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

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Doctoral Dissertation

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

By

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Abstract

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A Scenario-based Knowledge Construction System in Life Cycle Assessment

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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. The dissertation proposes *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. I 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.

Keyword: Multidisciplinary Knowledge, User-adaptive Ontology, Life Cycle Assessment, Ontology-based Knowledge Management, Collaborative Framework

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Glossary and Terminology

Glossary	Terminology
ISO	An acronym for International Organization for Standardization.
LCI	An acronym for – Life Cycle Inventory.
LCA	An acronym for Life Cycle Assessment.
LCIA	An acronym for Life Cycle Impact Assessment.
LCC	An acronym for Life Cycle Costing.
DQI	An acronym for Data Qualification Indicator.

Chapter 1

Introduction

Multiple-domain collaboration is a challenging task in knowledge engineering. To achieve a particular goal through collaboration, participants contribute their domain expertise through a lengthy discussion. Misunderstanding in such communication context is quite common when some terms are shared in more than one domain, causing two significant problems: (1) lexical ambiguity and (2) misleading semantics. Some of these terms do have separate meanings, while the rest share their meanings across domains in some degree. Therefore, recognition of these terms during the discussion will significantly reduce the chance of misunderstanding in multidisciplinary knowledge collaboration.

To cope with the challenging task, this research has an aim to provide a collaborative framework for supporting multidisciplinary communication of different stakeholders. Two essential functions are designed and conducted for addressing the problems into two functional parts of the collaborative framework: (1) a communicative function for recognizing lexical ambiguity, and (2) a collaborative function for avoiding misleading semantic. The conceptualization of knowledge enhances interoperability between these two functions and its processing within the collaborative framework, called a multidisciplinary domain ontology, and roles of these two functions are designed as follows: the communicative function has a role in reducing ambiguity in communication of stakeholder, and the collaborative function has a role in facilitating stakeholder to identify misleading concepts and to propose a new understanding in collaborative communication to a domain-specific community. Therefore, in this research approach, these designed two functions of a collaboration framework have particularly response in the necessary roles to interoperate the multidisciplinary knowledge

These two essential parts of the collaboration framework have proceeded in order to overcome the challenging task. This dissertation has mainly focused on the collaborative function overcoming misleading semantics in the second part. Then the first part in overcoming lexical ambiguity has been conducted in another research, and in this dissertation, the communicative function is used to present clarification of multidisciplinarity in a domain-specific knowledge. Therefore, the collaborative framework in this dissertation presents the collaborative function supporting multidisciplinary knowledge collaboration to interoperate with stakeholders by employing the multidisciplinary domain ontology, and to points out an alternative solution for solving miscommunication, causing by sending a cross-domain unawareness concept and receiving a misinterpretation concept.

Figure 1 The United Nations Educational, Scientific and Cultural Organization (UNESCO)[1] and adopted the Sustainable Development Goals (SDGs).

In the domain of sustainability science (Gruen et al., 2008), multiple disciplines have been proposed, as a current trend in improving the sustainability of natural systems for meeting demand, both of economy and society. A paradigm of Sustainable Development (SD) (European Union, 2010) has relevant disciplines based on three primary aspects: environmental protection, economic growth, and human development, as illustrated in Figure 1.

[1] The United Nations Educational, Scientific and Cultural Organization (UNESCO), (https://en.unesco.org/sdgs)

Regarding the multidisciplinary knowledge, the SD paradigm is an emergence of environmental management and preservation in different aspects (e.g., nature and society) that require the understanding of the fundamental characteristics. For example, a study of Life Cycle Assessment (LCA) could be used to explain how to calculate and manage the environmental resources through knowledge of an economic aspect, called Life Cycle Costing (LCC) (Milicic, Perdikakis, Kadiri, & Kiritsis, 2013). However, only the LCA knowledge cannot clearly explain for addressing the blind spot among LCA and LCC stakeholder perspectives, such as a problem of misinterpretation.

In order to understand stakeholder's perspectives and recognizing miscommunication problems, this research takes a term of *multidisciplinary knowledge* (Alvargonzález, 2011) into account in multiple perspectives of stakeholders, a blind spot (Holsapple & Joshi, 2002), because the knowledge sharing (T. Gruber, 1991) has a limitation within domain boundaries. Then, employing the multiple disciplines could be difficult for verification of an understanding of different perspectives. In this situation where stakeholder can contribute their knowledge for achieving collaborative goals, they need to share their knowledge through their communication to make an understanding, and other participants also follow these collaborative activities. Then a solution will be provided for a collaborative problem depending on their roles. However, misunderstanding can occur in their communication contexts consisting of a common term that mislead and has ambiguous semantics. Although the participants can recognize misleading terms, clarification of meaning and relevant knowledge is a difficulty when they express their understanding by contexts with existing multiple-domain terms that they are possible to separate meaning or to be shared as multidisciplinary knowledge.

For performing different research or business purposes, ontology development in the LCA domain has been constructed (Cappellaro, Masoni, Moreno, & Scalbi, 2002; M. Braescher and F. Monteiro and A. Silva, 2007; Muñoz, Capón-García, Laínez, Espuña, & Puigjaner, 2013; Takhom, 2013; Takhom, Ikeda, Suntisrivaraporn, & Supnithi, 2015) by interpreting ISO standard guidelines (International Organization for Standardization, 2002, 2006a). The research approach intends to establish domain ontology for serving business applications. Notwithstanding the LCA ontologies, the difficulty of manipulating domain ontologies 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 research challenge for domain stakeholders, especially for those who are inexperienced in working with domain ontology.

With the reason to overcome the research challenge, this research approach takes characteristics of a multidisciplinary approach (Alvargonzález, 2011; Bernard & Anita, 2006) into consideration in knowledge sharing and co-creation, and the understanding of the different domain perspectives. Therefore, breakthrough the blind spots of multiple perspectives, this research considers the multidisciplinary knowledge to manipulate in various domains in different viewpoints of stakeholders and intends to draw multiple-disciplinary thinking appropriately with problems outside normal boundaries and redefine cross-domain concepts.

1.1. Background of Research

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, SD paradigm (European Union, 2010) is proposed as a current trend in improving the sustainability of natural systems for meeting demand, both of economy and society. As depicted in Figure 1, 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) (Ciroth, 2007) 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 the 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.

1.2. Research Motivations and Problem Statements

The research introduces a collaborative framework for stakeholder's facilitation in knowledge construction of multiple domains. The framework provides a collaborative environment for supporting knowledge co-creation of different domain stakeholders (e.g., domain experts and knowledge engineers). An integrated approach of this study 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 (Horrocks, 2008).

Ontology development in the LCA domain has been constructed for performing different research or business purposes. Cappellaro et al. (Cappellaro et al., 2002) and Braescher et al. (M. Braescher and F. Monteiro and A. Silva, 2007) designed LCA ontology to represent ISO standard guidelines(International Organization for Standardization, 2002, 2006a). B. Bertin et al. (Bertin et al., 2012) designed another LCA ontology to represent a mathematical technique for presenting an application of electricity production processes, and E. Muñoz et al. (Muñoz et al., 2013) designed LCA ontology for business management. B. Sayan (Sayan, 2011) attempted presented LCA domain in an open framework. For the LCA domain in our research approach, we published two LCA ontologies, namely Ontology-Enhanced Life Cycle Assessment (O-LCA) ontology (Takhom, 2013) and Data Qualification for LCA (DQ-LCA) ontology (Takhom et al., 2015). O-LCA was our first ontology designing based on Description Logic language (Baader, Horrocks, & Sattler, 2004) that has the purpose of recommending 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 significant 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. Therefore, the research challenges are taken into account in designing the collaborative framework supporting activities of different stakeholders.

1.3. Research Objectives and Scopes

The goal of this research is enhancing interoperability of the multidisciplinary knowledge for relevant stakeholders in a domain-specific knowledge, especially in LCA domain, and supporting collaborative activities of the stakeholders by providing a collaborative environment. Therefore, objectives of this research are defined, as follows:

- To conceptualize a user-adaptive ontology for supporting multidisciplinary-domain knowledge existing an ontology curation system, which encourages activities of different domain stakeholders, in a collaborative situation.

- To provide a collaborative framework to enhance community-driven ontology-based application management (CD-OAM).

- To test the CD-OAM framework to work with MLCA ontology by qualitative evaluation in use case scenarios.

Concretely, for finding evidence of an existence of cross-domain in LCA domain, the research conducted a pilot study by taking into consideration in an approach of network text analysis (Diesner & Carley, 2004). Therefore, as a preliminary experiment, a pilot study has defined five subgoals, as follows:

1) *To identify sources of knowledge*: domain-specific data are surveyed sources of data and facilitating tool for data collections and handling. In a preliminary experiment, the sampling data are reviewed, such as from discussion contexts in forums of a community in environmental science.

2) *To propose pre-processing scripts for manipulating sources of knowledge*: we consider Python, a scripting language for natural language processing, such as extracting data, removing stop words, and mapping co-occurrence concepts.

3) *To propose of a cross-disciplinary codebook*: the research manipulates post-processing data based on a qualitative approach. The codebook is generated for supporting in classifying the co-occurrence concepts and analyze in multidisciplinarity of relevant domain knowledge.

4) *To establish the semantic network*: The collected data are used to generate a graph visualization for discovering and analyzing conceptual knowledge in a co-occurrence network.

5) *To evaluate the finding result*: cross-disciplinary concepts are assessed in a quantitative evaluation.

1.4. Contributions and Originalities

As mentioned the research questions, this dissertation proposes a collaborative framework based on community-driven ontology-based application management (CD-OAM) to overcome the research challenges. Therefore, the unique points of the research, extent of the research, and expected impact of the study are described as follows.

1.4.1. The unique points of the research

The unique points of the research aimed at the following novelties:

- A methodology in this dissertation is to analyze multiple-domain knowledge, and conceptualize multidisciplinary LCA domain ontology, underlying a paradigm of Sustainable Development.

- A multidisciplinary LCA ontology for interoperability cross-disciplinary concepts in a collaborative situation.

- Enhanced a collaborative capability for a collaborative framework based on community-driven ontology-based application management (CD-OAM).

1.4.2. Extent of the Research

Regarding these research objectives, the research intends to enhance a collaborative capability for the ontology-based application management (OAM) Framework (Buranarach, Thein, &

Supnithi, 2013), as a community-driven development platform of multidisciplinary Ontology. The collaborative framework of this research offers the following extent:

- To conceptualize the multidisciplinary LCA domain knowledge,
- To analyze sources of LCA domain knowledge: international standard guideline and critical case studies,
- To collaborate with stakeholders that are knowledgeable participators in providing insightful information, suggesting and verifying the finding concepts and relations,
- To demonstrate exploitation of cross-disciplinary concepts. The benefits of employing multidisciplinary domain ontologies is to use a collaborative framework for ontology development and carry out collaborative scenarios, and
- To support stakeholders to consolidate LCA knowledge in term of domain ontology underlying SD paradigm.

1.4.3. Expected impact of the research

The research approach attempts to enhance stakeholders in working with computer side by side (Horrocks, 2008). Knowledge representation of this research follows an ontology-based approach (Horridge & Bechhofer, 2011) in domain ontology development for multidisciplinary knowledge. The knowledge is analyzed and conceptualized by considering relevant domain knowledge because transferring knowledge of the relevant stakeholder's community is a laborious task requiring close collaborative activates among domain experts.

Although domain ontologies have been designed for adopting a variety of research activities, acquisition of comprehensive knowledge requires a steep learning curve from novices/practitioners. Therefore, expected impacts of the research have an intention to shorten the learning curve and to enhance a collaborative capability in knowledge construction.

Moreover, in human society, expected impacts of the research are contributions in a deeper understanding of the multidisciplinary knowledge, and inclusive participation engages and empowers a domain-specific community in sustainable knowledge, especially in environmental protection.

1.5. Organization and Contents

As depicted in Figure 2, this dissertation is organized structure and contents into six chapter, and details of each chapter are briefly explained as follows;

'Chapter 2: Background and Literature Review' introduces multidisciplinary knowledge including a paradigm of Sustainable Development (SD) and multidisciplinarity of Life Cycle Assessment (LCA) domain. Knowledge representation in the next section is explained regarding a semantic approach in order to develop domain ontologies and a collaborative approach for constructing the knowledge. The ontology is the language used to conceptualize knowledge from domain experts by explicit representation in a set of concepts and relations. Then, a collaborative approach is considered in ontology development. Afterward, related works on LCA domain ontologies and multidisciplinary aspects are reviewed, and the existence of ontology development frameworks based on a collaborative approach are defined features and limitations. The last section summarizes this research approach.

'Chapter 3: Research Methodology' purposes to present a methodology of this study. First, research approach and a pilot study are explained by two methods: a collaborative approach and a network perspective for discovering multidisciplinary knowledge. Next, the research approach is design and set by considering study population, sampling, and data-collection instrument. After that, the collected data are analyzed and formulated the hypothesis. The last section summarizes the research methodology and the research approach.

'Chapter 4: A Collaborative Framework' presents a collaborative framework including community-driven ontology-based application management, system design, and development. Based on the OAM framework in two tiers (data tier and application tier), this chapter next describes collaborative features in three tiers: collaboration tier, knowledge tier, and user tier. Then, development of a user-adaptive ontology is described knowledge elicitation, visualization by using the ontology editor, and ontological engineering processes. The last section summarizes the collaborative framework with the development of the user-adaptive ontology.

'Chapter 5: Collaborative Use Case Scenarios' introduces collaborative use case studies for a paradigm regarding multidisciplinarity knowledge. Next, each stakeholder is defined roles and activates in a collaborative situation, and the following section explains problem recognition and a solution for reducing misinterpretation problem. After that, the collaborative framework is exploited with the scenarios and demonstrated a scenario-based recommender system. The last section summarizes two use case scenarios, the problem of misinterpretation and exploitations of a collaborative framework.

'Chapter 6: Discussions, Conclusions, and Recommendations' explains an evaluation of the research findings including the questionnaire results and the collaborative use case scenarios based on user interaction in the collaborative framework. The following section discusses the experimental results from exploiting the collaborative framework. The last section summarizes research contributions and recommendations for future work.

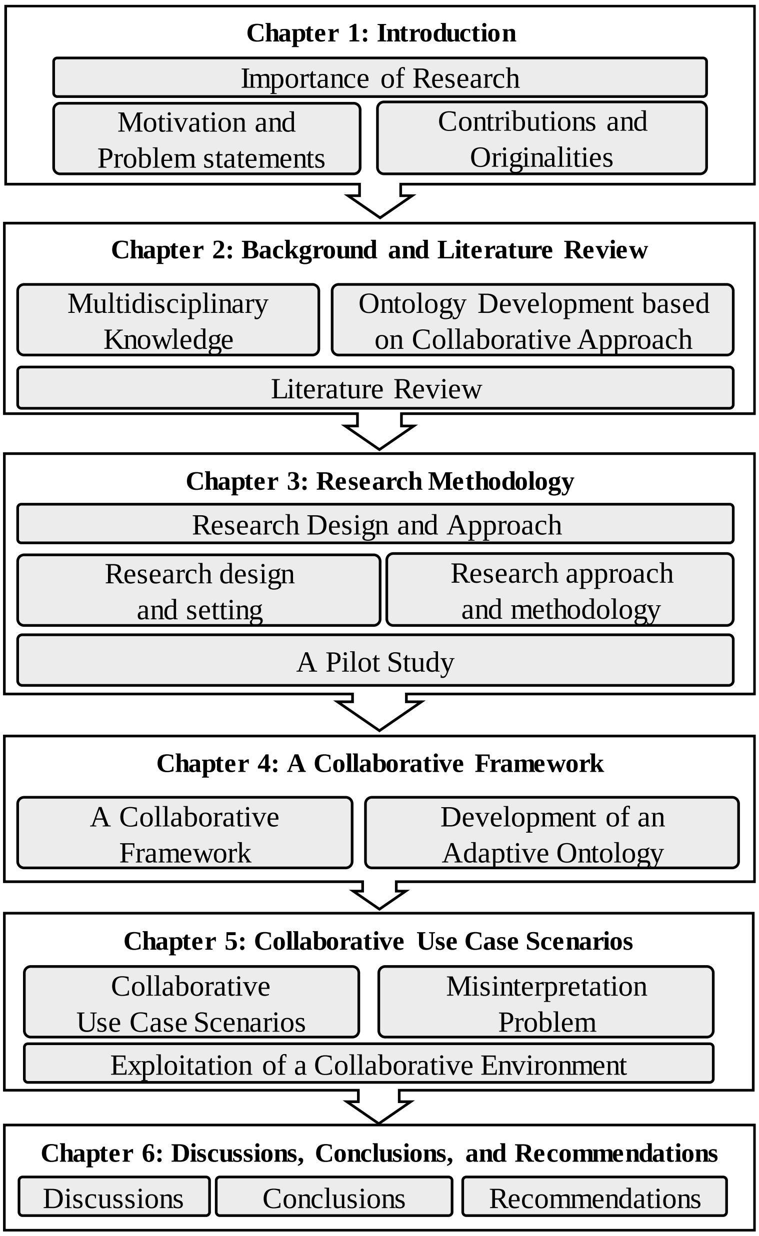

Figure 2 Dissertation Organization.

Chapter 2

Background and Literature Review

This chapter first introduces multidisciplinary knowledge by considering a paradigm of Sustainable Development (SD). The paradigm has characteristics of the knowledge involving multiple disciplines, especially in an environmental domain, called Life Cycle Assessment (LCA). In representing domain knowledge, a semantic approach is exploited for representing in next section. The ontology is the language used to conceptualize knowledge from domain experts by explicit representation in a set of concepts and relations. Related works on LCA ontologies are then reviewed and considered existing multiple-disciplines. Afterward, a collaborative approach is considered in enhancing ontology development. Existing LCA ontologies are defined by their features and limitations in a collaborative capability. Finally, the chapter summary remarks the research challenges in features and limitations of LCA ontologies with the collaborative approach.

2.1. Multidisciplinary Knowledge and Construction Approaches

As the attempt to discuss the reasons for a relationship between science (Alvargonzález, 2011), four different terminologies are taken into account in the meaning of the word '*discipline*' with its cognates.

This study intends to give reasons in support of an approach, typically with the aim of persuading to share knowledge and understanding in stakeholder perspectives. The word 'discipline' means a branch of knowledge, in the sense of using the word 'multidisciplinary.' Thus, the 'discipline' is a body of knowledge or skill that can be taught and learned.

As a social relationship, the word '*discipline*' is a core process between teachers and learners in the process of knowledge sharing. The discipline can become from technique, arts, skills, rhetoric, theology, and philosophy in a suitable situation., three knowledge establishments (Bernard & Anita, 2006) are clarified to analyze characteristics of interchanging knowledge, as follows:

1. *Multidisciplinary* is to draw on knowledge from different disciplines but stay within their boundaries.

2. *Interdisciplinary* is to analyze, synthesize and harmonize links between disciplines into a coordinated and coherent whole.

3. *Transdisciplinary* is to integrate the natural, social, and health science in a humanities context and transcends their traditional boundaries.

In this study, two additional disciplines based on (Jensenius, 2012) are used to describe an interrelation of the different disciplinarities regarding the multiple-domain problems. Five different types of discipline are described, as follows:

1. *Intradisciplinary*: working within a single discipline.

2. *Cross-disciplinary*: viewing one discipline from the perspective of another.

3. *Multidisciplinary*: people from different disciplines working together, each drawing on their disciplinary knowledge.

4. *Interdisciplinary*: integrating knowledge and methods from different disciplines, using a real synthesis of approaches.

5. *Transdisciplinary*: creating a unity of intellectual frameworks beyond the disciplinary perspectives.

The extended representation based on Jensenius have been used to describe different disciplinarities and clarify characteristics of an interrelation both of multidisciplinary and cross-disciplinary with other disciplinaries. The interrelation of the different disciplinarities has been considered in the meaning of the various disciplinarities. Taylor et al. (Taylor, Schwaibold, & Watson, 2015) considered the various disciplinarities in processes of team selection and development of the curriculum and discussed dealing with the academic. Next, Gardner (Gardner, 2017) addressed an issue of educational courses that students and educator can take advantage of a cross-disciplinary education that requires the collaboration of different academicals boundaries.

Two important terms are used to analyze characteristics of multiple-domain knowledge and interrelation between multidisciplinary and cross-disciplinary. Activities associated with different domain experts have determined the multiple-domain knowledge existing in their collaborative project. For this research study, therefore, the term '*multidisciplinary*' is the first chosen discipline that is an appropriate word for clarifying characteristics of specific-domain knowledge. The multidisciplinary means the people from different disciplines and professions join and make up the knowledge in a multidisciplinary community. Second, to identify a relation within the major domain, the term '*cross-disciplinary*' is to view one discipline from the perspective of another to understand the relation drawing to other knowledge boundaries. The cross-disciplinary is to determine in clarifying a crossing relation of two different domains underlying a paradigm of multidisciplinary knowledge. This term is used to analyze different perspectives of stakeholders.

For example, in a situation that stakeholder who has different disciplines working together, the multidisciplinary knowledge refers to their collaboration based on their disciplines. Under the same goal, viewing of different perspectives means to compresence a concept for cross-disciplinary to achieve new insight and to share similar epistemological assumptions in a complex problem or issue.

In other words, only a single discipline could not cover explanations to address *a gap* among the different perspective. Therefore, using knowledge from different domain has independent bodies. The different stakeholder needs to share their understanding when the single discipline does not cover the other relevant knowledge.

Several studies have been applied the multidisciplinary knowledge for solving problems and supporting an understanding of a collaboration between different domains as follows. In education fields, the approach (Chaudhry & Higgins, 2003) were extensive to find knowledge associated with curriculum involving academic disciplines of business, computing, and information, and to construct education programs. Next, in other circumstances, Heinrich et al. 2005 identified polyphenol contents by considering multidisciplinarity in nutraceuticals knowledge. Using antioxidants relies on the following cross-disciplinary knowledge: pharmacology, nutritional science, and anthropology.

In this research approach, multidisciplinarity in environmental science is our domain of interest involving many aspects of circumstance. A case of preserving environmental resources for future generation, *Sustainable Development* (*SD*) (European Union, 2010), is a paradigm that is a kind of multidisciplinary knowledge focusing more on three crucial aspects: economic development, social development, and environmental protection. Using the term 'SD' sometimes cannot cover explanations to address a gap among different stakeholder perspectives. The paradigm can be considered in a characteristic of multidisciplinarity (Alvargonzález, 2011; Bernard & Anita, 2006) in order to understand other related aspects, for example, how to share knowledge from different domain perspectives.

This research 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*. This study determines the multidisciplinary approach to manipulate in multiple domains in different viewpoints of stakeholders. Therefore, the multidisciplinary knowledge is the crucial term in this research. Many of the knowledge related to the research interest are intertwined in multiple-domain knowledge. Investigation of cross-disciplinary concepts existing in domain contexts is interested in knowledge construction.

2.1.1. A paradigm of Sustainable Development (SD)

As aforementioned in the previous section, an understanding of the fundamental characteristics of an interaction between nature and society is the importance of emerging environmental management and preservation concerning sustainability sciences (Gruen et al., 2008). The term *Sustainable Development* (SD) is to take current human needs of the Earth's limited resources into consideration in balancing technological advancement with the environmental survivability of future generations.

In an aspect of an *environmental impact assessment* (*EIA*), a domain knowledge in multidisciplinarity of the SD paradigm is *Life Cycle Assessment* (*LCA*). Knowledge of LCA is employed as the methodology of EIA that identifies, quantifies energy and materials used and released to the environment, and evaluates and implements opportunities to influence environmental improvements. Following the SD paradigm in a multidisciplinary approach, LCA is then applied to assist other disciplines to understand environmental impacts in their field of interest, as cross-disciplinary coordination. The international standard guidelines including ISO14040 (International Organization for Standardization, 2006a), 14044 (International Organization for Standardization, 2006b), and 14048 (International Organization for Standardization, 2002)) of LCA are employed to calculate the environmental impacts by several agencies, companies, and research fields that have different approach depending on their interpretation. Interpreted guidelines are utilized in many approaches such as a Life Cycle Inventory (LCI) database in information technology, Life Cycle Costing (LCC) in determining the most cost-effective option in an economic field, and knowledge structuring in semantic technology.

2.2. Ontology Development and a Collaborative Approach

2.2.1. Semantic Web ontology language

Semantic Web is an extension of the World Wide Web (Schreiber & Dean, 2004) that brings a structure in which information is formally defined, enabling computers and people to work in cooperation (Horrocks, 2008). The structure can be semantically computed that collects information and sets of inference rules that they can use to conduct automated reasoning. The function brings structure to the meaningful content of Web pages. The Semantic Web provides a language that expresses both data and rules for reasoning and allows rules from any existing knowledge representation system to be exported onto the Web, called ontologies.

Web Ontology Language is the most well-known definition commonly cited in the Semantic Web and Knowledge Representation communities from Gruber (T R Gruber, 1995), i.e.: "*An ontology is an explicit and formal specification of a conceptualization of a domain of interest*." In the philosophical aspect, ontology is a discipline that studies theory about the nature of existence. However, this study considers the computing and KR aspect. It is a kind of formal language for the rules as expressive as needed to allow the Web to reason as widely as desired. The most typical kind of ontology for the Web has taxonomy and a set of inference rules. The taxonomy defines classes of objects and relations among them. Ontology (Horrocks, 2008) is a way to formalize explicit and tacit knowledge and domain expertise by explicitly representing it with a set of concepts, i.e., conceptualization, and eliciting relations among them. Therefore, the Semantic Web provides a language to express data fields, concepts, concept relations, and rules for an inference system allowing us to conduct automated reasoning.

2.2.2. A collaborative framework

Regarding Groza et al. (Groza, Tudorache, & Dumontier, 2013)'s commentary mentioned state of the art and open challenges for knowledge curation. Community-driven knowledge curation has two major types of the knowledge curation systems supporting a community-driven approach as follows:

1. knowledge curation platforms aim to enable researchers and experts in a particular field to define, detail and explore the knowledge within that field via a quality-driven collaborative curation process, and

2. ontology curation systems focus on providing an environment in which experts can externalize and formalize the knowledge captured within a domain.

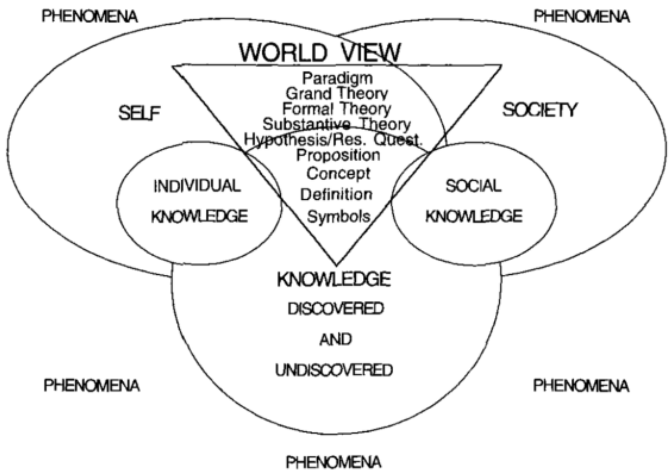

Figure 3 A multidisciplinary framework for theory building,
Circuits of Theory (Glazier & Grover, 2002).

Knowledge discovery in specific domains was next determined social knowledge. Glazier et al. (Glazier & Grover, 2002) proposed a framework for library and information studies that leads research that more accurately mirrors the role of disciplines, the influence of social factors on the construction of personal and social knowledge, and the research process. As illustrated in Figure 3, Glazier et al.'s framework, Circuits of Theory, presented three dialectically related modules and the taxonomy of theory within the existing social environment comprising in a social system. Phenomena are isolated and analyzed within the context of the research environment. While these three modules including Self, Society, and Knowledge, both discovered and undiscovered, the difference is the modules represented in the contextual variables that surround and contribute to the utilization of the taxonomy.

2.3. Literature Review

This section first explains two comparisons of ontology development: 1) development of LCA domain ontologies and 2) LCA ontologies in a multidisciplinary perspective. Next, an ontology development framework is explained based on a collaborative approach. Afterward, limitation of the existing works and motivation on a collaborative framework are explained.

2.3.1. Development of LCA domain ontologies

Since 2002, LCA knowledge and semantic web technology have interpreted the standard guideline (International Organization for Standardization, 2002, 2006a) and adapted to their specific objectives. Previous works on ontology development and implementation have been applied to LCA knowledge. Their characteristics are summarized and compared in Table 1.

Table 1 The development of domain-specific ontologies, Life Cycle Assessment (LCA).

Related work	**Reference source of LCA Domain**		**Semantic Web Technology**		**Reasoning**	**Software/ Application**
	LCA Framework ISO14040 ISO14044	Data Document Format ISO14048	Ontology Development RDF/XML	Ontology based-on OWL/DL		
Cappellaro et al., 2002		X	X			X
M. Braescher et al., 2007	X		X			
Bertin et al., 2012	X	X	X			
Muñoz et al., 2013	X		X		X	X
Sayan, 2011	X	X	X			X
Takhom et al., 2013	X	X		X	X	X

- **CASCADE ontology** designed the first LCA ontology project under a project, named the Cooperation and Standards Assessment Data in Europe (CASCADE) (Cappellaro et al., 2002). The project interprets LCA information in the standard data format guideline in ISO14048 (International Organization for Standardization, 2002). The data format ontology aims to accommodate standard development in design and manufacturing with their requirements for LCA. The project achievements were delivered in LCA ontology OWL(Schreiber & Dean, 2004), a W3C recommended ontology language. The ontology was utilized in a standard conversion software, a website, and a procedural guideline. For the collaborative aspect, LCA knowledge is interpreted by a domain expert, and a knowledge engineer constructed the ontology.

- **LCAO ontology** (Bräscher, Monteiro, & Silva, 2007) was designed and developed by the Brazilian Institute for Information in Science and Technology (IBICT). Their work concern the Follow-up of Life Cycle Assessment (FLCA) according to ISO 14040 (International Organization for Standardization, 2006a) standard guideline. The project provides the LCA framework, aiming at organization and retrieval of information, and a contribution to consensual vision. Their work presents an effort to construct the LCA framework from the interpretation of the standard guideline by knowledge engineers.

- **Bertin's ontology** (Bertin et al., 2012) was a case study of the U.S. energy impact data management. LCI data can also be semantically represented as manipulatable databases using relational algebra. This LCI ontology consists of economic activities considered as elementary processes linked together through interdependency relations. Their work presents a semantic approach to LCA knowledge that is applied to energy environmental impact data management. The data was analyzed and then interpreted. LCI can also be semantically represented as manipulatable databases using relational algebra. The ontology modeling by a mathematical technique for collaborative discussions among domain experts and knowledge engineers demonstrates the benefits of logical structures extraction.

- **Muñoz's ontology** (Muñoz et al., 2013) applied environmental ontology for enterprise resource management and the environmental assessment of enterprise system employed in a case study of a supply chain network design and planning in optimization problems of process scheduling. Regarding interdisciplinary approach, conceptualization requires collaboration among stakeholders (e.g., discussion) to integrate existing environmental ontologies with knowledge of enterprise resource planning.

- **O-LCA Ontology** was formalized by taking LCA knowledge: life cycle inventory and life cycle impact assessment into account in ontology designing. The knowledge has converted the knowledge into a well-structured and exchangeable form which facilitates information sharing and discussion among domain experts. An LCA ontology is represented formally in terms of Description Logic (DL). For a collaborative aspect, the ontology was designed from the interpretation of resources of knowledge including LCA standard guidelines and existing ontologies, and discussion with domain experts. The ontology requires knowledge formalization in conceptual design based on DL by knowledge engineering. For instance, constraints of concepts could be expressed effectively and inference with available reasoning services.

Although LCA ontologies have been designed and employed, the LCA knowledge is needed to be interrelated to other knowledge in case of achieving a goal under the SD paradigm. Therefore, different expertise from other domains is involved that a collaborative approach is considered to improve in using of LCA ontology.

2.3.2. Related LCA ontologies in perspectives of multidisciplinary domain

Many LCA ontologies based on Semantic approach (Da Silva et al., 2006) have been developed for explicating different domain perspectives. The related works are summarized by their characteristics considering two criteria: resources of knowledge, and cross-disciplinary domains. As illustrated in Table 2, LCA international standard guidelines (International Organization for Standardization, 2002, 2006a) are the primary sources of knowledge that standardize principle, framework, and data document format through a family of best-practice procedures. Next, LCA ontologies are considered to other domains in the aspect of a cross-disciplinary domain.

Table 2 A comparison of LCA ontology development considering two criteria: sources of knowledge and cross-disciplinary domains.

LCA Ontology Development	Resources of Knowledge	Cross-disciplinary Domain
Cappellaro et al., 2002	ISO14018	Industrial standards
M. Braescher et al., 2007	ISO14040, 14048	Follow-up of LCA
Bertin et al., 2012	ISO14040	Mathematics
Muñoz et al., 2013	ISO14040	Business management
Sayan, 2011	ISO14040	Software development
Takhom et al., 2013	ISO14040, 14048	Cleaning technology
Takhom et al., 2015	ISO14040, 14048	Data qualification
El Kadiri et al., 2015; Milicic et al., 2013	ISO14040, 14044	Life Cycle Costs

The CASCADE (Cappellaro et al., 2002) was the first LCA ontology designed by interpreting standard guidelines (International Organization for Standardization, 2002). 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 (M. Braescher and F. Monteiro and A. Silva, 2007) 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. (Bertin et al., 2012) 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. (Muñoz et al., 2013) 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 (Sayan, 2011) that presented LCA in linked data.

This research study has further examined LCA ontologies development and published elsewhere. Ontology-Enhanced Life Cycle Assessment (O-LCA) (Takhom, 2013) was the first ontology based on Description Logic (DL) (Baader et al., 2004). The ontology was formalized by taking standard guidelines (International Organization for Standardization, 2002, 2006a, 2006b) 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 (de Callejon & Day, 2013) approach. Lastly, I attempted to draw across the LCA domain to data qualification and Data Qualification for LCA (DQ-LCA) ontology (Takhom et al., 2015) represented in our second generation.

However, this research study intends to overcome the challenge of elaborating collaboration of multidisciplinary knowledge and encourage different domain stakeholders to work with existing LCA ontologies. In chapter 4, the development of a user-adaptive LCA ontology is described as supporting multidisciplinarity knowledge.

2.3.3. An ontology development framework based on a collaborative approach

With the rationale of ontology stakeholder collaboration, an ontology-based application management system (OAM Framework[2]) (Buranarach et al., 2016), is selected to simplify stakeholder's activities in collaborative development and implementation with a knowledge base as illustrated in Figure 4.

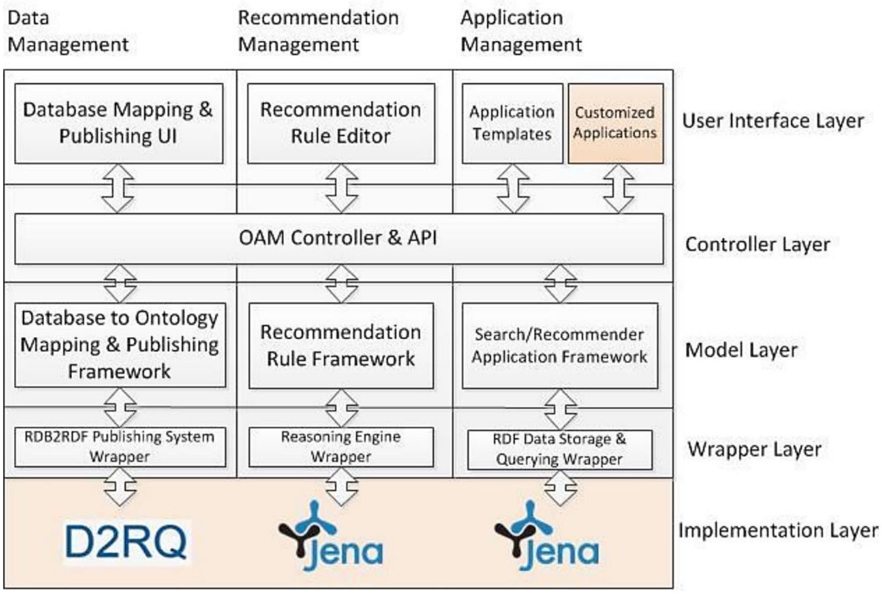

Figure 4 Multi-tier architecture of the OAM framework (Buranarach et al., 2016).

This research focuses on acquisition and accessing the knowledge base that is designed that consists of two main components:

1. **Knowledge Base** is a component built from resources of knowledge (e.g., existing ontologies, guideline document) analyzed and designed by domain experts. It consists of two subcomponents: 1) a domain ontology representing a knowledge structure to

[2] An Ontology Application Management (OAM) Framework for simplifying ontology-based semantic web application development, (http://text.hlt.nectec.or.th/ontology).

users by a visualization tool, 2) defined rules are created for inference in a decision model that use in generating recommendation results.

2. **Recommender Engine** is to process the ontology data in the W3C Web Ontology Language (OWL) (Schreiber & Dean, 2004) format in the knowledge base. The framework maps the database to ontology using the RDF model for ease of data manipulation. Thus, the rule-based knowledge can be applied by retrieving data from the mapping of knowledge base and database. The Jena API is mainly used in manipulating the knowledge base data.

2.3.4. Limitation of the existing works and motivation on a collaborative framework

For limitation of the existing works, the OAM Framework is a software platform that aims to simplify the development and maintenance of a semantic web and an ontology as well as to automate the implementation of a semantic search and a web service. The architecture of OAM is illustrated in Figure 5. Ontology development via OAM entails three fundamental steps and three user roles: domain experts, a knowledge engineer, and application developers.

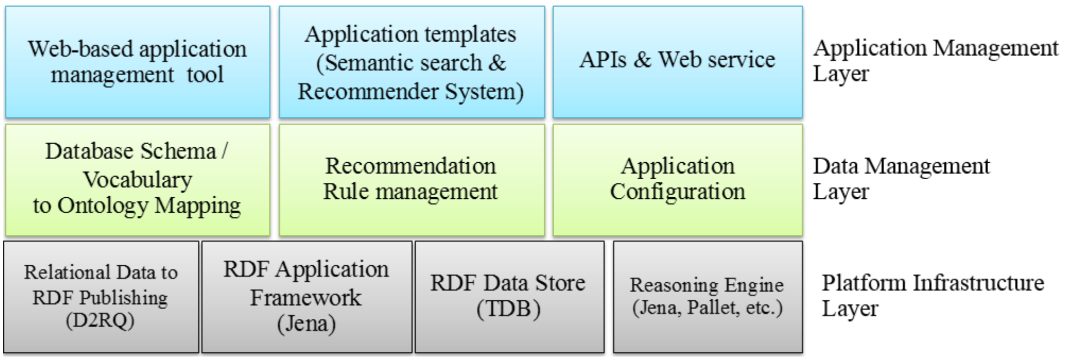

Figure 5 System architecture of OAM Framework (Buranarach et al., 2016, 2013).

First, a domain expert designs his ontology according to the task of interest and export it in the OWL format. On OAM, the knowledge engineer maps the ontology developed by the experts to the database schema and the vocabulary and imports it into the system. At this step, the knowledge engineer also maintains the current ontology according to the experts' requests via personal communication.

Second, the domain experts design recommendation rules for the current ontology in terms of Prolog-like first-order logic. The knowledge engineer then transcribes these rules into JENA Language via the Recommendation Rule Management Module. Finally, the knowledge users implement their knowledge-enhanced applications with the Application Configuration Module. At this stage, they can deploy a semantic search engine and a web service using the ontology developed by the domain experts.

The essential struggle in this multidisciplinary paradigm is the ontology development entirely relies on personal communication. This method is prone to the loss of communication; i.e., it is very hard to keep track of conversations and consensus as time goes by. The history of development evolution, or version control, plays a crucial role in community-based development, especially for a large-scale ontology, in which a group of domain experts, knowledge engineers and knowledge users are involved. These lacks necessitate the use of a tractable communication means where conversations and consensus are structurally organized for ease of bookkeeping, knowledge transcription, versioning, and deployment.

The research study is to propose an extension of the OAM Framework that incorporates the notion of thread-based webboard, version control, and status notification to solve the problems above. These features allow the community with the three user roles to co-create a large-scale ontology and maintain it using community endorsement. By doing so, the system and the knowledge grow along with the users' expertise.

The *community-driven approach* is suitable for the development of LCA ontology because of the following reasons. First, the domain experts specialize in their particular subfields of LCA. Since these fields sometimes share common knowledge, cross-checking becomes necessary in a large-scale development project. Second, the development of the LCA ontology is operated by a group of experts in parallel. In practice, they usually branch (or fork) the current version of the ontology to work on their own. This is causes in updating when the finished ontologies are to be merged back to the main ontology; thus, the need for version control. Third and last, some parts of the ontology have to be cross-checked by specialists from other relevant fields; for example, some parts of the ontology regarding earth and water can also be validated by geophysicists, chemists, and environmentalists.

2.4. Concluding Remarks

To conclude the second chapter, multidisciplinary knowledge is first introduced in the meaning of knowledge, in the sense of using the word *multidisciplinary*. Next, one of multidisciplinary knowledge, *Sustainable Development* (SD), is described in term of an understanding of the fundamental characteristics of an interaction between nature and society is the importance of emerging environmental management and preservation concerning sustainability sciences. Then, a semantic approach is explained in order to present domain knowledge and the language for expressing knowledge *ontology* used to conceptualize knowledge. Afterward, related works on LCA ontologies and a collaborative approach are reviewed and considered existing multiple-disciplines. Lastly, limitation of the existing works and motivation on a collaborative framework are determined. With this reason, the research approach focuses on multidisciplinary knowledge integration and crosschecking among domain experts and relevant stakeholders. An ontology-based application management framework regarding community-driven approach is reviewed. Therefore, the following chapter will introduce the methodology of this research study that intends to enhance a collaborative capability by providing communication, knowledge transfer and discuss the changes of the worked ontology with respect to immediate needs.

Chapter 3

Research Methodology

The purpose of the third chapter is to present a methodology of this research. First, research approach and a pilot study are explained by two methods: a collaborative approach and a network perspective for discovering multidisciplinary knowledge. Next, the research approach is design and setting by considering study population, sampling, and data-collection instrument. After that, the collected data are analyzed and formulated the hypothesis. The last section summarizes the research methodology and the research approach.

3.1. Introduction

The purpose of this research study was to identify and describe a phenomenon in multiple-domain knowledge and causes of misunderstanding in different domain perspectives. In evaluating the feasibility of multidisciplinarity in particular domains, a pilot study was conducted to improve this research study in designing before thoroughgoing research plan and reviewing the importance of a study approach.

Two potential methods were chosen including a network text analysis (NTA) for analyzing multidisciplinary perspectives, and feasibility in a collaborative approach. This chapter provides an explanation of essential elements of the research philosophy; additionally, the ontological and paradigmatic perspectives informing the study. Then the study design and setting are defined to study population, sampling, and data-collection instrument. As a studying paradigm, the theoretical framework underpinning the study is next described with the selected methods. The instrument designed for collecting sources of knowledge are explained. Afterward, the data analysis process is described in the process of in inspecting and modeling data with regarding the pilot study. The relevant stakeholders have defined their roles, and their activities are in considerations. Lastly, the research is summarized in the research methodology and the study approach.

This chapter explained the research design and methodology to find answers following the research questions. For research design, this study was planned to indicate the type of study undertaken. The research methods indicate each step: an instrument used, techniques implemented for accomplishing the research process (Mouton, 2001). Although some elements of the quantitative research were included in finding research phenomenon, this study focused more on a qualitative approach (Merriam, 1997).

For this study, a case study is to determine the qualitative research in a situation that has multiple-domain knowledge under a paradigm of environmental preservation. The study approach aims to gain a deeper understanding of employing environmental preservation in a collaborative project and sharing perspectives of different domain stakeholders. An understanding of this phenomenon of the case study follows the term of Merriam that was determined: "*how people do things and what meaning they give to their lives*" (Merriam, 2002). Then the design of this research approach has four general characteristics based on basic interpretive qualitative research (Merriam, 1997):

1. Have a formulated research purpose.
2. Be related to existing theories, published or unpublished.
3. Be well planned.
4. Be recorded carefully.

This study aims to describe a phenomenon of misunderstanding based on a qualitative study that is suitable and appropriate for the case study. An understanding of the knowledge in a case study was the research setting to observe and interpret based on a theory of constructivism. This study observed how the different stakeholders could define their understanding and share their knowledge through a collaborative situation. The study was placed within the interpretive paradigm and confined within a case study, the case of promoting environmental preservation through a paradigm consisting multiple-domain knowledge, and miscommunication of relevant domain experts, as the unit of the analytical process. The qualitative approach focused on data gathered mainly from question-answering contexts and documents both standard guidelines and case studies. An analytical result, which generated in a multiple-domain network, was also considered.

3.2. Research Design and Approach

3.2.1. Research design and setting

As aforementioned in Chapter 1, the study aims to break through the blind spots of multiple perspectives for manipulating various domains in different perspectives and draw multiple-disciplinary thinking appropriately with problems outside normal boundaries and redefine cross-domain concepts. In this chapter, therefore, the research approach organizes the working scenario into three following essential phases, as illtreated Figure 6.

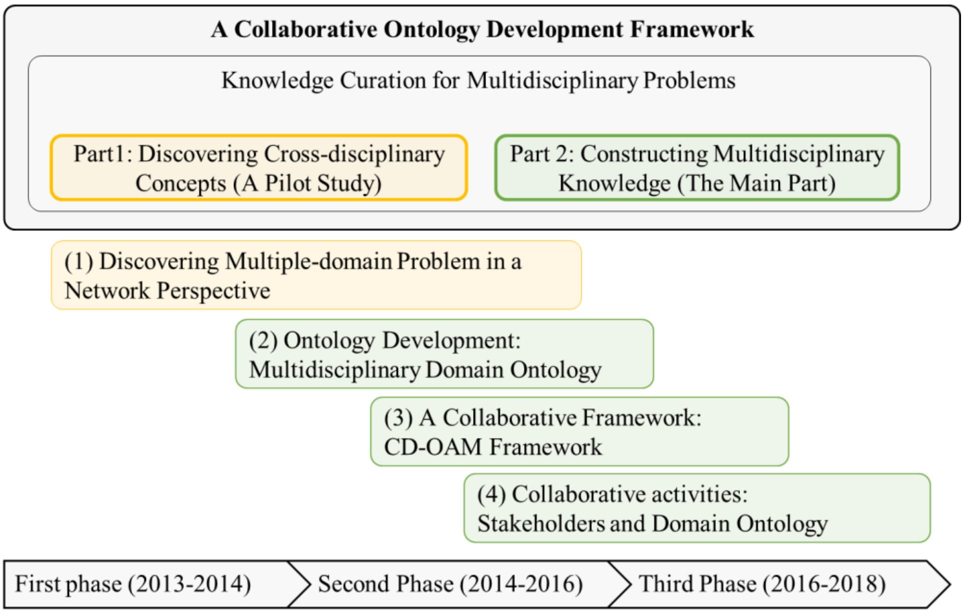

Figure 6 A pilot study (in yellow rectangles) and three crucial phases (in green rectangles) of the main research.

In the first phase, the research is the *development of domain ontologies for multidisciplinary knowledge*. An approach of Semantic Web (Schreiber & Dean, 2004) is used to analyze and conceptualize the knowledge into a computable representation that enables people to work with computers side by side (Horrocks, 2008). The approach allows us to express the knowledge by using *Web Ontology Language* (*OWL*) (Schreiber & Dean, 2004) for data fields, concepts, concept relations, and rules for an inference system allowing us to conduct automated reasoning. Therefore, the domain knowledge can be represented in concepts and exported to the Web, called ontologies.

The second phase is design and development a collaborative framework for supporting stakeholders to work with domain ontologies. This phase proceeds in a collaborative framework by following the supporting reasons. First, domain experts specialize in particular subfields of multidisciplinary knowledge. Crosschecking becomes necessary for a large-scale development project since these fields sometimes share common knowledge operated by a group of experts in parallel. Therefore, the second phase proposes a community-driven development platform of the multidisciplinary LCA Ontology (Takhom, Boonkwan, Ikeda, Suntisrivaraporn, & Supnithi, 2014) that is improving a collaborative capability for the Ontology-based Application Management Framework (OAM) (Buranarach et al., 2016).

In the third phase, a situation required multiple-domain knowledge is represented through a use case for capturing cross-disciplinary conceptual knowledge. All potential scenarios in a business planning are collected and analyzed in a requirement of knowledge sharing from different domain experts. All domain experts have defined stakeholder roles based on their field expertise. Each stakeholder is explicated collaborative activities for drawing cross-disciplinary concepts. Therefore, this phase considers a suitable case study that is suitable to explain a collaborative situation.

3.2.2. Research approach and methodology

As mentioned in the previous section, this dissertation has organized the flow of research methodology into three phases (as illustrated earlier in Figure 6). An enumeration of research methods is represented in each phase defined relevant chapters, including hypotheses, data collection, quantitative analysis, constructive design, interpretative analysis, conceptual modeling, use-case analysis, interpretative analysis, and qualitative analysis. These research methods are selected regarding research objectives and accentuating on the research scopes and limitations of the research approach.

As aforementioned the research objectives and scopes in Section 1.3, this research study is aiming to interoperate the multidisciplinary knowledge for relevant domain-specific stakeholders and enhance their collaborative activities. Therefore, a flow of research methodology, as illustrated in Figure 7, used in this dissertation, and the research method and briefly details are explained as follows.

In the first chapter, the importance of the research is described with the obstacles of different domain stakeholders in working with multiple-domain projects (Chapter 1). Then, the following chapter explains the background both of multiple-domain knowledge and domain ontology development, and reviews related works (Chapter 2).

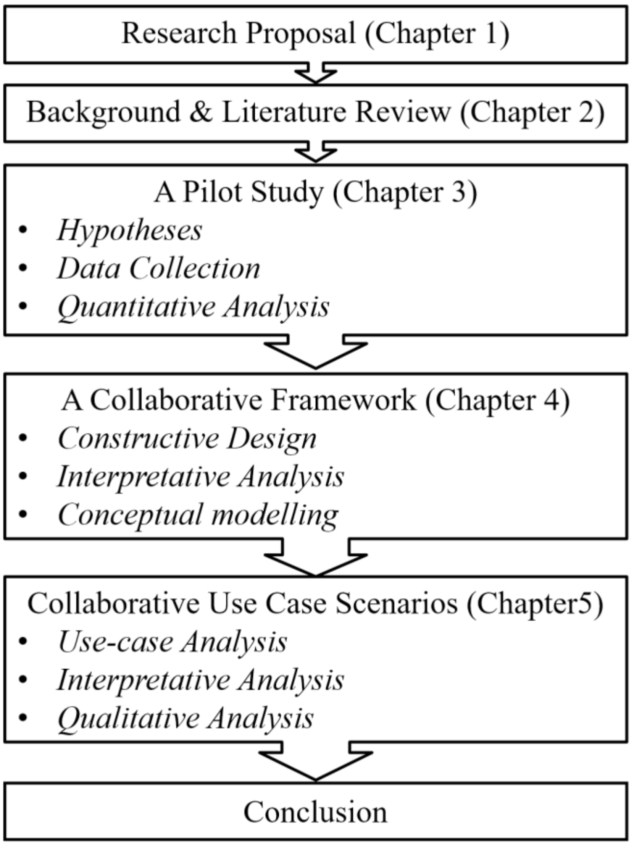

Figure 7 A flow of research methodology used in this dissertation.

A pilot study (Chapter 3) is prepared, as a preliminary experiment, to shorten compilation of the intended study components and outcomes. An expected result allows for looking forward at what kind of relevant domains exist in the multiple-domain paradigm, and how different stakeholders express their understanding. To achieving the first research objective (Section 1.3), Three research methods are conducted in this study, and the brief description of each method is described as follows. '*Hypotheses'* of this pilot study is a supposition that there is cross-disciplinary conceptual knowledge in a domain community. '*Data Collection*' is a source of knowledge that collected from a discussion forum that is a virtual place for information exchange and sharing through the discussion of participants. Lastly, '*quantitative analysis*' is a measurement of the quantities of cross-disciplinary pairs that are evaluated for feasibility of research approach

After getting evidence from of the preliminary experiment, *a collaborative framework* (*Chapter 4*) is considered in the appropriate environment based on '*constructive design'* purposed in term of a framework providing additional functions, as rationale design for enhancing the collaborative knowledge-based system. The framework is based on three required tiers: 1) system users, 2) knowledge, and 3) collaboration. The three tiers have functions supporting stakeholders in working with knowledge bases. Thus, the constructive design presents specialized function for roles and interests of system users. Next, to presenting the feasibility with the user-adaptive ontology, domain-specific problems are observed and collected, for example, an interpretation of different domain practitioners in utilizing international standard guidelines.

To conceptualize this proposed a user-adaptive ontological model in terms of for multidisciplinary knowledge. The MLCA ontology development needs to overcome the challenge of ontology-based architecture that is processes of ontology development. The developing processes take Noy et al.'s guideline (Noy & McGuinness, 2001) and organizing role-concepts (Kozaki, Kitamura, Ikeda, & Mizoguchi, 2002) into account in initializing the user-adaptive ontology. The first user-adaptive LCA ontology has been improved with existing domain ontologies for enhancing collaborative capability through knowledge construction system. In considering an aspect of multidisciplinarity, the user-adaptive MLCA ontology has been designed in varied aspects including industrial standards, follow-up of LCA, mathematics, business management, and cleaning technology

Collaborative use case scenarios (Chapter 5) are used a collaborative framework to evaluate interpretability of the user-adaptive multidisciplinary ontology. The scenarios are selected from practical use case to clarify a domain problem in the interpretation of international standard guideline. *'Use case analysis'* is selecting use-case scenarios in a domain-specific domain. This analysis is identifying the requirements for interpreting guideline documents from different perspectives. Therefore, the use case analysis is the foundation for improving a collaborative framework. Next, a selected case study is analyzed and interpret problems in collaborative activities using '*interpretative analysis*.' The problems are used to assess in '*qualitative analysis*' that a collaborative framework is exploited in how to solve the problem in Collaborative use case scenarios.

Lastly, finding results of three studies are described for answering the research questions and concluded in each research objectives.

3.3. A Pilot Study: Discovering multiple-domain problem in a network perspective

Following the research process, this section described the process to identify and analyze the problem in a small-scale preliminary study. A result of the study is analyzed for evaluating the feasibility and conducting research approach.

3.3.1. A network perspective for contexts analysis

Multidisciplinary knowledge (Bernard & Anita, 2006) refers to concepts and relationships between concepts that are used in several domains and have misinterpretations by different domain experts. The different understandings of the same terms lead to *blind spots* that obstruct shared and collaboration between different perspectives.

In the research approach, multiple perspectives of domain experts who have different perspectives need to be recognized when they work together on a collaborative project and share their expertise with other participants. Their discussion contexts need to be explained to the participants to understand the perspective of the others. Therefore, to clearly understand and determine the blind spot in their discussion contexts, specific cross-disciplinary concepts (Bernard & Anita, 2006) are identified as a mean to overcome the complex problems and issues in the collaboration. Particularly in educational research, Chaudhry et al. (Chaudhry & Higgins, 2003) used a similar approach to find multidisciplinarity in course descriptions from websites of universities, whereas. Daems et al. (Daems, Erkens, Malzahn, & Hoppe, 2014) targeted multidisciplinary knowledge in science curricula.

Regarding this research approach, a pilot study aims to discover multiple-domain from different perspectives of domain experts. Therefore, a hypothesis of this study is *cross-disciplinary concepts* (C^{cd}) existing in discussion contexts and then consider an experimental result to support different perspectives of understanding.

3.3.2. A discussion forum and participants

A discussion forum is an online accessible medium that allows exchanging information asynchronously instead of real-time face-to-face meetings. Participants (e.g., domain experts) can share information by posting questions and answers through a discussion forum under their interesting topic.

As a source of knowledge, a discussion forum has been chosen (Andresen, 2009) that is a virtual place for information exchange and sharing through the discussion of participants. The virtual place provides opportunities for exchange between domain experts in their areas of shared interest. Typically, two types of participants (or contributions) can be characterized as follows.

- *Questioners* who post a question, inquire on their posts and reply to other questions within their post.
- *Repliers* who answer a question on different issues based on their knowledge background and experiences.

Members of the discussion forum can communicate with each other, for example, a domain expert replies to practitioners to suggest or give a guideline for problem-solving. Each group has a different interesting domain. For example, a website, named '*StackOverflow*', allows programmers' group to share programming knowledge and experience, and *ResearchGate website* ("Question Answering (Q&A) under topic; Life-Cycle Assessment (LCA) from ResearchGate website, A social networking site for scientists and researchers to share papers," 2016) allows scientists to inquire research questions in a variety of research fields. As illustrated in Figure 8, the website facilitates supporting sections for their participants including (1) question searching, (2) posted questions, (3) questions' details with replied, and (4) research topics.

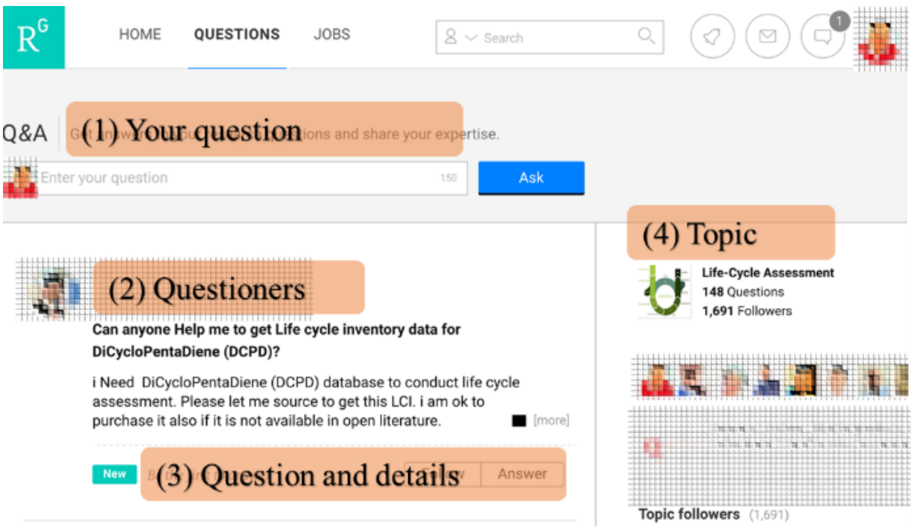

Figure 8 An example of a discussion forum of ResearchGate ("Question Answering (Q&A) under topic; Life-Cycle Assessment (LCA) from ResearchGate website, A social networking site for scientists and researchers to share papers," 2016).

3.3.3. A network perspective for contexts analysis

In order to discover the blind spots of different perspectives, approaches of textual analysis based on a network perspective are reviewed for representing interrelationship among texts.

Although a discussion forum is a freely accessible source of information, factors of limitations by Andresen's work (Andresen, 2009) are considered as follows:

1) *The massive volume of data* is a primary difficulty in assessment,
2) *Temporal sequences of the postings*, such as many answers to one question that a replier may respond to the second answer introduce non-linear structures, and,
3) It may be *difficult* and *time-consuming to gather information needed* to measure the quality of a participant's contribution.

In the analytical process of contexts in a discussion forum, *network text analysis* (*NTA*) (Carley, Columbus, & Azoulay, 2012; Daems et al., 2014) is an appropriate method of text mining. This research study employs the method to represent relations among terminologies of the domains of interest. As shown in Table 1, related NTA works are compared according to four criteria: (1) the interesting domains, (2) usage of a discussion forum, (3) multidisciplinary knowledge, and (4) specific usage of the NTA method. First, Aviv et al. (Aviv, Erlich, Ravid, & Geva, 2003) use the NTA method to analyze exchange in academic university courses. Hecking et al. (Hecking & Hoppe, 2015) next explore and analyze the types of users in MOOC discussion forums, visualizing the role patterns from collaboratively edited texts. Moreover, Daems et al. (Daems et al., 2014) use NTA to analyze contents of Q&A archive in conjunction with domain ontologies to assess learners' understanding of science concepts.

Following Hecking et al. and Daems et al., this research study intends to determine cross-domain concepts applying the NTA method (Carley et al., 2012; Daems et al., 2014). The method includes natural language processing for textual analysis. This work assumes that the NTA method can contribute us in discovering cross-disciplinary concepts, which are existing in a discussion context, and a breakthrough in different understanding from multiple perspectives of participants.

Table 3 A comparison of related works based on Network Text Analysis (NTA) approach.

Related Work	Domain	Discussion Forum	Multidisciplinarity	NTA Method
Andresen (Andresen, 2009)	General	X	X	
Hecking et al. (Hecking & Hoppe, 2015)	Education	X	X	X
Aviv et al. (Aviv et al., 2003)	Education	X	X	X
Chaudhry et al. (Chaudhry & Higgins, 2003)	Education		X	
Daems et al. (Daems et al., 2014)	Education	X	X	X
This research study	Sustainable Development	X	X	X

3.3.4. Discovering multidisciplinarity using a cross-disciplinary approach

As mentioned in the previous section, the *cross-disciplinary* approach is based on the NTA method. A goal of this approach is to discover cross-disciplinary concepts by considering the occurrence and positions of words in the source to form a network.

In this pilot study, a concept means a single idea represented by one or more words, as *vertices* (*v*), in a textual network. Semantic relationships of concepts from a primary domain to other domains are represented in *edges* (*e*). Each *e* has different in strength, weight, and types depended on the words' position to others (Carley, Pfeffer, Reminga, Storrick, & Columbus, 2013).

To represent relations among multiple domains, words of different types are mapped into a relational network, as a concept map with typed nodes and edges between such nodes. Pairwise connections of *v* connected by *e* are taken into consideration in a number of connection values, called edge weight (*W(e)*). The *cross-disciplinary concepts* (C^{cd}) are discovered by a weighted network that represents all pairwise connections defined numerical values of *w(e)*, called *a co-occurrence network.* Therefore, the network is a graphic visualization represented potential relationships domain concepts within a discussion context.

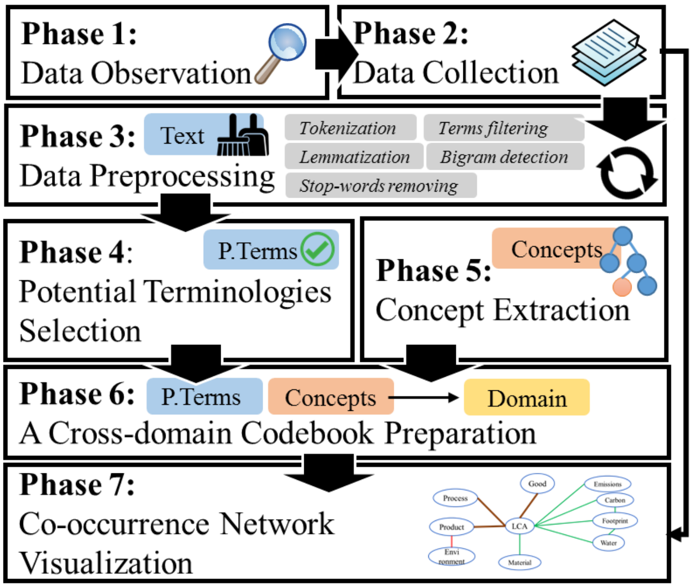

Figure 9 Seven phases in the workflow of the network text analysis (NTA) (Daems et al., 2014; Diesner & Carley, 2004).

As illustrated in Figure 9, seven phases in the workflow of the *network text analysis* (*NTA*) representing how to discover C^{cd}, and each phase is described as follows.

- *Phase 1: Data observation* is identifying available sources of knowledge.
- *Phase 2: Data collection* is gathering selected sources of knowledge with supporting tools for data manipulation.
- *Phase 3: Data preprocessing* is preparing data consisting of domain contexts, which explain how their use of a domain of interest by frequency, and compound with multi-word expressions in specific contexts.
- *Phase 4: Potential terminologies preparation* is considering existing terminologies that have potentials in conceptualizing domain concepts.
- *Phase 5: Concept extraction* is selecting concepts from domain ontologies regarding a semantic approach.
- *Phase 6: Cross-domain codebooks preparation* is an intermediary process associating the potential terminologies and the extracted concepts for categorizing relevant domains.

- *Phase 7: Co-occurrence network visualization* is generating interrelationships the potential terminologies and the extracted concepts existing in sources of knowledge.

3.3.5. Multidisciplinarity in Sustainable Development

The pilot study identifies cross-disciplinary concepts in discussion contexts underlying SD paradigm (European Union, 2010). The SD paradigm involves three crucial aspects including economic growth, social development, and environmental protection. The study is taken into account in their communication in employing LCA knowledge among different roles of participants. Domain experts share their information with other relevant domain experts in replying research questions in LCA domain. Questions and answers contexts are analyzed in LCA domain for discovering existing cross-disciplinary concepts. Therefore, an experimental scenario through seven phases of the NTA workflow, as described in Figure 9, is explicated as follows.

First, available sources of knowledge are observed (Phase 1) from the websites providing a discussion forum. Source of information is a social-networking website, named “ResearchGate” (“Question Answering (Q&A) under topic; Life-Cycle Assessment (LCA) from ResearchGate website, A social networking site for scientists and researchers to share papers,” 2016) that the website has a discussion forum for members, such as researchers and scientists. The members can discuss with others by posting question, suggestions or giving a guideline for problem-solving. The example of question answering (Q&A) contexts is showed in Figure 4.

Table 4 An example of question answering (Q&A) contexts ("Question Answering (Q&A) under topic; Life-Cycle Assessment (LCA) from ResearchGate website, A social networking site for scientists and researchers to share papers," 2016): economic terms (red italic) and LCA terms (green italic).

Topic	Life Cycle Assessment
Question	How to calculate *economic cost* of farming practices during *crop production?* Currently I want to calculate economic cost of crop production from soil preparation to crop harvest according to *life cycle assessment (LCA)*, but I am puzzled by: (1) Is there a term "economic footprint" to define this estimation, like carbon footprint? (2) What should I think about during the calculation?"
Answer	Choosing what *crops* or livestock to produce is an essential decision of any *farm business*. One critical *factor* in making that decision is the *cost of producing* the "enterprises" being considered. This is known as enterprise budgeting or cost of *production budgeting*. Enterprises are a single *crop* or livestock commodity that *produces* a marketable *product*. *Cost of Production (COP)* budgeting consists of estimating the costs associated with an enterprise and the expected revenue. This Factsheet outlines the process and use of *COP budgeting* for farm-level decision-making.

In order to collect resources in Phase 2, discussion contexts are extracted as textual data from question and answer (Q&A) pages. Each Q&A page is annotated content's structure in HyperText Markup Language (HTML) (Consortium & others, 2014), and a web clawing tool is chosen, Scrappy (Myers & McGuffee, 2015), for data retrieval. 148 questions and 92 replies are collected from the Q&A pages under the topic of "Life Cycle Assessment" and "LCA" from September 10, 2016, to October 30, 2016. All contexts of questions are analyzed with corresponding replies. Inefficient factors are also found, such as language, levels of expertise in each reply.

The collected contexts are then preprocessed in Phase 3 in natural language processing. Phase 4 considers the related domains regarding the SD paradigm. This pilot study selects two relevant domains including LCA for an environmental protection aspect, and economic as an economic growth aspect. As shown in Table 4, "Management," "LCA," and "LCI" are selected as LCA terms, and "Emission," "Footprint," "Energy," "Environmental," "Material" are selected as economic terms.

Table 5 Pairs of bigram in two relevant domains with term frequency.

Pair of Bigram	**LCA**	**Freq.**	**Economic**	**Freq.**
waste-management	waste	7	management	20
LCA-emissions	LCA	13	emissions	24
LCI-inventory	LCI	17	inventory	10
Footprint-product	footprint	37	product	8
waste-energy	waste	9	energy	21
environment-product	environment	34	product	9
social- material	social	4	material	23

In *concept extraction* (Phase 5), domain ontologies are explored corresponding to characteristics of the multidisciplinary knowledge and use them from reliable sources. O-LCA ontology is selected. OWL API (Horridge & Bechhofer, 2011) is used functions in order to extract concepts. As illustrated in Fig.3, 396 LCA concepts are extracted consisting of top concepts: Life Cycle Inventory (LCI) in a yellow group, Environmental Impact Assessment (EIA) concepts in blue group, and Data Quality Indicators (DQI) concepts in a red group. In the following phase, all extracted LCA concepts are categorized into relevant domains, whereas there is insufficient of a relevant domain, as economic. A glossary from Wikipedia (Glossary of economics, 2016) is used to extend relevant concepts by matching. The glossary contains 787 terminologies from economic word lists corresponding to the LCA domain.

In Phase 6, a cross-domain codebook is constructed by associating two crucial results: the potential terminologies extended an economic glossary and the extracted concepts. To match the results, a sequence of characters is searched by using a *regular expression* (*regex*) as a search pattern. The domain categories are initialized based on existing sources, and this study considers two domains regarding the SD paradigm: LCA and economic. Regarding *Bag of Words model* (Blei, 2012), the cross-domain codebook is to order concepts with defined categories. For searching of relevant terms, Regex are defined in two patterns: (1) ([0-9]+) \s+((\bword1\b), and (2) [0-9]+) \s+((\bword1\b)|(\bword2s\b)).

In the last phase (Phase 7), a co-occurrence network is generated by using "Connections and Texts" (ConText) (Diesner, 2014), the facilitate tools for constructing a network data. Two input data are the cross-domain codebook and a discussion context, and ConText is configured:

network type is a multi-mode network, a distance of sliding windows is 7, unit of analysis is text, and Aggregation is per corpus.

After that, a tool of network visualization, called Gephi (Bastian, Heymann, & Jacomy, 2009), is used for visualizing a co-occurrence network. Gephi's users can adjust the parameter for analyzing the visualization. In case of visualizing the co-occurrence network, as illustrated in Fig. 4, the result represents the pairwise connection of two relevant domains (LCA and economic). Gephi's parameters can be set as follows: graph type is an undirected graph, edge weight is set 20.0, attributes of node appearances in two types (Economic and LCA), and Force Atlas visualization in repulsion strange 3000 and gravity 0.2.

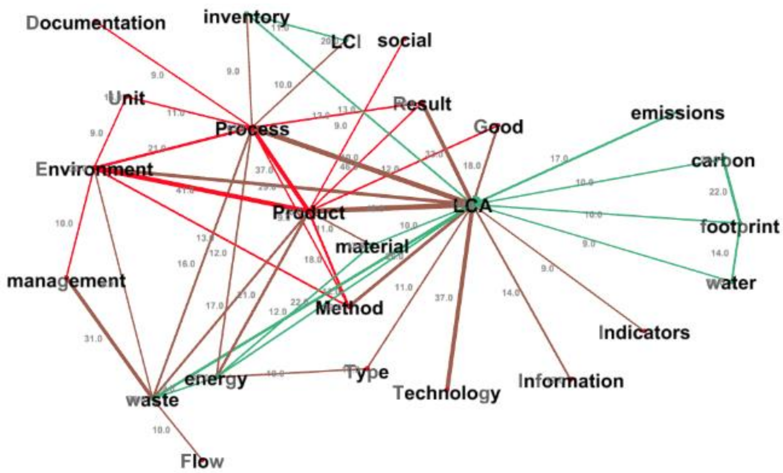

Figure 10 Co-occurrence network visualization generated by GePhi (Bastian et al., 2009): green lines for only LCA domain, red lines for only economic, and brown lines for two relevant domains (LCA and economic).

3.3.6. Experimental result

As illustrated in Fig.4, the experimental result presents the co-occurrence network visualization that *W(e)* more than 20 by setting a sliding window with the size of 7 words. These *A(e)* identify an interrelationship between two domains (LCA and economic) in three colors, and corresponding numbers are defined as a number of each *e* connected with other *e*, as follows:

- 17 brown *e* has *A(e)* occurring between two relevant domains (LCA and economic),
- 13 green *e* has *A(e)* occurring only in LCA, and
- 12 red *e* has *A(e)* occurring only in economic.

The network presents the highest coverage score of *I(e)* from a pair of C^{cd} (LCA and economic): 'Process' and 'LCA.' Therefore, the experimental scenario based on the NTA workflow can be used to discover C^{cd} that are the evidence of the existence of cross-disciplinary conceptual knowledge in Life Cycle Assessment (LCA) domain

3.4. Discussion and Summary

In this chapter, the research study first provided a description of the research design, methodology and a flow of research methodology with three studies are explained: the important of the research (Chapter 1) for describing the obstacles of different domain stakeholders to working with multiple-domain projects, the background and related works (Chapter 2), a pilot study (Chapter 3) for discovering multiple-domain problem in a network perspective, a collaborative framework (Chapter 4) for enhancing collaborative knowledge-based system, collaborative framework to evaluate interpretability in collaborative use case scenarios, and three studies are concluded at the last step of this research methodology.

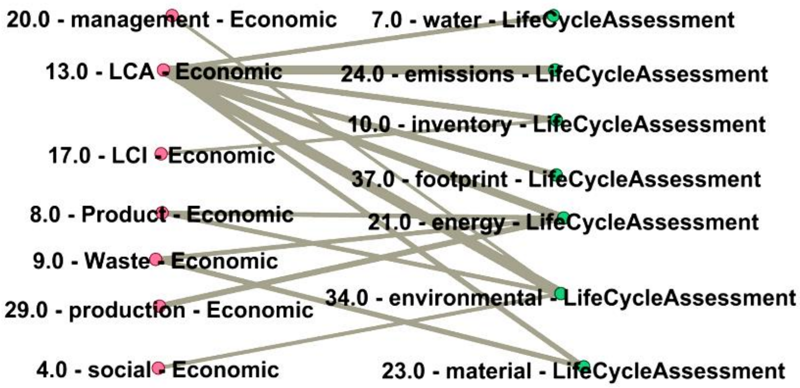

Figure 11 An excerpt of a bipartite graph matching co-occurrence terms from an economic domain (pink edges) to LCA domain (green edges).

As the result of the pilot study, the co-occurrence network presented the highest coverage score of the incident edge from LCA and economic domain that is a pair of cross-disciplinary concepts: 'Process' and 'LCA.' Therefore, the NTA workflow can be used to discover cross-disciplinary concepts, as the hypothesis of this study. To clarify, co-occurrence concept in a perspective of bipartite graph matching, Figure 11 illustrates an excerpt of a bipartite graph matching co-occurrence terms that prove us in an existing of multidisciplinarity in LCA discussion contexts. The figure represents the LCA terms are exiting in contexts of an economic domain that has roles to identify environmental impacts, such as ‘water footprint,’ and ‘emission.’

To summarize the pilot study in this chapter, discovering cross-disciplinary concepts through question and answer (Q&A) contexts can be discovered by employing the Network Text Analysis (NTA) technique in order to identify multidisciplinarity in multiple domain knowledge. Therefore, findings of the pilot study are summarized with overcoming open research challenges as follows. First, a discussion forum can be considered as a quantified source of knowledge with the NTA technique, especially in discovering and analyzing the multiple-domain problem in a network perspective domain concepts within a specific-domain community. Second, following the NTA workflow, the pilot can discover an interrelation among different disciplinary concepts within contexts of LCA community, and the result presented an interrelation of LCA domain to economic domain.

Chapter 4

A Collaborative Framework: Community-driven Ontology-based Application Management

The fourth chapter first presents a collaborative framework based on community-driven ontology-based application management (OAM), system design, and development. The following section describes collaborative features in three tiers: collaboration tier, knowledge tier, and user tier based on the OAM framework existing two tiers (data tier and application tier). Then, development of a user-adaptive ontology is described knowledge elicitation, visualization by using the ontology editor, and ontological engineering processes. The last section summarizes the collaborative framework with the development of the user-adaptive ontology.

4.1. A Collaborative Framework

4.1.1. Community-driven ontology-based application management

With the rationale of ontology stakeholder collaboration, as described in research objectives (Section 1.3), OAM Framework (Buranarach et al., 2016, 2013), is selected to simplify stakeholder's activities in collaborative development and implementation with a knowledge base as illustrated in Figure 12. OAM framework focuses on acquisition and accessing of the knowledge base that is designed consisting of two main components: 1) the knowledge base and 2) the recommender engine.

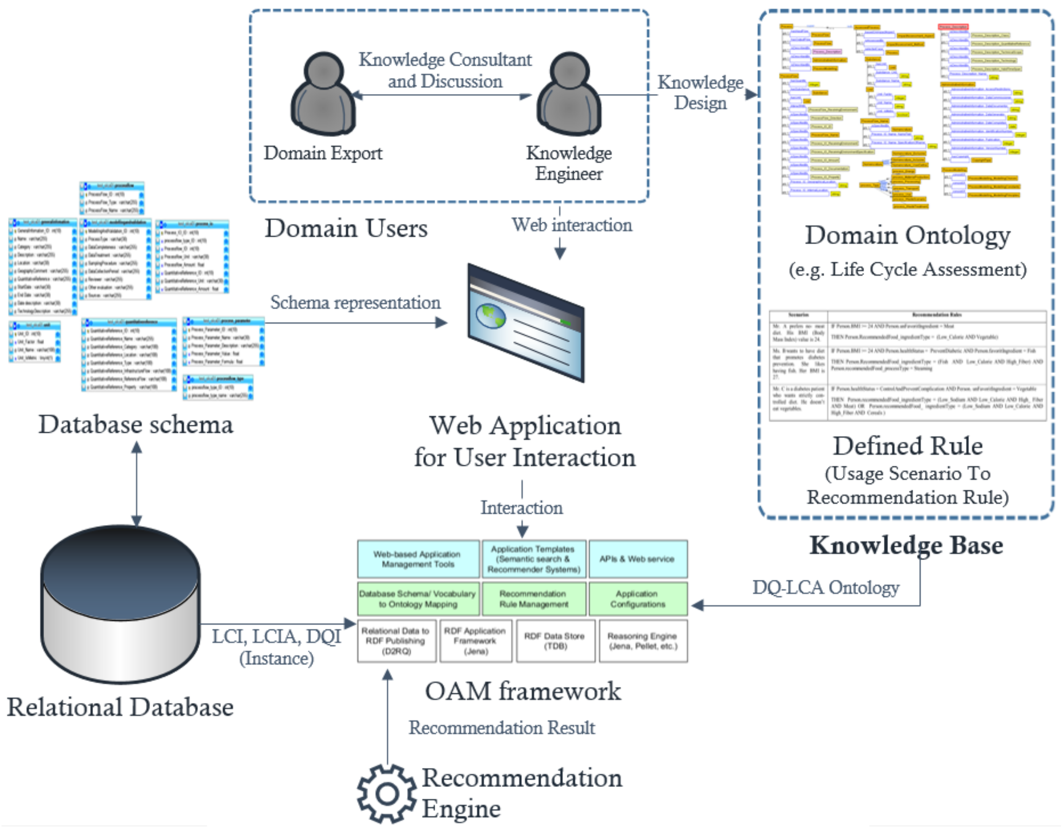

Figure 12 Collaborative interaction of domain stakeholders in the knowledge-based framework for a recommendation system (Buranarach et al., 2016, 2013).

To overcoming research objectives and cope with shortcomings in collaborative activities, three more tiers are introduced: user management with technical profiles, knowledge augmentation via a webboard, and community collaboration via the vote and endorsement system, on top of the existing OAM framework. When applying the design to the task of LCA domain, the research discovers additional needs to partition a large ontology to modularize the users' responsibilities and to provide thread-based conversation for keeping track of the topics.

For large-scale ontology that offers intra- and inter-community communication, voting and endorsement system, and version control, a collaborative framework is used to extend OAM framework. The system design first addresses three lacks in the traditional ontology development: (1) constructive communication among the relevant stakeholders, (2) consensual endorsement and voting system for the concept and structural augmentation, and (3) bookkeeping and version control.

Regarding the research objectives, the research purpose aims at the use of the OAM framework, as a community-driven development platform for ontology curation. The current OAM framework offers the following facilities:

1. an ontology management tool that allows the community to get involved in the evolution of the ontology,

2. a sandbox toolkit with application templates for a semantic search engine and a recommender system, where no programming skills are required, and

3. Application programming interfaces (APIs) and web service deployment for practical application development.

However, this research study intends to improve collaborative features that enable constructive communication among the stakeholders. The contribution of this research is to introduce OAM framework in the notion of modified webboard, where experts propose any concept and structural augmentations, and they have to be endorsed by the community. This work allows the system and the knowledge to grow along with the users' expertise. System design has specialized as per the roles and interests of the users. When applied to the field of LCA, the system envisages the following modifications in the following tiers.

- **User Tier:** Each user should specify his objectives, role, interest, and technical backgrounds regarding LCA. These users are then assigned to a different part of the ontology according to their request or technical backgrounds.

- **Collaboration Tier:** the community is able to partition (and repartition) the ontology via voting and endorsement for modularizing the user responsibilities.

- **Knowledge Tier:** There are at least two sources of knowledge in LCA: ISO standards and field data collection. Knowledge integration becomes a non-trivial issue because domain experts may have different perspectives on the received data. The webboard module has to offer a place for open discussion before leading to voting and endorsement. To keep track of the decision, a thread-based conversation is best suitable for this scenario.

4.1.2. System design and development

This dissertation introduces *a collaborative framework based on a community-driven ontology-based application management framework* (*CD-OAM*) (Takhom, Suntisrivaraporn, et al., 2014) that is designed by extending the canonical OAM Framework (shown as Data Tier and Application Tier, all in dashed borders) with three more tiers: Collaboration Tier, Knowledge Tier, and User Tier (all in solid borders). Multitier architecture of CD-OAM is illustrated in Figure 13.

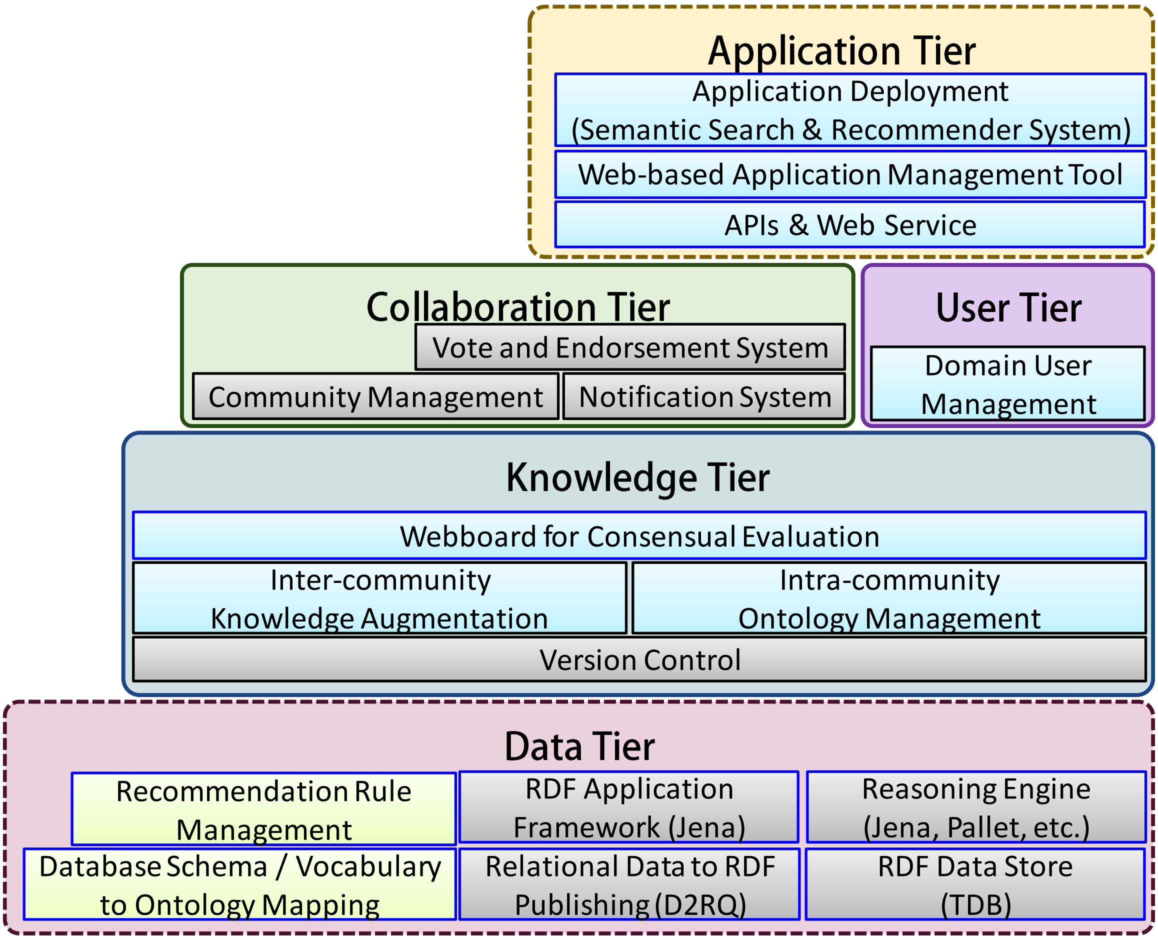

Figure 13 A system overview of a community-driven ontology-based application management framework (CD-OAM) (Takhom, Suntisrivaraporn, et al., 2014).

First, the User Tier facilitates the admin to manage domain expert members, including adding, deleting, and assigning to some of the communities. The users are required to create a profile annotated with their expertise so as to classify them with respect to their interests, technical backgrounds, and objectives. User policy is merit-based (Zhdanova & Shvaiko, 2006): the more a user participates in votings or change proposals, the more merits he gets.

Second, the Collaboration Tier, the heart of this framework, encourages the community-driven development of a large-scale ontology. It contains three modules: community management, vote and endorsement system, and notification system. The Community Management module allows the community's administrator to manage their members and their user roles. The Vote and Endorsement System prepares a platform for voting and endorsement by the community when changes in the ontology take place. Finally, the Notification System disseminates the voting results and changes to the community.

Finally, the Knowledge Tier is composed of four modules that facilitate both intra- and inter-community communication in large-scale ontology development and keep track of the evolution. This study assumes that a large-scale ontology can be separated into parts and distributed to all involved communities. The Intra-community Ontology Management Module (Groza et al., 2013) allows the community to manipulate the part of the ontology. The Inter-community Knowledge Augmentation Module facilitates the integration of each part of the ontology. Should modification is necessary; this can be voted and endorsed by all relevant communities. The community must endorse all proposed changes. The module 'Webboard' organizes a vote for intra- and inter-community changes in the ontology and approves the consensus. For example, an expert may propose to augment some concepts or the hierarchy in the Webboard. If changes are endorsed and committed, the history is kept in the Version Control Module.

4.1.3. Conceptualization

A collaborative framework has purposes including to support different domain stakeholder (e.g., domain experts, or practitioners), to encourage them starting collaborations, and to assist LCA and relevant-domain stakeholders in LCA community for achieving defined collaborative goals. A significant type of the knowledge curation is described in its type, purpose, and related challenge. Then, the framework is interpreted and described a process of conceptualization in this study context. Lastly, the definition of collaboration is explained and differentiated from other 'C' terms cooperation, coordination, and communication.

As aforementioned in development of LCA ontologies in LCA domain, this research is to provide a collaborative environment for relevant stakeholders that an emergence of *ontology curation systems type* using collaborative ontology (Groza et al., 2013). LCA ontology is refined from existing ontologies by knowledge sharing of domain experts "*ontology is a shared* *conceptualization of a domain*" (Thomas R Gruber, 1993). This study considers a consistency-drive knowledge for increasingly improvement of collaborative activities underlying a multidisciplinary paradigm. Therefore, a collaborative framework of this research approach supporting ontology curation process explains more details of collaborative features in Section 4.1.

To develop and classify the concepts from multidisciplinary knowledge, conceptualization is a significant process of a collaborative framework in order to deal with a specific domain. In case of SD paradigm, a multidisciplinary framework in this research aims to bound into collaborative activities of domain stakeholder working with multiple-domain phenomena that relevant domain contexts. A multidisciplinary framework 'Circuits of Theory' (as illustrated in Figure 3) was interpreted as the conceptualization model. For interpretative of this research approach, a *paradigm* of multidisciplinary knowledge is included in a triangle worldview. This research aims to capture their cross-disciplinary *concepts*. As *self* in LCA domain, a primary knowledge is an individual knowledge that I need to discovery existing cross-disciplinary *concepts* in collaborative goals. As *social knowledge* in relevant domains, different stakeholders share their understanding in a study concerning SD *society*.

In term of 'collaboration,' Mattessich et al. (Mattessich, Monsey, & Murray-Close, 2001), had differentiated definition of three 'Cs' of ways of working together: 'cooperation,' 'coordination,' and 'collaboration'. As shown in Table 6, the 'Cs' are compared in the essential elements of vision and relationships; structure, responsibility and communication; authority and accountability; and resources and rewards. To clarify the conceptualization in this study, the term 'collaboration' is differentiated with essential 'C' terms: 'coordination' and 'cooperation.' Regarding Mattessich et al. (Mattessich et al., 2001), three aspects including structure, responsibilities, and communication contexts are determined with aspect in contexts of this research study: ontological structure, stakeholders' role, communication contexts.

Table 6 Determination of three aspects in this study contexts based on essential ‘C’ terms: ‘coordination,’ ‘cooperation’, and ‘collaboration’: structure, responsibilities and communication contexts.

Contexts of this research study	**Essential Terms/Aspects**	**Cooperation**	**Coordination**	**Collaboration**
Ontological structure	Structure	Relationships are informal, each organization functions separately	Organizations assume needed roles but still functions separately	The new structure and formal division of labor are created
Stakeholders' role	Responsibilities	No joint planning is required	Some project-specific planning is required	Comprehensive planning is required including measures of success
Communication Contexts	communication contexts	Information is conveyed as needed	Communication roles are established, and channels for interaction created	Many levels of communication and channels for interaction are created

In the context of this research, three essential aspects (ontological structure, stakeholders roles, and communication contexts) are determined in three different terms: cooperation, coordination, and collaboration. First, the ontological structure is not appropriate for cooperation because the relationship is informal that not the aim to construct an ontology, and the role of each concept needed to define role but did not share concept properties. In collaboration aspect, the ontology structure should be formal, and role of each concept is defined. Second, the role of stakeholders in responsibilities aspect is not required in cooperation and has to define specific planning for them. In a collaboration aspect, the stakeholder has a responsibility in comprehensive planning for measuring they goals. Third, this dissertation did not focus on the communication contexts. If the contexts are determined in cooperation, they need to convey the message to each other and define a role for establishing their communication. In collaboration aspect, the contexts need to define a level of expertise in communication. Thus, the collaboration aspect is the most appropriate in case of determining problems in employing multidisciplinary knowledge.

4.2. Development of a User-adaptive Ontology

After preparing a collaborative framework, this section described the processes in the development of a user-adaptive ontology, as an initial ontology working with a collaborative framework. In this dissertation, The ontology development applied both of a guide to creating the initial ontology (Noy & McGuinness, 2001) and a fundamental consideration of ‘role’ and ‘relationship’ (Kozaki et al., 2002) for the user-adaptive ontology, there are six steps to consider including 1) determining scope, 2) considering reusability of existing domain ontologies, 3) enumerating terms, 4) defining classes, 5) refining relations, and 6) creating instances.

4.2.1. Processes of ontological engineering

Ontology development for LCA is a very challenging task. Standardized by the *International Organization for Standardization*[3] (*ISO*) 14040, 14044, and 14048, LCA is a family of best-practice procedures for information sharing and guidelines for environmental impact evaluation. It minimizes operations in the organization which affects the environment, to comply with laws, regulations, and other environmentally oriented requirements and continual improvement. Figure 3 shows the ISO guideline for LCA that consists of four main phases: (1) setting the goal and scopes (2) listing up life cycle inventory from a given supply chain (3) assessing the life cycle impacts and (4) data interpretation. The ontology for LCA is usually very large because there are numerous concepts and a complicated hierarchy and relations between them in the product’s life cycle.

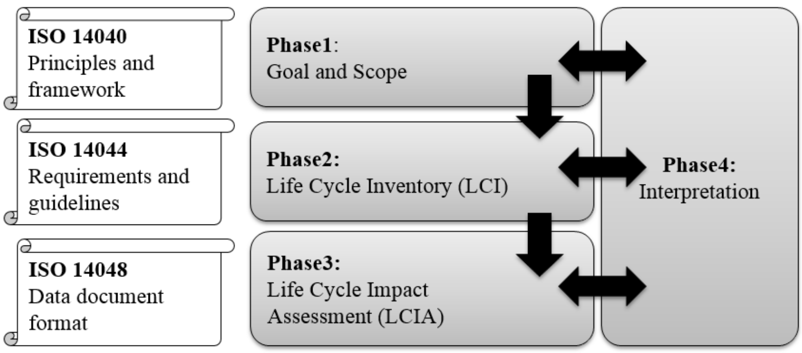

Figure 14 A family of international standards guideline (ISO) on LCA domain and four phases of LCA framework.

The LCA knowledge structure is explicated and visualized by using the ontology editor, Hozo, (Kozaki et al., 2002) as shown in Figure 16. The ontology is designed based on the ontology theory of Role-concept (Hiramatsu & Koide, 2004). Basic terms are distinguished by

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[3] ISO - The International Organization for Standardization is an international standard-setting body composed of representatives from various national standards organizations,(www.iso.org/news/2006/07/Ref1019.html).

the domain context. The representation of basic concepts can identify the relation with other corresponding concepts.

As aforementioned in Chapter 2, necessary concepts of the DQ-LCA ontology is analyzed and designed based on existing LCA ontologies. The ontology development involves defined concepts, concept hierarchies, concept properties and its constraints. The ontology contains 105 concepts, 21 object properties, 105 datatype properties, and 20 individuals. The LCA concepts are categorized into three groups of upper concepts (as depicted in Figure 15): Life Cycle Inventory concepts in the yellow rectangle group, Environmental Impact Assessment Concept in the blue rectangle group, and Data Quality Indicator concepts in the red rectangle group.

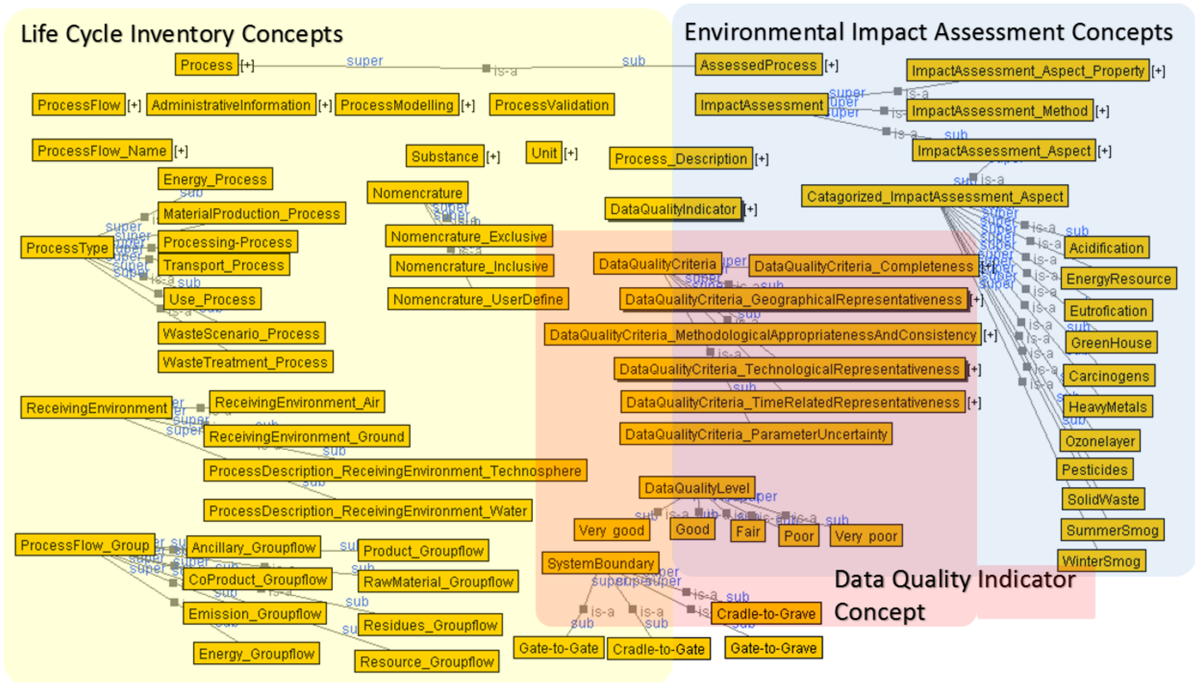

Figure 15 Three groups of upper concepts in our DQ-LCA ontology: 1) LCI concepts in a yellow group, 2) EIA concepts in blue group, and 3) DQI concepts in red group (Takhom et al., 2015).

Although I can organize the DQ-LCA ontology into three groups from necessary concepts of existing ontologies, one of our objectives is to present benefits of data quality measurement. Thus, I focus on two groups of concepts including 1) Life Cycle Inventory and 2) Data Quality Indicator.

Life Cycle Inventory Concept. The structure of the "*Life Cycle Inventory*" or LCI is the concept group of dataset inventory that formalizes data and its documentation describing the properties of the environmental process. As illustrated in Figure 16, the interpreted concepts are presented as follows:

1. "Process" concept, consisting of four main sub concepts, "Process Description," " Administrative Information," "Process Modelling," and "Input and Output Process Flows";

2. "*Assessed Process*" concept, an inheritance concept, consisting of "*Process*" and "*Assessment Method*";

3. The quantified concepts consisted of "*Quantity*" and "*Unit.*"

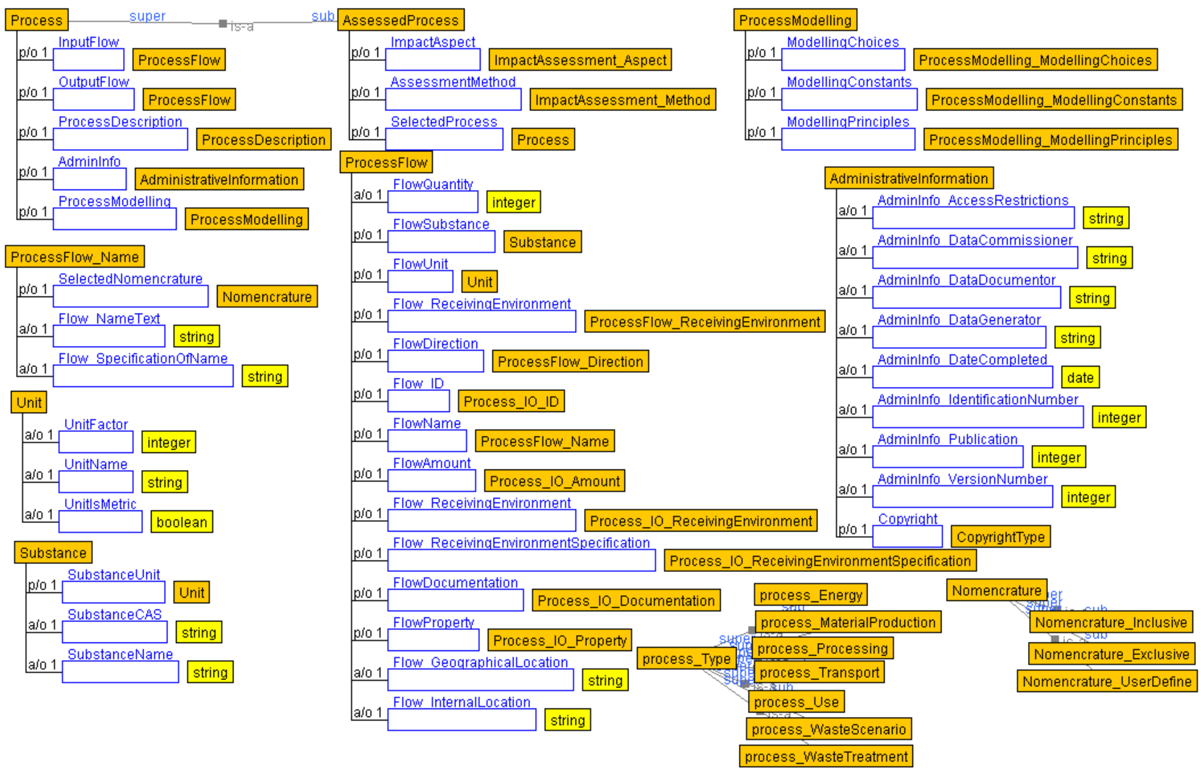

Figure 16 A group of Life Cycle Inventory (LCI) concepts in the DQ-LCA ontology (Takhom et al., 2015).

Data Quality Indicator Concept. This study constructs this concept for encouraging participation of domain experts.

As mentioned in the standard guideline (ISO14044), data quality requirements should be described to define the LCA scope clearly. The requirements specify the goal and scope, involving precision, completeness, representativeness, consistency, reproducibility, sources of the data, the uncertainty of the information and also coverage of time-related, geography, technology. To make the requirements quantifiable, I consider Product Environmental Footprint (PEF), a measure of all environmental impacts. The measure helps us to compromise two main concepts; LCI and DQI. I consider a related document from European Commission that explains and give an example of PEF approach. An official journal of European Commission (European Union, 2010) is analyzed and interpreted as a knowledge resource in a section of data quality requirements. The journal describes six criteria to adopt DQI knowledge based on PEF studies. Our ontology is designed to comply with Data Quality Indicator (DQI). The DQI concepts are associated with LCI concepts by indicating the quality of a process described in its concept description. As illustrated in Figure 17, DQI concepts have two object property and one datatype properties as follows:

- **Concept "*Data Quality Criterion*"** presents data quality used throughout the standard guideline (International Organization for Standardization, 2006b), consisting of six kinds of criteria:

    1) "*Technological Representativeness*";
    2) "*Geographical representativeness*";
    3) "*Time-related representativeness*";
    4) "*Completeness*";
    5) "*Parameter uncertainty*"; and
    6) "*Methodological Appropriateness and Consistency*."

- **Concept "*Data Quality Rating*"** presents the calculation of the achieved quality rating in six criteria of "*Data Quality Criteria*" concept, defining five level of "*Data Quality Level*."

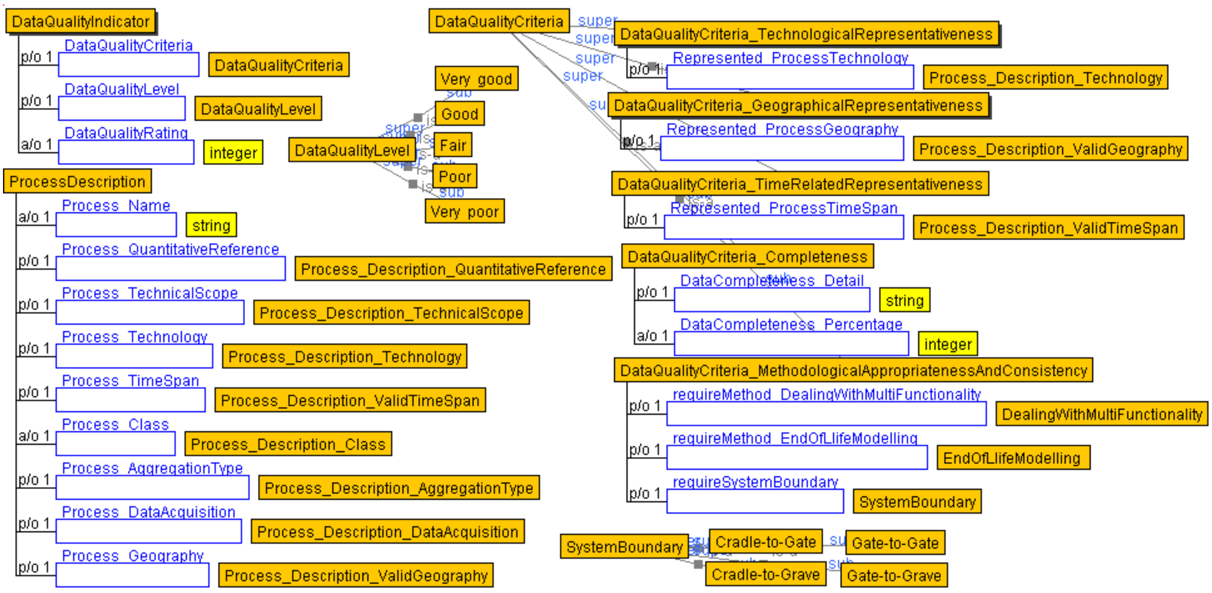

Figure 17 A group of Data Quality Indicator (DQI) concepts in the DQ-LCA ontology (Takhom et al., 2015).

4.3. Summary

In this chapter, a design for a community-driven development framework for large-scale ontology is presented where all relevant stakeholders can participate in the evolution of the ontology. Three additional layers: user management, knowledge augmentation, and community collaboration, respectively, are put on top of the OAM Framework to facilitate communications among the stakeholders, voting and endorsement, and version control. I can find that, in practice, ontology partitioning and thread-based conversation are also needed for teamwork as found in Life Cycle Assessment.

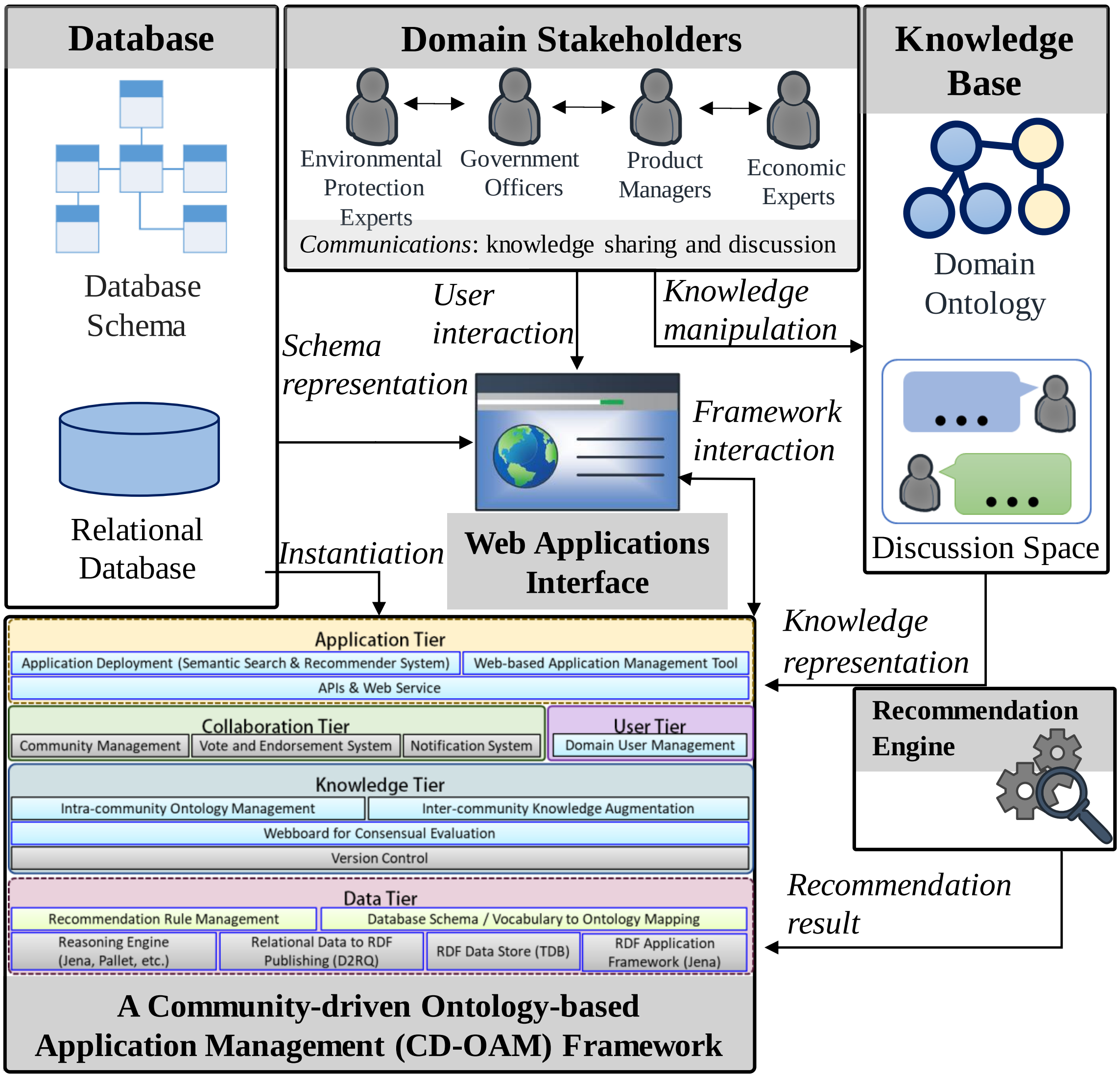

Figure 18 System overview of a community-driven ontology-based application management (CD-OAM) framework (Takhom, Suntisrivaraporn, et al., 2014)

A community-driven development framework for large-scale ontology offers intra- and inter-community communication, voting and endorsement system, and version control. The system design addresses three lacks in the traditional ontology development: (1) constructive communication among the relevant stakeholders, (2) consensual endorsement and voting system for the concept and structural augmentation, and (3) bookkeeping and version control. To cope with these shortcomings, I introduce three more tiers: user management with technical profiles, knowledge augmentation via a webboard, and community collaboration via the vote and endorsement system, on top of the existing the OAM Framework.

Chapter 5

Collaborative Use Case Scenarios

In the fifth chapter, two collaborative use case studies are presented regarding the research challenge in multidisciplinary knowledge as explained in Chapter 2. The first collaborative use case study explains a situation defining an industrial policy for measuring a process of data qualification. The second collaborative use case study is a collaborative situation that different stakeholder are defined roles and activates. Problem recognition and a solution are explained in order to reduce misinterpretation problem by exploitation of a collaborative framework. The end of this chapter explains summarizations of the use case scenarios.

5.1. Introduction

In order to elucidate how this research approach can cope obstacles in collaboration, two collaborative use case studies are represented underlying SD paradigm (as aforementioned in Chapter 2). The use case studies are first presented a general approach to work with problems and then a collaboration capability of the collaborative framework, CD-OAM, is exploited in how to solve those problems. Therefore, this chapter illustrates a realistic situation instead of abstract statements by employing an approach of *Specification by Example (SBE)* (Adzic, 2011) for capturing cross-disciplinary concepts within the collaborative use case scenarios. The first scenario presents a situation that an industrial policy requiring the standard policy to measure process quality, following data qualification, and the second scenario present a situation that a business planning requires knowledge from different domain experts to find the best solutions for achieving a business goal. Therefore, the SBE approach is suitable to explain in those two situations in the research study.

Note that in the scenarios of this dissertation, activities of government policymaker (GM) do not have only one role in these collaborative activities. In a practical situation, GM's activities depend on national policy in each period; for example, the GM has to interpret criteria for claiming ecolabelling in an aspect of environmental impact on electronic waste relying on national policy in case of promoting technology aspect.

5.2. A Scenario of Data Qualification in Life Cycle Inventory

In the first situation, a company has the aim to promote an environmentally friendly way for their product. Then, the purpose a goal to claim ecolabelling (Clift, 1993) by considering qualified data, in which follow an industrial policy. In order to achieve the aim, large data from production reports is determined by analyzing Life Cycle Inventory (LCI) data consisting of inputs of water, energy, and raw materials, and releases to air, land, and water. Therefore, relevant stakeholders including LCA domain experts and company's personnel are invited to discuss in defining the standard policy in the measurement of quality processes following data qualification

5.2.1. Stakeholder's roles and collaborative activities

Relevant stakeholders including LCA domain experts and company's personnel are defined their roles to participate in defining an industrial policy for data measurement. In this use case scenarios, they have to determine LCI data consisting of terminologies as vocabularies in this use case scenarios and controlling the scope of this collaborative activity. For that reason, the rules can be used in generating a quality process as the recommended result, and the terminologies can be used to describe a concept name and its relations in company's defined policy.

5.2.2. Criteria for assessment of the qualified LCA dataset

Regarding the situation, two domains, *Life Cycle Inventory* (*LCI*) and *Data Quality Indicator* (*DQI*), are taken into consideration in ontology development following a collaborative approach. The developed ontology is designed supporting the integration of rule-based knowledge, providing user-defined policies, in case of data qualification.

For pointing out benefits of the collaborative environment in this research approach, an ontology application management framework (CD-OAM) was improved for enhancing collaborative activities, especially in knowledge inference. The stakeholders are allowed to define the knowledge explication and recommendation rules based on usage scenario. Each rule-based concept was defined based on data measurement as DQI concepts, and user-defined policy concepts. Within the provided environment, LCA knowledge elicitation and visualization were used to encourage stakeholder, as domain experts, in participation with knowledge engineers. Domain experts and company's personnel transcribed the domain knowledge with knowledge engineers into concepts, concept relations, and individuals and then co-define inference rules, using the same semantics, and the technique to cope this problem is called *vocabulary control* (Ikeda, Hayashi, & Lai, 1999). This research study assumed that domain experts stipulate some assessment criteria for a qualified dataset. Therefore, the quality criteria for claiming ecolabelling (Clift, 1993) are described in process assessment as following conditions:

- Overall DQR should be fairer (lower than 4.0);
- Collected in Arkansas, United States only;
- Gathered from last five years from now (Fair);
- At least two method requirements of the PEF Guide: (System boundary should be the same, e.g., Cradle-to-Gate, Gate-to-Gate, and the end of life modeling requires an environmental burden).

Then, the usage scenario is analyzed and transformed into defined rules, as shown in Table 7.

Table 7 An example of the first use case scenario: a recommender system for environmental data qualification consisting of the user scenarios and the recommendation rules that applied.

Usage Scenario	Recommendation Rules
Goal: to claim the green label for rice product **Prerequisite criteria for qualify datasets**: - Overall DQR should be fairer (lower than 4.0) - Collected in Arkansas, United States only - Gathered from last five years from now (Fair) - At least two method requirements of the green labels guide: (1) System boundary should be the same, e.g. Cradle-to-Gate, Gate-to-Gate (2) The end of life modeling requires an environmental burden	IF *DataQualityIndicator.hasDataQualityRating* <= 4.0 AND *GeographicalRepresentativeness* = “Arkansas, UnitedStates” AND *TimeRelatedRepresentativeness* = Fair AND *MethodologicalAppropriatenessAndConsistency.requiredMethod* = (SystemBoundary = CradleToGate OR SystemBoundary = GateToGate) AND *MethodologicalAppropriatenessAndConsistency.requiredMethod* = (EndOfLifeMidelling = “EnvironmentalBurden”) THEN *UserDefinedPolicy.hasRecommendedProcess* = (*ProcessDescriptionName* AND *ProcessDescriptionType*) AND *UserDefinedPolicy.hasRecommendedQualifiedProcess* = (*DataQulityRating* AND *DataQulityCriteria*.isPresentedBy = *TechnologicalRepresentativeness* AND *DataQulityCriteria.isPresentedBy* = *GeographicalRepresentativeness* AND *DataQulityCriteria.isPresentedBy* = *Completeness* AND *DataQulityCriteria.isPresentedBy* = *MethodologyAppropriatenessAndConsistency*)

5.2.3. Semantic mapping between domain ontology and database

Despite visualization as ontology, compatibility between concept and its related data needed to make domain experts familiar with domain contexts. To instantiate individuals of a concept, I look for open data to collect and then to check contextual compatibility for concept and data mapping. Therefore, the requirements of this scenario are as follows:

- Open data;
- Collected data that are interpreted from ISO standard guideline (e.g., EcoSpold dataset format or ELCD data format);
- Specified-field of interest as agriculture domain.

In this research study, an agricultural domain in LCI data was taken into consideration in usability in concept checking, because the terms of this domain are a common understanding. Sampling data were instantiated by collecting LCI datasets from LCA Digital Commons Project at the National Agricultural Library[4] (NAL) that provides open access to LCI datasets

[4] LCA Digital Commons Project at the National Agricultural Library (NAL), (http://www.lcacommons.gov).

and an open source software. Next, the datasets describe qualitative information in term of numeric scores by applying methods of data quality analysis. Their methods are used to consider the data quality aspects by specifying the ISO standards in the differentiation of data quality. Then, the open datasets in EcoSpold data format, are collected from practitioners in RDF/XML syntax, for an infrastructure of their LCI dataset management system. Lastly, the datasets were transformed into ELCD Format and then stored in LCI database.

After preparing the dataset, the database was constructed as storage for the collected datasets and mapped data fields with domain concepts. A relationship between data fields and concepts is mapped from datasets in LCI database (e.g., "Geographical representativeness" and "Valid-geography") to concepts and concept properties in MLCA ontology. As illustrated in Figure 19, each concept has its properties including descriptive values and numerical values. In part of stakeholder activities (LCA domain experts, company's personnel, and knowledge engineers), they were allowed to discuss in interrelation among related concept properties and related definition in the data fields. In order to encourage their collaborative activities, CD-OAM framework provided a supporting feature, as an application system for mapping between OWL ontology and a relational database that can select concepts and map them with related data fields as depicted in Figure 20.

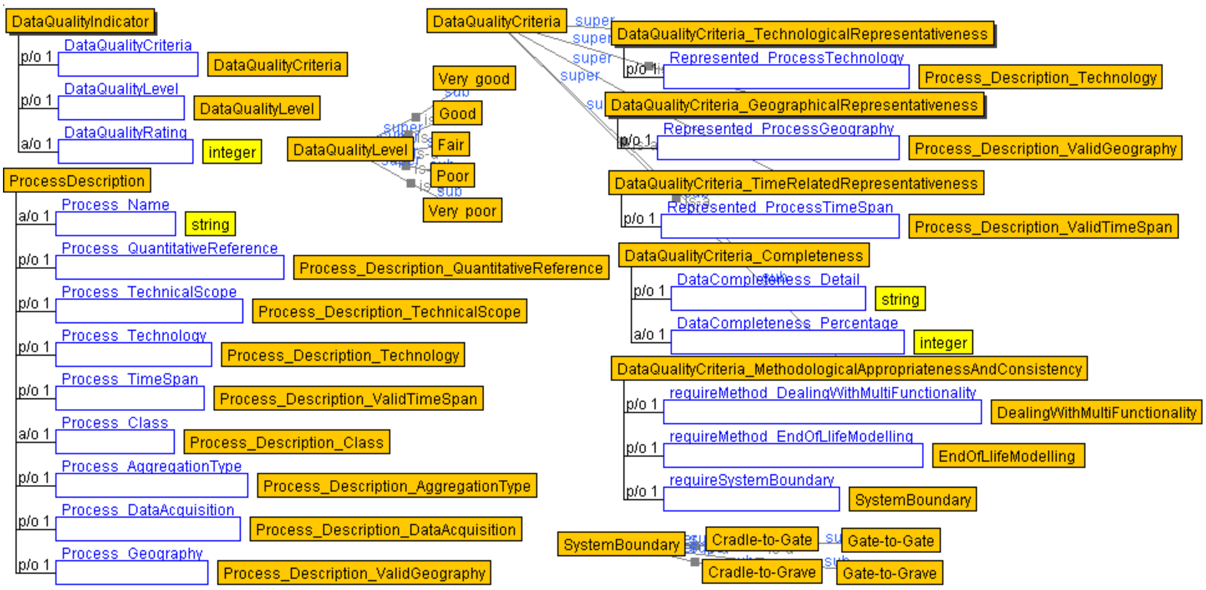

Figure 19 Multidisciplinary ontology for Life Cycle Assessment (MLCA): a group of Data Quality Indicator concepts.

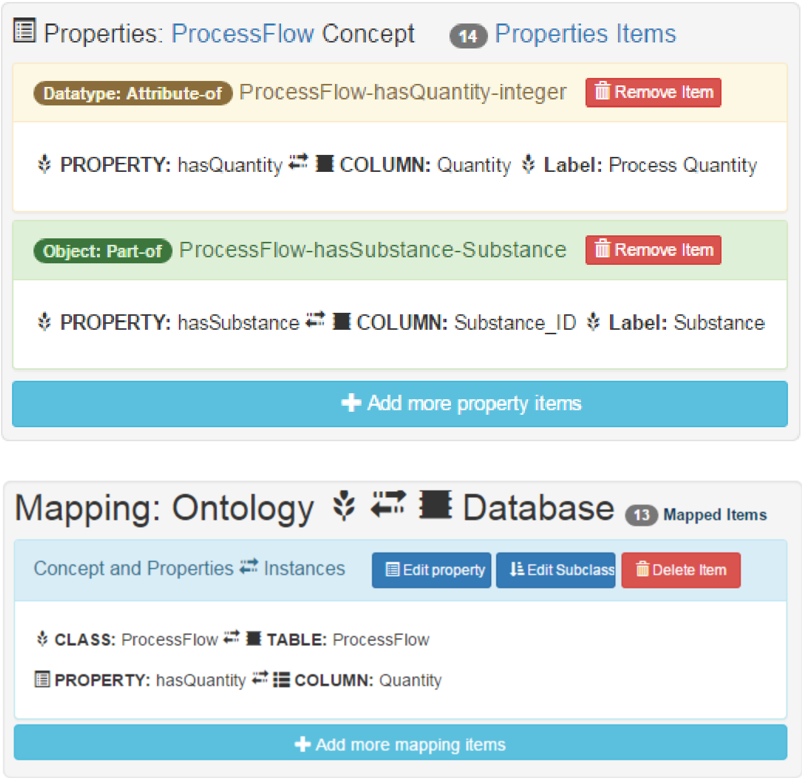

Figure 20 Mapping between ontology and database:
concept properties are considered with corresponding data fields

5.2.4. Semantic search and recommendation system

As aforementioned in Section 4.1 of Chapter 4, CD-OAM framework was designed for encouraging stakeholder to work with domain ontology by providing system features. The first feature is semantic search and the second feature recommendation system. Therefore, stakeholders can simplify collaborative activities among different domain stakeholders, and the features are described as follows.

For the first feature, *semantic search* allows LCA stakeholders to find concepts and instance by defining relevant concepts and conditions. The conditions for searching are categorized into two types of property: object type for defining concepts properties and data type for value properties (e.g., texts or numbers). These two properties are defined for domain users familiar with object properties. The object property is transformed into "part-of" relations with concept constraints (e.g., *hasSubstance*), and the datatype property is transformed into "attribute-of" relations with concept constraints (e.g., *hasQuantity*). By doing so, domain experts can understand the underlying semantics by selecting the related properties. After defining the concept properties, LCA stakeholders define values of each condition for searching. Finally, the instances of LCA concepts were displayed as the result of selected concept and defined conditions, as depicted in Figure 21.

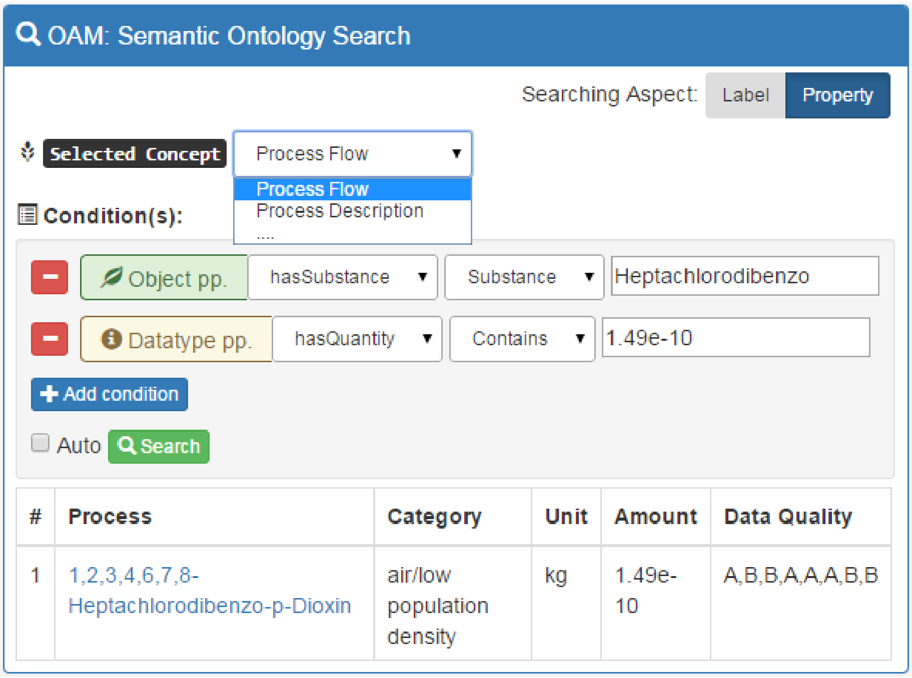

Figure 21 Semantic search: a supporting feature of CD-OAM framework.

For the second feature, *a recommendation system* was designed for simplifying deployment of recommendation rule management. The defined rules based on the scenario of data qualification are used in the implementation of a recommender system. The usage scenario defines prerequisite criteria of “LCI” concept to inference individuals that associated with “User-Defined Policy” concept, as depicted in Figure 22.

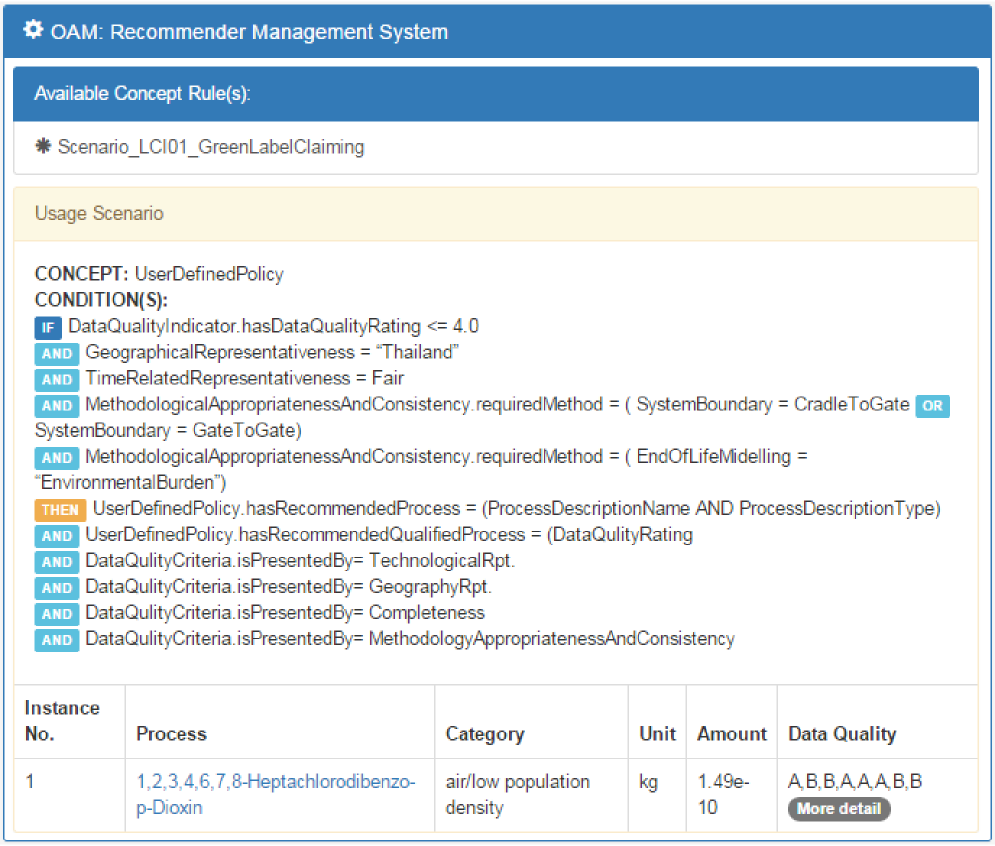

Figure 22 User-defined policy recommendation: a supporting feature of CD-OAM framework.

5.3. A Scenario in a Business Plan for Environmentally Friendly Products

In a situation aiming at promoting that a new product of a juice company, a business plan is prepared for the commercial investment. Two significant achievements are for the following purposes:

- 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-labeling, and 2) supporting sustainability in juice production.

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).

5.3.1. Stakeholder's roles and collaborative activities

As mentioned the scenario, Figure 23 elaborate collaborative activities in a sequence diagram and all stakeholders are defined by their abbreviations and participant's roles.

This research study categorizes the collaborative activities into two groups of stakeholders based on business objectives. The first group is a discussion of environmental data qualification with relevant data from a source of knowledge, such as production reports and environmental data. Stakeholders, who correspond to 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 8 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.

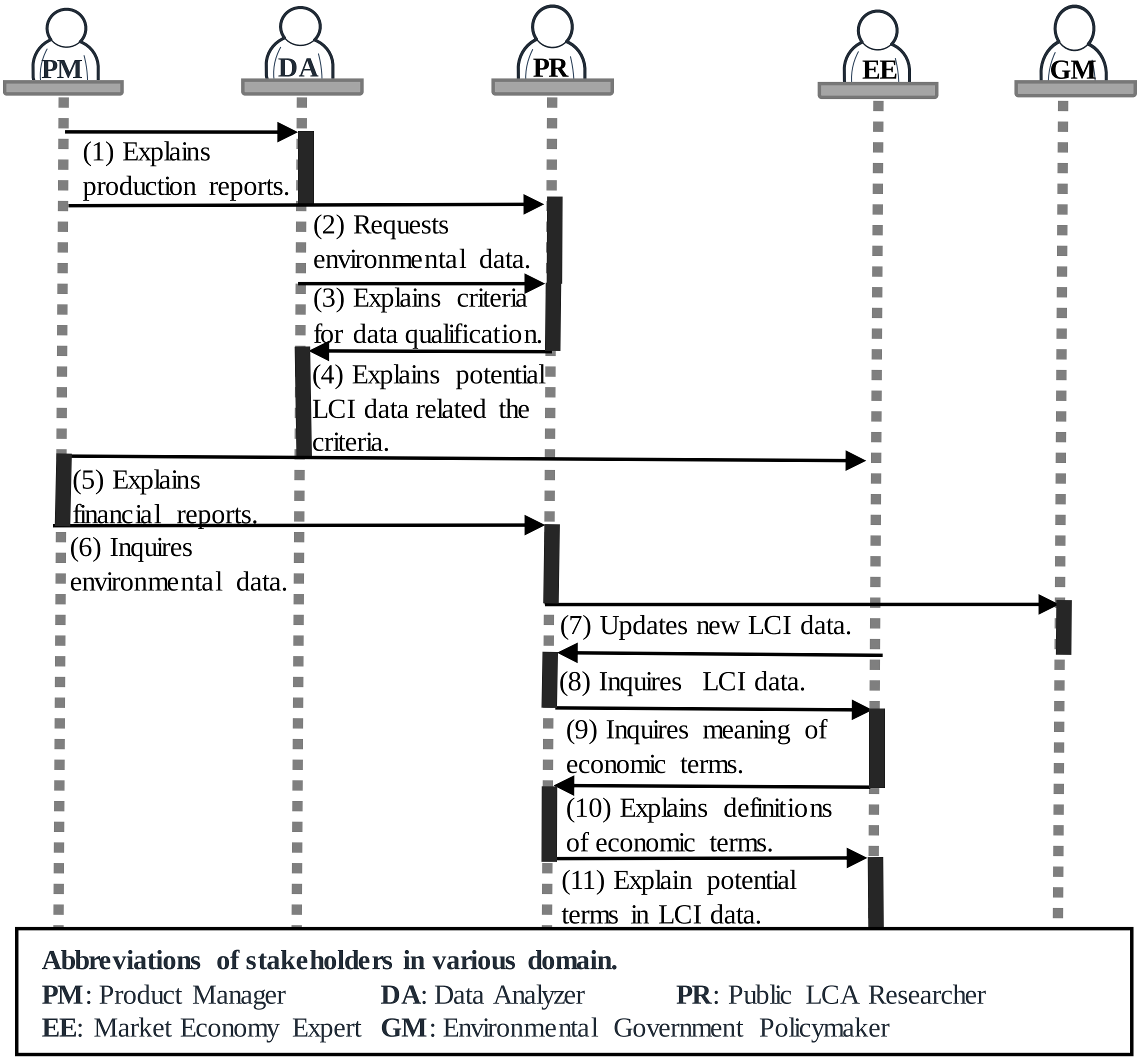

Figure 23 A sequence diagram of a collaborative scenario.

Table 8 Process details of a collaborative scenario in each collaborative activity 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 to 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 the investment in 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 maintenance and repair of real property, the 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?"

5.3.2. Recognition for solving misinterpretation problems

As illustrated in Figure 23, the research has the aim to address the problem of confusions and misinterpretations in collaborative activities. The research points out that the problem can occur in the collaborative scenario. The collaborative activities are separated 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 in 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 domains by taking into consideration LCI data and a case study of LCC calculation, as illustrated in Figure 24. 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 have different background and requirements. To point out causes of the problems, this study selects the second group to give more details in problem-solving.

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

Figure 24 An example of misinterpretation of two different domains:
Life Cycle Inventory (LCI) from ISO14048 (International Organization for Standardization, 2002) at the left, and Life Cycle Costing (LCC) calculation at the right.

A comparison in Figure 24 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 lifecycle of a product (International Organization for Standardization, 2002) (International Organization for Standardization, 2002). 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 (International Organization for Standardization, 2002). 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 the different perspectives that PR explains the LCA terms to EE and maps them to the LCC terms.

Table 9 A comparison of terms between two different domains:
Life Cycle Costing (LCC) and Life Cycle Assessment (LCA) domains.

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

Although the traditional approach can solve the misinterpretation problems, this approach still lacks other essential 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 dissertation, CD-OAM framework facilitates the stakeholders by providing a collaborative environment with domain ontology for solving misinterpretation problems.

5.3.3. Exploitations of a collaborative framework

As explained the scenario, misinterpretation problems can occur during collaborative activities. This research study intends 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 (Kozaki et al., 2002) that is a graphical ontology editor. Knowledge of the stakeholders is represented in forms of domain concepts and concept properties.

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 Figure 24, LCA domain is first analyzing in the employment of existing domain ontology. Keywords in Table 8 are extracted messages in the collaborative activities.

In the second group, PR mentions Gate-to-gate at the process (9) of Table 8 that the concept of the LCA terms can be identified by 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 Figure 25 is a cause of confusion during EE and PR discussion.

- Second, "Process Description" concept (3) in Figure 25 can use to define employee commuting (3) in Figure 24 by using a subsidiary concept, "process_name" concept in Figure 25.

- Third, concept properties of "Process Description" concept can define concepts roles for "Technical Scope" concept (4), and "Valid TimeSpan" concept (5) in Figure 25. Concerning a cross-disciplinary concept, the concept properties of "Process Description" concept (6) in Figure 25 can interlinks to the LCC domain in a lifetime in years.

- Finally, they can understand the lifetime of a process by the "Valid Timespan" concept (5) in Figure 25.

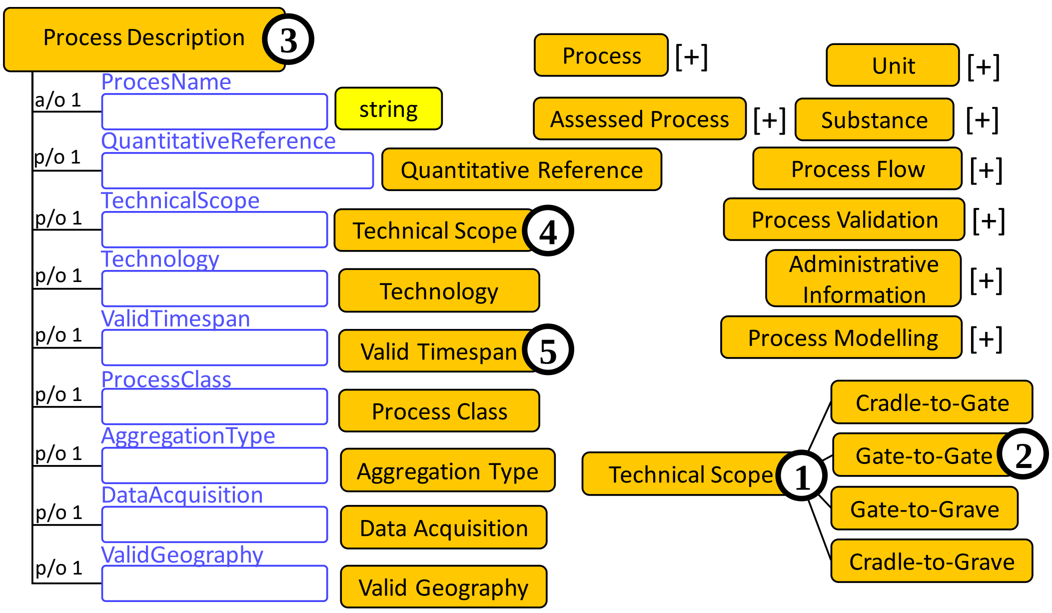

Figure 25 Multidisciplinary ontology for Life Cycle Assessment (MLCA): Life Cycle Assessment (LCA) concepts and concepts hierarchy.

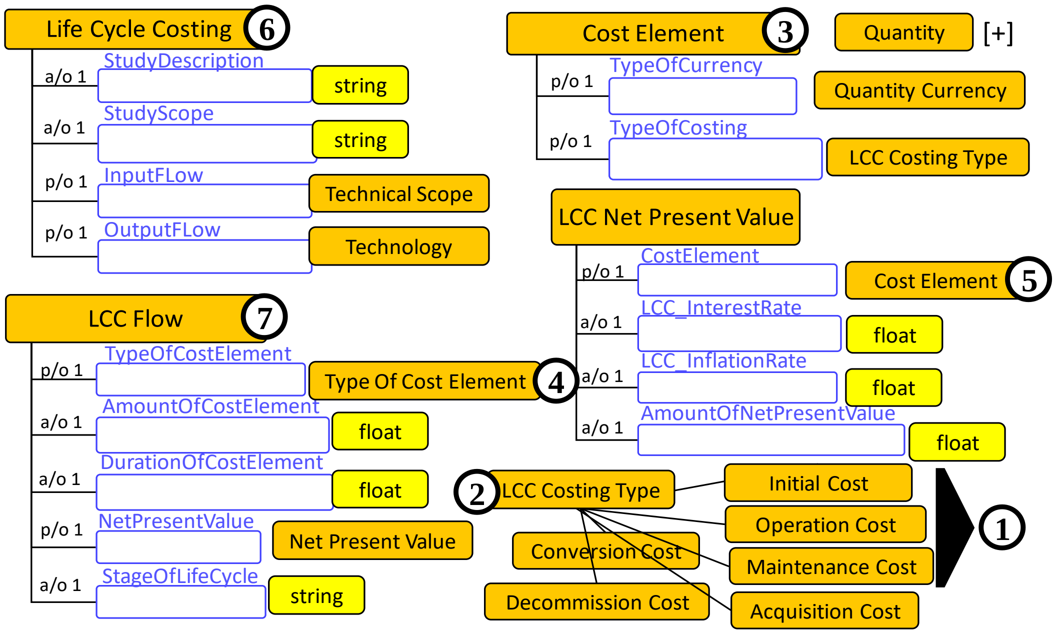

Figure 26 Multidisciplinary ontology for Life Cycle Assessment (MLCA): Life Cycle Costing (LCC) concepts and concepts hierarchy.

After understanding an ontological structure in LCA domain, I 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 I use LCC concepts from PLM Ontology (El Kadiri et al., 2015; Milicic et al., 2013). The LCC concepts are used to extend the MLCA ontology. Next, reference documents are the second source of knowledge that I consider an example of the LCC calculation (the right table of Figure 24). With the result of the ontological engineering processes, EE can identify the LCC terms as follows.

- First, EE mentioned the LCC terms in the process (8) Table 8, 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 *"CostingType"* concept (1) (2) in Figure 26.
- Second, by the result of analyzing the reference documents, I conceptualize *"LifeCycleCosting"* concept (7) in Figure 26 that has concept roles as *"LCC_Flow"* concepts (7). Each LCC flow is defined as the *"CostElement"* concept (2) that has a

concept role as the *“CostingType”* concept (3) in Figure 26 for identifying a type of currency.

With the result of ontological engineering processing, I can interlink between LCA and LCC domains by using the MLCA ontology. This research study considers 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 duration of the product, “DurationOfCostElement.” Stakeholder can share the “ValidTimeSpan” Concept (2) in Figure 27 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) (International Organization for Standardization, 2002).

- Second, for a concept property of “LCC_Flow” concept, “StageOfLifeCycle” concept (4) in Figure 27 has a concept role for defining input and output flows in the LCC calculation. Stakeholder can share “TechnicalScope” concept (1) in Figure 27 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”) (International Organization for Standardization, 2002).

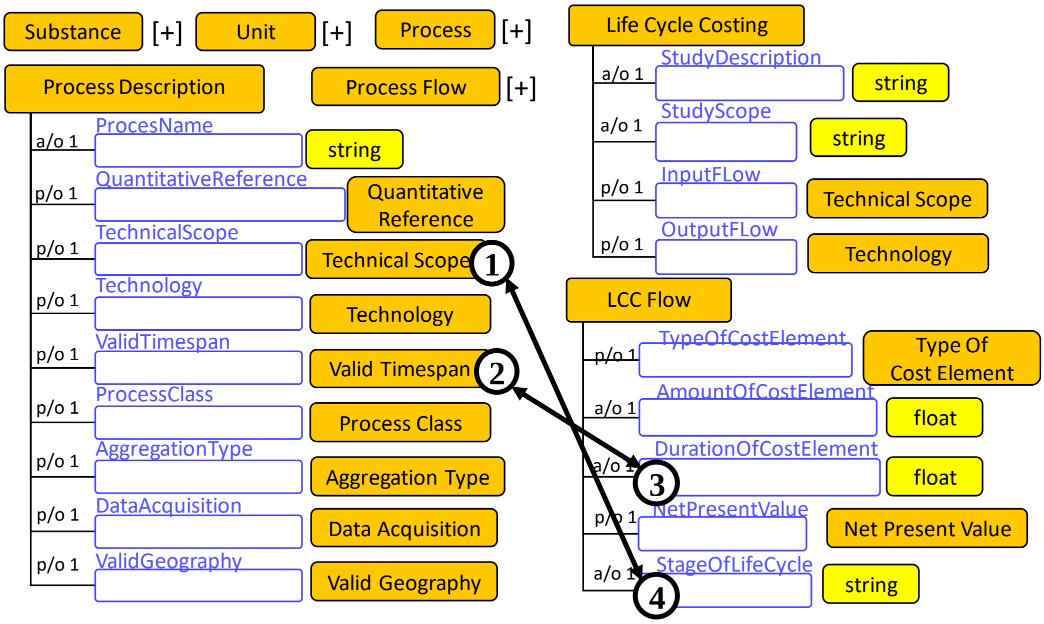

Figure 27 Excerpt of Multidisciplinary ontology for Life Cycle Assessment (MLCA): two areas have highlighted an interrelation from an environmental protection aspect to an economic aspect: from LCA concept properties to the LCC concept properties.

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 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 Figure 28, the "*LCC_Flow*" concept of the MLCA ontology is first presented with its property aspect in a label, "*Life Cycle Costing (LCC_Flow)*." Next, they 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, I 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.

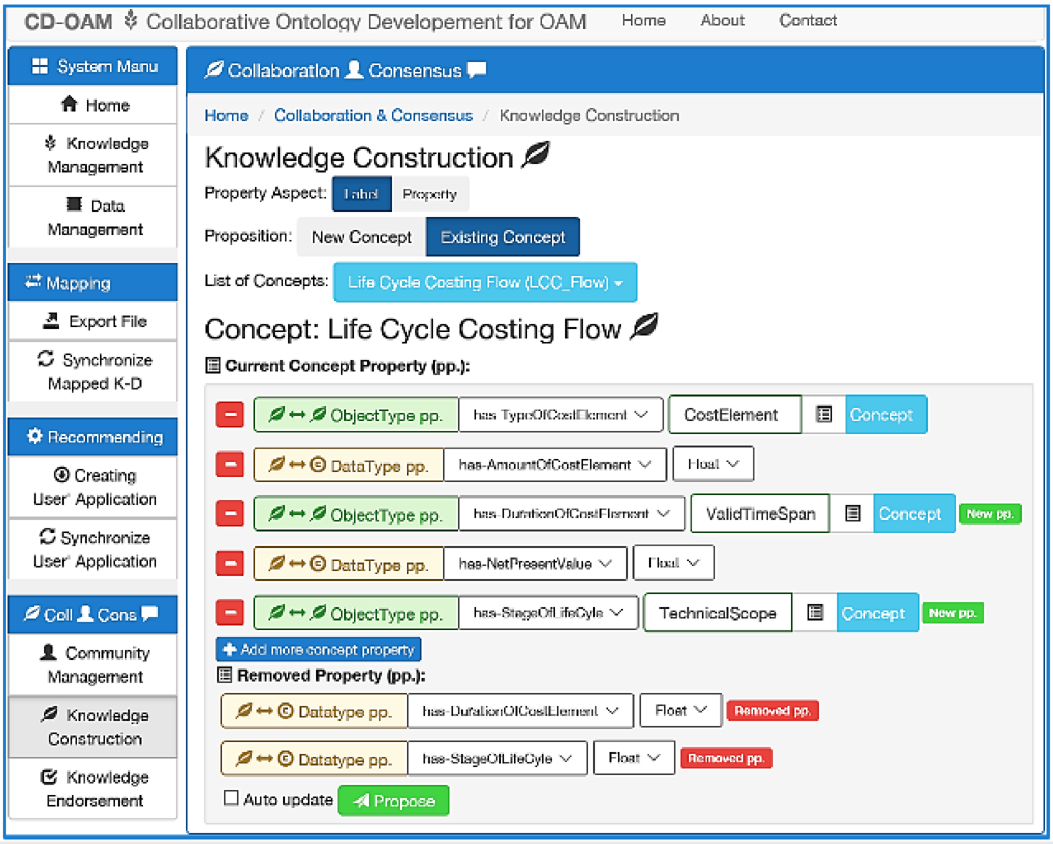

Figure 28 A knowledge construction system, called a community-driven ontology-based application management (CD-OAM) framework, supporting domain ontology incorporation.

As a result of the scenario, two different domains are shared concept roles. An interrelation between LCA and LCC domains is represented in the W3C Web Ontology Language (OWL) (Schreiber & Dean, 2004) that expresses multidisciplinary knowledge in groups of multiple domains and relations between them, as illustrated in Figure 29.

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 policymaker who has a specific agenda may need to see the overview of the knowledge, but the LCA researcher who has a specific aspect of 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.

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 >
```

Figure 29 Excerpt of Web Ontology Language (OWL) (Schreiber & Dean, 2004) representing relevant concepts in a different perspective and the whole concept.

5.4. Summary

This chapter presents two collaborative use case studies in order to overcome the research challenge underlying a multidisciplinary paradigm. The summarization in each scenario is explained as follows.

The first scenario presents CD-OAM framework with a collaborative approach among domain experts and knowledge engineers. A challenge in LCA knowledge curation is demonstrated by design and implementation of a recommender system. First, existing LCA ontologies and adopt necessary concepts in the group of *Life Cycle Inventory* (*LCI*) concepts were investigated, and then *Data Quality Indicator* (*DQI*) concepts are analyzed and interpreted. Next, LCI database was analyzed and constructed for storing LCI data from an open data provider. Afterword, stakeholders (domain experts, company personnel, and knowledge engineer) participated in order to create a knowledge base. CD-OAM framework provided the supporting feature for mapping LCI concepts to LCI database, and stakeholders were allowed to manipulate in mapping LCA concept with relevant data fields in LCI database. The mapping result was that stakeholders could check compatibility of concepts and data with knowledge engineer in the same semantic. In addition, stakeholders could simplify the developing process of a recommender system for qualified LCI processes based on prerequisite criteria transformed the industrial policy.

The second scenario elucidates CD-OAM framework in order to encourage different domain stakeholder working with under multidisciplinary knowledge. This scenario approach overcame three main challenges. First, stakeholders were allowed to create/modify/extend/reuse the MLCA ontology in order to manipulate cross-domain concepts. Second, the framework provided visualizations for supporting stakeholders in learning and exploring the ontological structure and also discovering the interrelation two domains: LCA and LCC domains. Third, this research study demonstrates this second scenario in well-defined processes for overcoming confusion and misinterpretation problems that occurred during collaborative activities. To overcome the problem, stakeholders can exploit the framework to explore and analyze concepts, relationships and structure of the ontologies for making an agreement on their new or modified concepts and concept relations. Therefore, the second scenario illustrated confusion and misinterpretation problems, and how the framework can be exploited in reducing the problems.

Chapter 6

Discussions, Conclusions, and Recommendations

In the last chapter, an evaluation of the research findings is first discussed in the collaborative use case scenarios based on user interaction in the collaborative framework. Next, the research contributions are summarized. The last section is recommendations for future work.

6.1. Discussion

The experimental result is discussed in two main points: (1) testing result and (2) limitations and concerning criteria, and details of each point are described, as follows.

6.1.1. Testing result

The CD-OAM in this dissertation is a framework for supporting collaborative ontology development (COD) that has four crucial components composed of (1) collaborative supporting, (2) ontology manipulation, (3) a set of tools in an ontology framework, and (4) relevant stakeholders in a domain of interest. Then, to consider a significant and limitation (Durán-Muñoz & Bautista-Zambrana, 2017) based on a COD framework, the framework in this dissertation concern in supporting multidisciplinary collaboration using a user-adaptive ontology as an initial knowledge of a domain-specific community. The ontology can represent a precise organization of domain-specific knowledge that makes stakeholders can identify their corresponding concepts, especially multidisciplinary concepts. Stakeholders have a possibility to understand concept levels through a hierarchical structure. Semantic search is the supporting feature providing systematicity in information retrieval. A stakeholder can point out the role-concept definitions of their corresponding concepts in related concepts or different with others. As the main research focus, the collaborative framework provides a classification of multidisciplinary concepts in representing multidimensionality.

For the testing result in chapter 5, two problems are determined regarding the research objective in tackling multiple-domain problems. However, there are formal problems in combining knowledge into ontology (Klein, 2001), as illustrated in Figure 31. The case study (Chapter 5) concerned in problems of mismatch between two different domains ontologies.

The first use case scenario focuses on explication sources of knowledge (e.g., ISO guidelines and LCI database) in order to employ the LCA knowledge underlying the multidisciplinary paradigm, SD and to understand the relevant concepts of LCI. Figure 32 represents their activities in formal problems that separate activities of four related stakeholders in the form of system flow.

The second use case scenario focuses on conceptualization considering two different concept scopes based on perspectives of domain experts. They try to understand and share concept properties under coverage of a business plan. Figure 33 represents their activities in formal problems that separate activities of four related stakeholders in the form of system flow.

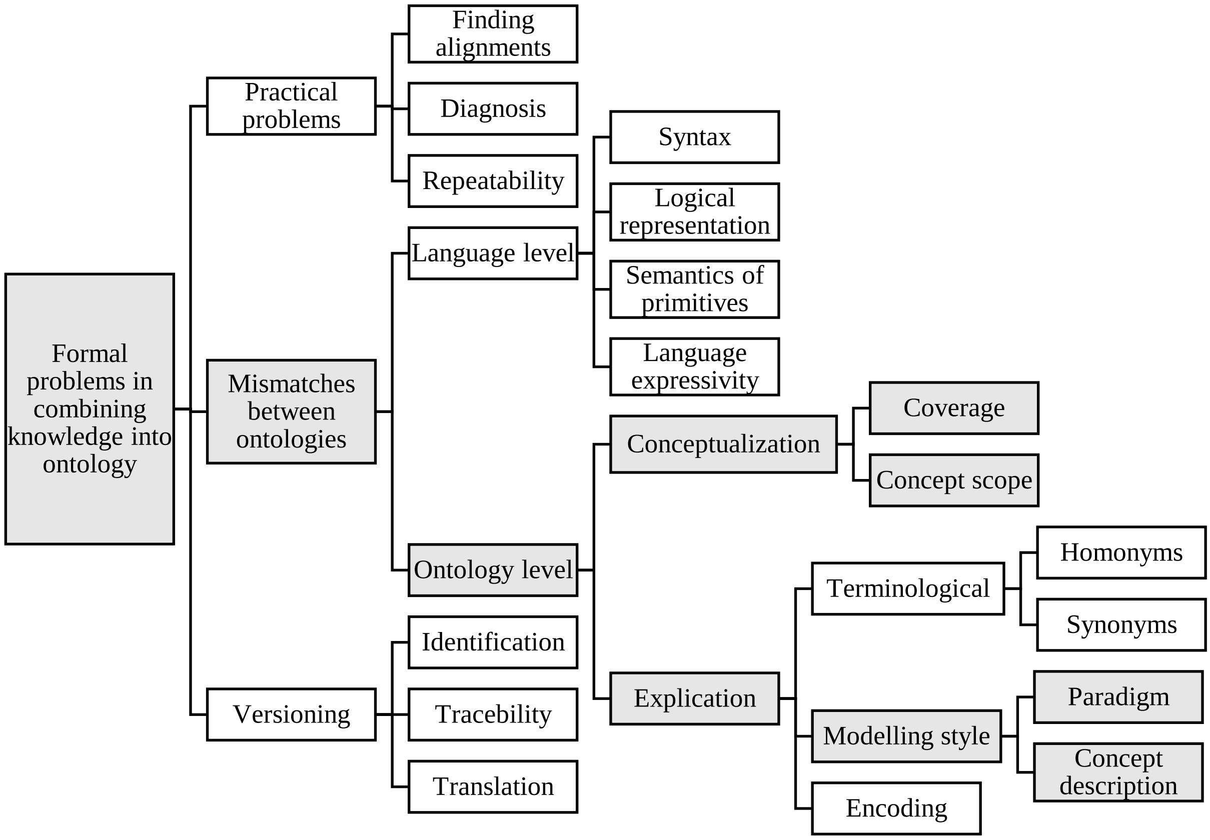

Figure 30 Formal problems in combining knowledge into ontologies (Klein, 2001).

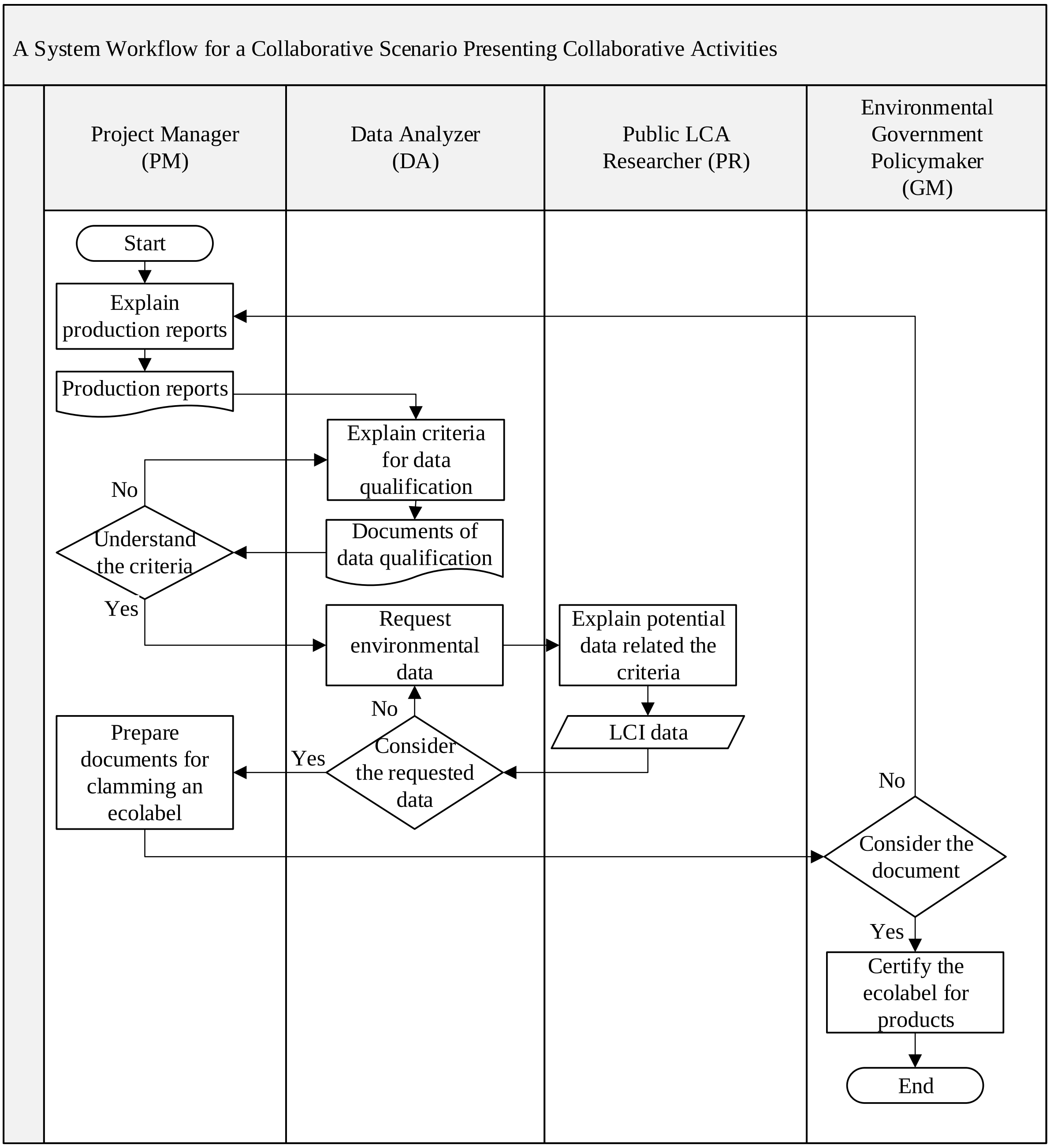

Figure 31 A system workflow of the first collaborative scenario in collaborative activities.

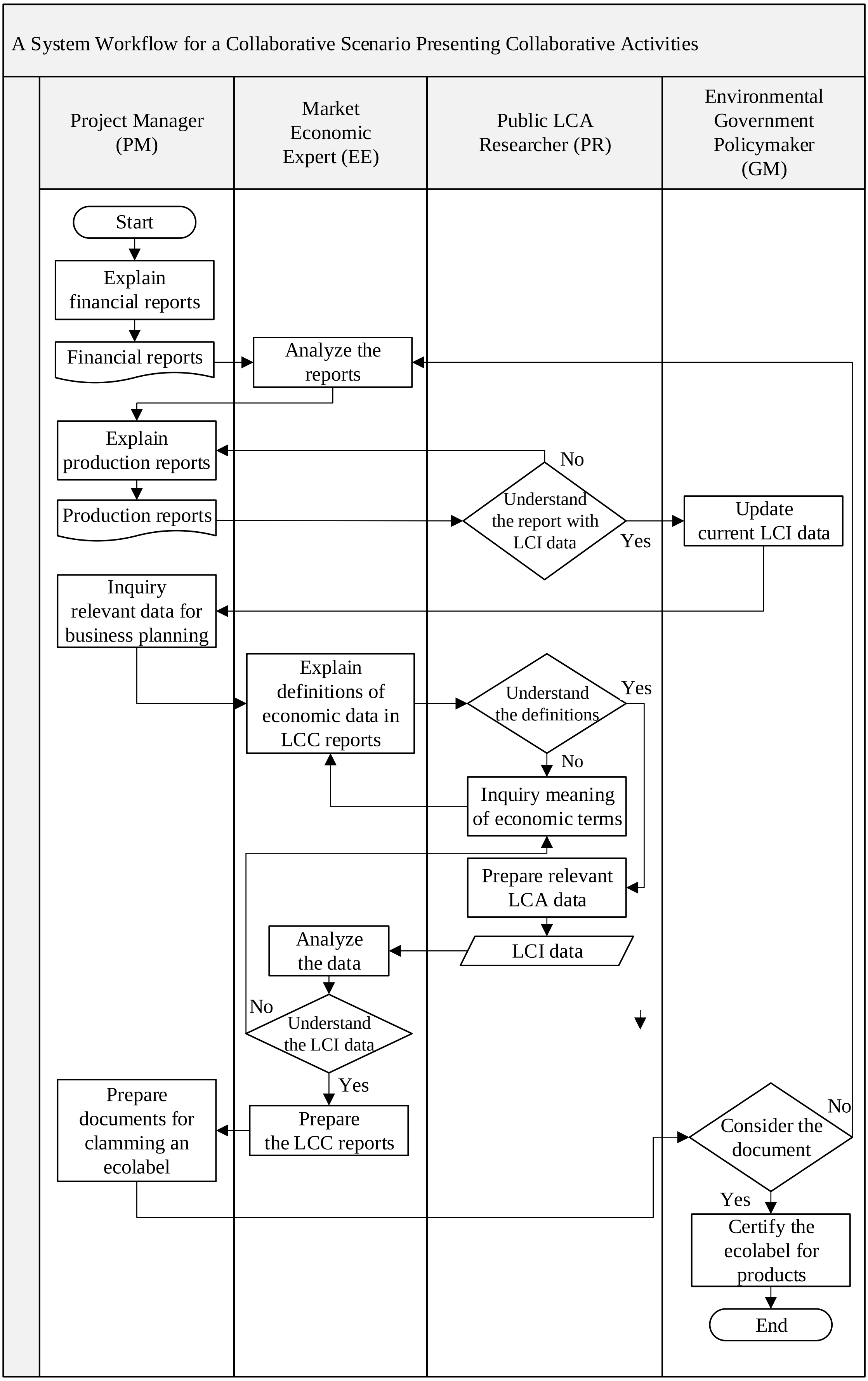

Figure 32 A system workflow of the second collaborative scenario in collaborative activities.

6.1.2. Limitations and concerning criteria

To discuss the important issue, the limitations of the CD-OAM framework are determined as follows.

First, although this dissertation support stakeholder to work with the user-adaptive ontology in combining the knowledge into the ontology considering multidisciplinary domains, they are not supported in a process ontology development. In case of representing a new understanding of stakeholder, knowledge acquisition can be an essential role in guiding stakeholder to contribute their understanding into domain ontologies. For example, in the process of software installation, one of the appropriate user's guidelines is 'Wizards' that explains each step of filing necessary information. And in the same way, the ontology development can be supported by Wizards. Recently, one attempt has been proposed a WIzard for DOCumenting Ontologies (WIDOCO) (Garijo, 2017) guiding stakeholder through the documentation process of their vocabularies.

Second, versioning system of the CD-OAM framework can support in the process of manipulating concepts, but a consistency of the ontology depends on stakeholder's understanding and agreement of their community. It could be a challenging task to support them in the process of checking inconsistency. One of the major limitations is expressing knowledge of multilingualism information, and the framework in this dissertation did not cover this task. For example, conceptualization by stakeholders could be defined by different languages. The second major limitation is lexicalization that can be a cause of misunderstanding in case of wrong labeling. For example, stakeholders purpose a new concept that makes others misunderstand its means of one or two languages. It could be a good opportunity to improve a collaborative framework in multilingual capabilities. Therefore, not only solving a collaborative problem can support stakeholders, but checking consistency in their communication can improve capabilities of the CD-OAM framework. For example, knowledge graph (Xiong, Power, & Callan, 2017) can checking multiple-domain concept and inconsistency when stakeholders propose their new knowledge in the framework.

Third, cross-platform codification is an important task in sharing knowledge across collaborative frameworks. For example, OWL is the famous ontological language for codifying domain ontologies. Knowledge converter (Kudryavtsev & Gavrilova, 2017) for various ontological languages can be a useful supporting tool for a different collaborative framework.

For example, stakeholders intend to work with domain ontologies in OIL, DAML+OIL. The converter can support them in the process of codification easily.

Fourth, as illustrated in Figure 30, concerning multiple-domain problems in combining knowledge into ontologies (Klein, 2001), This dissertation presents two problems in a mismatch between two different domains including conceptualization and modeling style. However, there are two remaining unsolved problems is terminologies and encoding. Besides, to understand their communication language, this work did not handle language levels of stakeholders such as their logical representation, or language expressivity in their communication contexts.

Fifth, a capability of stakeholder in the practical problems depends on their understanding that this practical result is supporting them in finding the alignment of relevant concepts and concepts properties. If they did not define a collaborative goal or description of relevant concepts, it would be challenging to share cross-disciplinary knowledge. A diagnosis process requires in case of a consequence of a specific mapping as an unforeseen implication.

Sixth, the CD-OAM framework provides supporting features to keep track on versioning, but the system should be improved a responsibility in a level of difficulty including an unambiguous reference to the proposed definition.

In addition, concerning criteria are discussed as follows.

The first concern is rule-based knowledge representations that are limited to basic equations describing concepts (Czarnecki & Sitek, 2013), although the provided framework with rule-based approaches can be integrated into ontology systems, in case of LCA domain. While this research approach to handle data quality evaluation, the prevalence of collaborative ontology approaches provides a level of generality by a richer semantic representation. For example, expressivity of the OWL language can describe concept constraint such as “exists,” “all,” “at least,” “at most,” “exactly.” The elements of the OWL language have at least two lower language layers: Resource Description Framework (RDF) and; RDF Schema.

The second concern is aiming at knowledge-based sustainability with the collaborative approach, this research study presented curation of LCA knowledge that utilizes LCI concepts for compatible manipulation with concept properties of DQI concepts in part of data quality criteria. The recommended result from the ontology meets this research object that participation of domain experts can define their understanding and create the inference concepts based on defining rules.

The last concern is constructing ontology from many sources of knowledge (e.g., international standard guidelines ISO, the official journal from European Commission, and existing ontologies) and was improved by designing with domain experts and knowledge engineers, the issue that some concepts in the knowledge structure, may contradict the logical constraint. In a traditional approach, all stakeholders need to solve their contradictions by consensus. For example, there are several ways to name data fields having the same functions, disallowing cross-platform compatibility and data conversion.

6.2. Conclusions

In a situation that stakeholder who has different disciplines working together, the multidisciplinary knowledge refers to their collaboration based on their disciplines. The difficulty in multiple-domains collaboration is a miscommunication from several perspectives. Under the same goal, viewing of different perspectives means to compresence a cross-disciplinary concept to achieve new insight and to share similar epistemological assumptions in a complex problem or issue.

This dissertation presents a collaborative environment for curating multidisciplinary domain ontology in case of a collaboration of different domain stakeholders. Overcoming the research challenge has conducted two working scenarios: establishing recognition of a cross-disciplinary and providing an environment to work with multidisciplinary knowledge. The objective in this dissertation focuses on providing a collaborative framework for enhancing collaborative activities of different stakeholders. Therefore, the results of the overcome challenges and research value to society are concluded with as follows.

First, a user-adaptive ontology for multidisciplinary LCA domain (MLCA) can present a central cohesive knowledge to work with stakeholders. The MLCA ontology supports collaborative activities in create/modify/extend/reuse organizational knowledge. Structural knowledge present interrelation between concepts of relevant domains supporting their understanding in terms of cross-domain concepts.

Second, a collaborative framework based on a community-driven ontology-based application management framework (CD-OAM) is a knowledge-based framework with a collaborative approach among different stakeholders, such as domain experts and knowledge engineers. The framework allows the stakeholders to explore the ontological structure in visualizations, to and analyze concepts, relationships, and structure of the ontologies, and to point out interrelation between two relevant domains.

Third, the provided framework can overcome a collaborative situation that misinterpretation problems have occurred in case of employing underlying a multidisciplinary paradigm. The testing case in this study is to promote Life Cycle Assessment (LCA), an environmental domain underlying a multidisciplinary paradigm of Sustainable Development (SD). Collaborative activities of different stakeholders are supported that they can identify an interrelation between economic aspect (e.g., LCC) and environmental aspect (e.g., LCA).

In a side of the challenging task of multidisciplinary knowledge collaboration, the contributions in this dissertation have overcome the challenge in misleading semantic in the second part of the main research. The CD-OAM framework provides a collaborative function including three necessary components: a user-adaptive ontology, a set of supporting tools with the testing result with suitable problems, and relevant multiple-domain stakeholders. In another side, the first part of the main research has provided the communicative function for tackling the challenge in lexical ambiguity. Therefore, semantically integrated functions in these two parts: communication and collaboration, would achieve completion of the collaborative framework supporting the multidisciplinary-knowledge collaboration of different stakeholders.

Lastly, in an aspect of human society, contributions of this dissertation provide a collaborative environment base on semantic technology encouraging people in a deeper understanding and working with the multidisciplinary knowledge. The system for knowledge curation aims to engage the participation of different domain to maintain every crucial domain in a new paradigm shift through the collaborative environment of this research study.

6.3. Recommendations

Although this study has determined more on the specific recommendations, in order to enhance a collaborative capability, following recommendations can be generalized for improvement in future works. In the recommendation, the employing multidisciplinary knowledge (e.g., in the paradigm of Sustainable development) can be considered in another domain requiring knowledge from relevant domains. For example, the Internet of Things (IoT) (Gubbi, Buyya, Marusic, & Palaniswami, 2013) refers to computing concepts describing a paradigm of daily life and internet connectivity through different objects. The IoT paradigm required an understanding of technology devices for achieving business goals. An online market aims to collect behaviors data from purchasing online products to forecast future direction on commercial investment. Next, the research aims to incorporate conflict detection and cross-disciplinary concept similarity into the multidisciplinary knowledge. The second recommendation of the research approach can be enhanced collaborative capabilities of the framework by considering augmentation. In the additional recommendation, a designing system for ontology curation can improve aims at incorporating the notions of conflict detection and concept similarity by conforming user experience.

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