

Proceeding Paper

The Common Greenhouse Ontology: An Ontology Describing Components, Properties, and Measurements inside the Greenhouse [†]

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Abstract: Modern greenhouses have systems that continuously measure the properties of greenhouses and their crops. These measurements cannot be queried together without linking the relevant data. In this paper, we introduce the Common Greenhouse Ontology, a standard for sharing data on greenhouses and their measurable components. The ontology was created with domain experts and incorporates existing ontologies, SOSA and OM. It was evaluated using competency questions and SPARQL queries. The results of the evaluation show that the Common Greenhouse Ontology is an innovative solution for data interoperability and standardization, and an enabler for advanced data science techniques over larger databases.



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1. Introduction

Greenhouses are used to grow vegetables and plants year-round. The climate in the greenhouse has a considerable influence on the growth of the crops. Therefore, it is important to optimally control the climate. Increasingly, more tools become available to help with this, such as climate computers, sensors, and other systems. All these systems produce different data, such as temperatures, crop growth, and weather statistics, which are stored in different databases. In this paper, we introduce the Common Greenhouse Ontology (CGO). It provides a semantic alignment of different databases, as well as a standard for high-tech greenhouses and their components.

The CGO was created in the framework of a national project “Data-Driven Integrated Greenhouse Systems” (DDINGS). In this project, a platform was created to connect databases and perform data analysis [1]. In that work, we also introduced a first version of the CGO. Since then, we fully developed the CGO with different modules, a broad set of classes that describe the components of greenhouses, and an integration with other ontologies such as the Semantic Sensor Network ontology [2] and the Ontology of units of Measure [3].

In the agricultural domain, multiple ontologies and linked open databases have been developed. A well-known example is AGROVOC [4], a large agricultural thesaurus. There are also search engines for agricultural ontologies such as AgroPortal [5]. Many ontologies can be found on these platforms, such as the Plant Phenology Ontology [6]. These ontologies provide an extensive collection of concepts in the agriculture domain, however, there does not yet exist an ontology on greenhouses. As such, we developed the CGO to provide a standard on high-tech greenhouses and their elements, and to stimulate

data integration. Some concepts from greenhouses do exist in other ontologies, which the CGO uses where possible.

2. Materials and Methods

An ontology is a formal model of the structure of a domain. It captures relevant concepts and describes the relations between these concepts [7]. The CGO was developed with domain experts and focuses on greenhouse-related concepts and measurements. Several ontology development methods were consulted and applied at various stages of development, including SABiO [8], and Ontology 101 [9]. The CGO also makes use of other ontologies: the Semantic Sensor Network ontology (SSN), which includes the Sensor, Observation, Sample, and Actuator ontology (SOSA), and the Ontology of units of Measure (OM).

Observations are an important aspect of the CGO. In the CGO, the SOSA ontology is used to model observations. In Figure 1, a simplified version of SOSA's architecture of observations is shown in green. The observation in the example is the thickness of a stem (of a flower) and the stem is the part that is observed, the Feature of Interest. The property we are observing is its thickness, the Observable Property. The Feature of Interest and the Observable Property, but also the result, are linked to the Observation, the center of the architecture to which all elements are connected.

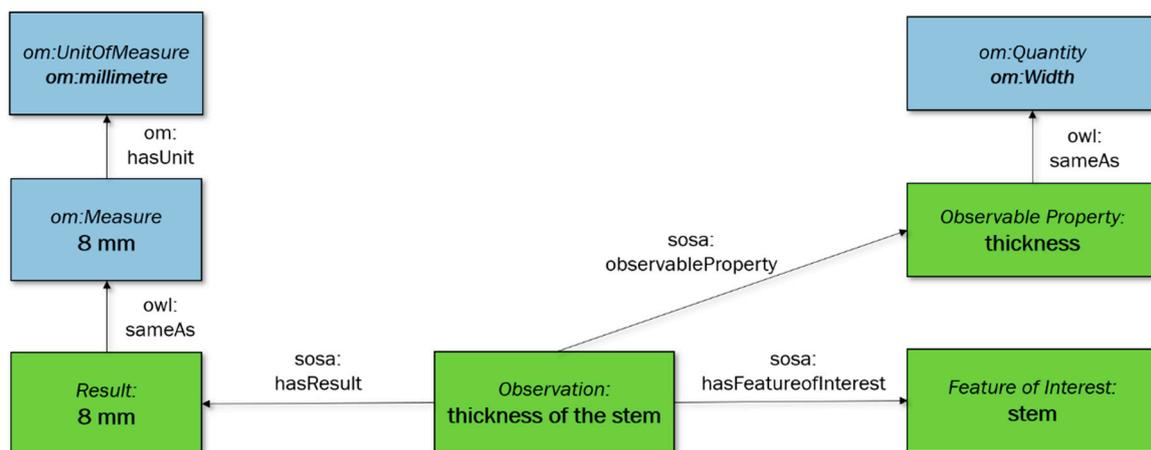


Figure 1. Design of measurements in CGO and its integration with SOSA and OM.

The Ontology of units of Measure (OM) is an OWL ontology for the domain of quantities, measurements and units of measure [3]. OM provides the possibility to link aspects of an observation to a quantity and a unit. A schematic overview of how this is implemented in CGO is given in Figure 1. From a *cgo:Class* (e.g., *thickness*), a link to an *om:Quantity* (e.g., *om:Width*) can be provided. The results are linked to a numerical value through an *om:NumericalValue* (this is not shown in Figure 1 for reasons of simplification) and to a unit through *om:hasUnit*.

3. Common Greenhouse Ontology

The CGO contains 382 classes, 99 properties (both data and object properties), and 12 individuals. This includes the classes and properties from the SOSA ontology. For an overview of all classes and their hierarchy in the ontology, consult the ontology itself (https://ontology.tno.nl/ddings/Greenhouse_ontology_v1.3.ttl, accessed on 22 November 2021). We can divide the content into four main categories: the greenhouse, which is the center concept of the ontology; features, which are the set properties of the greenhouse such as its dimensions; parts, which are the objects that can be found in greenhouses; and finally, measurements. The measurements in the greenhouse are modeled using SOSA [2] and OM [3] as can be seen in Figure 1. SOSA classes are connected to CGO classes by being

superclasses of possible Features of Interest and Observable Properties, OM classes are connected to data properties of CGO and as a subtype of `sosa:Result`.

Each of the categories contain a variety of classes. The parts category contains over 150 classes and provides an elaborated, yet not complete, overview of parts of a high-tech greenhouse. Important subsets are systems and construction hierarchies. The systems subset describes a wide set of systems in a greenhouse ranging from broader ventilation systems to specific geothermal heat pumps. The construction subset includes classes such as screens and ventilation vents. These classes are all connected to the center of CGO, the greenhouse class, by the object property “part of”. As mentioned above, measurements are modeled through SOSA, but features of the greenhouse, such as its orientation and location, are expressed with data properties.

4. Evaluation

For testing the completeness of the CGO, we created competency questions (CQ) in collaboration with greenhouse experts. Competency questions are for an ontology what the requirements are for a software. Competency questions can be questions about the data, the relations between concepts, and broader analytical questions. In Table 1, five examples of CQs are shown. The complete set of CQs was created through several practical use cases and can be found in the CGO. For querying, SPARQL queries were made from these CQ's, and restrictions were expressed using SHACL constraints.

Table 1. This table shows five examples of CGO CQs.

What is the location of sensor X?	Which sensors hang next to the ridge foils?	What is the delivered heating power based on pipe X at time Y and location Z?
What is the size of the ridge foils?	For which crops are ridge foils used?	

Three sets of restrictions were defined via SHACL: cardinality restrictions constrain the properties of greenhouse parts, the observation time is validated to have a normalized time interval, and we constrain which features and observable properties can co-occur. The domain and range restrictions were modeled via OWL constraints. All CQs included in the CGO can be answered using its classes and properties together with sensor data (for more information about the data see [10]), thereby providing a complete ontology for expressing greenhouses and their components.

5. Conclusions

Modern high-tech greenhouses have systems that continuously make measurements which cannot be queried together without linking the relevant data. In this paper, we introduced the Common Greenhouse Ontology, a standard for sharing data on greenhouses and their measurable components. The ontology was created with domain experts and incorporates existing ontologies, SOSA and OM. It includes subsets of systems, construction parts, and features such as the location of the greenhouse. It was evaluated using competency questions, and SPARQL queries. The results of the evaluation show that the Common Greenhouse Ontology can answer competency questions from different use cases. For future work, the ontology can be expanded by forming competency questions from new use cases. Another interesting direction would be to connect it to other standards and platforms such as AGROVOC [4]. Expanding the CGO will further increase its value as a data interoperability and standardization solution.

Supplementary Materials: The CGO can be downloaded online at https://ontology.tno.nl/ddings/Greenhouse_ontology_v1.3.ttl (accessed on 22 November 2021).

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Informed Consent Statement: Not applicable.

Data Availability Statement: Data available in a publicly accessible repository. The data presented in this study are openly available in DDINGS-CGO at <https://gitlab.com/ddings/common-greenhouse-ontology> (accessed on 22 November 2021).

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References

1. Verhoosel, J.P.C.; Nouwt, B.; Bakker, R.M.; Sapounas, A.; Slager, B. A Datahub for Semantic Interoperability in Data-Driven Integrated Greenhouse Systems. In Proceedings of the EFITA Conference, Rhodes Island, Griekenland, 7–29 June 2019.
2. Neuhaus, H.; Compton, M. The semantic sensor network ontology. In Proceedings of the AGILE Workshop on Challenges in Geospatial Data Harmonisation, Hannover, Germany, 2 June 2009.
3. Rijgersberg, H.; Wigham, M.L.I.; Top, J.L. How semantics can improve engineering processes: A case of units of measure and quantities. *Adv. Eng. Inform.* **2011**, *25*, 276–287. [[CrossRef](#)]
4. Caracciolo, C.; Stellato, A.; Morshed, A.; Johannsen, G.; Rajbhandari, S.; Jaques, Y.; Keizer, J. The AGROVOC linked dataset. *Semant. Web* **2013**, *4*, 341–348. [[CrossRef](#)]
5. Jonquet, C.; Toulet, A.; Arnaud, E.; Aubin, S.; Yeumo, E.D.; Emonet, V.; Graybeal, J.; Laporte, M.A.; Musen, M.A.; Pesce, V.; et al. AgroPortal: A vocabulary and ontology repository for agronomy. *Comput. Electron. Agric.* **2018**, *144*, 126–143. [[CrossRef](#)]
6. Stucky, B.J.; Guralnick, R.; Deck, J.; Denny, E.G.; Bolmgren, K.; Walls, R. The plant phenology ontology: A new informatics resource for large-scale integration of plant phenology data. *Front. Plant Sci.* **2018**, *9*, 517. [[CrossRef](#)] [[PubMed](#)]
7. Guarino, N.; Oberle, D.; Staab, S. What Is an Ontology. In *Handbook on Ontologies*; Staab, S., Ruder, R., Eds.; Springer: Berlin/Heidelberg, Germany, 2009; pp. 154–196.
8. de Almeida Falbo, R. Experiences in using a method for building domain ontologies. In Proceedings of the 16th International Conference on Software Engineering and Knowledge Engineering, Banff, AB, Canada, 20–24 June 2004.
9. Noy, N.; McGuinness, D. Ontology development 101: A guide to creating your first ontology. *Development* **2001**, *32*, 1–25.
10. Bouter, C.; Kruiger, H.; Verhoosel, J. Domain-Independent Data Processing in an Ontology Based Data Access Environment using the SOSA. In Proceedings of the Joint Ontology Workshops 2021, Episode VII: The Bolzano Summer of Knowledge, Co-located with the 12th International Conference on Formal Ontology in Information Systems (FOIS 2021), and the 12th International Conference on Biomedical Ontologies (ICBO 2021), Bolzano, Italy, 11–18 September 2021.