IEEE Access
Multidisciplinary | Rapid Review | Open Access Journal

Received January 16, 2022, accepted January 21, 2022, date of publication January 26, 2022, date of current version February 4, 2022.

Digital Object Identifier 10.1109/ACCESS.2022.3146331

Towards a Usable Ontology: The Identification of Quality Characteristics for an Ontology-Driven Decision Support System

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ABSTRACT Achieving quality in use (i.e., the higher-level quality objectives) is now widely accepted for building a usable system and software product. However, ontology engineering is a discipline for which the quality theories are not yet well developed and adapted and thus, ontology engineering still does not have an agreed methodology and standards for ontology evaluation. As a result, an ontology-driven system may consist of a badly engineered ontology that is not usable. This will in turn cause an adverse effect on the quality in use of the corresponding system. It is necessary to alleviate this problem by formulating an evaluation methodology and standards towards producing a usable ontology particularly targeting an ontology-driven system. It is evident through the literature as well as our practical experience through an agricultural ontology-driven Decision Support System (DSS) that quality in use of the system is tightly coupled with the quality of the ontology. As the first step towards this, we explored the well-established quality theories in system and software engineering to adapt and enhance the quality concepts defined so far in the ontology engineering domain. In the light of this study, we devised an ontology quality approach that guides developers to produce ontologies by avoiding quality issues to make ontology-driven DSSs usable. The proposed approach was exemplified using a use case from the agriculture domain. This research could be a foundation to inspire and assist ontology engineers to rethink about ontology quality from a broader view in developing a usable ontology.

INDEX TERMS Agriculture, context of use, ontology quality, quality assessment, quality in use, software quality.

I. INTRODUCTION

Nowadays, ontologies are increasingly incorporated in information systems due to the distinct capabilities that they have such as sharing a common understanding of the structure of information among people or software agents, enabling reuse of domain knowledge and use as a knowledge base for decision-making [1]–[3]. Additionally, ontologies have the significant feature of inferencing knowledge from explicit facts which is not available in other repositories like glossaries, databases, dictionaries, thesaurus and data models [2], [4], [5]. However, these capabilities would not be beneficial for ontology-driven DSSs unless a good quality well-engineered ontology is produced. The literature reveals that a well-engineered ontology significantly improves the quality of the ontology content and structure [6]–[11]. Thus, producing a good quality ontology is important as it would affect the overall system quality and in turn, the user satisfaction [6]–[9]. This situation has been clearly emphasized in [8], [10], [11]. These researchers have highlighted that a substandard ontology with an incomplete definition has produced incomplete information for multiple user queries and moreover, an incorrect definition has adversely affected the accuracy of the results that are produced upon that definition. We also practically experienced this situation through our ontology-driven DSS (i.e., Ontology for Sri Lankan

The associate editor coordinating the review of this manuscript and approving it for publication was Kostas Kolomvatsos.

Agriculture: http://137.154.179.224/oms/ and the mobile application: https://govinena.lk/) which was developed for the agriculture domain in order to support the decision-making process of farmers in Sri Lanka [12]–[14]. Of which, the user-centered ontology [13] is the core component of our system where all required agriculture knowledge is stored. It was designed to generate answers for user queries based on their contexts such as crop type, location, preferences, tasks, available equipment and materials. Even though the system has been verified as a good solution by domain experts in realistic terms, it is not actively used among real users (i.e., farmers). The reason for this was investigated through serval interviews conducted with farmers. In the light of these interviews, it was revealed that the answers received from the system for user-queries are incomplete and inconsistent. This was further explored in the domain of pest and disease management by analyzing the answers received for the CQs from the agriculture ontology against the answers verified by the domain experts and users. It could be observed that for 56% CQs the system has produced incomplete answers and for 40% CQs the answers received were inconsistent. From the ontological perspective, these problems have occurred due to a handful of issues in both the ontological content (i.e., knowledge base) and the structure (i.e., schema) such as missing axioms (with respect to object property assertions, class assertions, disjointness) and incorrect axiom definitions (such as incorrect individuals, and literal values of data properties) as pointed out previously by [8], [10], [11]. This shows that even a very few quality issues in the ontology can lead to a number of incomplete and inconsistent results for user queries. Consequently, this effect creates a negative user attitude towards the system adversely affecting its usability in use.

Accordingly, it is clearly evident that a good quality ontology is necessary to make the overall ontology-driven DSS usable. Consequently, quality assessment of ontology content and structure is essential before it is deployed in a system. Nonetheless, quality is considered as a judgment and not a feature [9], [15]–[18]. Thus, quality should be taken into account relative to the intended user needs of the system [17], [19]. Hence, the quality assessment varies from domain to domain. Not only that it may even vary for different use cases in a single domain [20]. For instance, DBpedia [21] is a generic ontology that has been created by aggregating details provided in Wikipedia info boxes. It facilitates users to semantically query the information and is good at providing information for general interests. Nevertheless, it does not work well for specific domains such as medical, agriculture, and defense [22]. Hence, a specific ontology for a specific domain should be produced based on the specific requirements of that domain.

The quality theories with the relevant quality criteria, metrics and assessment methodologies are well established and recognized in the domain of system and software engineering. Based on these theories, the human-centered design approach is followed to make a usable system [23]. To this end, at early stages (i.e., requirement analysis and design), the quality requirements which are to be achieved through a system should be elicited from user needs in a specified context. Then, these quality requirements should be evaluated and ensured through the software development life cycle [17], [19], [24]. Hence, eventually, the system should meet the *quality requirements* that are derived from *user needs* in order to achieve quality in use.

Fig. 1 presents how the quality requirements specified at the higher level get penetrated to the external and internal levels of the software product. The specified quality requirements (Fig. 1, No.1) can be further decomposed into sub-quality requirements which are to be achieved from each component (i.e., software, database, ontology, hardware) of the system internally and externally (Fig. 1, No.2) [17], [25], [26]. Accordingly, the internal quality requirements of each component should be verified by the developers during the software development which is called white box testing. Then, the entire product is to be tested after the development and integration in the software environment (i.e., external quality), which is called black-box testing [27]. Eventually, the final product should be tested in the real environment to validate whether the user needs are achieved (i.e., quality in use), through a usability test [17]. All these assessments will lead to producing a quality software solution at the end of the development process which eventually becomes a usable product. This has been further discussed in Section II.

It is evident that for ontology-driven DSSs the ontology is a significant component that would affect the quality in use of the system. Hence, it is mandatory to ensure that a good quality ontology is modeled concerning the user needs in a specified context. That will in turn strongly influence the overall system quality. This is further illustrated in Section IV. However, the non-existence of agreed methodologies and standards for ontology evaluation results in producing poorly engineered ontologies that are not capable of catering to the intended user needs of the ontology. This will eventually result in an ontology-driven solution that is unacceptable and thus, not used by the user. For instance, in developing the user-centered ontology with respect to our ontology-driven DSS, TOVE (Toronto Virtual Enterprise) methodology (i.e., Gruninger and Fox methodology) was adopted [28]. Based on this methodology, the development of the ontology was initiated by analyzing the CQs [28]. Then, the gathered CQs were converted into the axioms in First-Order Logic and modeled the ontology accordingly [13]. At the end of the development, as usual, the quality of the content was evaluated by analyzing the answers of CQs provided through the ontology with the support of domain experts [29]. In addition to that, the quality of the structure was assessed using the OOPs web-based tool [30]. The internal consistency was ensured with the reasoner available in the ontology development tool (i.e., FaCT++ reasoner) [31], [32]. The main weakness of the ontology development methodology that we have followed

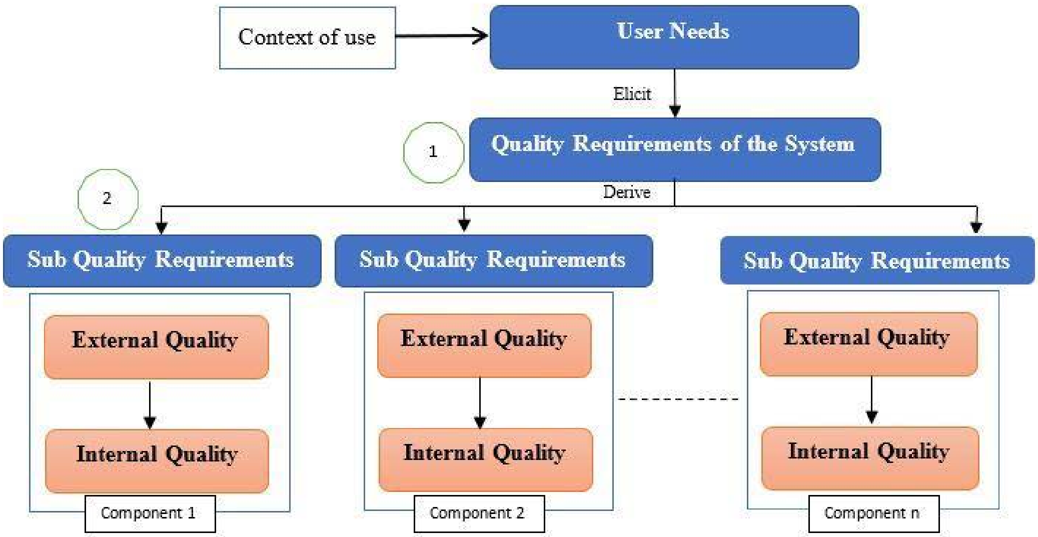

FIGURE 1. Tracing software quality requirements from user needs.

under TOVE is not tracing the internal and external ontology quality requirements from the user needs in the context. Consequently, the essential quality characteristics which could be derived from the user needs of the given context such as domain completeness, external consistency, and conciseness have not been taken into account in developing the ontology. Thereby, at the end of the development, the ontology was unable to successfully answer the user queries [33].

To alleviate this problem, initially, the existing works on ontology quality were thoroughly reviewed [34], because a good quality ontology has a positive impact on the quality in use of the overall system as explained above. In light of the literature review, we realized that there are no agreed methodologies, models, and approaches in developing a quality ontology or assessing ontology quality. However, there are significant research contributions based on ontology quality as identified and highlighted in Section III. Based on this, a systematic review was performed [35] and thus, we recognized that the findings in the domain of ontology quality could be enhanced and formalized with the existing quality theories defined in software engineering (Section II). Correspondingly, a conceptual approach was constructed and proposed for ontology quality as a foundation for future research as presented in Section IV. The proposed approach was further illustrated with a use case in agriculture in Sections V and VI. Although, we do not claim that the proposed approach is complete and well established. It will be a step towards streamlining the quality assessment of ontologies.

II. QUALITY IN THE SOFTWARE LIFE CYCLE

Fig. 2 presents the conceptual approach of system and software quality according to ISO/IEC 25010 [24], [36], [37]. It presents how the higher-level quality objectives (i.e., user needs) are getting incorporated in the software life cycle (Fig. 2).

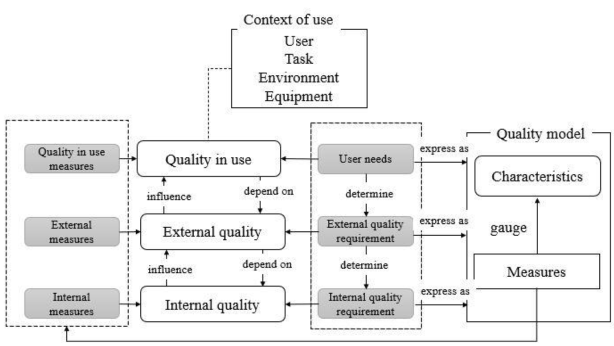

FIGURE 2. Quality in the software life cycle [19], [24].

Quality in use is how users perceive the quality of the software product when it is used in a specified context. This has been defined as "the degree to which a product or system can be used by specific users to meet their needs to achieve specific goals with effectiveness, efficiency, freedom from risk and satisfaction in specific contexts of use" [37]. In achieving quality in use, analyzing the context of use is essential to understand the context that will apply in the system to be developed and to realize the quality requirements associated with the user needs for the system (Fig. 2). The context of use is defined as "users, tasks, equipment (hardware, software and materials), and the physical and social environments in which the software product is used" [36], [37].

In brief, quality in use is an outcome of interaction when a product is used in a particular context of use. Thus, based on the user-specified context of use, the quality in use can be measured for example in terms of effectiveness, efficiency, satisfaction, context coverage and freedom from

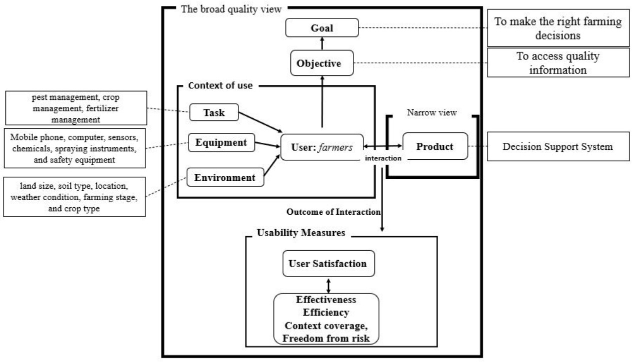

FIGURE 3. The broad view of quality: Quality in use.

risk as illustrated in [37]. To achieve quality in use through the system, it should be identified what set of quality requirements the system should meet with respect to the user needs. As illustrated in Fig. 2, the system requirements can be elicited from the user needs and then, they can be specified as the external quality requirements of the system (i.e., hardware and software). This set of external quality requirements provides goals for the internal design of each component of the system (i.e., database, web application, user interfaces, hardware devices). Based on these goals, the set of internal requirements can be specified.

Furthermore, each quality requirement derived in each stage (i.e., external/internal) can be viewed as characteristics. Thus, the quality requirement can be assessed using a set of measures (Fig. 2: Quality model). Therefore, the measures can be used to ensure whether the corresponding internal and external quality requirements are being achieved through the development. For instance, consider that *the correct information should be produced through the system* is defined as a quality requirement of the DSS. Then, the corresponding characteristic related to this requirement is *functional correctness* that can be measured using *the number of correct answers provided through the system* at the external level (i.e., after the development of the relevant component). Correspondently, at the internal level, if the information is retrieved from a database, then, the database can be internally inspected by checking *data accuracy* using the related measures such as *the number of incorrect data values in the database*, *the number of incorrect entity mappings* and *the number of incorrect queries* embedded in the database application. Accordingly, achieving the quality in use depends on the external quality which in turn depends on the associated internal quality.

To further illustrate the concept described in Fig. 2, we considered a DSS in agriculture (Fig. 3). DSS is vital for the agriculture domain, especially, for farmers to make the right decision at the right time. In developing such a system, the context of use should be taken into account as described above. With respect to the DSS in agriculture, the context of use can be defined as ''the main users of the system are the farmers who may have different attitudes, literacy, culture, and preferences. The possible tasks that users can perform are pest management, crop management, and fertilizer management. The physical and social environments are farm location, cultivated crop, land size, soil type, weather condition, farming stage, and rural/urban areas. The equipment would be a type of devices (mobile, computer, sensing devices), spraying instruments, safety equipment and material (chemicals, fertilizers, fungicides) that the farmers use''. Accordingly, when providing information for farmers, the context of use also has to be taken into account. If the DSS fails to provide the right information to the specified context, then, the farmers are unable to make the right decision. Thus, in turn, they will not satisfy with the system. To this end, the system fails to meet quality in use. However, this could be a failure of the external quality of the system (i.e., functional completeness, functional accuracy, functional appropriateness). Out of the set of external characteristics, if the functional completeness is taken into account, it could fail due to the negative consequence of the internal attribute such as *missing agriculture data values with respect to the specified context* or *missing database queries embedded in the database application* or *missing entity mapping*. Therefore, it is vital to identify how the quality in use is traced to the external characteristics (i.e., external quality) which in turn gets mapped to the associated internal characteristics (i.e., internal quality).

However, this high-level quality approach (Fig. 2) so far has not been taken into account in determining ontology quality, although it is essential as we highlighted in Section I. Thus, an effort was made in this study to construct an approach for ontology quality concerning the broad quality view which is the quality in use.

III. LITERATURE REVIEW

Currently, there are methods, models, tools and approaches available for ontology quality assessment (Table 1). In addition to that, several attempts have been made to develop methods by adopting theories from system and software Engineering namely the ROMEO methodology [15], Semiotic Metric Suite [39], the cohesion and coupling metrics [6], and OQuaRE [40]. However, there is no evidence regarding any method or an approach for ontology quality assessment that has considered quality from a broader view.

The ROMEO methodology [15] has been introduced to identify a set of internal measures for ontology evaluation by adopting the GQM (Goal-Question-Metric) approach [26]. GQM describes a way of deriving a set of measures in relation to the goal of the software product. To this end, a set of questions are defined by tracing the goal of the software product and figuring out the related quality characteristics to be achieved. Then, the associated measures with respect to quality characteristics are derived. The same approach has been described in the ROMEO methodology assuming the goal of ontologies already has been defined. Thus, there is no clear explanation on how the goal of ontologies is derived; whether it is from user needs or based on the requirements

TABLE 1. Comparision of the existing works.

Tools and Methods	Theories Adapted	Description	Domain Independency	Evaluation Aspects
ROMEO methodology [15]	The GQM (Goal-Question-Metric) approach [26]	A methodology to derive a set of internal ontology measures from ontology roles	YES	Internal Quality
The Semiotic Metric Suit [39]	A semiotic approach of IS design [49]	A suite of metrics to assess the quality of an ontology	YES	Internal Quality
Cohesion and Coupling metrics [6]	Object-oriented Concepts (Cohesion) in Software Engineering [41]	A set of measures to assess the cohesiveness of ontologies	YES	Sub Characteristics of Internal Quality
OQuaRE [40]	The SQuaRE standard for Software product Quality [37]	A framework for evaluating the quality of ontologies	YES	Internal and external Quality
OntoQA[43]	Ontology theories and empirical studies	A set of measures to evaluate the internal ontology quality	YES	Internal Quality
OntoMetric [44]	OntoQA Measure definitions [43]	An online tool for evaluating the internal ontology quality	YES	Internal Quality
OOPS! [30]	ontology theories in [50] and empirical studies	An online tool to check ontology pitfalls	YES	Internal Quality
A quality model of McDaniel et al [45]	The Semiotic Metric Suit [39]	A suite of metrics to assess the quality of an ontology	YES	Internal Quality
OntoCheck [46]	Ontology theories and empirical studies	A tool to verify ontology naming conventions and metadata completeness	YES	Sub Characteristics of Internal Quality
OntoQualitas [41]	ROMEO methodology [15]	A set of characteristics and measures for ontology evaluation	NO	Internal and Quality in use (Partially)
A quality model of Zhu et al [42]	Ontology theories and empirical studies	A set of characteristics measures for ontology evaluation	NO	Internal Quality and External Quality
Data-driven evaluation [51]	Information Retrieval, Ontology theories and empirical studies	A technique for ontology evaluation	YES	Internal Quality
Golden standard-based evaluation [52]	Ontology theories and empirical studies	A technique for ontology evaluation	YES	Internal Quality
Application-based evaluation [53]	Ontology theories and empirical studies	A technique for ontology evaluation	YES	Internal Quality and External Quality
Human-based evaluation [8], [54]	Ontology theories and empirical studies	A technique for ontology evaluation	YES	Internal Quality, External Quality and Quality in use

of designers. However, this method can be utilized as a complementary method under the quality evaluation from a broader view to derive measures. The Semiotic Metric Suite [39] has been defined to assess the internal quality of ontologies that is based on the semiotic approach which has been initially introduced for the Information Systems (IS) design. Basically, the semiotic metric suite provides a set of measures that is independent of any application and domain. Thus, it is difficult to use in evaluating whether an ontology satisfies the quality requirements in a specified context. The cohesion and coupling metrics [6] are also a set of internal measures that can be used to evaluate the modularity of ontologies. It has been developed based on the object-oriented concept proposed in [41].

OQuaRE [40] is a framework for evaluating the quality of ontologies that has been constructed based upon the SQuaRE standard [37]. Mainly, the OQuaRE provides a quality model which comprises the same set of quality characteristics defined in the SQuaRE standard such as reliability, operability, maintainability, compatibility, transferability and functional adequacy. Additionally, the structural characteristic to evaluate the structural features of the ontology has been introduced to the model. Moreover, under each characteristic, a set of sub-characteristics have been listed with associated measures upon ontology theories [42]. However, it solely considered ontology as a software artifact and thus it has ignored the semantic aspect that is vital for ontologies when processing meaningful interpretations. Moreover, OQuaRE is difficult to adopt in using quality assessment of ontologies as it is more subjective [43], [44].

In addition to the mentioned methods, many tools are available online for ontology quality assessment namely OntoQA [45], OntoMetric [46], OOPS! [30], the quality model of McDaniel *et al.* [47] and OntoCheck [48]. All of these are introduced for internal quality evaluation of ontologies independent of any application and domain (Table 1). The OntoQualitas [43] and the model of Zhu *et al.* [44] are the quality models which have been developed for specific requirements. The former one has used ROMEO methodology to derive internal measures of ontologies. It has however not defined whether the ontology requirements were specified from the user perspective or the designer perspective. The latter one Zhu *et al.* [44] has not described a method that has been used for their model development.

In addition to that, there are several evaluation techniques namely data-driven evaluation, golden standard-based evaluation, application-based evaluation, and human-based evaluation [34], [55]. These techniques can be adopted when evaluating different layers of ontologies such as syntactic, structure, semantic, vocabulary, and context after the development of ontologies. For instance, the data-driven evaluation assesses the ontology against the corpus that is used for ontology modeling [51]. This approach is good for evaluating vocabulary, structure and semantic layers of ontologies. The same layers can be evaluated using the golden standard-based technique [52]. However, it uses another ontology known as standard or reference ontology for the evaluation assuming that it has the agreed quality. The application-based technique performs quality evaluations by deploying ontologies in an application [53]. Thus, it observes the quality of ontologies in a particular context (i.e., context layer). The human-based evaluation performs the quality assessment with the intervention of domain experts and users [8], [54]. Thus, this technique supports the evaluation of all layers of an ontology. It has been realized that the described techniques can be associated with the different stages (i.e., quality in use, external quality, internal quality) of the broader quality view. For instance, the data-driven and the golden standard techniques can be adopted to evaluate the internal quality of ontologies. The application-based technique can be utilized to assess the quality in use and external quality of ontologies. The human-based evaluation can be adopted for quality assessment under all three aspects.

Moreover, it can be concluded that the existing works have mostly focused on developing tools and methods for internal quality evaluation of ontologies, mainly, considering general quality requirements and not particularly targeting quality requirements elicited from user needs. However, as stated in Section I, quality is a judgment. Thus, the quality requirements to be assessed could vary from one domain to another domain. Not only that, but within the same domain also these requirements may even vary from one context to another context. Thus, it has been realized that internal and external quality assessments of ontologies should be carried out considering the user needs in a specified context of use. In fact, limiting the quality evaluation based on designers' requirements is not sufficient to produce a usable ontology. Thus, still, there is an open research area to develop an approach for ontology quality assessment considering the higher-level quality objectives (i.e., a broader quality view).

IV. ONTOLOGY QUALITY ASSESSMENT APPROACH

The broad quality view that was drawn for ontology quality in an ontology-driven DSS is presented in Fig. 4. It considers quality under three main scopes namely operational environment, system environment, and ontology environment (i.e., the term *ontology environment* is used to refer to the domain and conceptualization scopes of ontology) [19], [24]. It also presents how the user needs get penetrated to the external quality and then, to the internal quality of an ontology. It should be specifically mentioned that we have only adopted the software quality approach (Fig. 2) for assessing the ontology quality as illustrated in Fig. 4. However, we have not adopted the same characteristics and measures provided in ISO/IEC 25010 directly for ontologies. This is due to the fact that ontology is specified as a conceptualization, which consists of concepts that are expected in the world being represented, and relationships among them. Thus, it is difficult to adopt the measures proposed in ISO/IEC 25010 for ontologies. For instance, OQuaRE [40] is an approach that has been developed by adopting the same characteristics proposed in ISO/IEC 25010. However, the researchers [43], [44] have shown that the measures of the characteristics adopted under OQuaRE are difficult to be evaluated in practice from the ontological perspective. Moreover, the semantic evaluation, which is particularly significant as an essential quality characteristic for ontologies, has not been considered under their approach [43], [44]. Thus, to this end, we identified a set of characteristics and measures for ontologies through a systematic review on ontology quality [35], specifically, considering the internal and external quality. As a result, Fig. 5 was brought up in order to provide a general understanding of what set of quality characteristics can be associated with each stage (i.e., external, internal) of an ontology. Mainly, the characteristics were classified considering the ontology quality aspects that are further discussed in the subsequent sections.

A. QUALITY IN USE AND USER NEEDS

Quality in use of the ontology-driven DSS can be defined as the extent to which the system meets the user needs in specified contexts of use. When assessing the quality in use of a particular system in the operational environment, the quality of each component (i.e., ontology, database, software, hardware) of the system is not assessed separately. Instead, the quality in use is assessed with respect to the combined effect of the quality characteristics of the overall system components [24]. For instance, the quality in use of an ontology-driven DSS is the combined effect of ontology quality, the software quality and hardware quality that the system consists of. However, the quality of an ontology would eventually contribute towards the quality in use of the ontology-driven DSS that is evaluated at the operational level. To this end, the required quality of an ontology can be determined by inspecting the associated measures of quality in use of the overall system [37]. For instance, when an ontology-driven system for document searching is taken into account, *the time spent to complete the searches successfully* (in terms of received relevant documents in a specified context) by users is a measure of efficiency (i.e., a measure of quality in use). This measure could depend on the quality characteristics of ontology and also the other system components such as document preprocessor, query engine, and index engine [56], [57]. For example, the mentioned measure depends on *the structural properties of the ontology*, also *the efficiency of the reasoner, the efficiency of the query engine* and *the index engine*. Nevertheless, in this study, we have not emphasized how the quality in use of ontology-driven DSSs is evaluated in the operational environment. We only focus on the external and internal quality characteristics of the ontology that contribute towards the quality in use of the overall system.

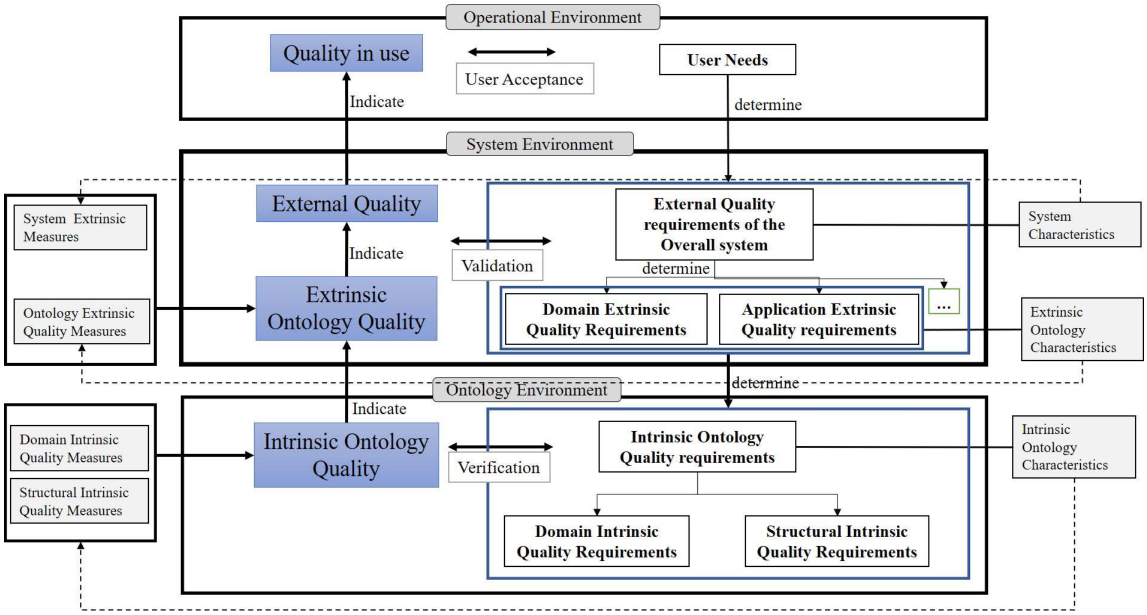

FIGURE 4. Quality approach for ontology-driven DSSs adopted from the software product quality approach [24] [37].

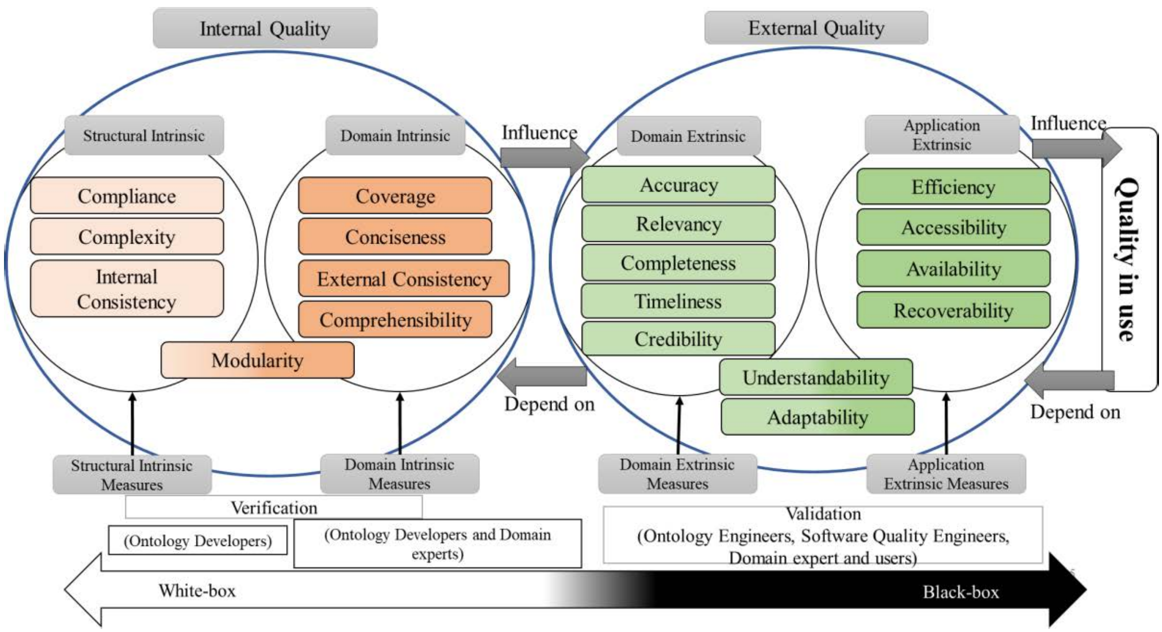

FIGURE 5. Quality characteristics associated with the ontology evaluation space.

In summary, it is evident that the quality of each component of the system would contribute towards the quality of the overall system. Based on the theories adopted in software engineering, we identified that user needs can be specified as quality requirements which are to be expected from the overall system (i.e., ontology, software, hardware), which in other words represent the quality in use in terms of specific contexts of use. Accordingly, the identified quality requirements can be used to determine the external and internal quality of each component of the system. This way, the external and internal quality of an ontology can be determined against the quality requirements that are derived based on the user needs.

B. ONTOLOGY EXTERNAL QUALITY AND QUALITY REQUIREMENTS

External quality refers to "*the extent to which a system satisfies stated and implied needs when used under specified conditions*" [58]. Particularly, it is the outcome of the total characteristics of the system components which will be evaluated in the system environment against the external quality requirements (Fig. 4). The quality requirements which are to be met through the system can be elicited from user needs as illustrated in Section II and they can also be viewed as characteristics for the external quality [24], [26], [37].

These quality requirements can further be segregated into the quality requirements which are to be achieved from each component of the system. In Fig. 4, only the association between user needs and ontology quality requirements has been illustrated as the main focus of this study is ontology quality. Similarly, the quality of other system components (i.e., hardware, software) also should be considered to achieve the overall external quality (i.e., system requirements) of an ontology-driven system and to achieve quality in use. To this end, the approaches and methods explained in [23], [26], [37], [58] can be adapted to derive quality characteristics and measures for the software and hardware components based on the specified context of use.

From the ontological point of view, the quality requirements to be met by an ontology in the system environment can be further classified into two groups considering the aspects of the ontology evaluation namely *application extrinsic quality requirements* and *domain extrinsic quality requirements* [59], [60]. These quality requirements are assessed by considering an ontology as a part of the system using the paradigm of Blackbox evaluation. Thus, at this level, the internal content and structure of the ontology are not taken into account. Moreover, at this external level, ontology developers can perform the quality assessment with the support of domain experts and software quality engineers, perhaps with users (Fig. 5). The external quality characteristics associated with these aspects (i.e., domain extrinsic and application extrinsic) can be used to validate whether the right ontology is built for the intended purpose [61]. To this end, the *domain extrinsic requirements* consist of requirements that are associated with the domain knowledge that the ontology is used in modeling. For instance, if an ontology-driven DSS in agriculture is considered, the possible quality requirements can be given for example as *providing sufficient crop information for users, correct control methods for diseases and providing only the relevant information*. The possible quality characteristics that can come under the domain extrinsic characteristics are *accuracy, relevancy, completeness, timeliness,* and *credibility* (Fig. 5, Table 2). If we consider the characteristics: *accuracy, relevancy* and *completeness*, then, the answers provided to the CQs through the ontology can be analyzed to measure these characteristics in the system environment. This has been further explained under Section V and Section VI using a use case in agriculture.

The *application extrinsic requirements* consist of the ontology requirements that are specifically needed by an ontology-driven application and these requirements are independent of the domain knowledge [60]. For instance, the *efficiency of the ontology in producing information for user queries after integrating with a software application*. The possible characteristics related to *the application extrinsic quality requirements* are *efficiency, accessibility, availability,* and *recoverability* (Fig. 5, Table 2). These characteristics can also be gauged using the corresponding measures in the system environment. For instance, if we consider *efficiency,* then, it can be measured by analyzing the response time of the ontology for CQs in the system environment.

In addition to that, *understandability* and *adaptability* can be considered as characteristics that are associated with domain extrinsic and application extrinsic aspects. For instance, from the domain extrinsic point of view, *understandability* can be considered as whether an ontology provides domain information to users in a specified context without ambiguity and whether the domain information is expressed in appropriate languages, symbols and units. On the other hand, from the application extrinsic aspect, *understandability* can be considered as whether the ontology provides information/annotations in a way that it can be easily interpreted/represented through software applications. Similarly, *adaptability* can be considered as the ability of the ontology to be modified with the evolving user requirements (i.e., domain extrinsic aspect). Moreover, *Adaptability* can also be considered as an ability to get adjusted to the requirements of the software that the ontology gets integrated (i.e., application extrinsic aspect). Thus, the characteristics: *understandability* and *adaptability* can be associated with both domain extrinsic and application extrinsic aspects.

Table 2 provides the definitions for each characteristic of external ontology quality including details of stakeholders who are involved in the quality assessment. Additionally, relationships to other characteristics at the internal level are also presented. Moreover, a few associated measures for each of the characteristic have been illustrated in Table 2. An interested reader may refer to the article [35] for further details. However, to provide an insight for researchers and practitioners, the associated measures related to the selected use case are elaborated in Sections V and VI, and how the quality assessment takes place is explained under the same section.

C. ONTOLOGY INTERNAL QUALITY AND QUALITY REQUIREMENTS

Internal quality is the totality of attributes of the internal design of a product [58]. From the ontological point of view, the internal quality of ontology is the totality of properties of the content and structure of the ontology. It can be evaluated in the ontology environment against the internal ontology quality requirements in order to verify whether the ontology is being modeled in the right way [61]. These quality requirements can be derived from the external quality requirements of the ontology.

The structural intrinsic and domain intrinsic are two aspects of internal ontology evaluation [59], [60]. Thus, the internal ontology quality requirements can be distinguished as *structural intrinsic quality requirements* and *domain intrinsic quality requirements*. The *structural intrinsic* quality requirements can include the requirements related to the

TABLE 2. External ontology quality characteristics.

*(ODT- ontology development team, SDT- software development team). The listed characteristics are evaluated in the system environment

Characteristic	Definition	Examples for the measures	Stakeholders*	Relationships
Accuracy	The degree to which an ontology provides the correct results with the needed degree of precision [11], [62], [63].	The number of CQs that received the correct answers.	ODT, Domain Experts, and End Users	Depends on ontology internal consistency, external consistency, conciseness and ontology compliance
Relevancy	The degree to which an ontology provides information relevant to the specified tasks [11], [62].	The number of CQs that received the relevant answers for the specified context.	ODT, Domain Experts, and End Users	Depends on ontology conciseness and compliance
Completeness	The degree to which an ontology provides sufficient information with respect to the specified tasks [11], [62], [63].	Functional coverage: the number of CQs that received sufficient answers for the specified context.	ODT, Domain Experts, End Users	Depends on ontology coverage and compliance
Timeliness	The degree to which the current data are available in ontology for the task at hand [11], [62].	Difference between the last modified time of the original/target sources and the last modified time of the particular knowledge in the ontology.	ODT and Domain Experts	Depends on the system mechanism that used to update the knowledge
Credibility	The degree to which an ontology is accepted or regarded as true and believable in a specified context of use [11], [62].	The number of other ontologies that link to the target ontology or the number of positive user feedback given on the ontology.	ODT, Domain Experts, and End Users	Depends on the system mechanism that used to acquire and share the knowledge
Efficiency	The degree to which the ontology can be processed in providing the expected level of performance by utilizing the appropriate amount and types of resources in a specific context of use [11], [62], [63].	Response time, the number of resources utilized. Structural properties (i.e., complexity) mentioned in Table III are good predictors for efficiency.	ODT, SDT, and End Users	Depends on ontology modularity compliance and complexity [16], [65]
Accessibility	The degree to which an ontology can be easily accessed through an application [11], [62], [63].	The measures of characteristics: complexity, modularity, and comprehensibility are good predictors for accessibility (Table III) [35].	ODT, SDT, and End Users	Depends on the system mechanisms
Availability	The availability of an ontology when required for a specified task [30]	This has been measured w.r.t. YES/NO scenarios. To this end, the following type of questions can be asked. "is an ontology made available to the application that the ontology is integrated (i.e., as RDF file/ as HTML)? is documentation of an ontology made available?" [11]	ODT and SDT	Depends on the system mechanisms
Recoverability	The degree to which the ontology can re-establish a specified level of performance and recover the data directly affected in the case of a failure [40].	Mean recovery time, Backup data completeness [58]	ODT and SDT	Depends on the system mechanisms
Understandability	The degree to which ontology information can be comprehended, without ambiguity and is expressed in appropriate languages, symbols and units in a specific context of use [11], [62].	The number of competency questions that received answers in the human-readable language with appropriate context terms, symbols and units in a specified context.	ODT, Domain Experts End Users, and SDT	Depends on ontology comprehensibility, compliance and system information representation mechanism
Adaptability	The degree to which an ontology can change (i.e., add, remove, update) with the evolving requirements without altering the ontology definitions which have already been verified [11], [62], [63].	The number of competency questions that were correctly answered after the changes. The *Complexity* measures can be used to predict the ontology adaptability (Table III) [35].	ODT, Domain Experts End Users, and SDT	Depends on ontology modularity, compliance and complexity [6], [64]

syntactic and *structure* of the ontology. Then, the *domain intrinsic* quality requirements consist of the *content-related* ontology requirements. Accordingly, the possible characteristics associated with the *structural intrinsic* aspect are *syntactic compliance, complexity and internal consistency* (Fig. 5) and the possible characteristics related to the *domain intrinsic* aspect are *conciseness, coverage, comprehensibility* and *external consistency* (Fig. 5). *Modularity* can be viewed as a characteristic associated with both structural and domain intrinsic aspects. To this end, *modularity* could be considered as a structural characteristic when ontology modularity is performed upon the structural notions such as depth of the ontology, root nodes, breadth and fan-out of the ontology [6], [64]. On the other hand, from the domain intrinsic point of view, ontology modularization can be performed to decompose an ontology into multiple ontologies in such a way to enhance the cohesion if the ontology consists of multiple unrelated topics.

Moreover, the measure of the *structural intrinsic* characteristics can be automated as they do not depend on the domain knowledge that is used to model the ontology. For instance, the *complexity* of an ontology can be measured by calculating *the number of classes, number of attributes, number of binary relationships, absolute depth/breadth, average depth, the average number of leaf-children in a node* and many more measures are there [35]. Furthermore, many artifacts have been introduced to measure the structural intrinsic characteristics such as OOPS! [30], reasoners [31], OntoQA [43], OntoMetrics [44] and OntoCheck [46] (Table 3).

However, to evaluate the *domain intrinsic* characteristics some understanding of the domain knowledge is required [60]. Thus, the ontology developers (i.e., ontology engineers) require the assistance of domain experts to evaluate (i.e., manually/semi-automatically) the domain intrinsic quality against the *domain intrinsic* quality requirements [66]. Table 3 presents the definitions of the characteristics of internal quality and examples for the measures. Additionally, the possible tools that can be used for the assessment and the relationships to the external characteristics are also presented.

It is noteworthy that quality cannot be perfectly achieved due to the difficulties in capturing all user needs before the system design, even after the several iterations of the quality assessment. This is due to the reason that (i) the user needs are evolving, (ii) different users have different needs in relation to their operational environments, even in the same context and (iii) users may not be aware of their real needs. Nevertheless, the essential (i.e., necessary and sufficient) ontology quality requirements should be ensured through a system with respect to the specified context [60], [67]. For instance, if an ontology-driven system for document searching is considered, the main goal of developing such a system is to quickly retrieve the relevant document. Thus, in such a system, the efficiency of ontology is an essential user need and it should be ensured through quality evaluation. However, for an ontology-driven DSS in healthcare, the quality of the information in terms of accuracy, relevancy and timeliness are highly required than efficiency due to the fact that users seek the right information to make the right health decisions. Similarly, the presented characteristics in Fig. 5 are not equally important for all contexts and it is necessary to derive the set of characteristics required for the given context. The main objective of our proposed approach is to present how quality requirements affect the evaluation aspect of ontology and to provide an understanding of possible characteristics associated with the ontology developed to cater for a particular context. In the subsequent section, we demonstrate how the proposed approach can be used as a basis to derive quality requirements of an ontology from the broad quality view, and in turn to derive corresponding measures. Finally, we presented how the derived measures are used to evaluate the quality of the ontology against the quality characteristics elicited from user needs to achieve quality in use.

V. USE CASE ANALYSIS

A. USER REQUIREMENTS OF AN ONTOLOGY-DRIVEN SYSTEM IN AGRICULTURE

An ontology-driven DSS is worthwhile for agriculture to manage the complexity of information and to make the decision-making process easy for users. For instance, to make the right decision, farmers require to gather information from various sources such as domain experts, peer farmers, agriculture departments, perhaps from websites, and books [12], [13], [68]. Moreover, some of this information is multi-faced and heterogeneous. Thus, it takes considerable time to synthesize the gathered information in making the right decision. Even more, it is a difficult task for farmers who do not have good analytic skills. To this end, an ontology-driven DSS can be developed to minimize the mentioned difficulties. The ontology which embedded in such a system enables structuring the information gathered from various sources with automatic knowledge inference. This in turn not only enables farmers to access explicitly represented knowledge but also provides additional knowledge which is generated by the reasoners/classifiers from the explicit representation. Mostly, ontologies in this type of system are used as knowledge bases after populating with instance data [9], [13]. By considering this role of the ontology in a DSS, the quality requirements analysis is performed to exemplify the presented approach in Section IV considering the agriculture domain. To this end, the agriculture domain in Sri Lanka has been taken into account [13].

Based on the proposed approach, the quality requirements of the system should be elicited from the user needs for the system to achieve quality in use. Thus, the previous empirical studies [33], [68] were adopted, where the researchers have elaborated the essential user needs that are being expected from a DSS developed for commercial farmers who cultivate vegetables in Sri Lanka. Based on that, a set of essential quality requirements were specified with the assistance of domain experts and through several interviews with farmers who use Govi Nena mobile application (https://govinena.lk/). To this end, pest and disease management was taken as the initial scope because it has been identified as the main informational need out of many other informational needs in the agriculture domain [68]. Accordingly, the *context of use* for the use case of our study and the evaluation was specified as follows;

- *Users*: commercial farmers who cultivate vegetables (i.e., brinjal) and have experience in using mobile applications
- *Task*: pest and disease management
- *Equipment*: smart mobile phone, the Govi Nena mobile application (i.e., an ontology-driven DSS)
- *Environment*: crop type: brinjal, farming stage: growing stage, up countries in Sri Lanka, small and medium scale farm (farm size of 0.25 acre to 2 acres)

TABLE 3. Internal ontology quality characteristics.

The listed characteristics are evaluated in the ontology environment.

Characteristic	Definition	Examples for the measures	Assessment tools/methods	Stakeholders	Relationships
Compliance	The degree to which the ontology is being constructed in accordance with the rules, specifications and guidelines defined in the ontology representation language [30].	The total number of breached rules in the ontology.	The reasoners [31] and OOPS! [30] supports to detect breached syntaxes/rules.	Ontology Engineers	Influences ontology relevancy, accuracy, completeness and understandability
Complexity	The extent of how complicated the ontology is [16], [63].	The number of (non-inheritance) relationships, the number of nodes with several parents, the number of classes, number of attributes, number of binary relationships, Absolute depth/breadth, average depth, The average number of leaf-children in a node, etc.	The tools Protégé [32], OntoQA [43] and OntoMetrics [44] calculate the complexity measures.	Ontology Engineers	Influences ontology efficiency [16]
Internal Consistency	The degree to which an ontology is free from logical/formal contradictions with respect to particular knowledge representation and inference mechanisms [8].	The number of logical consistencies.	Reasoners [31] support detecting the internal consistencies	Ontology Engineers	Influences ontology accuracy [8]
Conciseness	The degree to which the information included in the ontology is useful and precise [8].	The number of classes with the same formal definition, the number of redundant subclass-of relations, the redundant instance-of relations in the ontology.	The development tools [32] and OOPS! [30] can be used with the assistance of domain experts to gauge the measures.	Ontology Engineers, Domain Experts	Influences ontology relevancy and accuracy
Coverage	The degree to which an ontology covers the information (i.e., definitions) in the relevant domain [8].	Precision and recall of concepts, relationships and attributes.	The matching tools can be used to gauge the measures [43] [15]/ or manual methods can be followed.	Ontology Engineers, Domain Experts	Influences ontology functional completeness [43]
Comprehensibility	The degree of annotations (i.e., metadata) of an ontology and how its elements enable users (i.e., ontology developers and consumers) to understand the appropriateness of the ontology for a specified context of use [48], [50].	The number of annotations used to describe the ontology entities. The use of naming conventions.	OntoCheck [48] and development tools [32] support verifying these measures or it can be observed manually.	Ontology Engineers, Domain Experts	Influences ontology understandability [48], [50]
External Consistency	The degree to which the definitions (i.e., axioms) in an ontology are coherent with respect to the real world [8].	Precision and recall of concepts, relationships and attributes. The ratio of correct concepts, the average ratio of correct instances and the average ratio of correct relations.	The measures can be gauged manually with the support of domain experts or the matching tools can be used to gauge the measures [43] [15].	Ontology Engineers, Domain Experts	Influences ontology accuracy [8]
Modularity	The degree to which an ontology is composed of discrete subsets (i.e., modules of a graph, sub-graphs) such that a change to one component has a minimal impact on other components [6], [64].	The number of ontology partitions, the number of minimally inconsistent subsets, the average value of axiom inconsistencies, the number of root nodes and the maximal length of simple paths.	The tools Protégé [32], reasoners [31], OntoQA [43], OntoMetrics [44] can be used to observe the measures.	Ontology Engineers	Influences ontology efficiency [6], [50], [64].

Consequently, the key quality requirements for the considered context were listed as given below for vegetable cultivation;

a) The system should provide necessary and sufficient contextual information on pest and disease management.

b) The system should provide trustworthy information on pest and disease management.

c) The system should present pest and disease information in local languages.

d) The system should provide updated information on pest and disease management.

e) The system should be easily accessible.

f) The system should facilitate getting feedback.

g) The system should facilitate information storage and reuse.

TABLE 4. Ontology extrinsic quality characteristics and measures in relation to the user quality requirements.

Characteristics	Measures	Range	Optimal value
a	**Question (Q1): Does the ontology provide contextual information in a specified context of use?**		
Relevancy	The number of CQs that received the relevant answers for the specified context is divided by the total number of CQs [39].	[0 : 1]	1
a	**Question (Q2): Does the ontology provide necessary and sufficient information in a specified context of use?**		
Completeness	The number of CQs that received sufficient answers for the specified context is divided by the total number of CQs [35].	[0 : 1]	1
b	**Question (Q3): Does the ontology provide the correct information in a specified context of use?**		
Accuracy	The number of CQs that received correct answers for the specified context is divided by the total number of CQs [39].	[0 : 1]	1
b	**Question (Q4): is the information provided through the ontology believable in a specified context of use?**		
Credibility	The number of times ontology has been used [39] OR The number of positive recommendations given for the provided knowledge/information by the users. OR Whether the information/knowledge is obtained from credible sources.	[0 : n] [0 : n] [YES/NO]	n n YES
c	**Question (Q5): is the information provided through the ontology expressed in appropriate languages, symbols and units in a specified context of use?**		
Understandability	The number of CQs that received answers in the human-readable language (or the language that can be interpreted to other languages) with appropriate context terms, symbols and units in a specified context is divided by the total number of CQs [39].	[0 : 1]	1
d	**Question (Q6): Does the ontology provide updated information in a specified context of use?**		
Timeliness	Difference between the last modified time/date of the original/target sources and the last modified time/date of the ontology [11]	[0 : n]	0

When considering these requirements, ***e, f*** and ***g*** depend merely on the software and hardware components of a system. For instance, the requirement ***e*** considers whether the system can be easily used by farmers with the widest range of characteristics and capabilities [37] (i.e., user-friendly UI, device compatibility, user-friendly technologies). Therefore, in modeling our approach, the focus was given on the requirements: ***a - d*** as these quality requirements define the quality characteristics expected from the ontology. Moreover, they can further be transformed to external and in turn to internal quality requirements of ontology.

B. EXTERNAL ONTOLOGY QUALITY REQUIREMENTS

At this stage, the Goal-Question-Metric (GQM) method [26] was adapted to specify the respective characteristics and associated measures for the requirements ***a – d***. For instance, the identified requirements were gradually refined into questions (i.e., Q1, Q2, Q3, Q4, Q5 and Q6). Thereafter, the identified questions were mapped with the corresponding quality characteristics and the appropriate measures for each characteristic were drawn accordingly based on a literature review [15], [33], [43] (Table 4).

In illustrating this further, the requirement ***a*** for example defines two aspects. One aspect is whether the information is sufficient for the task (**Q1**) and it denotes the characteristic *completeness* of the information obtained from the ontology. Another aspect is whether it is relevant to the user context (**Q2**) which indicates the characteristic *relevancy* of the information provided by the ontology. The requirement ***b*** defines the necessity of trustworthiness of the information. This implies that the information received from the ontology should be true (**Q3**) and believable by users in a specific context of use (**Q4**) [69]. Thus, the questions **Q3** and **Q4** indicate the requirement of maintaining the information characteristics *accuracy* [11] and *credibility* respectively [11], [33], [62]. The requirement ***c*** highlights the need of presenting the information based on different localities (i.e., information localization) enabling users to easily understand. Thus, it describes the characteristic: *understandability* of information (**Q5**) [69]. Finally, the requirement ***d*** considers whether the up-to-date information is maintained in a specified context, thus preserving the *timeliness* of the information (**Q6**). Additionally, the corresponding measures for each specified characteristic were identified by defining a value range and an optimal value that can be obtained for that measure (Table 4). For instance, the *number of competency questions (CQs) correctly answered out of the total CQs* can be defined as an external measure of *accuracy* that can have the value range **[0: 1]** where *one* implies that the ontology answers for all CQs accurately and *zero* implies that none of the CQs received correct answers through the ontology.

When considering the characteristics: *credibility* and *timeliness*, these characteristics tightly couple with the mechanism that the system used to acquire information. For instance, *credibility* refers to the extent to which information is accepted or regarded as believable [33], [62], [69]. In order to achieve this, information should be gathered from credible sources and it should be verified by the domain experts and users. Therefore, the system should be set up with a mechanism to incorporate the verified information into the ontology and to get feedback. Same for *timeliness,* it refers to the degree to which the current data are available in ontology for the task at hand [33], [62]. Thus, a mechanism should be developed to regularly obtain updated information from credible sources. Consequently, the characteristics: *credibility* (**Q4**) and *timeliness* (**Q6**) are difficult to be transformed into the internal characteristics of the ontology.

Therefore, by taking the remaining characteristics into account, the internal ontology properties that influence the external ontology quality were derived.

C. INTERNAL ONTOLOGY QUALITY REQUIREMENTS

To identify a set of internal characteristics with measures corresponding to the questions: **Q1, Q2, Q3** and **Q5** in Table 4 above, the same methods explained (i.e., the GQM method) under Sub-Section B in Section V were repeated. However, the ROMEO methodology [15] also can be adapted in this stage, which is similar to the GQM, and the ROMEO methodology has proposed a set of guidelines specifically considering ontologies to derive internal measures from ontology external requirements.

Moreover, for the sake of simplicity, an OWL ontology (https://www.w3.org/TR/owl2-syntax/) was taken into account in defining the characteristics and measures for quality requirements under the study. After identifying the characteristics and measures, the corresponding value range and optimal value related to each measure were defined (Table 6-9). In addition to that, the measures were classified based on whether they are attached to the schema level (i.e., structure) or the data level (i.e., knowledge base) of the ontology [11], [70]. Moreover, Table 5 presents the notations that were used to express the ontology elements and the measures derived.

1) RELEVANCY (Q1): DOES THE ONTOLOGY PROVIDE CONTEXTUAL INFORMATION IN A SPECIFIED CONTEXT OF USE?

To provide information based on the context, the ontology should contain relevant definitions (i.e., axioms) to produce relevant information. On the other hand, this implies that the ontology does not store any unnecessary or redundant definitions either explicitly or implicitly [15], [43], [71]. This requirement (**Q1**) can be subdivided by concerning two aspects of internal ontology quality. For example, from the *domain intrinsic* aspect, the ontology should not contain unnecessary definitions with respect to the domain knowledge in the specified context (**Q1.1**) and this has been viewed as *conciseness* of ontology [15], [43], [71]. From the *structural intrinsic* aspect, the ontology should not contain redundant definitions (**Q1.2**) and this reflects whether the ontology complies (i.e., *compliance*) with certain ontology best practices (i.e., standards, conventions, and rules) [72], [73]. Some examples are, an ontology should not have identical classes with different names, ontology relationships should not be defined twice explicitly or implicitly if they can be inferred from explicit definitions [30], [71]. The questions **Q1.1** and **Q1.2** were further subdivided into questions as follows and corresponding measures for each characteristic were identified as illustrated in Table 6.

Q1.1: Does the ontology consist of unnecessary definitions outside of the context?

- **Q1.1.1.** Does the ontology consist of classes outside of the specified context [15]?

TABLE 5. Formal notations.

Notation	Definition
O	An OWL ontology of domain of interest.
F	A reference OWL ontology or standard OWL ontology of domain of interest.
O_C	A set of classes in O.
O_I	A set of individuals in O.
O_R	A set of object properties (i.e., relations between classes) in O.
O_A	A set of data properties (i.e., attributes of a class) in O.
O_{IR}	A set of object properties between individuals in O.
F_C	A set of classes in F.
F_I	A set of individuals in F.
F_R	A set of object properties (i.e., relations between classes) in F.
F_A	A set of data properties (i.e., attributes of a class) in F.
F_{IR}	A set of object properties between individuals in F.
C	The number of classes in O.
I	The number of individuals in O.
R	The number of object properties in O
A	The number of data properties in O.
HR	The number of hierarchical relationships in O.
C_{SFD}	The number of classes with the same formal definitions in O.
I_{SFD}	The number of individuals with the same formal definitions in O.
R_{RSR}	The number of redundant subclass-of relations in O.
R_{RIR}	The number of redundant instance-of relations in O.
C_{CNCA}	The number of classes with a set of disjoint direct subclasses and without covering axiom in O
C_{CDSC}	The number of classes with a set of disjoint direct subclasses in O.
SPND	The number of subclass-partitions is defined on classes without the corresponding disjoint constraint.
C_{CDC}	The number of classes with a set of direct subclasses in O.
C_{LCNS}	The number of leaf classes with at least one set of necessary and sufficient conditions.
C_{LC}	The number of leaf classes.
R_{DR}	The number of object properties with domain and range in O.
A_{DR}	The number of data properties with domain and literals in O.
C_{CON}	The number of connected classes in O.
C\`	The number of used classes or classes with individuals in O.
I_{OPA}	The number of individuals with object property assertion
R_C	The number of object properties with characteristics in O.
A_C	The number of data properties with characteristics in O.
T_C	The number of class terms relevant to the specified context in O.
T_R	The number of object property terms relevant to the specified context in O.
T_A	The number of data property terms relevant to the specified context in O.
$C_{Annotated}$	The number of classes with annotations in O.
$R_{Annotated}$	The number of object properties with annotations in O.
$A_{Annotated}$	The number of data properties with annotations in O.
$I_{Annotated}$	The number of Individuals with annotations in O.
$RSFD_C$	The ratio of classes with the same formal definition as other classes in O.
$RSFD_I$	The ratio of individuals with the same formal definition as other individuals in O.
RRSR	The ratio of number of redundant subclass-of relations in O
RRIR	The ratio of redundant instance-of relations in O.
R_{IOR}	The number of instance-of relations in the ontology
ESPO	The ratio of classes with a set of disjoint direct subclasses and without a covering axiom in O.
SPO	The ratio of subclass-partitions is defined on classes without the corresponding disjoint constraints in O.
RLCN	The ratio of leaf classes with at least one set of necessary and sufficient conditions in O.
RNHRDR	The ratio of non-hierarchical properties with domain/s and range/s in O.
RADR	The ratio of data properties with domain/s and literal/s in O.
RCC	The ratio of connected classes in O.
RIOP	The ratio of individuals with object property assertion in O.
ESPCC	The number of subclass partitions with common classes in O.
ESPCI	The number of subclass partitions with common individuals in O.
RAC	The ratio of annotated classes in O.
RAR	The ratio of annotated object properties in O.
RAA	The ratio of annotated data properties in O.
RAI	The ratio of annotated individuals in O.
SNC	Same naming conventions in O.

- **Q1.1.2.** Does the ontology consist of relationships (i.e., object properties) outside of the specified context [15]?

TABLE 6. Internal quality characteristics and measures in relation to Q1.

Question	Measure	Schema /Data	Range	Optimal Value
Domain Intrinsic Aspect - Conciseness				
1.1.1	Precision (O_C; F_C) = $\|O_C \cap F_C\|/ \|O_C\|$	Schema	[0:1]	1
1.1.2	Precision (O_R; F_R) = $\|O_R \cap F_R\|/\|O_R\|$	Schema	[0:1]	1
1.1.3	Precision (O_I; F_I) = $\|O_I \cap F_I\| / \|O_I\|$	Data	[0:1]	1
1.1.4	Precision (O_A; F_A) = $\|O_A \cap F_A\|/\|O_A\|$	Schema	[0:1]	1
Structural Intrinsic Aspect - Compliance				
1.2.1	$RSFD_C = (C_{SFD}/C)$	Schema	[0:1]	0
1.2.2	$RSFD_I = (I_{SFD}/I)$	Data	[0:1]	0
1.2.3	$RRSR = (R_{RSR}/HR)$	Schema	[0:1]	0
1.2.4	$RRIR = (R_{RIR}/ R_{IOR})$	Data	[0:1]	0

*Precision can be calculated with respect to the corpus, or terms list that are verified by the experts when the standard ontology is not available to the specified context.

- **Q1.1.3.** Does the ontology consist of individuals outside of the specified context [15]?
- **Q1.1.4.** Does the ontology consist of class attributes (i.e., data properties) outside of the specified context [43]?

Q1.2: Does ontology contain redundant definitions?

- **Q1.2.1**. How many identical classes are modeled using different names [15]?
- **Q1.2.2.** How many identical individuals are modeled using different names [15]?
- **Q1.2.3.** How many redundant subclass-of relationships (explicit/implicit) are found in the ontology [15]?
- **Q1.2.4.** How many redundant instance-of relationships (explicit/implicit) are found in the ontology [15]?

2) COMPLETENESS (Q2): DOES THE ONTOLOGY PROVIDE NECESSARY AND SUFFICIENT INFORMATION IN A SPECIFIED CONTEXT OF USE?

To provide all necessary information, all the required ontology definitions (i.e., axioms) to produce the results should be included in the ontology explicitly or should be inferred from the explicit definitions [71]. However, completeness cannot be proved. Instead, the ontology definitions (i.e., axioms) which are missing with respect to the specified context can be observed. Incompleteness also can occur from both *structural* and *domain* intrinsic aspects. Under the *domain intrinsic* aspect, incompleteness refers to whether the ontology has missing definitions with respect to the specified context. Thus, it concerns the ontology context *coverage* (**Q2.1**). Under the *structural intrinsic* aspect, incompleteness defined as is missing of fundamental definitions (i.e., axioms) related to the structure of ontologies (i.e., ontology compliance) (**Q2.2**). For example, this includes missing definitions of domain and range, missing inverse property and equivalence [30]. Question Q2.1 and Q2.2 were further subdivided as given below and related measures were recognized as shown in Table 7. Notably, the derived measures should be evaluated after reasoning the ontology (i.e., inferred ontology) which contains both explicitly defined definitions and the additional definitions inferred from the explicit definitions.

Q2.1. Are some definitions (i.e., axioms) not available in the ontology with respect to the specified context?

TABLE 7. Internal quality characteristics and measures in relation to Q2.

Question	Measure	Schema/ Data	Range	Optimal Value
Domain Intrinsic Aspect - Coverage				
2.1.1	Recall (O_C; F_C) = $\|O_C \cap F_C\| / \|F_C\|$	Schema	[0:1]	1
2.1.2	Recall (O_R; F_R) = $\|O_R \cap F_R\| / \|F_R\|$	Schema	[0:1]	1
2.1.3	Recall (O_I; F_I) = $\|O_I \cap F_I\| / \|F_I\|$	Data	[0:1]	1
2.1.4	Recall (O_A; F_A) = $\|O_A \cap F_A\| / \|F_A\|$	Schema	[0:1]	1
2.1.5	Recall (O_{IR}; F_{IR}) = $\|O_{IR} \cap F_{IR}\|/ \|F_{IR}\|$	Data	[0:1]	1
2.1.6	$ESPO = C_{CNCA}/C_{CDSC}$	Schema	[0:1]	0
2.1.7	$SPO = SPND/C_{CDC}$	Schema	[0:1]	0
2.1.8	$RLCNS = C_{LCNS}/C_{LC}$	Schema	[0:1]	1
Structural Intrinsic Aspect - Compliance				
2.2.1	$RNHRDR = R_{DR}/R$	Schema	[0:1]	1
2.2.2	$RADR = A_{DR}/A$	Schema	[0:1]	1
2.2.3	$RCC = C_{CON}/C$	Schema	[0:1]	1
2.2.4	Concept richness = C`/C	Data	[0:1]	1
2.2.5	$RIOP = I_{OPA}/I$	Data	[0:1]	1

- **Q2.1.1.** Are some classes in the ontology not available with respect to the specified context [15], [43]?
- **Q2.1.2.** Are some relationships (i.e., object properties) in the ontology not available with respect to the specified context [15], [43]?
- **Q2.1.3.** Are some individuals in the ontology not available with respect to the specified context [15], [43]?
- **Q2.1.4.** Are some attributes (i.e., data properties) in the ontology not available with respect to the specified context [15], [43]?
- **Q2.1.5.** Are some relationships between individuals in the ontology not available with respect to the specified context [15], [43]?
- **Q2.1.6.** Are some subclasses of a given parent class in the ontology not available with respect to the specified context [15], [43], [71]?
- **Q2.1.7.** Are some subclass-partitions defined on classes in the ontology without the corresponding disjoint constraint over the subclasses sets [15], [43], [71]?
- **Q2.1.8.** Are some necessary and sufficient conditions in the ontology not available with respect to the specified context [15], [43]?

Q2.2. Does the ontology structure and content contain incomplete definitions?

- **Q2.2.1.** Does the ontology contain relationships (i.e., object properties) without domain and range [15], [43], [71]?
- **Q2.2.2.** Does the ontology contain attributes (i.e., data properties) without domain and range [15], [43], [71]?
- **Q2.2.3.** Does the ontology contain unconnected classes [45]?
- **Q2.2.4.** Does the ontology contain classes without individuals [45], [71]?
- **Q2.2.5.** Does the ontology have isolated individuals (without class type) [45]?

3) ACCURACY (Q3): DOES THE ONTOLOGY PROVIDE CORRECT INFORMATION IN A SPECIFIED CONTEXT OF USE?

To provide accurate information to the context, ontology representation should be correctly modeled with respect to

TABLE 8. Internal quality characteristics and measures in relation to Q3.

Question	Measure	Schema /Data	Range	Optimal Value
Domain Intrinsic Aspect – External Consistency				
3.1.1	Precision $(O_C; F_C) = \lvert O_C \cap F_C \rvert / \lvert O_C \rvert$	Schema	[0:1]	1
3.1.2	Precision $(O_R; F_R) = \lvert O_R \cap F_R \rvert / \lvert O_R \rvert$	Schema	[0:1]	1
3.1.3	Precision $(O_I; F_I) = \lvert O_I \cap F_I \rvert / \lvert O_I \rvert$	Data	[0:1]	1
3.1.4	Precision $(O_A; F_A) = \lvert O_A \cap F_A \rvert / \lvert O_A \rvert$	Schema	[0:1]	1
3.1.5	Precision $(O_{IR;} F_{IR}) =$	Data	[0:1]	1
3.1.6	$RUC = (R_C+A_C) / (R+A)$	Schema	[0:1]	1
Structural Intrinsic Aspect – Internal Consistency/Compliance				
3.2.1	ESPCC	Schema	[0: n]	0
3.2.2	ESPCI	Data	[0: n]	0
3.2.3	Circularity Errors	Schema	[0: n]	0

the specified context [9]. For that, all required definitions (i.e., axioms) with regards to the context should be correctly defined in the ontology. To this end, ontology developers can adapt ontology design patterns that not only provide associated solutions for commonly occurring modeling problems but also support maintaining consistent ontology representation [72]–[74].

Ontology correctness is defined in different terms such as fidelity in [9], semantic correctness in [15], [43], and consistency in [71]. All of these terms refer to whether the ontology is free from contradiction with the specified context. For instance, in the agriculture context, Brinjal is a vegetable crop. However, if it is defined in an ontology as an individual of Fruit (ClassAssertion (:Fruit: Brinjal)), then the ontology is not consistent or correct with respect to the real context.

By adapting the term consistency, an internal ontology requirement was identified as whether the ontology definitions are consistent with the specified context (**Q3.1**). This requirement is associated with the *domain intrinsic* aspect as domain knowledge is required to determine the correctness and thus, it can be viewed as *external consistency* (Fig. 5). Not only that, the structural and syntactic correctness is complementary to external consistency. Therefore, from the *structural intrinsic* aspect, a requirement can be defined as the ontology should be free from internal contradictions (i.e., *internal consistency and compliance*) (**Q3.2**). For example, the same instances cannot be defined under two concepts that are disjoint. Based on the derived requirements (Q3.1 and Q3.2), further, the sub-questions were defined as follows and measures were identified as illustrated in Table 8.

Q3.1. Does the ontology capture the specified context correctly?

- **Q3.1.1.** Does the ontology capture classes of the specified context correctly [15]?
- **Q3.1.2.** Does the ontology capture relationships (i.e., object properties) between concepts of the specified context correctly [15]?
- **Q3.1.3.** Does the ontology capture individuals of the specified context correctly [15]?
- **Q3.1.4.** Does the ontology capture the class attributes (i.e., data property) of the specified context correctly?
- **Q3.1.5.** Does the ontology capture relationships between individuals of the specified context correctly [15]?
- **Q3.1.6.** Does the ontology capture object property/data property characteristics in a specified context [15]?

Q3.2. Is the ontology free from internal contradiction?

- **Q3.2.1.** Does the ontology include two or more classes that share the same set of subclasses [15], [71]?
- **Q3.2.2.** Does the ontology include two or more classes that share the same set of individuals [15], [71]?
- **Q3.2.3.** Does ontology contain circularity errors [15], [71]?

4) UNDERSTANDABILITY (Q5): IS THE INFORMATION PROVIDED THROUGH THE ONTOLOGY EXPRESSED IN APPROPRIATE LANGUAGES, SYMBOLS AND UNITS IN A SPECIFIED CONTEXT OF USE?

To provide information that can be easily comprehended, the ontology classes, properties and entities should be labeled in human-readable languages or labeled in a way that it can be interpreted into the human-readable language through software applications. Moreover, providing the human-readable metadata about an ontology and its elements such as comments, description of symbols and units in a specified context is significant to improve understandability. From the *domain intrinsic* aspect, it can be considered whether ontology elements are labeled using the human-readable terms (i.e., *comprehensibility*) in a specified context (**Q5.1**). From the *structural intrinsic* aspect, further, it can be observed whether ontology elements are described using annotations (i.e., metadata) and labeled using the same naming conventions (**Q5.2**) [30]. This also ensures clean and consistent representations in the ontology, which is also discussed as a part of the *presentation ontology design patterns* [72], [73]. This requirement is associated with the *compliance* characteristics of the ontology. Based on **Q5.1** and **Q5.2**, the sub-questions were derived as follows and the corresponding measures are listed in Table 9.

Q5.1. Can the labels of the ontology be understood in a specific context?

- **Q5.1.1.** Has the ontology used context terms to label the elements (i.e., classes, object properties, data properties) [39]?
- **Q5.1.2.** Has the ontology used context terms to label the individuals [39]?

Q5.2. Does the ontology contain metadata and the same naming conventions?

- **Q5.2.1.** Does the ontology have annotated classes [30], [50]?
- **Q5.2.2.** Does the ontology have annotated relationships (i.e., object properties) [30], [50]?
- **Q5.2.3.** Does the ontology have annotated attributes (i.e., data properties) [30], [50]?
- **Q5.2.4.** Does the ontology have annotated individuals [30], [50]?
- **Q5.2.5.** Has the ontology used the same naming conventions [30]?

TABLE 9. Internal quality characteristics and measures in relation to the Q5.

Question	Measure	Schema /Data	Range	Optimal Value
Domain Intrinsic Aspect - Comprehensibility				
5.1.1	Clarity = $(T_C+T_R+T_A)/(C+R+A)$	Schema	[0:1]	1
5.1.2	$Clarity_{Individual} = T_I/I$	Data	[0:1]	1
Structural Intrinsic Aspect - Compliance				
5.1.1	RAC = $C_{Annotated}/C$	Schema	[0:1]	1
5.1.2	RAR = $R_{Annotated}/R$	Schema	[0:1]	1
5.1.3	RAA = $A_{Annotated}/A$	Schema	[0:1]	1
5.1.4	RAI = $I_{Annotated}/I$	Data	[0:1]	1
5.1.5	SNC	Schema Data	[YES/NO]	YES

After identifying the required internal and external quality characteristics, ontology developers can gauge each of the characteristics at the relevant stage using respective measures to ensure that the required quality is being achieved. Typically, many tools and plugins are available to measure the structural intrinsic quality as illustrated in Table 3. For instance, internal consistency (i.e., Q3.2) can be ensured by using reasoners such as Fact++, Hermit, Pellet, OpenPellet that can be easily plugged into ontology developing tools [31]. Also, OOPS! [30] and OntoMetric [46] are web-based tools that can be easily accessed to check the pitfalls (i.e., Q1.2., Q2.2.1, Q3.2, Q5.2) and richness (i.e., Q2.2, Q5.2) of the ontology respectively. Nevertheless, the characteristics that come under the domain intrinsic aspects are very context-dependent and extra effort is required to assess them automatically. With regards to our example, precision and recall are the measures defined to assess the characteristics such as *coverage*, *external consistency* and *conciseness*. However, for that, a golden standard ontology is required that has been verified as a good quality ontology in the considered context. These types of ontologies are rarely available and thus, it is necessary to go with other options such as the standard corpus-based evaluation (i.e., using recommended corpus in a specified context) or manual evaluation with domain experts and users [34], [55]. Then, to assess the quality characteristics in the extrinsic aspect, the intervention of domain experts and users is essential. In this way, a comprehensive broad quality assessment can be executed for ontologies to guarantee their good quality and in producing a usable ontology-driven system. The subsequent section demonstrates the empirical evidence in performing the quality evaluation against the derived quality requirements.

VI. EVALUATION AND RESULTS

Ontology quality evaluation was performed against the identified quality requirements under two phases using OWL ontologies considering the context of use specified in Section V above.

The objective of Phase 01 is to observe whether the built ontology (i.e., cropDisorderV1.owl, Fig. 8) for the system Govi Nena is fit for the intended needs (i.e., quality in use) in a specified context of use. Phase 02 was performed in order to investigate whether the existing agricultural ontologies available in repositories can be used and adapted for the specified context to build a usable ontology rather than building an ontology from scratch. To this end, the quality of the existing ontologies was assessed against the specified requirements in the considered context. Fig. 6 and Fig. 7 illustrate the flow of the evaluation followed under each phase and subsequent Sections A and B elaborate them respectively. Moreover, the basic metrics of all ontologies used for the evaluation are presented in Table 10.

A. EVALUATION RESULTS OF PHASE 01

Evaluation of domain extrinsic and domain intrinsic aspects of the ontology (i.e., cropDisorderV1.owl) in Govi Nena application could be carried out either as a survey with end-users and experts or by assessing it against a rather complete knowledge source produced for the relevant context. Due to the current pandemic situation, it became impossible to conduct a survey with a group of end-users. Then we had the challenge of finding a reasonably complete and up-to-date knowledge source that covers the relevant context. To this end, we used the terminology list and a document produced by domain experts including Packages of Practices (POP) adapted by farmers with respect to different crops as a reference to assess the domain extrinsic and domain intrinsic characteristics of the ontology (Fig. 6). The PoP is a structured document that consists of a set of instructions and information related to crops in a specified context as explained in [75]. For this research, the PoP document was used which contains the knowledge specifically defined for the Brinjal crop. Most significantly, the PoP document produced for each crop is regularly updated by agronomists based on the evolving farmer needs and domain knowledge [75]. Notably, the knowledge defined in the PoP document is considered as a reasonably complete, up to date and credible reference for quality assessment under the study. Accordingly, the domain extrinsic characteristics were measured by analyzing the answers produced through the ontology for the CQs with the information and knowledge provided in the PoP (Table 11). The answers were retrieved for CQs by executing the DL queries and SPARQL queries through the ontology. Furthermore, the domain intrinsic measures were assessed by comparing the terminology list and PoP provided by the experts.

The measures of structural intrinsic aspects are calculated manually inspecting the results provided through OOPS! and protégé (i.e., Basic Metrics) tools [30], [32]. Notably, the measure of relevancy in the domain extrinsic aspect was not assessed separately due to the fact that the PoP used for evaluation only contained information and knowledge relevant to the considered context. To this end, the accuracy of the answers produced to the CQs with respect to the PoP in the specified context was calculated to obtain the relevancy measures.

TABLE 10. Basic metrics of ontologies used for the evaluation process.

Basic Metrics	cropDisorderV1.owl	OCD1.owl	OCD2.owl	OCD3.owl	OCD4.owl	cropDisease.owl
Class count	69	8	34	15	22	8
Object property count	86	14	0	18	12	12
Data property count	39	15	0	20	15	0
Individual count	1136	82	325	72	70	1009
Annotated class count	69	0	0	0	5	0
Annotated Object Property count	86	0	0	0	0	0
Annotated Data Property count	39	0	0	1	0	0
Annotated Individual count	0	0	0	0	0	0
SubClassOf	34	0	0	5	14	0
EquivalentClasses	20	0	0	0	12	0
DisjointClasses	339	1	2	0	4	0
FunctionalObjectProperty	16	0	0	2	0	0
InverseFunctionalObjectProperty	0	0	0	0	0	0
TransitiveObjectProperty	2	0	0	0	0	0
SymmetricObjectProperty	0	0	0	0	0	0
AsymmetricObjectProperty	52	0	0	2	0	0
ReflexiveObjectProperty	0	0	0	0	0	0
IrrefexiveObjectProperty	52	0	0	2	0	0

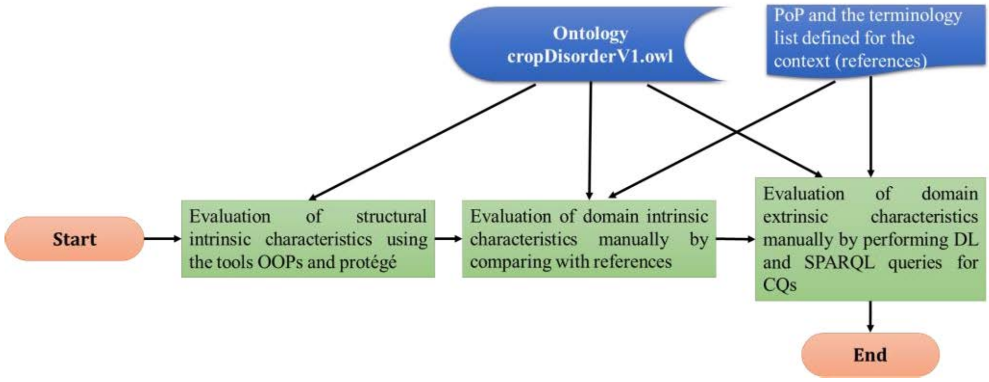

FIGURE 6. Flow chart of evaluation Phase 01.

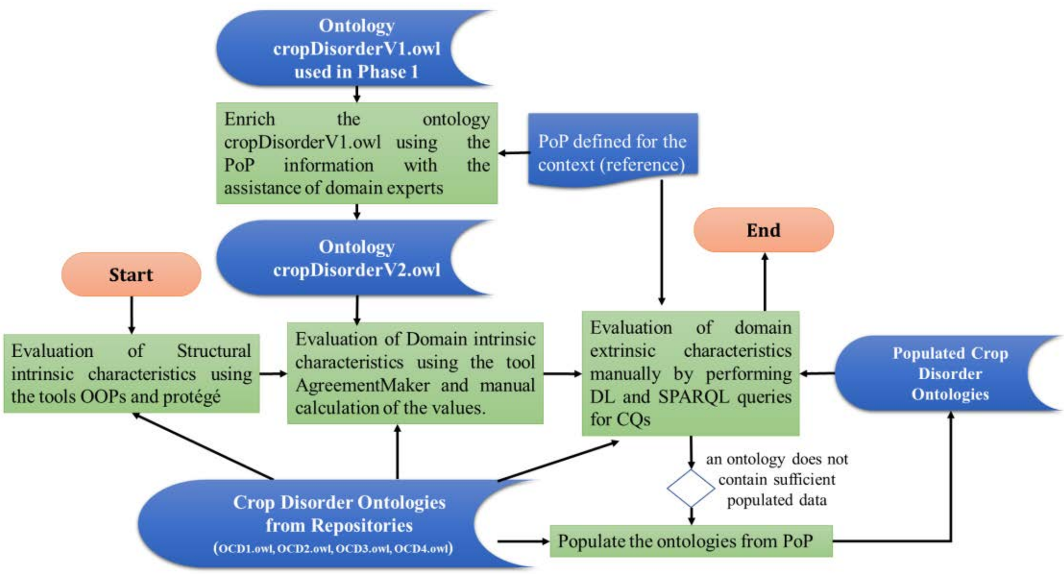

FIGURE 7. Flow chart of evaluation Phase 02.

TABLE 11. Quality evaluation of crop disorder_V1 ontology.

Measure		Value
Extrinsic Ontology Quality		
Completeness		0.09
Accuracy & Relevancy (Out of non-empty CQs)		0.6
Credibility		YES
Understandability (Out of non-empty CQs)		0.53
Timeliness (2021-07-19 - 2016-10-16)		5 years
Intrinsic Ontology Quality	Schema/Data	
Relevancy		
Precision (O_C, F_C)	Schema	1
Precision (O_R, F_R)	Schema	1
Precision (O_A, F_A)	Schema	1
Precision (O_I, F_I)	Data	1
$RSFD_C = (C_{SFD}/C)$	Schema	0
$RSFD_I = (I_{SFD}/I)$	Data	0
$RRSR = (R_{RSR}/HR)$	Schema	0
$RRIR = (R_{RIR}/ R_{IOR})$	Data	0
Coverage		
Recall (O_C, F_C)	Schema	0.94
Recall (O_R, F_R)	Schema	0.91
Recall (O_A, F_A)	Schema	0.97
Recall (O_I, F_I)	Data	0.94
Recall (O_{IR}, F_{IR})	Data	0.44
$ESPO = C_{CNCA}/C_{CDSC}$	Schema	0.2
$SPO = SPND/C_{CDC}$	Schema	0.58
$RLCNS = C_{LCNS}/C_{LC}$	Schema	0.21
$RNHRDR = R_{DR}/R$	Schema	0.95
$RADR = A_{DR}/A$	Schema	1
$RCC = C_{CON}/C$	Schema	0.97
Concept richness = C\`/C	Data	0.96
$RIOP = I_{OPA}/I$	Data	0.84
Accuracy		
Precision (O_{IR}, F_{IR})	Data	1
$RUC = (R_c+A_c) / (R+A)$	Schema	1
ESPCC	Schema	0
ESPCI	Data	0
Circularity Errors	Schema	0
Understandability		
$Clarity = (T_C+T_R+T_A)/(C+R+A)$	Schema	1
$Clarity_{Individual} = T_I/I$	Data	1
$RAC = C_{Annotated}/ C$	Schema	1
$RAR = R_{Annotated}/ R$	Schema	1
$RAA = A_{Annotated}/ A$	Schema	1
$RAI = I_{Annotated}/ I$	Data	0
SNC	Schema,Data	YES

1) RESULTS ANALYSIS

Based on the domain intrinsic and structural intrinsic evaluation, it was found that there are no major quality issues in the schema level (i.e., structure) of the ontology. However, only a few missing classes and missing properties were detected related to the crop varieties and the pest/disease prevention techniques. In addition to that, it has been observed that the precision values of classes, object properties and data properties have received the optimal value. This implies that the ontology does not contain elements outside of the considered context and that the ontology schema is correctly designed. The reason for that is ontology was initially modeled as a domain ontology under the guidance of domain experts to provide relevant information to farmers in Sri Lanka [13], [29]. However, when considering the knowledge base level, the coverage of relationships between

TABLE 12. Domain extrinsic evaluation of ontologies.

Measure (schema level)	OCD1.owl	OCD2.owl	OCD3.owl	OCD4.owl	cropDisease.owl
Completeness	0.48	0	0.41	0.59	0.15
Accuracy & Relevancy (Out of non-empty CQs)	0.31	-	0.09	0.31	0.75

individuals (i.e., *Recall*(O_{IR}, F_{IR}) = 0.44) in a specified context is considerably low. Consequently, 91% CQs received incomplete answers and 40% of CQs are inaccurate out of the completed CQs with respect to the specified context. This is also a result of outdated information as the ontology has not been updated in the past five years. Moreover, the annotations related to individuals have not been provided (i.e., $RAI = 0$) which is significant for ontology understandability. As a result, 47% CQs received answers without appropriate units, measurements and terms. For instance, the ontology provided a control method for Bacterial Wilt disease in Brinjals as "crop rotation with non-solanaceous crops". It is difficult for farmers to understand what *non-solanaceous* crops are. To this end, the ontology should be enhanced with metadata describing the term *non-solanaceous* with examples such as potato, tomato, eggplant, and pea eggplant.

B. EVALUATION RESULT OF PHASE 02

Under this phase, we searched for online crop disorder ontologies to be used for evaluation. To this end, only one ontology named crop disease (CD)[1] was identified relevant to the considered context that was available in the AgroPortal[2] (APPENDIX: Fig. 13). In addition to that, the remaining ontologies were collected from local repositories where the research students upload their ontologies for the secondary data (Fig. 9-13). Consequently, five ontologies were selected to inspect whether they can be reused for the specified context. Due to this intention, ontology quality evaluation was not performed in the operational/system environments and only the external and internal quality assessments of ontologies were carried out. Moreover, the measures related to the knowledge base (i.e., data level) have not been assessed. This is due to the fact that the ontologies which are available in the repositories have not been populated with sufficient data as their main aim is to provide a model for a particular domain of interest instead of a knowledge base. Through the evaluation, it provides evidence that the derived measures related to schema level can be utilized to evaluate the existing ontologies when reusing them for a given context and the results are presented in Table 12 - 16.

Since the selected ontologies have not been sufficiently populated with instance data, all the CQs received

[1]Crop Disease (CD) ontology: http://agroportal.lirmm.fr/ontologies/CD?p=classes&conceptid=http%3A%2F%2Fwww.semanticweb.org%2Fmac%2Fontologies%2F2018%2F4%2Funtitled-ontology-24%23Crop

[2]AgroPrtal: http://agroportal.lirmm.fr/

TABLE 13. Intrinsic evaluation with respect to relevancy.

Measure	OCD1.owl	OCD2.owl	OCD3.owl	OCD4.owl	cropDisease.owl
Conciseness					
Precision (O_C, F_C)	0.75	0.62	0.47	0.45	0.75
Precision (O_R, F_R)	1	-	0.89	0.92	0.25
Precision (O_A, F_A)	0.47	-	0.35	0.53	0
Compliance					
$RSFD_c = (C_{SFD}/C)$	0	0	0	0	0
$RRSR = (R_{RSR}/HR)$	0	0	0	0	0

TABLE 14. Intrinsic quality evaluation with respect to completeness.

Measure	OCD1.owl	OCD2.owl	OCD3.owl	OCD4.owl	cropDisease.owl
Coverage					
Recall (O_C, F_C)	0.09	0.30	0.10	0.45	0.09
Recall (O_R, F_R)	0.16	0	0.18	0.13	0.03
Recall (O_A, F_A)	0.18	0	0.18	0.21	0
$ESPO = C_{CNCA}/C_{CDSC}$	0	0	0	0.33	0
$SPO = SPND/C_{CDC}$	0	0	1	0.25	0
$RLCNS = C_{LCNS}/C_{LC}$	0	0	0	0.89	0
Compliance					
$RNHRDR = R_{DR}/R$	1	-	1	1	1
$RADR = A_{DR}/A$	1	-	1	1	-
$RCC = C_{CON}/C$	1	0	0.93	1	1

TABLE 15. Intrinsic quality evaluation with respect to accuracy.

Measure	OCD1.owl	OCD2.owl	OCD3.owl	OCD4.owl	cropDisease.owl
External Consistency					
Precision (O_C, F_C)	0.75	0.62	0.47	0.45	0.75
Precision (O_R, F_R)	1	-	0.89	0.92	0.25
Precision (O_A, F_A)	0.47	-	0.35	0.53	0
$RUC = (R_c+A_c) / (R+A)$	0	-	0.09	0	0
Internal Consistency/Compliance					
ESPCC	0	0	0	0	0
Circularity Errors	0	0	0	0	0

TABLE 16. Intrinsic quality evaluation with respect to understandability.

Measure	OCD1.owl	OCD2.owl	OCD3.owl	OCD4.owl	cropDisease.owl
Comprehensibility					
$Clarity = (T_C+T_R+T_A)/(C+R+A)$	1	1	1	1	0.7
Compliance					
$RAC = C_{Annotated}/ C$	0	0	0	0.23	0
$RAR = R_{Annotated}/ R$	0	0	0	0	0
$RAA = A_{Annotated}/ A$	0	0	0.05	0	0
SNC	NO	YES	NO	YES	YES

inappropriate or empty (i.e., null) answers with respect to the Brinjal PoP. Thus, it is difficult to understand the completeness, relevancy, accuracy and understandability of the schema of ontologies using CQs in the domain extrinsic aspect. To this end, the ontologies were populated using the data gathered from the PoP of the Brinjal crop and these ontologies were then used to observe the domain extrinsic measures by obtaining answers for the CQs through the ontologies (Fig. 7). Accordingly, the completeness and accuracy measures were calculated and results were reported in Table 12.

To evaluate the domain intrinsic quality of the selected ontologies, the ontology cropDisorderV2 was taken as a reference ontology. The cropDisorderV2 is the enriched version of the crop disorder ontology (i.e., cropDisorderV1) that was modified with the assistance of domain experts by resolving the quality issues detected in the previous evaluation phase. Thus, it has been considered that the cropDisorderV2 ontology is usable for the specified context and it was used as the reference in assessing the quality of the ontologies selected for this evaluation phase. To this end, the tool AgreementMaker [76] was used to match the selected ontologies with the reference ontology (i.e., cropDisorderV2). The similarity threshold was set to 0.6 and the matching techniques: word matcher, string matcher, structural matcher, and property matcher were also performed. To evaluate the measures related to the structural intrinsic aspect, the tools protégé, and OOPS! were utilized [30]–[32]. Accordingly, the results were presented in Table 13 - 16.

1) RESULTS ANALYSIS

The ontologies collected from the repositories have a considerable number of quality issues related to the domain intrinsic aspect with respect to the specified context. Due to this reason, they in turn produced empty and inaccurate answers for the CQs. Specifically, coverage of ontology elements (i.e., concepts, relationships and attributes) is significantly low. Notably, OCD2.owl does not contain relationships (i.e., object properties) and attributes (i.e., data properties). Therefore, the measures associated with relationships and attributes have received minimal value. Moreover, none of the ontologies have defined whether the relationships and attributes (i.e., RUS) are functional, transitive, symmetric, asymmetric, reflexive or irreflexive. Consequently, inconsistent and incomplete answers have been received for the CQs in the domain extrinsic evaluation. For instance, OCD3.owl has defined *DiseaseEvent* concept and connected it with *Disease* concept using the relationship *hasDisease* to uniquely identify a particular crop disease related to an event. However, the relationship has not been defined as functional and in turn, an instance of *DiseaseEvent* can be mapped with multiple instances of *Disease* with the relationship *hasDisease*. This causes to generate a result with multiple diseases for a *DiseaseEvent* and in turn, the CQs that depend on this mapping produce inconsistent answers.

However, the structural intrinsic quality (i.e., compliance) of ontologies is comparatively good except for the quality measures related to understandability (Table 16). Understandability issues occur due to none of the ontologies have provided metadata/ sufficient metadata (i.e., concept

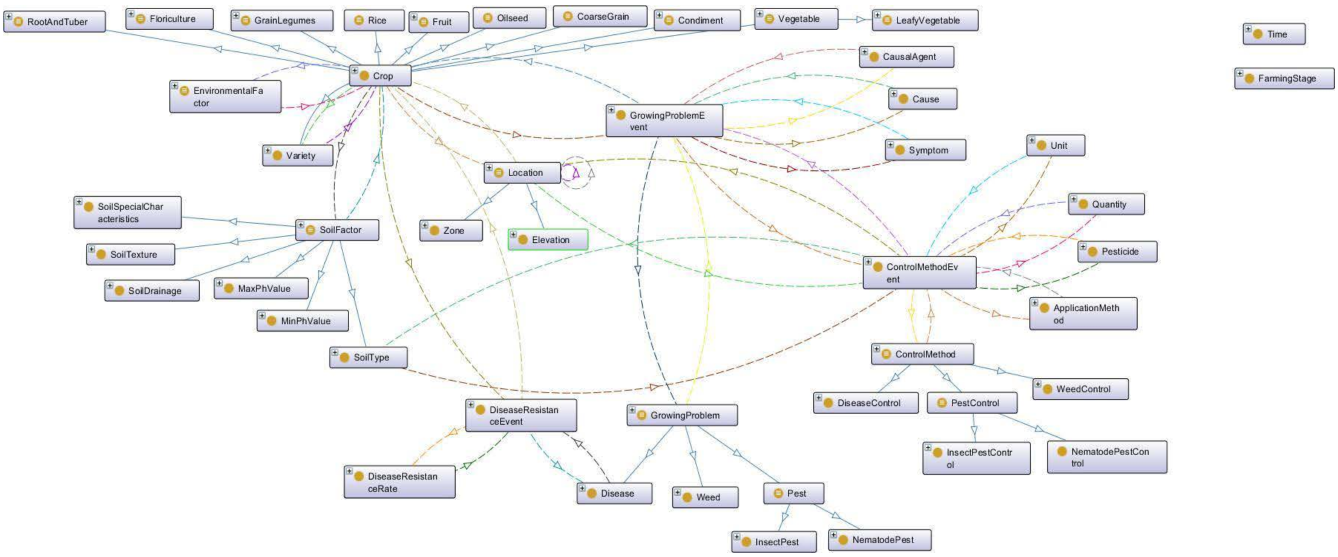

FIGURE 8. Crop disorder ontology (cropDisorderV1.owl).

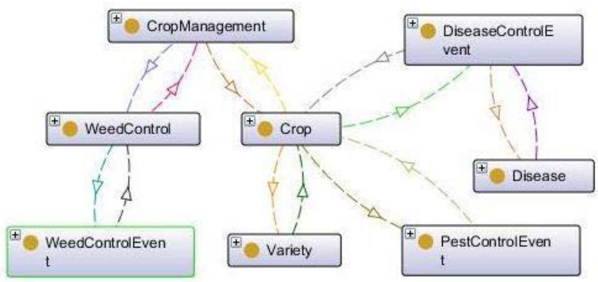

FIGURE 9. OCD1.owl ontology.

annotation, relationship annotation and attribute annotation) about the ontology elements. Moreover, OCD1.owl and OCD3.owl have used different naming conventions when labeling the elements.

In recommending the quality of an ontology, it is possible to suggest thresholds or weights for each measure/characteristic depending upon the specified context. For example, if certain characteristics are significant for a given context a higher weight or a threshold can be assigned. In this study, however, we assumed that all the defined measures are significant for a given characteristic and moreover, all the defined characteristics are important from the ontology quality perspective. To this end, if all the values obtained for given measures of a particular characteristic are close to the optimal values, then, that characteristic is acceptable in the given ontology. In this way, if all the defined characteristics become acceptable, then, the ontology quality can be considered as adequate, thus, making it a usable ontology for the given context and vice versa. Accordingly, none of the ontologies available in repositories can be recommended to use for the considered context. When considering the completeness of ontologies, OCD4.owl has covered context elements that is 26% in average ($Recall\ (O_C, F_C) = 0.45$, $Recall(O_R, F_R) = 0.13$, $Recall(O_A, F_A) = 0.21$). However, it is comparatively high against other ontologies. Moreover, OCD4.owl has covered context relationships precisely which is 92% (Table 15). Accordingly, OCD4.owl answered 60% of CQs. It can be concluded that OCD4.owl is acceptable for use in terms of completeness compared to other ontologies. Nevertheless, it is required significant effort to make it a usable ontology with respect to the derived quality requirements in the specified context.

VII. CONCLUSION

It has been realized that the quality in use of ontology-driven systems depends primarily on the quality of the ontology. However, it is no longer sufficient to limit the quality evaluation of ontology against the ontology designers' requirements. Thus, it also should consider the user needs with respect to a specified context of use. To this end, the study proposed an approach that presents how this higher-level quality objective (i.e., user needs) gets mapped to the external and internal ontology quality (Fig. 4). Furthermore, based on the approach, how the quality requirements can be derived for different aspects of the ontology namely structural intrinsic, domain intrinsic, domain extrinsic and application extrinsic in relation to the user requirements were demonstrated. Moreover, the quality characteristics that have been identified through the systematic review were mapped with these aspects (Fig. 5). Thereby, we tried to provide an insight to the researchers and practitioners on what set of quality characteristics can be used for the evaluation. However, the quality characteristics associated with an ontology should be determined based on the context of use. Thus, many empirical studies on the approach concerning different use cases are required to be performed.

Through this study, a use case in the agriculture domain was considered and the corresponding quality requirements for different aspects of an ontology were obtained based on the presented approach. Moreover, it has been illustrated how the measures can be specified with respect to the derived quality characteristics based on the given quality requirements and how these measures can be utilized to determine the quality of an ontology for a specified context. To this end, we exemplified quality evaluation based on the derived quality requirements under two phases. Firstly, we exemplified how the specified quality measures can be used to improve the quality of the existing ontology with respect to the user needs. Secondly, empirical evidence was provided on how the derived measures can be utilized for selecting an ontology for a specified context of use from a set of ontologies. It has been revealed that the structural quality of the existing ontologies is relatively good. This may be due to the presence of significant methods and tools for structural evaluation. Consequently, it has been shown that extra effort is required to resolve the ontology quality problems related to domain intrinsic and domain extrinsic aspects. In fact, it is useful to follow the approach presented from the beginning of the development to minimize the occurrence of quality problems in operational environments. To this end, having a set of formal guidelines based on the approach is essential to systematically specify the external and internal ontology quality requirements. Thereby, it can be used as a basis to ensure good quality throughout the ontology development. This has been set as the next goal of the study and expects to provide empirical evidence of the benefits of using the approach in developing a usable ontology.

APPENDIX

Snapshots of ontologies used for the evaluation process.

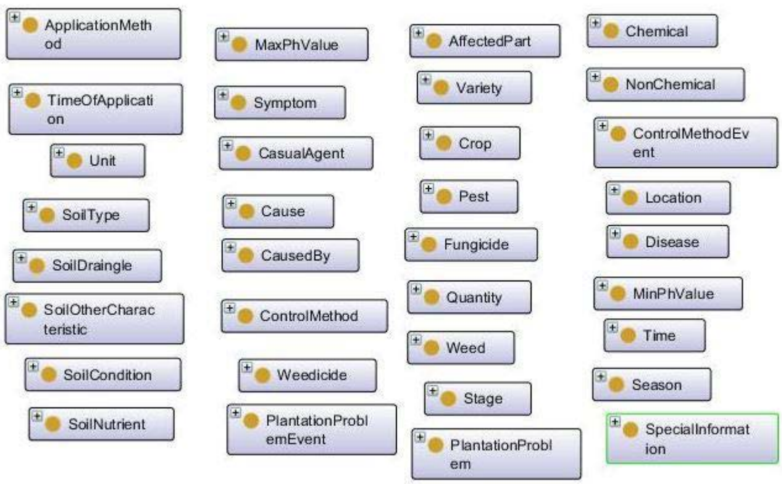

FIGURE 10. OCD2.owl ontology.

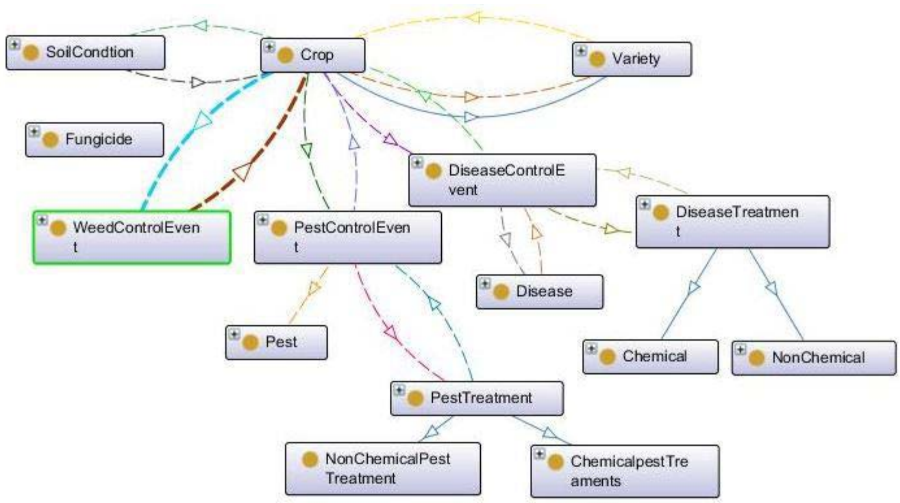

FIGURE 11. OCD3.owl ontology.

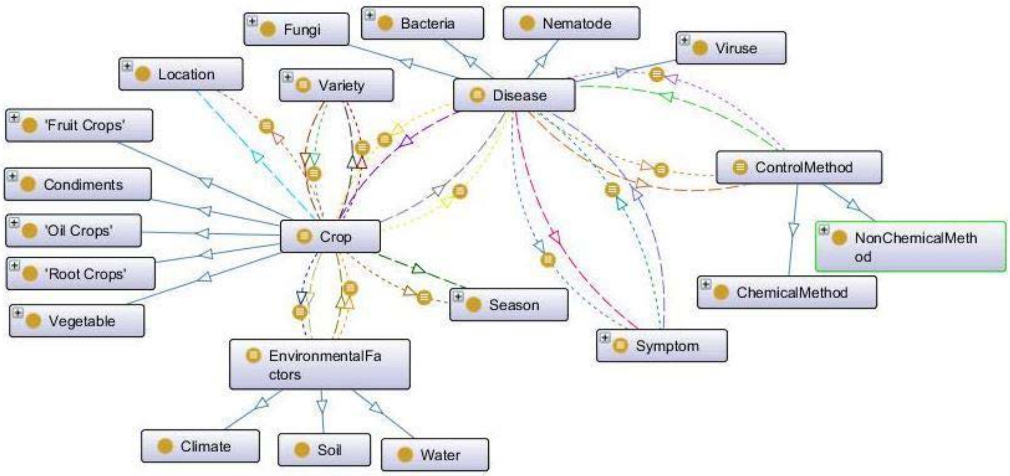

FIGURE 12. **OCD4.owl ontology.**

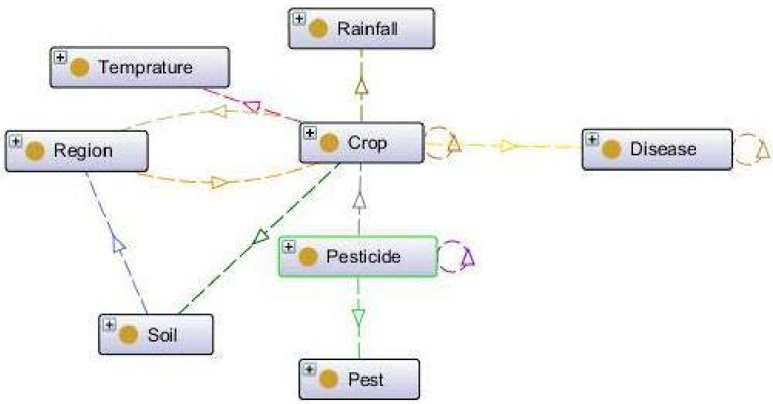

FIGURE 13. **cropDisease.owl ontology available in AgroPortal.**

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