3 An excerpt of three upper concepts in the MLCA ontology: 1) LCA concepts in a green circle, 2) LCC concepts in a blue circle and 3) DQI concepts in a yellow circle.

3.3 Ontological Engineering Processes

We design *a multidisciplinary LCA (MLCA) ontology* by analyzing characteristics of multidisciplinary knowledge in a domain of interest. An instruction of Noy and McGuinness [23] methodology provides us elaborative processes for the improving an adaptive LCA ontology as following instructions.

As illustrated in Fig. 2, three sources of knowledge are gathered as follows. First reference documents (1) are characteristics of multidisciplinary knowledge in the LCA domain, and the second source of knowledge, as domain experts (2) give comments and consults us in the ontological engineering processes. Lastly, existing LCA ontologies (3) are analyzed multidisciplinarity with our LCA ontologies (O-LCA and DQ-LCA ontologies) and re-used by considering a colligative ontology approach [24].

Moreover, we also survey other domains based on the SD paradigm, in this paper, LCC domain is chosen to elaborate benefits of multidisciplinary ontology in the following section. As literature in Sect. 2.2, we select LCC ontology, namely Product Life Cycle Management (PLM) Ontology [16], [17], to represent an efficient and convenient method for structuring and modeling the LCC domain in a case of manufacturing company. Therefore, a result of our adaptive ontology development is MLCA ontology containing 396 concepts, 21 concepts properties, 105 datatype properties, and 20 instances. As depicted in Fig. 3, the MLCA ontology is categorized upper concepts into three groups including 1) LCA concepts in a green circle, 2) LCC concepts in a blue circle, and 3) DQI concepts in a yellow group.

4. A Collaborative Use Case Scenario

4.1 A Collaborative Scenario

For capturing concepts in multidisciplinary knowledge, a collaborative scenario is illustrated a realistic situation instead of abstract statements by employing *Specification by Example (SBE)* [25] approach. The scenario of a business planning is introduced in a situation that requires knowledge sharing from different domain experts to find business solutions for achieving company goals. All domain experts are defined stakeholder roles based on their field expertise. Each stakeholder are explicated collaborative activities for drawing cross-disciplinary concepts. Therefore, we choose the SBE approach that is suitably to explain the a collaborative situation.

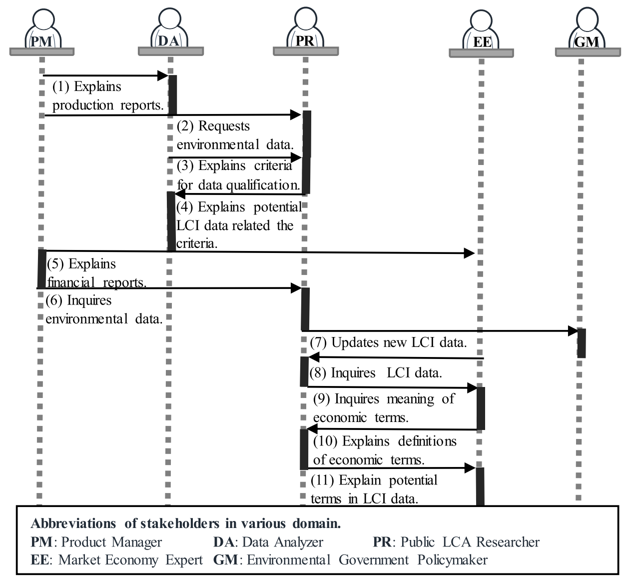


Fig. 4 A sequence diagram of a collaborative scenario.

The juice company aims to promote a new product, and they prepare a business plan before investing. Two major achievements are proposed as follows. The first achievement is taking the marketing advantages and defining criteria for expected outcomes including simplifying business decision, providing direction of the product marketing and taking their business completive advantages. The second achievement is promoting an environmentally friendly product by considering two criteria: 1) encouraging satisfiability from the consumer by adding eco-labelling, and 2) supporting sustainability in juice production.

In order to overcome both achievements, the company determines two objectives: 1) qualifying effective data from production reports and environmental data and 2) documenting life cycle costing analysis for environmental impact assessment and promoting eco-friendly products. The company has a collaborative meeting and invites relevant stakeholders in various fields of expertise including a product manager, a market economy expert, a data analyzer, and two government officers (an environmental government policymaker and a public LCA researcher).

4.2 Roles and Activities for Collaboration

As mentioned the scenario, Fig. 4 elaborate collaborative activities in a sequence diagram and all stakeholders are de-

Table 2 Process details of a collaborative scenario in each collaborative activities with communicating messages.

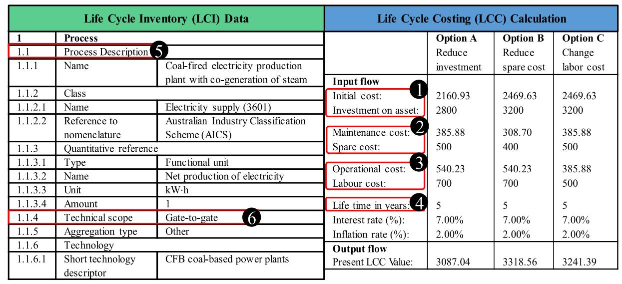
Process	Collaborative Activity	Message in Communication
(1)	PM explains production reports to DA.	"Our company can provide production reports."
(2)	DA requests environmental data from PR.	"We need to analyze the reports with your environmental data."
(3)	DA explains criteria for data qualification to PR.	"We can quantify the environmental data, and it has data that follows our criteria, such as location information."
(4)	PR explains potential LCA terms that relate with the criteria.	"I think LCI data defined criteria in data fields, such as geographical data."
(5)	PM explains financial reports to EE.	"Our company collected economic data in financial reports."
(6)	PM provides production reports to PR and inquires LCI data.	"Our production reports include related process information of company's production."
(7)	PR analyzes the production reports, and updates new LCI data to GM.	"We can analyze production reports with LCI data, and update results to government officers for claiming green labels."
(8)	EE inquiries LCI data in a part of production from PR to calculate LCC report.	"Our LCC study has economic terms: initial cost and operation and maintenance cost. Can we use process information in LCA data to understand investment on assets?"
(9)	PR inquiries meaning of economic terms from EE.	"I ensure the economic terms should be available in gate-to-gate of LCI data, and the process information only defines the process name and examples. Please give me more details.
(10)	EE explains definitions of economic terms to PR	"The initial cost is incurred during the design and construction process operation and maintenance cost. The term is data of maintenance and repair of real property, an operation of utilities, and provision of other services, such as labor cost, energy cost, raw material cost".
(11)	PR explain that the economic data are available in LCI, and inquiries EE again for making the same understanding.	"Do you mean gate-to-gate data in LCI? That is described in the technical scope of the process as your initial cost?"

fined their abbreviations and participant's roles.

We categorize the collaborative activities into two groups of stakeholders based on business objectives. The first group is a discussion in environmental data qualification with relevant data from a source of knowledge, such as production reports and environmental data. Stakeholders, who correspond in the first objective, are *a product manager (PM)*, *a data analyzer (DA)* and *a public LCA researcher (PR)*. The second group is documentation of *Life Cycle Costing (LCC)* analysis, and PM, PR, and a *market economic expert (EE)* are the stakeholders to achieve the second objective. In order to explain more details, Table 2 defines process numbers in each collaborative activity. From process number (1) to (11), collaborative activity mentions a message in communication between different domain stakeholders during their meeting.

Table 3 A comparison of terms between LCC and LCA domains.

LCC term	LCA term
Initial Cost Investment on the asset	Technical Scope Gate-to-gate
Operation Cost Employee commuting"	Technical Scope Gate-to-gate
Maintenance Cost Equipment storage rooms"	Technical Scope Gate-to-gate



Life Cycle Inventory (LCI) Data		
1	**Process**	
1.1	Process Description ❺	
1.1.1	Name	Coal-fired electricity production plant with co-generation of steam
1.1.2	Class	
1.1.2.1	Name	Electricity supply (3601)
1.1.2.2	Reference to nomenclature	Australian Industry Classification Scheme (AICS)
1.1.3	Quantitative reference	
1.1.3.1	Type	Functional unit
1.1.3.2	Name	Net production of electricity
1.1.3.3	Unit	kW·h
1.1.3.4	Amount	1
1.1.4	Technical scope	Gate-to-gate ❻
1.1.5	Aggregation type	Other
1.1.6	Technology	
1.1.6.1	Short technology descriptor	CFB coal-based power plants

Life Cycle Costing (LCC) Calculation			
	Option A Reduce investment	**Option B** Reduce spare cost	**Option C** Change labor cost
Input flow			
Initial cost: ❶	2160.93	2469.63	2469.63
Investment on asset:	2800	3200	3200
Maintenance cost: ❷	385.88	308.70	385.88
Spare cost:	500	400	500
Operational cost: ❸	540.23	540.23	385.88
Labour cost:	700	700	500
Life time in years: ❹	5	5	5
Interest rate (%):	7.00%	7.00%	7.00%
Inflation rate (%):	2.00%	2.00%	2.00%
Output flow			
Present LCC Value:	3087.04	3318.56	3241.39

Fig. 5 An example of misinterpretation of two different domains: Life Cycle Inventory (LCI) from ISO14048 [7] at the left, and Life Cycle Costing (LCC) calculation at the right.

4.3 Problem Recognition for Solving Misinterpretation

As illustrated in Fig. 4, this paper intent to address the problem of confusions and misinterpretations from collaborative activities. The problem can occur in the collaborative scenario. We separate the collaborative activities into two groups of stakeholders: the first group from the process (1) to (4), and the second group from the process (5) to (11). The problems are recognized when the stakeholders attempt to discuss and share their understanding with other participants. Based on background and expertise, each stakeholder guides other participants for achieving the objectives by using a general approach as follows.

In the first group, DA has to explain criteria for presenting representativeness of data quality qualification, such as technology, time, and geographical locations. After that, PM provides the production reports and requests DA to select relevant environmental data with PR. Based on their backgrounds, DA needs to know the quantitative data and PR need to identify specific types of data. Misinterpretation problems occur when they try to share information, as illustrated in Table 3 from the process (4) to (5). The problem of the first group can be a consequence of the problem to the second group as follows.

The second group discusses a relationship between two different domain by taking into consideration in LCI data and a case study of LCC calculation, as illustrated in Fig. 5. First, EE gives economic terms to PR from LCC calculation table at the right table, such as Initial cost (1), Maintenance cost (2), and Operational cost (3). Then EE interprets the economic terms that are described Process Description (5) in LCI data at the left table. Then PR tries to explain the economic terms for ensuring EE's perspective. The economic term should be identified in types of a process flow, Technical scope (6), in the LCI data at the left table, such as Gate-to-gate (6). To recognize their problem, EE who has the background in marketing and economics, need to know numbers in the production process by analyzing the financial data and an example of LCC calculation. Then PR share his experience in defining types of process and need to ensure that the economic data should be defined by technical scope (6). Therefore, in this situation, EE have different perspectives with PR that can lead them to misinterpretation problems. The economic terms from EE should not only consider with many terms of LCA aspect, but the terms also need to be interpreted by PR and agree in the same perspective.

Both discussion groups have problems of misinterpretation that mislead them to get confusion problems by crucial factors, such as different background and requirements in qualitative and quantitative data, or general and specific data. All the factors can be a cause when different stakeholders are having different background and requirements. To point out causes of the problems, this paper selects the second group to give more details in problem solving.

A comparison at Table 3 presents a traditional approach for solving misinterpretation problems. Stakeholders compare relevant terms to related domains and use them for explaining in the meeting. First, PR explains a definition of LCA terms: Technical scope and Gate-to-gat (6) that are described in the process of the operations covering the full life-cycle of a product [7]. However, EE ensures that LCC terms should relate to Process Description (5), and then tries to give more information for describing what kind of the process should be given a descriptive name, and its position in a classification system [7]. Lastly, they compare the terms of two different domains, as illustrated in Table 3. The economic terms (Initial cost, Operation cost, and maintenance cost) can be linked in Technical Scope. Therefore, EE and PR can understand their different perspectives that PR explains the LCA terms to EE and maps them to the LCC terms.

Although the traditional approach can solve the misinterpretation problems, this approach still lacks other important and relevant information such as data properties, information hierarchy, and priorities of terms, which are essential for finding the understanding of the terms. Thus, in this paper, we propose a framework that facilitates the stakeholders by providing a collaborative environment with domain ontology for solving misinterpretation problems.

4.4 Collaborative Framework Exploitations

As explained the scenario, misinterpretation problems can occur during collaborative activities. The intent of this paper is to support a collaboration of different stakeholder by introducing the CD-OAM framework. In order to reduce the problem, the framework provides a facilitating feature in knowledge-bases visualization based on Hozo [22] that is a graphical ontology editor. Knowledge of the stakeholders is represented in forms of domain concepts and concept properties.

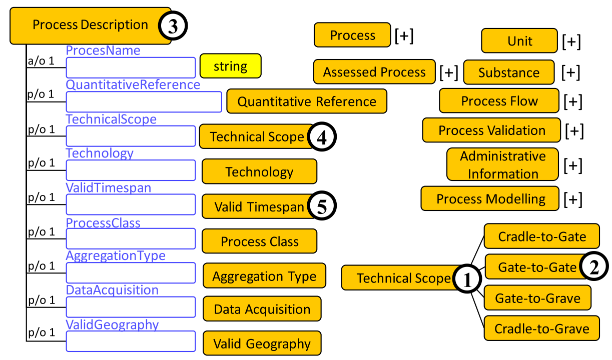


Fig. 6 The MLCA ontology: LCA concepts and concepts hierarchy

As described in the scenario, different stakeholders can overcome their problems by taking into account in an ontological structure that the MLCA ontology covers three domains: LCA, LCC, and DQI. As illustrated in Fig. 5, LCA domain is first analyzing in the employment of existing domain ontology. We extract keywords from Table 2 that have messages in the collaborative activities.

In the second group, PR mentions Gate-to-gate at the process (9) of Table 2 that the LCA terms can be identified the concept by the CD-OAM framework visualizes LCA concepts and concepts hierarchy as follows.

- First, PR can understand that *"Technical Scope"* concept (1) is a parent concept of *"Gate-to-Gate"* concept (2) that is a type or the scope of the studied system. Then, process description (6) in Fig. 6 is a cause of confusion during EE and PR discussion.
- Second, *"Process Description"* concept (3) in Fig. 6 can use to define employee commuting (3) in Fig. 5 by using a subsidiary concept, *"process_name"* concept in Fig. 6.
- Third, concept properties of *"Process Description"* concept can define concepts roles for *"Technical Scope"* concept (4), and "*Valid TimeSpan"* concept (5) in Fig. 6. Concerning a cross-disciplinary concept, the concept properties of "*Process Description"* concept (6) in Fig. 6 can interlinks to the LCC domain in life time in years.
- Finally, they can understand lifetime of a process by the "*Valid Timespan"* concept (5) in Fig. 6.

After understanding an ontological structure in LCA domain, we employ ontological engineering processes for interlinking the LCA concepts with an expected economic keyword at in process (6) of Table 2.

In this problem-solving process, existing LCC domain ontologies are considered as the first source of knowledge that we use LCC concepts from PLM Ontology [16], [17]. The LCC concepts are used to extend the MLCA ontology. Next, reference documents are the second source of knowledge that we consider an example of the LCC calculation (the right table of Fig. 5). With the result of the ontologi-

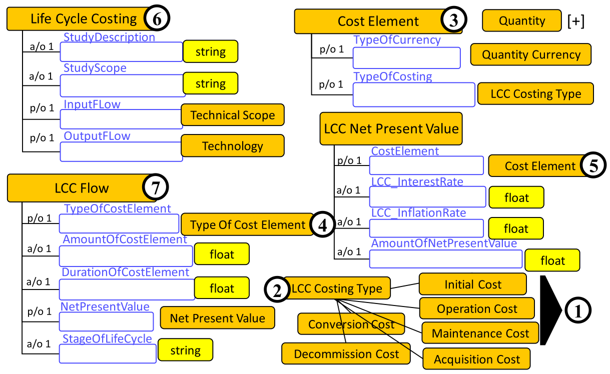


Fig. 7 The MLCA ontology: LCC concepts and concepts hierarchy.

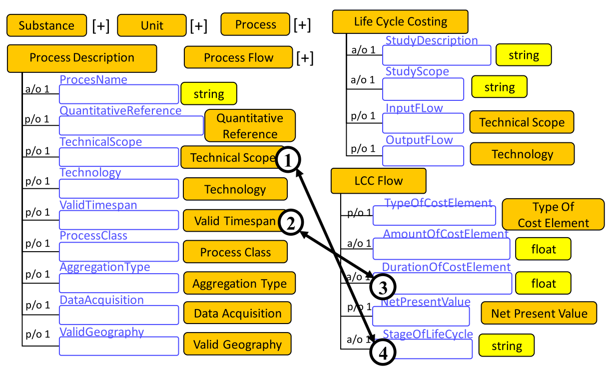


Fig. 8 Excerpt of the MLCA ontology: two areas are highlighted an interrelation from an environmental protection aspect to an economic aspect: from LCA concept properties to the LCC concept properties

cal engineering processes, EE can identify the LCC terms as follows.

- First, EE mentioned the LCC terms in the process (8) in Table 2, can be identified by considering the extended LCC concepts of the MLCA ontology. The LCC term including Initial cost, Operation cost and Maintenance Cost, are available in a subsidiary concept of *"Costing-Type"* concept (1) (2) in Fig. 7.
- Second, by the result of analyzing the reference documents, we conceptualize *"LifeCycleCosting"* concept (7) in Fig. 7 that has concept roles as *"LCC_Flow"* concepts (7). Each LCC flow is defined the *"CostElement"* concept (2) that has a concept role as the *"Costing-Type"* concept (3) in Fig. 7 for identifying a type of currency.

With the result of ontological engineering processing, we can interlinked between LCA and LCC domains by using the MLCA ontology. We consider each flow of LCC calculation that can use object properties from the LCA concepts as follows:

- First, a concept property of "*LCC_Flow*" concept (3) in Fig. 8 has a concept role for defining durations of the product, *"DurationOfCostElement*." We can share the *"ValidTimeSpan"* Concept (2) in Fig. 8 as an object property of the "*LCC_Flow*" concept, because both concepts have the same roles, as a cross-disciplinary concept, that describe time span during which the model of the process may be valid (e.g., five-year validation cycle) [7].
- Second, for a concept property of "*LCC_Flow*" concept, *"StageOfLifeCycle"* concept (4) in Fig. 8 has a concept role for defining input and output flows in the LCC calculation. We can share *"TechnicalScope"* concept (1) in Fig. 8 as an object property of *LCC_Flow*" concept, because both concepts have the same role, as a cross-disciplinary concept, that identifies several operations covering the full lifecycle of a product (e.g., "gate-to-gate") [7].

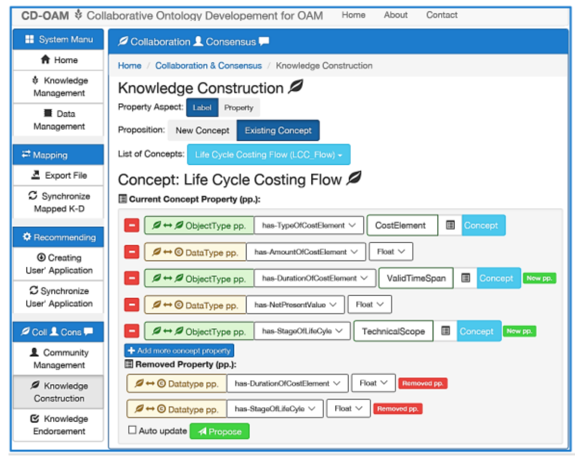


Fig. 9 A knowledge construction system from CD-OAM framework supporting domain ontology incorporation

Finally, the framework can support PR to identify and explain LCA concept, and EE can recognize and identify parts of LCC data. Moreover, the CD-OAM framework provides one more facilitating feature, a knowledge construction system, supporting in knowledge construction. EE and PR can propose an interrelationship of LCA to LCC concepts from their discussion result to other participants to make an agreement by employing the MLCA ontology. The system can update the existing concepts and propose for community consensus, as follows.

As illustrated in Fig. 9 the "*LCC_Flow*" concept of the MLCA ontology is first presented with its property aspect in a label, "*Life Cycle Costing (LCC_Flow)*." Next, their can update an "*existing concept"* option at the *proposition* panel. Then, the concept properties, "*DurationOfCostElement*" and "*StageOfLifeCycle*," are removed by clicking on minus signs. In order to add new concept properties from LCA domain, as cross-disciplinary domain, we click the "*add more concept property*" option, and then concept properties, "*ValidTimeSpan*" and the "*TechnicalScope*," are interlinked to the "*LCC_Flow*" concept. The updated concept properties are remarked as the new concept property, *New pp*. Finally, the "*LCC_Flow*" concept is proposed by clicking the "propose" button for making a consensus.

As a result of the scenario, two different domains

Concept in stakeholder perspectives

“Process Description” Concept in EE’s perspective

```
<owl:Class rdf:ID="Process">
 <rdfs:label>Process</rdfs:label>
   <rdfs:subClassOf><owl:Restriction>
  <owl:onProperty rdf:resource=
               "#has_ProcessDescription" />
   <owl:allValuesFrom rdf:resource=
            "#Process_Description" />
   </owl:Restriction></rdfs:subClassOf>
</owl:Class>
```

“Technical Scope” Concept in PR’s perspective

```
<owl:Class rdf:ID=
"Process_Description_TechnicalScope">
 <rdfs:label>Technical Scope</rdfs:label>
</owl:Class>

<owl:Class rdf:ID="Gate-to-Gate">
 <rdfs:label>Gate-to-Gate</rdfs:label>
 <rdfs:subClassOf rdf:resource=
"#Process_Description_TechnicalScope"/>
</owl:Class>
```

Shared concept properties of LCA and LCC domains

```
<owl:Class rdf:ID="Process_Description">
 <rdfs:label>Process Description</rdfs:label>
  <rdfs:subClassOf><owl:Restriction>
<owl:onPropertyrdf:resource=
     "#has_TechnicalScope" />
   <owl:allValuesFrom rdf:resource=
      "#Process_Description_TechnicalScope" />
   </owl:Restriction></rdfs:subClassOf>
</owl:Class>
< owl:Class rdf:ID=
      "Process_Description_TechnicalScope">
  <rdfs:label>Technical Scope</rdfs:label>
</ owl:Class >
< owl:Class rdf:ID="Gate-to-Gate">
  <rdfs:label>Gate-to-Gate</rdfs:label>
  <rdfs:subClassOf rdf:resource=
      "#Process_Description_TechnicalScope" />
</ owl:Class >

< owl:Class rdf:ID="LCC_Flow">
  <rdfs:label>LCC Flow</rdfs:label>
  <rdfs:subClassOf><owl:Restriction>
   <owl:onProperty rdf:resource=
      "#has_DurationOfCostElement" />
      <owl:allValuesFrom rdf:resource=
      "#Process_Description_ValidTimeSpan" />
    </owl:Restriction></rdfs:subClassOf>
  <rdfs:subClassOf><owl:Restriction>
   <owl:onProperty rdf:resource=
      "#has_StageOfLifeCycle" />
   <owl:allValuesFrom rdf:resource=
      "#Process_Description_TechnicalScope" />
    </owl:Restriction></rdfs:subClassOf>
</ owl:Class >
```

Fig. 10 Excerpt of Web Ontology Language (OWL) [26] to represent relevant concepts in different perspective and whole concept.

are shared concept roles. An interrelation between LCA and LCC domains is represented in the W3C Web Ontology Language (OWL) [26] that expresses multidisciplinary knowledge in groups of multiple domains and relations between them, as illustrated in Fig. 10.

As presented in our approach, not only the framework is supporting in a collaboration of two different domains, such as LCA and DQI, or LCA and LCC, another relevant domain can also employ the CD-OAM framework for solving misinterpretation problem. For example in a political domain, a policy maker who has a specific agenda may need to see the overview of the knowledge, but the LCA researcher who has a specific aspect in environmental data analysis. Misinterpretation problem can occur when two different backgrounds. Therefore, to reduce the problem, the CD-OAM framework is a supplemental system for encouraging their collaboration.

5. Discussion and Conclusion

In this paper, we introduce a community-driven ontology-based application management (CD-OAM) framework encouraging different domain stakeholder to work with multidisciplinary knowledge. Our research approach attempted to overcome three main challenges in ontology creation. The first challenge is to introduce a collaborative approach allowing stakeholders to create/modify/extend/reuse the MLCA ontology and to present their understanding of cross-domain concepts. Second, the CD-OAM framework provides visualizations to support stakeholders to learn and explore the ontological structure and to discover interrelationships between LCA and LCC domains. Third, we demonstrate well-defined processes for overcoming confusion and misinterpretation problems that occurred during collaborative activities. To overcome such problems, stakeholders can use our framework to explore and analyze concepts, relationships and structure of the ontologies in order to make an agreement on new or modified concepts and their relationships. We elaborate problem situation in a collaborative scenario and illustrate how the framework can reduce confusion and misinterpretation problems, the framework can be used in other domains for reducing confusion and misinterpretation problems.

In future work, we aim to incorporate conflict detection and concept similarity into the knowledge augmentation module for enhancing collaborative capabilities of the framework.

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