AN INTER OPERABLE SEMANTIC MODEL FOR SOLAR POLYHOUSE

A PROJECT REPORT

Submitted by

DHEEPAN KANNA P [CB.EN.U4CSE19112]
SUVANESH D T [CB.EN.U4CSE19317]
RAGHUL K B [CB.EN.U4CSE19346]

in partial fulfillment for the award of the degree

of

BACHELOR OF TECHNOLOGY

IN

COMPUTER SCIENCE AND ENGINEERING

AMRITA SCHOOL OF COMPUTING

AMRITA VISHWA VIDYAPEETHAM

COIMBATORE - 641 112

JUNE 2023

AMRITA VISHWA VIDYAPEETHAM

AMRITA SCHOOL OF COMPUTING, COIMBATORE – 641 112

BONAFIDE CERTIFICATE

This is to certify that the project report entitled **AN INTER OPERABLE SEMANTIC MODEL FOR SOLAR POLYHOUSE** submitted by DHEEPAN KANNA P [CB.EN.U4CSE19112],SUVANESH D T [CB.EN.U4CSE19317] ,RAGHUL K B[CB.EN.U4CSE19346],in partial fulfillment of the requirements for the award of Degree **Bachelor of Technology** in Computer Science and Engineering is a bonafide record of the work carried out under our guidance and supervision at the Department of Computer Science and Engineering, Amrita School of Computing, Coimbatore.

Dr.Gowtham Ramesh
Associate professor
Department of CSE

Dr.Vidhya Balasubramanian
Principal
Department of CSE

Evaluated on:

INTERNAL EXAMINER

EXTERNAL EXAMINER

DECLARATION

We, the undersigned solemnly declare that the project report **AN INTER OPERABLE SEMANTIC MODEL FOR SOLAR POLYHOUSE** is based on our own work carried out during the course of our study under the supervision of Dr.Gowtham Ramesh, Associate professor, Computer Science and Engineering, and has not formed the basis for the award of any other degree or diploma, in this or any other Institution or University. In keeping with the ethical practice in reporting scientific information, due acknowledgement has been made wherever the findings of others has been cited.

Dheepan Kanna P[CB.EN.U4CSE19112]- signature
Suvanesh D T [CB.EN.U4CSE19317]- signature
Raghul K B[CB.EN.U4CSE19346]- signature

ABSTRACT

Efficient data management and integration are crucial in the field of food science and industry, given the vast volumes of data generated. Food dehydration, a traditional food processing technique, has seen a resurgence in the industry. However, the properties of dehydrated food are highly influenced by environmental conditions. To address this, the Solar Polyhouse has emerged as a cost-effective solution for large-scale drying of agricultural and agro-industrial products.One of the valuable feature in semantic modelling is that they are easy to extend as relationships and concept matching are easy to add to existing ontologies.Currently there is no interoperable semantic model linking Food, Sensor, Building domain and networking domain i.e. ontology does not exist.This Project mainly aims in the development of interoperable applications across different domains.Developing a knowledge graph for this will be very much beneficial. It helps in extracting food processing information along with building,sensor data and its networking data in an easier way without the requirement of a domain expert. This Project describes the creation of an interoperable semantic model that merges building data, food data, sensor data, and network data smoothly. By leveraging a knowledge graph based on an interoperable ontology of food, sensors, buildings and networking data, the required information can be extracted using SPARQL queries without a domain expert..

ACKNOWLEDGEMENT

We would like to express our deep gratitude to our beloved Satguru **Sri Mata Amritanandamayi Devi** for providing the bright academic climate at this university, which has made this entire task appreciable. This acknowledgment is intended to thank all those people involved directly or indirectly with our project. We would like to thank our Pro Chancellor **Swami Abhayamritananda Puri**, Vice Chancellor **Dr.Venkat Rangan.P** and **Dr.Bharat Jayaraman**, Dean, Faculty of AI & Computing(Computing), Amrita Vishwa Vidyapeetham for providing us with the necessary infrastructure required for the completion of the project. We express our thanks to **Dr.Vidhya Balasubramanian**, Chairperson, Department of Computer Science Engineering and Principal, School of Computing, Amrita Vishwa Vidyapeetham, **Dr.C.Shunmuga Velayutham and Dr.N.Lalithamani,** Vice Chairpersons of the Department of Computer Science and Engineering for their valuable help and support during our study. We express our gratitude to our guide, **Dr.Gowtham Ramesh** for their guidance, support and supervision. We feel extremely grateful to **Dr. Venkataraman D, Dr. M Senthilkumar, Mr. Dayanand V, Ms. Shanmuga Priya S** for their feedback and encouragement which helped us to complete the project. We would also like to thank the entire fraternity of the Department of Computer Science and Engineering and Sony-SSUP team. We would like to extend our sincere thanks to our family and friends for helping and motivating us during the course of the project. Finally, we would like to thank all those who have helped, guided and encouraged us directly or indirectly during the project work. Last but not the least, we thank God for his blessings which made our project a success.

DHEEPAN KANNA P [CB.EN.U4CSE19112]

SUVANESH D T [CB.EN.U4CSE19317]

RAGHUL K B [CB.EN.U4CSE19346]

TABLE OF CONTENTS

LIST OF FIGURES

Chapter 1

INTRODUCTION

This Project work focuses on the development of an interoperable ontology by integrating mulitple ontologies from different domains. The aim of this project is to create a unified semantic framework that enables seamless interaction and data exchange across multiple domains, fostering interoperability and knowledge integration.Ontologies play a crucial role in representing knowledge in a structured and machine-readable manner. They provide a common vocabulary and set of relationships that facilitate effective communication and information sharing between different systems and applications. By combining the domain-specific ontologies, we aim to create a comprehensive interoperable ontology that encompasses food properties, sensing devices, building topology, and polyhouse networking operations.

By offering an interoperable semantic model specifically created for describing sun drying polyhouse data, this paper seeks to overcome this issue. The project's major goal is to create a compact, interoperable generic semantic model that enables seamless communication between things related to food, sensing, observation, actuation, and solar drying polyhouses.

1.1 Motivation

Food is a vital and necessary resource for life.A healthy lifestyle necessitates the consumption of high quality food.As the world's population grows, there is an urgent need to increase agricultural production sustainably, reduce post harvest losses, and ensure that people suffering from hunger and malnutrition have access to nutritious food.Food safety and security are essential for obtaining high-quality food.This level of security should be maintained at all stages.Some food items may not be available all year.As a result, it becomes critical to store food in order to have it available at all times.Various properties of the food may be affected during the drying process.There is a possibility of nutrient loss at times.As a result, it is necessary to store, monitor, and analyse those changes.There are currently no ontologies that support this drying food process.Food processing ensures food safety by eliminating or reducing harmful microorganisms, toxins, and contaminants present in raw materials. It also enables the development of convenient and ready-to-eat food options that align with busy lifestyles and changing dietary preferences. Convenience foods, including pre-cut fruits and vegetables, canned meals, and microwaveable products, provide quick and easy meal solutions for consumers.Techniques like pasteurization, sterilization, and thermal processing help prevent foodborne illnesses and ensure the microbiological safety of food.There are currently databases with restrictions, such as data that is locked within a specific region.Different databases will be inaccessible to applications.Different databases' data may not be inter operable with one another.As a result, tracing the details across multiple sites becomes difficult.

Creating a knowledge graph for this will be extremely beneficial.It facilitates the extraction of food processing information without the need for a domain expert.A fundamental requirement for the successful completion of this project is the facilitation of a seamless exchange of project information throughout the entire life cycle of a construction facility as well as between multiple, interdisciplinary stakeholders.Because of the industry's fragmented structure, this information supply chain is frequently rebuilt from the ground up with each new project organisation, resulting in new custom data structures for each project, represented in individual ever-changing unstructured spreadsheets and documents.It aids in backtracking whenever an anomaly is encountered.It also makes it easier to extract information about a specific category or feature.

1.2 Problem Definition

An interoperable semantic model for representing polyhouse data. Designing and developing a light-weight interoperable generic semantic model to facilitate interaction between food, sensing, observation, actuation, and polyhouse entities defined in and across the polyhouses is the main objective of this project.

1.3 Approach

The current limitations of databases pose challenges in terms of data accessibility and interoperability. Data is often confined within specific regions or databases, making it difficult for applications to access information from different sources. This lack of interoperability hinders the traceability and integration of details across various sites. To address these challenges, the development of a knowledge graph emerges as a beneficial solution.By constructing a knowledge graph,the solar polyhouse domain can benefit from enhanced information retrieval capabilities. The knowledge graph allows for the extraction of relevant polyhouse related information in a more straightforward manner, eliminating the need for constant reliance on domain experts. This accessibility empowers users to explore and retrieve data without specialized knowledge, facilitating the utilization of valuable insights.Moreover, the knowledge graph enables efficient backtracking when anomalies or inconsistencies arise within the data. By tracing the interconnected relationships within the graph, it becomes easier to identify and resolve issues, ensuring the integrity and reliability of the information.The knowledge graph offers the advantage of extracting information specifically. Users can navigate through the graph or can use SPARQL to extract relevant data points related to their specific needs, facilitating targeted information retrieval and analysis .

1.4 Outline

Through this project, we demonstrate the practical application and effectiveness of the interoperable ontology by showcasing use cases and scenarios in the food industry by presenting use cases and situations in the agricultural sector, we illustrate the usefulness and efficacy of the interoperable ontology in this study. The results illustrate the potential of combining various ontologies to overcome interoperability issues and develop semantic technology. The suggested method has implications for improving data interoperability, decision-making, and operational optimisation in polyhouse agriculture and food production. // In general, the creation of this interoperable ontology offers the research community significant insights on the design and fusion of ontologies from many fields. The findings open up new opportunities for semantic technology research and application in transdisciplinary sectors and support the creation of intelligent farming systems. .

Chapter 2

LITERATURE SURVEY

2.1 Literature Survey

2.1.1 FoodOn: a harmonized food ontology to increase global food traceability, quality control and data integration

FoodOn is a widely adopted and comprehensive food ontology that encompasses a broad range of elements related to the domain of food. It serves as a standardized resource for representing and organizing knowledge about food, enabling effective data integration and knowledge sharing across various applications and domains within the food industry. The ontology is built upon the foundation of the Langual vocabulary, which encompasses 14 aspects covering diverse dimensions of food-related information. These aspects include food sources, plant and animal species, food preservation methods, cooking techniques, packaging, consumer groups, labeling, and more. By incorporating such a comprehensive set of aspects, FoodOn provides a holistic representation of the diverse facets of the food domain. One of the notable strengths of FoodOn is its reuse of terms from other ontologies, as well as its widespread adoption by other ontologies. This promotes interoperability and consistency in the representation of food-related concepts across different knowledge domains. By reusing terms from existing ontologies and being reused by others, FoodOn facilitates seamless integration with other resources and ontologies, enhancing data exchange and interoperability.The utilization of FoodOn in various applications has been instrumental in advancing food-related research and development.

FoodOn stands as a vital and widely accepted food ontology that encompasses a comprehensive range of elements related to food. Its foundation in the Langual vocabulary, reuse of terms from other ontologies, and widespread adoption by other ontologies highlight its significance in promoting data interoperability and knowledge integration in the food domain. The ontology's extensive coverage and practical applications make it a valuable resource for researchers, practitioners, and stakeholders working in the food industry.

2.1.2 FoodKG: A Semantics-Driven Knowledge Graph for Food Recommendation

In this paper, the authors present the development and implementation of a Food knowledge graph targeting customers seeking a healthy diet considering allergy and health concerns. The knowledge graph is designed to provide a valuable resource for users to access information about food ingredients and recipes that align with their dietary requirements.The study outlines the process of developing the knowledge graph, including the collection and integration of relevant data sources. It highlights the methods employed for maintaining and updating the knowledge graph to ensure its accuracy and relevance.The authors also emphasize the practical applications of the knowledge graph, particularly in offering a SPARQL-based service. This service enables users to search for recipes based on non-allergic ingredients, thereby supporting individuals with specific dietary restrictions.The integration of the knowledge graph into these applications enhances the user experience by providing personalized recommendations and facilitating informed food choices. By leveraging the power of SPARQL queries, users can easily filter and select recipes that align with their dietary preferences, promoting healthier eating habits.

Overall, this study demonstrates the value and potential of the Food knowledge graph in addressing the needs of customers with dietary considerations. The presented applications offer a user-friendly and efficient way for individuals to discover and select recipes based on non-allergic ingredients, contributing to a healthier and more personalized diet.

2.1.3 The SSN Ontology of the W3C Semantic Sensor Network Incubator Group

The Semantic Sensor Network (SSN) ontology, developed by the Semantic Sensor Network Incubator group (SSN-XG) of the World Wide Web Consortium (W3C), is a powerful resource for describing sensors and their associated capabilities, measurement processes, observations, and deployments. This ontology, based on the Web Ontology Language (OWL 2), provides a standardized framework for representing sensor-related information and facilitating interoperability among sensor networks and applications.The SSN ontology enables the comprehensive description of sensors, including their functionalities, features, and properties. It allows for the representation of various sensor capabilities, such as measuring temperature, humidity, or pressure, and provides a rich vocabulary to describe the measurement processes involved.Furthermore, the SSN ontology captures the act of sensing itself, enabling the modeling of sensor observations and the resulting data. It allows for the representation of observation values, time stamps, and metadata associated with sensor readings, facilitating the integration and analysis of sensor data in various applications.The ontology also considers sensor deployments, allowing for the description of sensor networks, spatial arrangements, and environmental contexts. This information is crucial for understanding the sensor data within its specific context and enables the development of context-aware applications and services.

The SSN ontology offers a standardized and comprehensive framework for describing sensors, their capabilities, measurement processes, observations, and deployments. By adopting this ontology, sensor networks and applications can achieve interoperability, enhance data integration and analysis, and enable the development of context-aware and intelligent systems in various domains. The SSN ontology is a valuable resource for researchers, practitioners, and stakeholders in the field of sensor networks and the Internet of Things (IoT).

2.1.4 FIESTAIoT Project: Federated Interoperable Semantic IoT/cloud Testbeds and Applications

The Fiesta-IOT ontology, developed by Rachit Agarwal, serves as a valuable resource for achieving semantic interoperability among various Internet of Things (IoT) ontologies and taxonomies. Unlike other existing ontologies that focus on a specific domain or application, Fiesta-IOT aims to bridge the gap between different IoT ontologies by incorporating and connecting existing ontological concepts.The ontology integrates fundamental concepts from several established ontologies and taxonomies, including DUL, M3-lite, WGS84, Time, IoT-lite, and SSN. By leveraging these existing ontologies, Fiesta-IOT ensures compatibility and semantic alignment with a wide range of IoT-related concepts and entities.The adoption of Fiesta-IOT allows for seamless integration and communication between different IoT systems and applications, as it provides a common semantic framework for representing and interpreting IoT data and interactions. It facilitates the exchange of information and knowledge across heterogeneous IoT environments, enabling enhanced interoperability and collaboration.By connecting and reusing concepts from various ontologies, Fiesta-IOT promotes the standardization and harmonization of IoT-related terminologies and semantics. This fosters better understanding and integration of IoT technologies, applications, and services, leading to improved efficiency, scalability, and interoperability in the IoT ecosystem.

The Fiesta-IOT ontology offers a semantically interoperable solution for integrating and connecting existing IoT ontologies and taxonomies. By incorporating fundamental concepts from multiple ontologies, it provides a common semantic framework for achieving interoperability and harmonization in the IoT domain. The adoption of Fiesta-IOT facilitates seamless communication and collaboration among different IoT systems and applications, contributing to the advancement and widespread adoption of IoT technologies.

2.1.5 BOT: the Building Topology Ontology of the W3C Linked Building Data Group

The BOT (Building Topology Ontology) ontology serves as a valuable tool for achieving semantic interoperability and data integration in the Architecture, Engineering, Construction, Owner, and Operator (AECOO) industry. The ontology is designed to work alongside other ontologies, allowing for the representation of diverse aspects such as product information, sensor observations, Internet of Things (IoT) devices, complex geometry, and project management data.By leveraging the BOT ontology, the AECOO industry can achieve a simplified and standardized approach to representing the relationships between various components within a building. The ontology aims to explicitly specify the essential connections and interdependencies among sub-components of a building, facilitating a comprehensive and interconnected representation of information.A key focus of the BOT ontology is to enable semantic interoperability by reusing terms and concepts already expressed in well-known vocabularies. This approach ensures consistency and alignment with established standards, enhancing the compatibility and integration of data within the AECOO industry.By adopting the BOT ontology, stakeholders in the AECOO industry can realize the benefits of a future semantic web-driven environment. The ontology provides a means of describing interconnected information within the industry, supporting efficient data exchange, collaboration, and decision-making processes.

The BOT ontology offers a practical solution for achieving semantic interoperability and data integration in the AECOO industry. By providing a standardized framework for representing building components and their relationships, the ontology enhances the interconnectedness and exchange of information. The adherence to reusing terms from well-known vocabularies ensures compatibility with existing standards. The adoption of the BOT ontology contributes to the realization of a semantic web-driven AECOO industry, facilitating improved data interoperability and collaboration among stakeholders.

2.1.6 ToCo: An Ontology for Representing Hybrid Telecommunication Networks

This paper presents the development of the TOUCAN Ontology (ToCo) and the Device-Interface-Link (DIL) ontology design pattern for communication networks. The research focuses on the fundamental classes and relationships that constitute the ontology, providing a comprehensive understanding of its structure and functionalities. This advancement is part of a larger initiative aimed at addressing the convergence of telecommunication networks across various technology sectors.The ontology development progress serves as a basis for observing and summarizing the DIL pattern, which can describe a wide range of networks. The ToCo ontology, built upon the DIL pattern, encompasses the physical infrastructure, channel quality, services, and users within heterogeneous telecommunication networks spanning multiple technology domains.The paper highlights recent projects that utilize ToCo as examples and showcases the ontology's practical applications and use cases. These projects demonstrate how ToCo can effectively model and represent diverse telecommunication networks, supporting the analysis, design, and management of communication infrastructures.The development of ToCo and the integration of the DIL pattern contribute to the advancement of communication networks by providing a standardized and comprehensive ontology framework. The research presented in this paper lays the foundation for future developments in the field, fostering interoperability, knowledge integration, and collaboration among stakeholders in the telecommunication industry.

This paper presents the development and utilization of the TOUCAN Ontology (ToCo) and the Device-Interface-Link (DIL) ontology design pattern for communication networks. It discusses the ontology's fundamental classes and relationships, addressing the convergence of telecommunication networks across technology sectors. The ToCo ontology, based on the DIL pattern, offers a comprehensive framework for modeling heterogeneous telecommunication networks. The paper includes examples and use cases that demonstrate the practicality and effectiveness of ToCo in various projects, further contributing to the advancement of communication networks.

2.1.7 Knowledge extraction using semantic similarity of concepts from Web of Things knowledge bases

This paper was developed by Vamsee Muppavarapu is a Ph.D. candidate at Amrita Vishwa Vidyapeetham, specializing in smart building interoperability. Dr. Gowtham Ramesh is an Associate Professor at the same institution, focusing on information security and the Semantic Web. Dr. Amelie Gyrard has expertise in Semantic Interoperability for IoT and is involved in various standardization activities. Mahda Noura is a Ph.D. candidate at Technische Universität Chemnitz, with research interests in IoT, Web of Things, Semantic Web, AI planning, and human-computer interaction. It addresses the challenges of developing interoperable applications in the IoT domain, where significant effort is currently required to manually code requirements for knowledge transfer. To mitigate this, an interoperable platform is proposed to enable seamless communication between heterogeneous IoT devices. The W3C Web of Things (WoT) is highlighted as a crucial step towards IoT device interoperability, integrating the Web ecosystem with "Things" and providing a unified interface across different protocols. However, WoT still lacks semantic interoperability due to limited standard vocabularies for describing IoT application domains. To address this limitation, the paper presents a semantic similarity-based approach to automatically identify and extract common concepts from sixteen popular ontologies in smart home and smart building domains. The proposed method aims to reduce the effort required to develop a domain ontology. The extracted concepts are evaluated by domain experts and deemed sufficient for describing the smart home and smart building domains. This research contributes to facilitating interoperability and reducing development efforts in the IoT field, providing insights and practical guidance for developers and researchers working on IoT applications.

2.2 Summary

Each of the mentioned ontologies addresses specific aspects of different domains, such as building topology, food, IoT, and communication networks. By integrating these ontologies, you can achieve a comprehensive and holistic representation of complex systems that involve multiple domains.Secondly, interoperability is crucial in today's interconnected world. The ability to seamlessly exchange and integrate data across diverse domains enhances collaboration, knowledge sharing, and decision-making processes. By developing an interoperable ontology, you provide a standardized framework that allows different systems, applications, and stakeholders to communicate effectively, irrespective of the domain-specific terminology or structures they use.Furthermore, the integration of multiple ontologies promotes reuse and reduces redundancy. Rather than reinventing concepts and terms, you can leverage existing ontologies and extend them as needed. This not only saves time and effort but also fosters consistency and alignment with established standards and vocabularies.

Additionally, an interoperable ontology enables cross-domain analysis and reasoning. By combining ontologies from different domains, you can explore complex relationships and gain valuable insights that may not be apparent when considering each domain in isolation. This interdisciplinary approach can lead to novel discoveries, innovative solutions, and improved decision-making.Overall, the development of an interoperable ontology combining these ontologies holds immense potential for enhancing data integration, collaboration, and knowledge sharing across diverse domains.

Chapter 3

PROPOSED SYSTEM

3.1 System Design

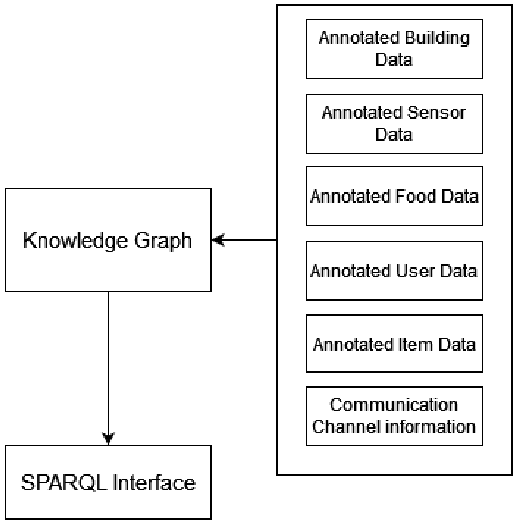


Figure 3.1: Modules of the proposed solution

The system design described above provides a high-level overview of the different stages and components involved in developing the polyhouse ontology.The construction of the knowledge graph involves the collection, annotation, and integration of the building, sensor, food, networking, item and user data.The knowledge graph of this polyhouse requires the information of the above mentioned domains which need to be annotated from the selected ontologies i.e, BOT, FoodOn, FIESTAIOT, ToCo to meet the needs and potray the data of our solar polyhouse.This includes detailed representations of the building structure, sensor observations, food products,netwroking data, item and user data.The interoperablity of these domians together produces the final output of the problem.The Knowledge graph with the real time values when added to the respective classes can be used to extract the required real time information of the polyhouse using SPARQL query.

3.1.1 Architecture Diagram

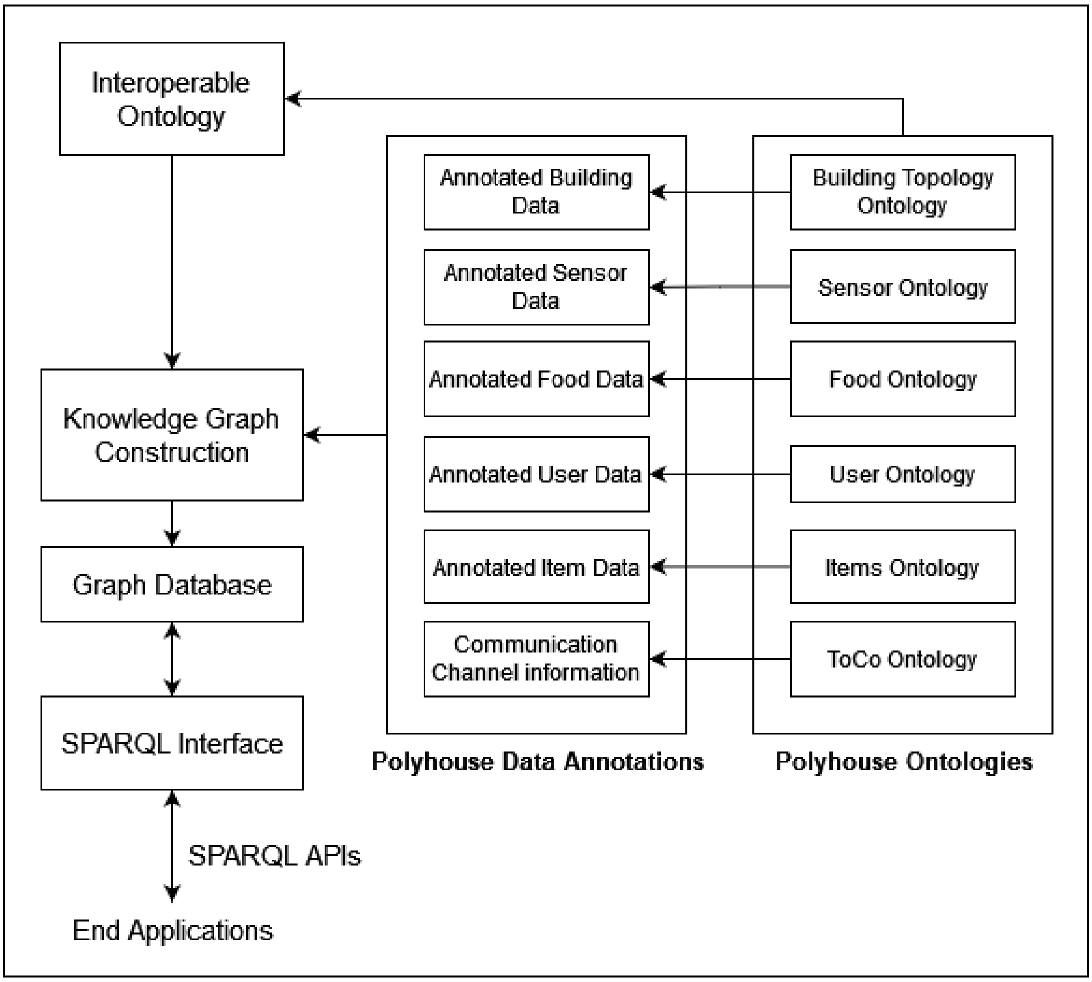


Figure 3.2: Architecture Diagram of the proposed solution

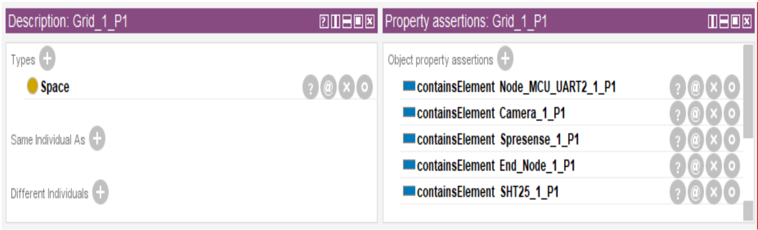
The architecture diagram of the project showcases the high-level structure and modules of the system. It illustrates the integration of the different modules which is linked with each other to achieve the desired functionality.In this project, the data from the multiple domains are integrated together to from an interoperable ontology which is then loaded into the graph data base and represented as a knowledge graph.The required information can be extracted from the knowledge graph through the SPARQL.

3.1.2 Modules description

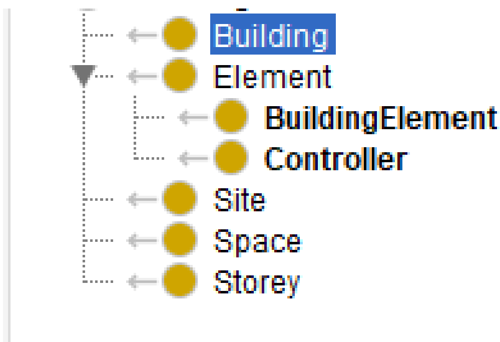
The categorization of modules based on different domains is a crucial aspect of this project, aiming to facilitate interaction and data transfer between these domains. The ultimate goal of the project is to achieve interoperability, enabling seamless communication and data exchange between multiple domains. This objective holds significant importance in today's interconnected world, where diverse systems and applications need to collaborate and share information effectively.

Annotated Building Data

In this project, 3D modeling of the polyhouse was performed using Sketchup Pro (V 22.0.316). The polyhouse was modeled with the given dimensions in feet, including details of objects and materials. The width and length of the polyhouse are 12 feet and 40 feet, respectively, with a ramp at the front for transporting food items. The roof is covered with a polyethylene sheet supported by aluminum pipes. The polyhouse is logically partitioned into three grids, each containing a node. The first and third grids have end nodes, while the second grid has an edge node. Sensors are mounted on sensor mounts, and an exhaust fan controlled by the exhaust controller and turbo-vent are present to regulate the temperature.Once the modeling is completed, the software considers the entire model as a single entity. Since the polyhouse consists of different entities made of different materials, grouping of these entities is necessary. This grouping results in individual objects with names, descriptions, and other properties in addition to their basic geometry. To manage these details, the individual objects are classified according to the project workflow using the IFC 4 classification system. The classified 3D model is exported in the IFC file format, and to overcome the complex structure and size limitations of IFCowl, the Building Ontology Topology (BOT) is used.The IFC file is converted to BOT in the turtle file format using the IFCtoLBD converter. Each classified group is now in the form of a URI, making it easily accessible. In Protégé, the ontology is loaded, and an object property, bot:has3DModel, is created to add the geometry. The geometry is added in the wavefront OBJ format, and the OBJ files of each group are pushed into the GitHub repository. New individuals with the OBJ file URI are created and connected with the existing individuals using the has3DModel property.



(a) Grid1 in BOT



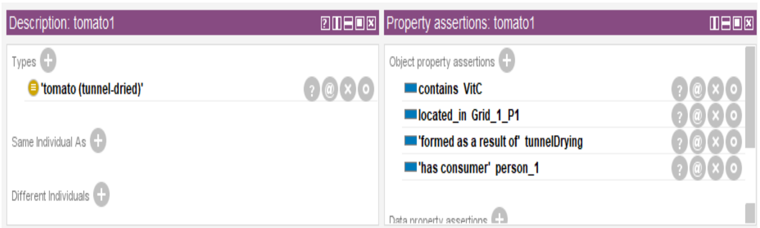
(b) Classes in BOT

Figure 3.3: FoodOn

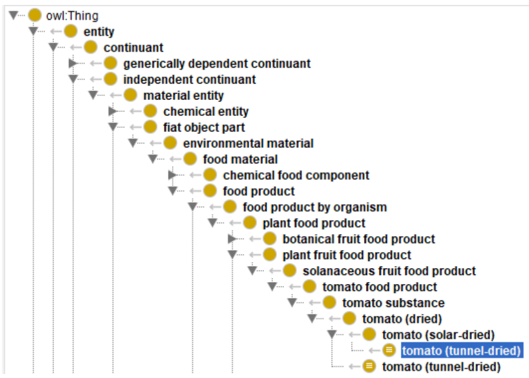
Annotated Food Data

The focus of FoodOn on dried food items is limited, particularly in relation to types of natural heat drying. To address this gap, we have enhanced the ontology by incorporating missing information pertaining to specific types of natural heat drying techniques. In particular, we have introduced a new class called "solar drying," which is a subclass of the existing class "natural heat drying". Within the solar drying category, we have further specified a subclass called "solar tunnel drying". In terms of the specific food items considered for drying in a polyhouse, our ontology now includes four entities: tomato, moringa leaf, peanut, and copra. To reflect the solar drying process, we have created subclasses for each of these food items. For instance, "Peanut (solar-dried)" is a subclass of the existing "peanut (whole, dried)" category. Since there was no pre-existing class for "moringa" in FoodOn, we have constructed an entire hierarchy for moringa with respect to tunnel drying under the class "plant leaf vegetable food product".Furthermore, we have introduced subclasses for "copra" based on the drying method. These include "copra (solar-dried)" as a subclass of the existing "copra" category and "copra (tunnel-dried)" as a subclass of "copra (solar-dried)". Similarly, "tomato (solar-dried)" is now a subclass of the existing class "tomato (dried)", and "tomato (tunnel-dried)" is a subclass of "tomato (solar-dried)".

By incorporating these additions and enhancements, our extended FoodOn ontology now encompasses a more comprehensive representation of dried food items, particularly focusing on solar and tunnel drying methods. This enriched ontology will facilitate better categorization, classification, and interoperability of dried food products in research, industry, and other relevant domains.



(a) Grid1 on BOT

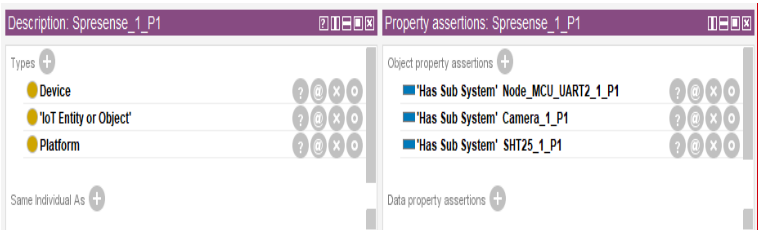


(b) Classes in FoodOn

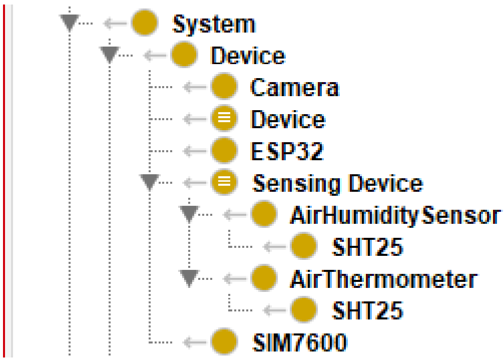
Figure 3.4: FoodOn

Annotated Sensor Data

In the FiestaIOT ontology, we have incorporated the sensors present in the polyhouse based on their respective class hierarchy. The polyhouse itself is added under the a feature of interest class. To represent the sensors responsible for monitoring humidity and temperature, we have included the SHT25 sensor under the system class, which in turn is added under the sensing devices subclass. Additionally, the SIM76000 module, Camera, and ESP32 devices are also included in the ontology as they are present in the edge nodes and end nodes of the polyhouse.To capture the sensor observations, we have created an Observation class and associated it with the respective sensors under their respective device names. Individual instances are created for each class based on the three grids present in the polyhouse. The edge node is situated in grid 2, while the end nodes are located in grid 1 and grid 3. Each node hosts a spresence entity, such as spresence1-P1 in polyhouse1, which is of type Device, IOT entity, or object. The Spresence entity consists of specific components like Node-MCU-UART1-P1, Camera1-P1, and SHT1-P1, which are connected using the property "Has Subsystem." We create individuals for each device in every node and also for the sensor observations.To establish the temporal context, we note down the time instances alongside the observations. This enables us to query the sensor observation values along with their corresponding time instances. Each observation is of type "observation" and is associated with the observed sensing device, the observation sampling time represented by the grid-time-instance, and the observation result represented by grid-Sensor-output.



(a) Spresence1 in FIESTAIOT



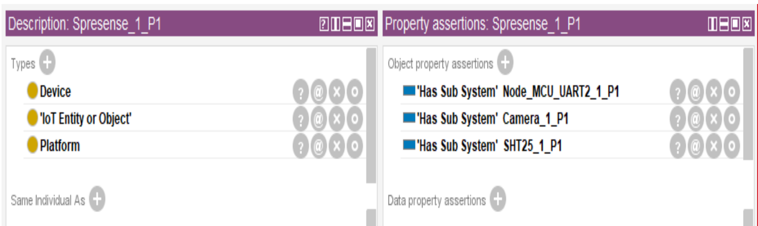
(b) List of Devices in FIESTAIOT

Figure 3.5: FIESTAIOT

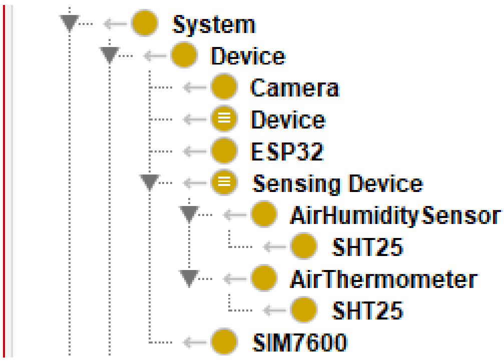
By incorporating these elements into the FiestaIOT ontology, we have established a comprehensive representation of the sensors, devices, observations, and temporal aspects within the polyhouse environment. This enriched ontology facilitates seamless integration, interoperability, and querying of sensor data, enabling advanced analysis, monitoring, and control in smart polyhouse applications.

Annotated Networking Data

In addition to the FiestaIOT ontology, the ToCo (Topology and Communication) ontology plays a significant role in depicting the communication and networking aspects within the polyhouse environment. The ToCo ontology focuses on the interaction and data flow between the nodes present in the polyhouse.Within the polyhouse, the nodes in Grid 1 and Grid 3 send their observations to the edge node located in Grid 2. To represent the devices involved in this communication, we have added entities such as Camera, ESP32, Router, Server, SHT25, SIM7600, and Spresense under the System device class in the ToCo ontology. These devices facilitate data collection, processing, and transmission within the polyhouse network.To capture the networking infrastructure, the ToCo ontology includes wired and wireless links. The wired links are represented by entities such as CSI, I2CBUS, Soft Serial, and UART2, which depict the physical connections between devices. On the other hand, the wireless network is represented by LTE association and WiFi Association, which illustrate the wireless communication capabilities between devices.



(a) Spresence1 in ToCo



(b) List of Devices in ToCo

Figure 3.6: ToCo

Furthermore, the ToCo ontology incorporates classes to represent both quantitative and qualitative measurements. The ObservationandMeasurements class captures the observations made within the polyhouse, while the units associated with these measurements are represented under the units class. This allows for the inclusion of specific measurement values and units in the ontology, enabling precise and standardized representation of the observed data. By integrating the ToCo ontology with the FiestaIOT ontology, we can provide a comprehensive representation of the communication and networking aspects within the polyhouse environment. This enables researchers and developers to analyze and study the communication patterns, data flow, and networking infrastructure in smart polyhouse systems.

Annotated Item Data and Annotated User Data

User ontology promotes interoperability and integration across different systems and applications. By standardizing the representation of user information, it facilitates the exchange and sharing of user models between various systems and platforms. By representing items and their properties, the ontology enables the creation of comprehensive and structured product catalogs of the food products. This allows users to search, analyse and compare food items based on specific criteria.

3.1.3 Ontology Integration

The integration of the multi domain ontology is integrated with the right property to form a triples and semantically correct.In the Bot ontology, the relationship between the classes "bot:Building" and "bot:Storey" is established through the property "bot:containsStorey". The class "bot:Site" is connected to "bot:Building" through the property "bot:building". Within the "bot:Storey" class, there are elements represented by the class "bot:elements", and these elements are interconnected through the property "bot:containsElements". Additionally, each "bot:Storey" has a space, and this relationship is defined using the property "bot:hasSpace". The integration of the Bot ontology with FoodOn ontology is achieved through the property "located in", specifically with the example of "tomato(dried)" located in the "bot:Space".The FoodOn ontology provides detailed information about food products. In the FoodOn ontology, the class "tomato(dried)" is included in the class hierarchy, such as "tomato substance", "tomato food product", "solanaceous fruit food product", "plant fruit food product", and

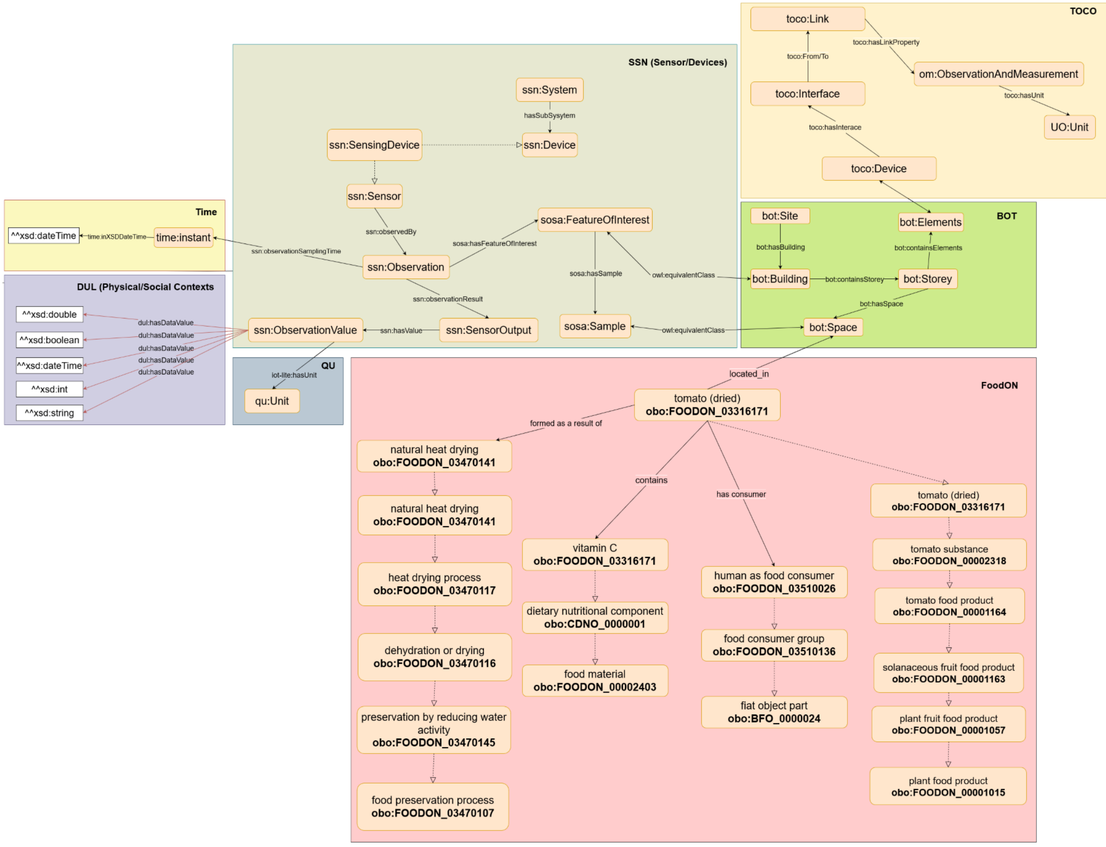


Figure 3.7: Integration of Ontologies

"plant food product". The "tomato(dried)" class is a result of the "natural heat drying" process and is associated with the class "vitamin C".From an interoperability perspective, the "bot:space" class is considered an equivalent class of "SOSA:sample", and the "bot:building" class is an equivalent class of "SOSA:FeatureofInterest" in the SSN ontology. The "SOSA:FeatureofInterest" class contains samples from the "sosa:Sample" class. The "ssn:observation" class represents the feature of interest through "sosa:FeatureofInterest" and has an observation result in the "ssn:SensorOutput" class. The "ssn:observation" class itself contains the value in "ssn:ObservationValue".

The "ssn:system" class includes the subsystem "ssn:Device", which is a type of "ssn:sensingDevice". The "ssn:sensingDevice" class is also categorized as an "ssn:Sensor" and is associated with the "ssn.observation" class through the property "observedBy". The "bot:elements" class is equivalent to the "toco:device" class. The "toco:Device" class has an interface represented by "toco:interface", which can be connected through "toco:link". The "toco:link" class includes the property "om:ObservationandMeasurement", which has a unit represented by "UO:unit".

3.1.4 Federation of Ontologies

The federation of ontologies, specifically BOT, FoodOn, FIESTAIOT, and ToCo, plays a pivotal role in our project on solar polyhouses. By combining and integrating these ontologies, we aim to create a comprehensive and interoperable knowledge representation framework that encompasses various domains relevant to solar polyhouse systems.BOT (Building Ontology Topology) provides the foundation for representing the architectural design of the polyhouse. It offers classes such as "Building," "Storey," and "Space" that allow us to model the physical structure and spatial organization of the polyhouse. Additionally, BOT facilitates the relationship between different components, such as how storeys contain elements and spaces, enabling a detailed representation of the polyhouse's internal structure.FoodOn ontology is integrated to enhance the representation of food products within the polyhouse. By leveraging FoodOn's rich hierarchy of food classes, we can classify and describe various food items such as tomatoes, moringa leaves, peanuts, and copra. This integration allows us to capture detailed information about these food products, including their drying methods (such as natural heat drying or solar drying) and nutritional properties. FIESTAIOT ontology is utilized to represent the sensor observations and devices within the polyhouse. Through FIESTAIOT, we can model sensors like SHT25, SIM7600 module, camera, and ESP32, along with their respective observations. This ontology enables us to capture and analyze data related to temperature, humidity, and other environmental parameters, providing valuable insights into the polyhouse's conditions.ToCo ontology complements the overall federation by representing the communication and networking aspects within the polyhouse. It allows us to model devices, interfaces, and links, facilitating the understanding of how different components interact and exchange data. By incorporating ToCo, we can represent wired and wireless links, establish associations between devices, and capture relevant observation and measurement units.

The federation of these ontologies enables us to create a comprehensive knowledge representation of solar polyhouses, encompassing the architectural design, food products, sensor observations, and communication infrastructure. This integration promotes interoperability, allowing information to be exchanged seamlessly across different domains. It also enhances scalability and extensibility, as new ontologies can be easily integrated to capture emerging concepts and expand the knowledge representation.

3.1.5 Challenges in developing integrated polyhouse ontology

Extensive research was necessary to comprehend the complexities of solar polyhouses, including their architectural design, sensor technologies, food processing needs, tracking the communication and user-related data. Obtaining domain-specific data and making sure it was accurate and relevant were essential elements in creating a trustworthy ontology. Making an extensible and adaptable ontological structure and making it semantically correct was another issue.This multi domain ontology required the correct integration of the domains and making it interoperable with the respective properties was really important. The polyhouse domain is intricate and multifaceted, with many hierarchies and interdependencies. It is difficult to manage technicians in this field successfully due to the industry's unique peculiarities.The industry's fragmented structure is one of its problematic traits. Additionally, during a project's entire life cycle, multidisciplinary stakeholders from several professions who each use unique software tools must collaborate and share information. Iterative refinement and careful thought were necessary to develop an ontology that was well-structured and could handle many concepts, relationships, and attributes. The ontology's overall usability and efficiency has to be balanced with the need for detail.

3.1.6 Overview of the Polyhouse ontology and its Competency Questions

The solar polyhouse ontology developed in this project serves as a valuable tool for the food processing industry, enabling the extraction of comprehensive information related to various aspects of the polyhouse. This includes detailed representations of the building structure, sensor observations, food products, and user data. In order to ensure the effectiveness and usability of the ontology, the following Competency Questions (CQs) have been carefully addressed below.

CQ1 What are the tangible components of a polyhouse solar dryer system?

CQ2 Which materials and properties are essential for constructing a polyhouse solar dryer?

CQ3 What do the 3D models of polyhouse grid or element structures look like?

CQ4 What food items can be dried using a polyhouse solar dryer?

CQ5 What food items, sensor devices, microcontrollers, actuators, and communication devices are associated with a polyhouse solar dryer system?

CQ6 What is the nutrient content of food products dried in a polyhouse solar dryer?

CQ7 What edge or end nodes and their sub-components are present in a polyhouse solar dryer system?

CQ8 What sensors and monitoring devices are integrated into a smart solar polyhouse dryer to collect data on environmental conditions such as temperature, humidity, and solar radiation?

CQ9 How can various components, sensors, and devices within a smart polyhouse be connected and integrated using wired or wireless communication technologies?

CQ10 What is the schematic of wired and Wi-Fi networks for inter- and intra-polyhouse communication?

The above questions identifies sensing devices in a grid,determines processed food items, and explores networking communications. It also focuses on extracting observed food properties,highlights the motivation for specific food product extraction, and extracts sensor observations for a food item in a grid. By addressing these CQs, the developed ontology enables users to gain a comprehensive understanding of the solar polyhouse, its operations, and the data associated with it.

Chapter 4

IMPLEMENTATION

In this section, the detailed explanation of the implementation of the solar polyhouse ontology is delivered.In this Project,The First Requirement is the 3D model of the building and a 3D modelling software like Revit, Sketchup Pro etc., to design the model and modify its IFC properties. In this project 3D modelling of the polyhouse was done using Sketchup Pro (V 22.0.316) .The Polyhouse was modelled with the given dimensions (In Foot) and with the details of the Objects and the materials present.Once the modelling is completed, the software treats the entire model as a single entity. Because this polyhouse is made up of many entities constructed of various materials, the entities must be grouped. The grouped pieces had become independent objects as a result of grouping. Apart from the fundamental geometry, these objects can contain names, descriptions, and so on. Individual items can be classified to handle these information. Because our project process necessitates the use of BIM, we may convert SketchUp objects categorised using the IFC schema into the open BIM data interchange standard, IFC. To classify the items in this project, we used the IFC 4 categorization system.Secondly after the IFC4 classifiaction of the entities,IFC file is exported from the sketchup.The IFC file is now converted to LBD file through IFCtoLBD converter.THe LBD file is basically the RDF file and the Basic skeleton of the BOT is completed.The LBD file is now loaded into the the ontology editor called Protégé, which is an open source ontology editor and a framework for building intelligent systems.In Protégé, the ontology is structured and edited to match the requirements of our solar polyhouse.The Logical partitioning, the sensing devices and the all the elements were added as individuals in the respective classes and relationships were established through the right choice of the properties.The 3D model of the solar polyhouse is shown in the figure below.

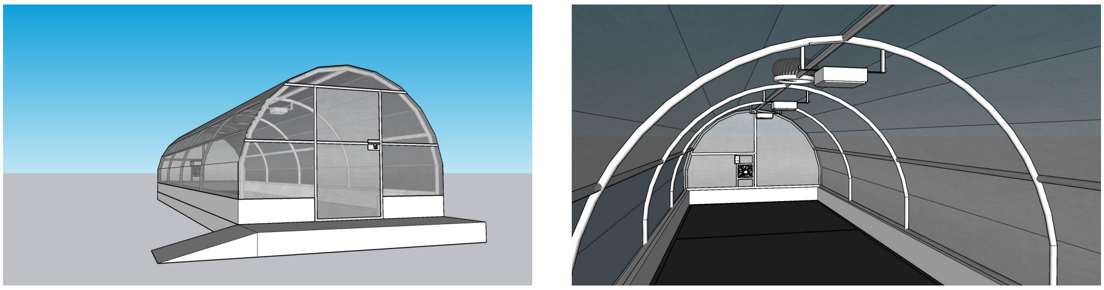


Figure 4.1: 3D Model of the polyhouse

The Building ontology is designed and with BOT as a base, the FIESTAIOT is now structured and modified with the same classes and individuals of the BOT.The sensing devices which is of class element in BOT, but it will be of class device in FIESTAIOT. Similarly, all the devices are configured and the interoperablity of BOT and FIESTIOT is achieved. In FoodOn ontology, the food items which is processed in our solar polyhouse is added in the respective class based on the hierarchy and its location of the food item placed for processing i.e, grids is added as an instance, which can be interoperable with the existing BOT and FIESTAIOT.Lastly, ToCo ontology is modified based on the networking communication that takes place within the polyhouse and the instances and the properties are added.As an end result, the ineroperable ontology containing all the polyhouse details is converted into knowledge graph with the tool GraphDB[v 4.2.2].GraphDB is a semantic graph database. It also contains a SPARQL endpoint to query the graph.The ontology is loaded into GraphDB and the real time values of the polyhouse is given as an input to the knowledge graph using NodeJS.Once the real time values add the knowledge to the graph,the required information can be extracted using SPARQL queries.

```
PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX : <http://amrita.sony.org/terms#>
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
PREFIX bot: <https://w3id.org/bot#>
PREFIX ssn: <http://purl.oclc.org/NET/ssnx/ssn#>
PREFIX amrita: <http://amrita.sony.org/terms#>
select ?element where {
    ?p rdf:type amrita:Polyhouse .
    ?p bot:hasStorey ?storey .
    ?storey bot:containsElement ?element .
    ?element rdf:type ssn:Device .
}
```

	element
1	amrita:Camera_1_P1
2	amrita:Camera_2_P1
3	amrita:Camera_3_P1
4	amrita:Node_MCU_UART2_1_P1
5	amrita:SHT25_1_P1
6	amrita:Sensor_to_Analog_1_P1
7	amrita:Spresense_1_P1
8	amrita:Node_MCU_soft_serial_2_P1
9	amrita:SHT25_2_P1
10	amrita:SIM7600_P1
11	amrita:Sensor_to_Analog_2_P1
12	amrita:Spresense_2_P1
13	amrita:Node_MCU_UART2_3_P1
14	amrita:SHT25_3_P1
15	amrita:Sensor_to_Analog_3_P1

Figure 4.2: SPARQL

Chapter 5

RESULTS AND DISCUSSION

Once the Interoperable ontology is constructed, A suitable repository is created and configured in the GraphDB as required.An endpoint is created and the real time values are included in the respective classes and then the required information can be extracted with SPARQL.The Solar polyhouse in the form of knowledge graph which holds the information of multiple domains which can be used to understand and extract the required information.The Below figures represents the different instances and classes of the solar polyhouse and the properties that establish the connection between them.

Figure 5.1: Visualisation of Grid1 of the polyhouse

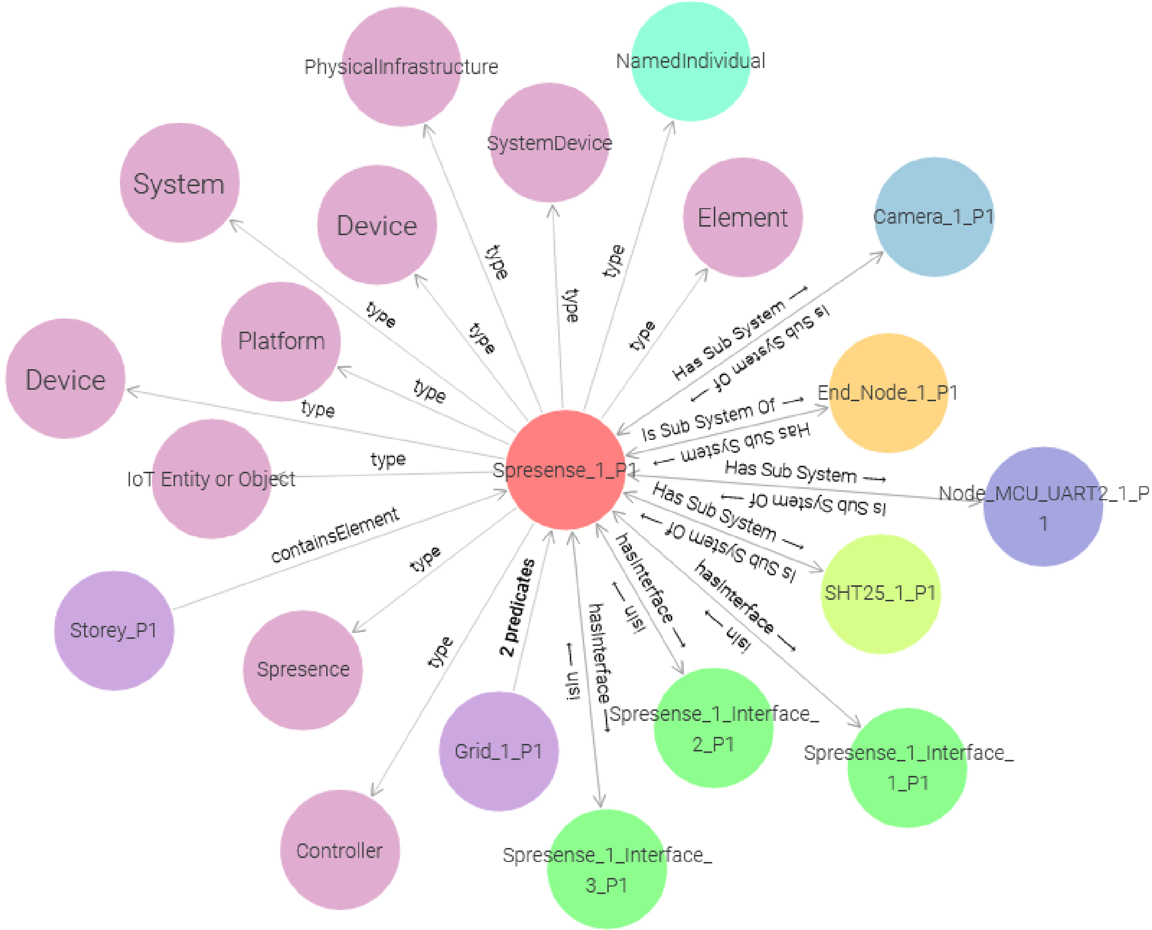


Figure 5.2: Visualisation of Spresence1

The figure presented above provides a comprehensive visualization of the class "Spresence1 P1" within the context of the polyhouse1 grid1. This class represents the Spresence device, which is a device deployed within the polyhouse1 grid1. The class "Spresence1 P1" establishes relationships with other classes and instances through various properties such as "HasSubSystem," "HasInterface," and "IsSubSystemOf." Within the class "Spresence1 P1," there are three interfaces: "Spresence1Interface1," "Spresence1Interface2," and "Spresence1Interface3." These interfaces facilitate communication and interaction between the Spresence device and other components or subsystems within the polyhouse1 grid1.The Spresence1 device is composed of three subsystems: Camera1, Node-MCU-UART2, and SHT25. These subsystems work in conjunction with the Spresence device to perform specific functions and tasks within the polyhouse environment.

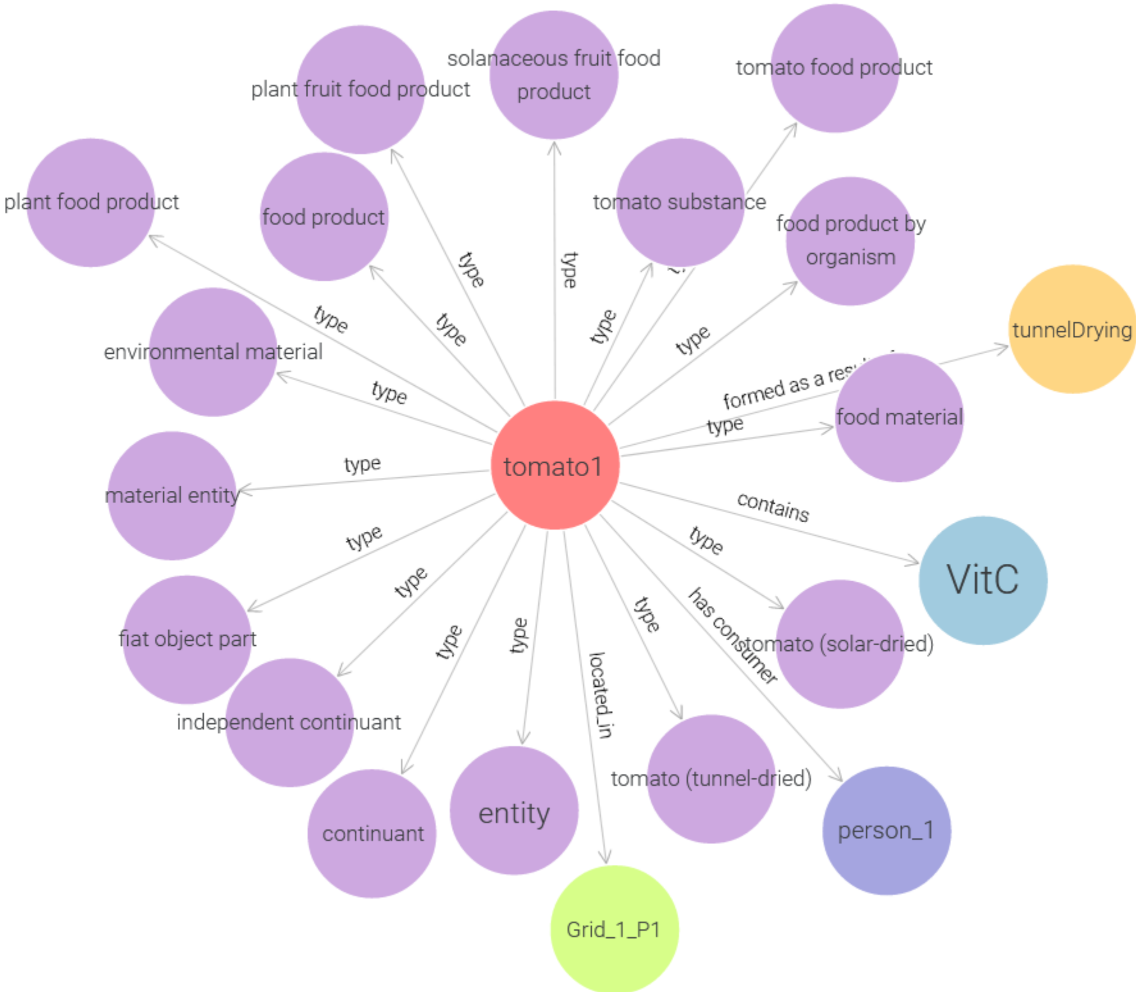


Figure 5.3: Visualisation of food product(tomato1)

The tomato (dried) entity can be classified as a continuant, specifically an independent continuant, falling under the category of material entity. It is further categorized as a fiat object part, specifically an environmental material, within the hierarchy of food materials. The tomato (dried) is classified as a food product, specifically a plant food product, belonging to the solanaceous food product group. More specifically, it is classified as a solanaceous fruit food product, highlighting its botanical origin.This representation distinguishes between different types of dried tomatoes, such as tomato (solar-dried) and tomato (tunnel-dried), indicating the specific drying methods used. The physio chemical properties of the tomato is also add to the respective class.

Figure 5.4: Visualisation of list of devices

The list of devices is shown in the above figure which is of type Device in the polyhouse ontology. All the devices present in the each grid is visualised here with their respective property.For example SHT25 is a sensing device which is of type device and present in the every grid of the polyhouse. Similarly the devices such as camera, SIM7600, ESP32, Router are the sub classes of the class Device which related with the property subclassof.

5.1 How the CQs are addressed

The ontology is evaluated using competence questions to offer a full assessment of its efficacy in addressing major components of solar polyhouses. The competence questions are efficiently answered by creating and executing SPARQL queries, allowing the extraction of useful information relating to the architectural design, sensor observations, food product specifics, and user-related data linked with solar polyhouses.The competence questions are used to assess an ontology's capacity to give useful insights and enable data retrieval. The researchers may guarantee that the ontology fits the needs of the domain and successfully collects the relevant information by creating the ontology to coincide with these questions.To provide a comprehensive evaluation, the paper includes figures that showcase the query results. These figures visually represent the retrieved data and demonstrate the ontology's effectiveness in extracting the desired information. The inclusion of query results adds a layer of transparency and enables readers to observe the ontology's performance in addressing the competency questions.

```
PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX bot: <https://w3id.org/bot#>
PREFIX amrita: <http://amrita.sony.org/terms#>
PREFIX toco: <http://purl.org/toco/>
select distinct ?interface ?Link ?Interface ?device where {
#   ?spresence rdf:type amrita:Spresence .
    amrita:Spresense_2_P1 toco:hasInterface ?interface .
    ?interface toco:hasWiredLink ?Link .
    ?Interface toco:hasWiredLink ?Link .
    ?device toco:hasInterface ?Interface .
    FILTER(?device !=  amrita:Spresense_2_P1)

}
```

	interface	Link	Interface	device
1	amrita:Spresense_2_Interface_1_P1	amrita:I2CBus_N2_1_P1	amrita:SHT25_2_Interface_1_P1	amrita:SHT25_2_P1
2	amrita:Spresense_2_Interface_2_P1	amrita:CSI_N2_1_P1	amrita:Camera_2_Interface_1_P1	amrita:Camera_2_P1
3	amrita:Spresense_2_Interface_3_P1	amrita:SoftSerial_N2_1_P1	amrita:SIM7600_Interface_2_P1	amrita:SIM7600_P1
4	amrita:Spresense_2_Interface_4_P1	amrita:UART2_N2_1_P1	amrita:Node_MCU_2_Interface_2_P1	amrita:Node_MCU_UART2_2_P1
5	amrita:Spresense_2_Interface_5_P1	amrita:SoftSerial_N2_2_P1	amrita:Node_MCU_Soft_Serial_1_Interface_1_P1	amrita:Node_MCU_Soft_Serial_1_P1

Figure 5.5: SPARQL query to extract the list of all devices attached to a Spresence of Grid2.

```
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
PREFIX bot: <https://w3id.org/bot#>
PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX : <http://amrita.sony.org/terms#>
PREFIX sosa: <http://www.w3.org/ns/sosa#>
PREFIX ssn: <http://purl.oclc.org/NET/ssnx/ssn#>
PREFIX dul: <http://www.loa.istc.cnr.it/ontologies/DUL.owl#>
PREFIX time:<http://www.w3.org/2006/time#>
PREFIX amrita: <http://amrita.sony.org/terms#>

select DISTINCT ?element where {
    ?polyhouse rdf:type :Polyhouse.
    ?polyhouse bot:hasStorey ?storey .
    ?storey bot:containsElement ?element .
    ?element rdf:type ssn:SensingDevice.
}
```

	element
1	amrita:SHT25_1_P1
2	amrita:SHT25_2_P1
3	amrita:SHT25_3_P1

Figure 5.6: SPARQL query to extract the list of all Sensing devices present in the polyhouse.

```
PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX toco: <http://purl.org/toco/>
PREFIX amrita: <http://amrita.sony.org/terms#>
PREFIX bot: <https://w3id.org/bot#>
select * where {

    amrita:Polyhouse_1 bot:hasStorey ?storey.
    ?storey bot:containsElement ?element.
    ?element rdf:type toco:Device.
}
```

	storey	element
1	amrita:Storey_P1	amrita:Camera_1_P1
2	amrita:Storey_P1	amrita:Camera_2_P1
3	amrita:Storey_P1	amrita:Camera_3_P1
4	amrita:Storey_P1	amrita:Node_MCU_UART2_1_P1
5	amrita:Storey_P1	amrita:SHT25_1_P1
6	amrita:Storey_P1	amrita:Spresense_1_P1
7	amrita:Storey_P1	amrita:Node_MCU_soft_serial_2_P1
8	amrita:Storey_P1	amrita:SHT25_2_P1
9	amrita:Storey_P1	amrita:SIM7600_P1
10	amrita:Storey_P1	amrita:Spresense_2_P1
11	amrita:Storey_P1	amrita:Node_MCU_UART2_3_P1
12	amrita:Storey_P1	amrita:SHT25_3_P1
13	amrita:Storey_P1	amrita:Spresense_3_P1

Figure 5.7: SPARQL query to extract the list of devices present in the polyhouse.

```
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
PREFIX bot: <https://w3id.org/bot#>
PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX sosa: <http://www.w3.org/ns/sosa#>
PREFIX ssn: <http://purl.oclc.org/NET/ssnx/ssn#>
PREFIX dul: <http://www.loa.istc.cnr.it/ontologies/DUL.owl#>
PREFIX time:<http://www.w3.org/2006/time#>
PREFIX amrita: <http://amrita.sony.org/terms#>

select * where {
    ?polyhouse rdf:type amrita:Polyhouse.
    ?polyhouse bot:hasStorey ?storey .
    ?storey bot:containsElement ?element .
    ?element rdf:type amrita:SHT25 .
    ?observation ssn:observedBy ?element .
    ?observation ssn:observationResult ?sensorOutput .
    ?observation ssn:observationSamplingTime ?time.
    ?time time:inXSDDateTime ?Instant.
    ?sensorOutput ssn:hasValue ?sensorObservation .
    ?sensorObservation dul:hasDataValue ?result
    }
```

	polyhouse	storey	element	observation	sensorOutput	time	Instant	sensorObservation	result
1	amrita:Polyhouse_1	amrita:Storey_P1	amrita:SHT25_1_P1	amrita:grid_1_observatic	amrita:grid_1_sensor_ou	amrita:grid_1_time_insta	"2001-10-26T21:32:52"^^xsd:dateTime	amrita:grid_1_hum_obse	"81.0"^^xsd:double
2	amrita:Polyhouse_1	amrita:Storey_P1	amrita:SHT25_1_P1	amrita:grid_1_observatic	amrita:grid_1_sensor_ou	amrita:grid_1_time_insta	"2001-10-26T21:32:52"^^xsd:dateTime	amrita:grid_1_temp_obs	"29.002"^^xsd:double
3	amrita:Polyhouse_1	amrita:Storey_P1	amrita:SHT25_1_P1	amrita:grid_1_observatic	amrita:grid_1_sensor_ou	amrita:grid_1_time_insta	"2001-10-26T21:32:53"^^xsd:dateTime	amrita:grid_1_hum_obse	"81.1"^^xsd:double
4	amrita:Polyhouse_1	amrita:Storey_P1	amrita:SHT25_1_P1	amrita:grid_1_observatic	amrita:grid_1_sensor_ou	amrita:grid_1_time_insta	"2001-10-26T21:32:53"^^xsd:dateTime	amrita:grid_1_temp_obs	"29.003"^^xsd:double
5	amrita:Polyhouse_1	amrita:Storey_P1	amrita:SHT25_2_P1	amrita:grid_2_observatic	amrita:grid_2_sensor_ou	amrita:grid_2_time_insta	"2001-10-26T21:32:54"^^xsd:dateTime	amrita:grid_2_hum_obse	"81.2"^^xsd:double
6	amrita:Polyhouse_1	amrita:Storey_P1	amrita:SHT25_2_P1	amrita:grid_2_observatic	amrita:grid_2_sensor_ou	amrita:grid_2_time_insta	"2001-10-26T21:32:54"^^xsd:dateTime	amrita:grid_2_temp_obs	"29.004"^^xsd:double
7	amrita:Polyhouse_1	amrita:Storey_P1	amrita:SHT25_2_P1	amrita:grid_2_observatic	amrita:grid_2_sensor_ou	amrita:grid_2_time_insta	"2001-10-26T21:32:55"^^xsd:dateTime	amrita:grid_2_hum_obse	"81.3"^^xsd:double
8	amrita:Polyhouse_1	amrita:Storey_P1	amrita:SHT25_2_P1	amrita:grid_2_observatic	amrita:grid_2_sensor_ou	amrita:grid_2_time_insta	"2001-10-26T21:32:55"^^xsd:dateTime	amrita:grid_2_temp_obs	"29.005"^^xsd:double
9	amrita:Polyhouse_1	amrita:Storey_P1	amrita:SHT25_3_P1	amrita:grid_3_observatic	amrita:grid_3_sensor_ou	amrita:grid_3_time_insta	"2001-10-26T21:32:56"^^xsd:dateTime	amrita:grid_3_hum_obse	"81.4"^^xsd:double
10	amrita:Polyhouse_1	amrita:Storey_P1	amrita:SHT25_3_P1	amrita:grid_3_observatic	amrita:grid_3_sensor_ou	amrita:grid_3_time_insta	"2001-10-26T21:32:56"^^xsd:dateTime	amrita:grid_3_temp_obs	"29.006"^^xsd:double
11	amrita:Polyhouse_1	amrita:Storey_P1	amrita:SHT25_3_P1	amrita:grid_3_observatic	amrita:grid_3_sensor_ou	amrita:grid_3_time_insta	"2001-10-26T21:32:57"^^xsd:dateTime	amrita:grid_3_hum_obse	"81.5"^^xsd:double
12	amrita:Polyhouse_1	amrita:Storey_P1	amrita:SHT25_3_P1	amrita:grid_3_observatic	amrita:grid_3_sensor_ou	amrita:grid_3_time_insta	"2001-10-26T21:32:57"^^xsd:dateTime	amrita:grid_3_temp_obs	"29.007"^^xsd:double

Figure 5.8: SPARQL query to extract the list of all the nodes that can communicate with each other and its bandwidth.

```
PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX : <http://amrita.sony.org/terms#>
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
PREFIX bot: <https://w3id.org/bot#>
PREFIX ssn: <http://purl.oclc.org/NET/ssnx/ssn#>
PREFIX food: <http://purl.obolibrary.org/obo/>
PREFIX amr-food: <http://amrita_food.org/terms#>
PREFIX amrita: <http://amrita.sony.org/terms#>
select * where {
    ?p rdf:type amrita:Polyhouse .
    ?p bot:hasStorey ?storey.
    ?storey bot:hasSpace ?space.
    ?foodsproduct food:RO_0001025 ?space.
}
```

	p	storey	space	foodsproduct
1	amrita:Polyhouse_1	amrita:Storey_P1	amrita:Grid_1_P1	FOODON_00001002:tomato1

Figure 5.9: SPARQL query to extract the list of food product in grid1.

Chapter 6

CONCLUSION

In conclusion, the creation of the polyhouse ontology faced a number of difficulties that were successfully overcome to provide an important tool for the food processing sector. To assure the ontology's dependability and relevance, in-depth study was conducted together with consultation with subject experts. By balancing granularity and usability, the adaptable and extendable ontology framework was created to handle the complex and multidimensional character of the polyhouse domain.By fusing the polyhouse ontology with pre-existing ontologies and standards in the weather, energy, and agricultural domains, smooth data sharing and integration were made possible. In order to guarantee that the ontology could manage large-scale installations and enable future expansion, scalability issues were also taken into account.The process of developing the ontology required actively involving stakeholders and encouraging community acceptance. The polyhouse ontology sought to promote cooperation and shared contributions by actively communicating and spreading knowledge among industry workers, researchers, and academics.

A thorough framework is provided by the polyhouse ontology for the extraction of important data from solar polyhouse building structures, sensor observations, food items, and user data. Users may quickly and effectively utilise SPARQL queries to get the needed information by answering the Competency Questions (CQs) of the ontology.The successful creation of the polyhouse ontology creates possibilities for future growth and study. The ontology might be broadened to incorporate other areas, such temperature control, automation, and predictive analytics. In conclusion, the polyhouse ontology is a significant tool for the food processing sector, simplifying information extraction and delivering insights for enhanced operations and decision-making. The obstacles encountered during the ontology's development were successfully handled, resulting in a resilient and flexible resource that may contribute to developments in solar polyhouse systems and related disciplines.

Chapter 7

FUTURE ENHANCEMENT

The proposed solution for the semantic model in this paper focuses on the data of a single solar polyhouse. However, to enhance its applicability and extend its scope, future enhancements can be made to design the semantic model for multiple solar polyhouses. This extension would involve developing a comprehensive ontology structure that can effectively capture and represent the intricacies of multiple polyhouses and their interconnections.To provide a more detailed and precise understanding of the solar polyhouse domain, the inclusion of Weather, Energy, and Agriculture domain-related ontologies is recommended. By integrating these ontologies, the semantic model can capture and represent additional information related to weather conditions, energy management, and agricultural aspects, thereby offering a more holistic view of the solar polyhouse system. Furthermore, to improve user interaction and accessibility, the development of an interactive user interface is suggested. This interface would enable users to easily load the semantic model, navigate the data, and extract the required information through a querying interface. Additionally, incorporating data visualization capabilities into the interface would facilitate a more intuitive and interactive exploration of the semantic model, enhancing the overall user experience.In order to achieve interoperability with other related domains, it is important to establish connections and mappings with existing ontologies and standards in those domains.

REFERENCES

[1] Dooley, Damion Griffiths, Emma Gosal, Gurinder Buttigieg, Pier Luigi Hoehndorf, Robert Lange, Matthew Schriml, Lynn Brinkman, Fiona Hsiao, William. (2018). FoodOn: a harmonized food ontology to increase global food traceability, quality control and data integration. npj Science of Food. 2. 10.1038/s41538-018-0032-6.

[2] Compton, Michael Barnaghi, Payam Bermudez, Luis García Castro, Raúl Corcho, Oscar Cox, Simon Graybeal, John Hauswirth, Manfred Henson, Cory Herzog, Arthur Huang, Vincent Janowicz, Krzysztof Kelsey, David Phuoc, Danh Lefort, Laurent Leggieri, Myriam Neuhaus, Holger Nikolov, Andriy Page, Kevin Taylor, Kerry. (2012). The SSN Ontology of the W3C Semantic Sensor Network Incubator Group. Web Semantics: Science, Services and Agents on the World Wide Web. 17. 10.1016/j.websem.2012.05.003.

[3] Rasmussen, Mads Holten Lefrançois, Maxime Schneider, Georg Pauwels, Pieter. (2020). BOT: the Building Topology Ontology of the W3C Linked Building Data Group. Semantic Web. 10.3233/SW-200385.

[4] Serrano, Martin Gyrard, Amelie Tragos, Elias Nguyen, Hung. (2018). FIESTAIoT Project: Federated Interoperable Semantic IoT/cloud Testbeds and Applications. 425-426. 10.1145/3184558.3186199.

[5] Zhou, Qianru Gray, Alasdair Stephen, McLaughlin. (2019). ToCo: An ontology for representing hybrid telecommunication networks.

[6] Muppavarapu, Vamsee Ramesh, Gowtham Gyrard, Amelie Noura, Mahda. (2021). Knowledge extraction using semantic similarity of concepts from Web of Things knowledge bases. Data Knowledge Engineering. 135. 101923. 10.1016/j.datak.2021.101923.

[7] Noy, N. F., McGuinness, D. L. (2001). Ontology development 101: A guide to creating your first ontology. Stanford knowledge systems laboratory technical report KSL-01-05 and Stanford medical informatics technical report SMI-2001-0880.

[8] Studer, R., Benjamins, V. R., Fensel, D. (1998). Knowledge engineering: principles and methods. Data Knowledge Engineering, 25(1-2), 161-197.

[9] Gruber, T. R. (1995). Toward principles for the design of ontologies used for knowledge sharing. International Journal of Human-Computer Studies, 43(5-6), 907-928.

[10] Uschold, M., Gruninger, M. (1996). Ontologies: principles, methods and applications. Knowledge engineering review, 11(2), 93-136.

[11] Staab, S., Studer, R. (Eds.). (2004). Handbook on ontologies. Springer Science Business Media.

[12] Gruber, T. R. (1993). A translation approach to portable ontology specifications. Knowledge acquisition, 5(2), 199-220.

[13] Haussmann, Steven Seneviratne, Oshani Chen, Yu Ne'eman, Yarden Codella, James Chen, Ching-Hua Mcguinness, Deborah Zaki, Mohammed. (2019). FoodKG: A Semantics-Driven Knowledge Graph for Food Recommendation. 10.1007/978-3-030-30796-7_10.