A Modular Ontology For Smart Campus

Lynda Djakhdjakha[1], Hamadoun Cisse[2] and Brahim Farou[1]

[1]LabSTIC laboratory, Department of Computer Science 8 mai 1945 - Guelma University Guelma , Algeria
[2]Department of Computer Science 8 mai 1945 - Guelma University Guelma , Algeria

Abstract
In the last few years, with the rapid growth of the Internet of Things (IoT), ontologies have been considered as the most significant solution to resolve the heterogeneity problem in smart campus. Although the number of proposed ontologies is expanding and growing at an extremely rapid rate, there are still several significant challenges that the smart campus must overcome, including the lack of a common structure to represent all campus knowledge. In this work, we propose a modular ontology for smart campus within the IoT aspect; which incorporates several modules including building module, teaching module, classroom module, tools module, green-space module, parking module, organisational module, activity module, actor module and sensor module. It simplifies the comprehension of the hall of the domain by the comprehension of each module. The proposed ontology was conceptualized, formalized and implemented using OWLReady2; and validated in a real smart attendance system in the department of computer science at Guelma University.

Keywords
Internet of Things (IoT), Modular Ontology, Ontology, OWL, OWLReady2, Smart Campus, SWRL

1. Introduction

Nowadays, the connected objects have changed every part of our lives as a result of the rapidly expanding use of the technology known as the Internet of Things (IoT). At a university campus, IoT takes the form of sensors that may be installed in hallways, classrooms, amphitheaters, buildings, parking spaces, laboratories and libraries; to improve the learning process and make life easier and intelligent for both academic and non-academic personnel.

These sensors are connected to the Internet to gather data on temperature, humidity, movements, attendance, etc. Based on the information gathered by these sensors, university administrators may monitor the learning environments for students, make decisions, and enhance almost all campus operations. All these features require that gathered data can be exchanged in standardized formats.

Although the IoT is expanding and growing at an extremely rapid rate, there are still several significant challenges that the smart campus must overcome, including the problem of a semantic interoperability.

Semantic Web ontologies are considered as the most significant solution to resolve this problem by providing a common vocabulary that enables and facilitates the exchange of information

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djakhdjakha.lynda@univ-guelma.dz (L. Djakhdjakha); h.cissehamadoun@gmail.com (H. Cisse); farou.brahim@univ-guelma.dz (B. Farou)
0000-0001-9596-3077 (L. Djakhdjakha); 0000-0001-9161-5278 (H. Cisse); 0000-0002-1609-6006 (B. Farou)

between different systems [1] [2]. An ontology can model a domain of discourse defined by a set of representative primitives such as classes, properties, and relationships [3].

Over the last years, ontologies have seen widespread use in the smart campus [2], [1], [4], [5], [6], [7] and [8]. However, the dilemma is that, at this time and to our best knowledge, there isn't a relevant semantic model that can represent every element of a smart campus knowledge. Additionally, developing a single ontology that encompasses all knowledge or connecting existing ontologies is extremely challenging tasks

Thus, to help overcome these barriers, we have in this paper, used semantic web technology to develop a new resource of smart campus Knowledge within the IoT aspect as an IoT modular ontology. A modular Ontology can be defined as decomposing potentially large and monolithic ontologies into a set of smaller and interlinked modules[9]. Therefore, An ontology module can be considered as a loosely coupled and self-contained Component of an ontology that maintains relationships to other ontology modules [9]. Thereby, ontology modules are themselves ontologies [10].

The proposed semantic model uses the Web Ontology Language (OWL2)[11] and Semantic Web Rule Language (SWRL)[12] to enrich the structure [13]. It incorporates ten modules (actors, activities, sensors, green spaces, classrooms, parking spaces, buildings, etc.) for describing the university domain within the integration of the IoT aspect. It is implemented using the OWLReady2 of Python and used by a relevant smart application in the computer science department in Guelma university.

This paper is structured as follows: the first section describes prior work in this context and situates the proposed model among them; section 2 introduces the new IoT modular ontology; section 3 is devoted to the implementation and section 4 concludes the work with some perspectives.

2. Related Work

We situate our work in the area of smart campus. We focus on modular ontology within IoT aspect and concentrate on recent research papers addressing both ontologies and modular ontology for smart campus.

As a first step, Google Scholar is used to collect more than 900 articles. Considering only works published between 2016 and 2022, there are 605 articles remaining. By eliminating articles with no citations, not written in English, duplicates and unavailable articles, we end up with 52 articles. Finally, after a thorough reading, only 22 articles were selected. Figure 1 shows the use of ontologies in smart campus systems.

The key finding is that several ontologies were proposed to cope with different representations of smart campus, but they were still incomplete and inexpressive in terms of access to all the smart campus related concepts, including its structure (e.g. faculties, departments, green spaces, etc.), and management processes (e.g a management system for the distribution of lecturers charges, a management system for effecting lecturers [14]).

Also, there are certain sub-domains that have not yet been covered. Moreover there is not a common knowledge that incorporates all sub-domains of a smart campus and enables

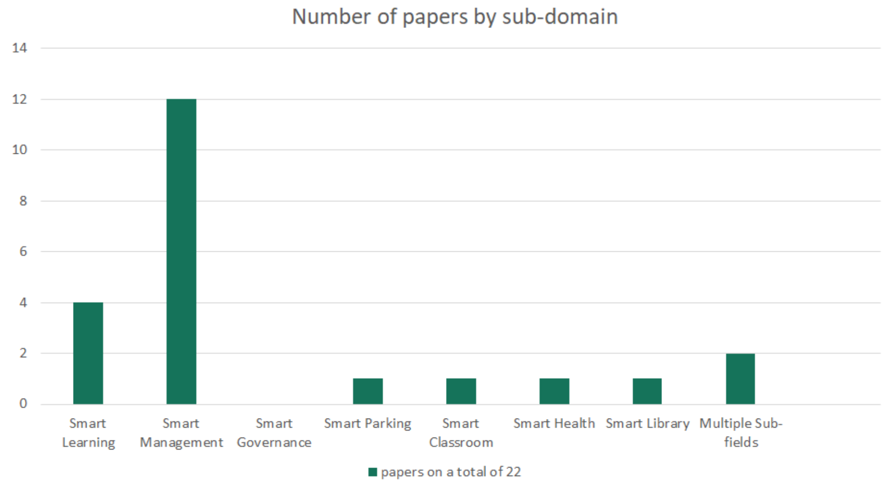

Figure 1: Ontologies in Smart Campus

semantically interoperable information exchange.

In the second issue, we have not found modular ontologies for the smart campus however, we've discovered that a smart campus can be defined as a small-scale smart city applied for campuses of a university [15]. Many works have been identified by considering this definition. Thus in [16], authors proposed a modular ontology for smart building named as "RealEstateCore", which is constructed as two base modules (Metadata and Core), and several domain-specific modules . It provided classes and properties that support modeling of devices, modeling of buildings, and modeling of contractual situations relating to these buildings. Furthermore in [17], authors design an integration ontology that characterizes the relationships between the SensorThings API, IndoorGML, and CityGML data models in an indoor space with consideration of different views of "things" in the IoT. This integration ontology can be used to integrate data from various resources for supporting different smart city applications.

In contrast to the cited works that consider a part of smart campus knowledge, we propose to represent the smart campus knowledge by proposing a common and modular ontology shared by all the academic personnel so as to come up with a common shared vocabulary in order to ensure semantic interoperability between smart classroom system, smart learning system, smart parking system, smart management system, smart attendance system; and smart governance system.

3. A Modular Ontology for Smart Campus

The construction of the IoT-modular ontology is based on NeOn methodology [18]. It is a methodology aimed at guiding modular ontology development process. In this work, we accept that a module is a sub-ontology that makes sense from the standpoint of either an application or a system [19]. We develop the modular ontology from the scratch because the reuse of existing smart campus ontologies, or their adaptations is very difficult for several reasons including :

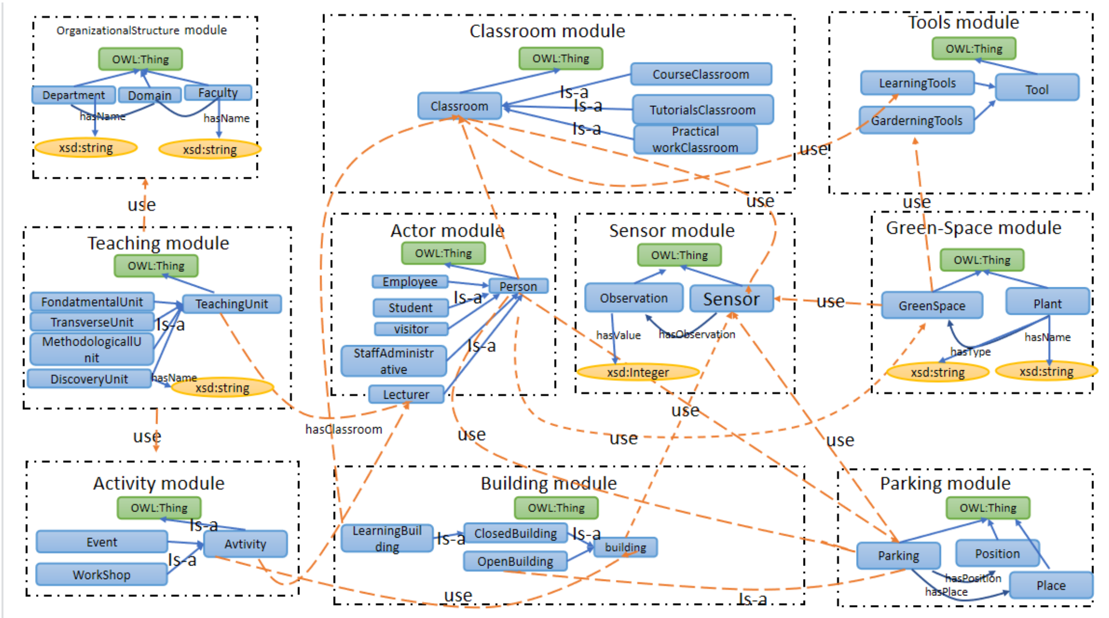

Figure 2: Modules of the Modular Ontology

firstly, existing smart campus ontologies can be very difficult to interpret and extend due to their complexity and size. Secondary, ontologies for smart campus are often not available.
Our IoT-modular ontology incorporates several modules (Figure 2):

- The Organizational_Structure module is an ontology module that focuses on capturing and representing the organizational structure of universities. It includes classes and properties that describe various elements of the university structure, such as faculties, domains, departments, levels, specialties, sections, and groups. Additionally, it represents the relations and connections between these elements.
  - Faculties: This class represents the different faculties within a university. Faculties often consist of multiple departments.
  - Domain: The domain class refers to a specific area of study or knowledge domain within a faculty.
  - Department: The department class represents the individual departments within a faculty.
  - Level: This class denotes different academic levels within a department or program.
  - Specialty: The specialty class represents specialized areas of study within a department. It includes specific fields and sub-fields.
  - Section: The section class refers to subgroups, created based on different factors such as class schedules and teaching staff. Sections are used to manage and organize students in smaller groups within a larger department.
  - Group: The group class represents student groups within a section. It is used to track and manage students who have similar academic requirements.

The Organizational_Structure module includes various properties that establish relations between these classes, allowing for the representation of the connections and hierarchies within the organizational structure. For example, properties like "hasDepartment" can be used to indicate the affiliation of a department with a faculty, and "hasSpecialty" can be used to associate a specialty with a department.

- Parking module focuses on capturing and representing information related to parking places, including their positions and states :
  It includes properties that establish relationships and capture additional information such as "hasPosition" which links a parking place to its position, and "hasState" which connects a parking place to its state, etc.
- Tools module : Covers different tools used in smart campus including:
  - LearningTools class: This class represents educational resources, technologies used within the smart campus to facilitate teaching and learning processes. It has as sub-classes: DigitalLearningPlatforms, EducationalSoftwareApplications, InteractiveWhiteboards, SimulationSoftware, OnlineCollaborationTools, etc.
  - GardeningTools class: This class represents equipment used for maintaining green spaces within the smart campus environment.
  - CommunicationTools class: This class represents tools that facilitate effective communication and collaboration within the smart campus. Such as : EmailSystems, MessagingPlatforms, VideoConferencingSoftware, OnlineCollaborationPlatforms, etc.
  - SafetyAndSecurityTools class: It represents tools crucial for maintaining a secure and protected campus environment. It has sub-classes such as: SurveillanceCameras, AccessControlSystems, IntrusionDetectionSystems, EmergencyNotificationSystems, FireAlarmSystems, IncidentManagementSoftware, etc.
  - EnergyManagementTools class: It describes tools that monitor and optimize energy usage within the smart campus.
  - MobilityAndTransportationTools class: It covers tools focused on optimizing transportation and mobility within the smart campus.

  The Tools module includes classes and properties specific to each type of tool, enabling a comprehensive representation of the tools and their functionalities within the smart campus ontology.
- Green-Space module: The Green-Space module focuses on capturing and representing information about the green spaces and plants within the university campus:
  - GreenSpaces class: represents the designated areas of greenery within the campus, such as gardens, parks, courtyards, etc. It has properties such as name, location, size, purpose (e.g., relaxation, study area, sports field).
  - Plant class: This class represents the different types of plants, trees, shrubs, and flowers present within the green spaces of the campus. It has data-properties such as species, common name, botanical name, characteristics, and maintenance requirements. The green-spaces module has relationships with other modules, such as the Building module (to identify the buildings adjacent to the green spaces), the Sensor module (to monitor environmental conditions for optimal growth), etc.

- Teaching module: It focuses on capturing and representing concepts related to different teaching units within the smart campus such as:
  - FundamentalUnit: This class represents the fundamental units of teaching within the smart campus. These units typically cover core disciplines. Each fundamental unit has data-properties such as its name, description, learning objectives, and prerequisites.
  - TransversalUnit: This class represents the transversal unit, which refers to a teaching unit that cuts across multiple disciplines. The transversal unit has properties such as its name, description, learning outcomes, and interdisciplinary focus.
  - MethodologicalUnit: This class represents the methodological units, which focus on teaching specific methodologies, techniques, and approaches applicable to various disciplines. Each methodological unit has data-properties such as its name, description, instructional methods used and practical applications.

    The teaching module has relationships with other modules such as the Organizational-structure module (to identify the specific structure associated with each teaching), the Actor module (to link to the academic persons involved in delivering the teaching), etc.
- Classroom module: It focuses on capturing and representing information about the classrooms within the smart campus. It aims to provide a comprehensive understanding of the physical spaces dedicated to teaching and learning activities including:
  - CourseClassroom: This class represents classrooms specifically designated for delivering regular course lectures and instructional sessions. It has data-properties such as its capacity, seating arrangement, etc.
  - PracticalWorkClassroom: This class represents classrooms or laboratory spaces used for conducting practical activities related to coursework. It has data-properties such as safety features, etc.
  - TutorialClassroom: This class represents classrooms where small group tutorials and interactive sessions take place. It has data-properties such as smaller seating capacity, collaborative furniture, interactive displays, and whiteboards.
- Sensor Module constitutes a core module within the smart campus ontology. It focuses on capturing and representing information about the various sensors deployed across the university structures. The module plays a crucial role in collecting real-time data and monitoring different aspects of the campus environment.
- Building Module:The Building Module covers concepts related to buildings and their associated spaces within the smart campus. It aims to provide a comprehensive representation of the campus infrastructure including:
  - Building class: This class represents individual buildings within the smart campus. Each building has data-properties such as its unique identifier, name, address, floor area, construction year.
  - Office class: This class represents offices and administrative spaces within the smart campus buildings. It has data-properties such as the office number, occupant details (e.g., staff members, department), and equipment available in the office.

The building module has relationships with other modules, such as the Classroom Module (to identify the classrooms within each building), and the Actor Module (to link to the academic personnel or staff members occupying the office).

- Activity Module covers concepts related to different activities realized within the smart campus. It aims to capture and represent information about the various events, programs, and engagements taking place in the campus environment:
  - Activity class: This class represents individual activities conducted within the smart campus. Each activity has data-properties such as its unique identifier, name, description, date, time, duration, organizer, target audience and activity program. It has sub-classes as: Event class Workshop class and Seminar class.

  The activity module has relationships with other modules such as the Building Module (to identify the location of the activity) and the Actor Module (to link to the academic personnel, students, or external participants involved in the activity).
- Actor Module constitutes an other core module that focuses on collecting classes related to academic persons within the smart campus. It aims to capture and represent information about individuals who play various roles in the campus community, including lecturers, employees, staff-administrative, and more.
  - AcademicPerson class: It represents individuals who are part of the academic community within the smart campus. It has properties such as : identifier, name, contact information, academic qualifications, role position, department.
  - Lecturer class : represents individuals who hold teaching positions within the smart campus. It has properties such as the lecturer's specialization, teaching experience, research interests, and responsibilities they hold within the academic department.
  - Employee class: represents individuals who are employed by the smart campus in non-teaching roles. It includes properties such as the employee's job title, unit of employment, work responsibilities, and specific skills.
  - StaffAdministrative class: represents individuals who serve in administrative or support roles within the smart campus.

  The actor module has relationships with other modules such as the Building Module (to identify the primary work location of actors), the Teaching Module (to associate actors with specific courses or teaching activities), the Classroom Module (to identify the classrooms where actors conduct lectures), and the Activity Module (to associate actors with specific events or programs they are involved in).

4. The Use of the Proposed Modular Ontology

The IoT-modular ontology was developed using the OWLReady2 [20], which is a Python library for working with OWL ontologies. The modular ontology approach allows for the organization and representation of different concepts and entities related to the smart campus. Based on the developed IoT-modular ontology, a new architecture for IoT modular-ontology-based management systems was designed (Figure 3). This architecture provides a framework for managing various aspects of the university campus.

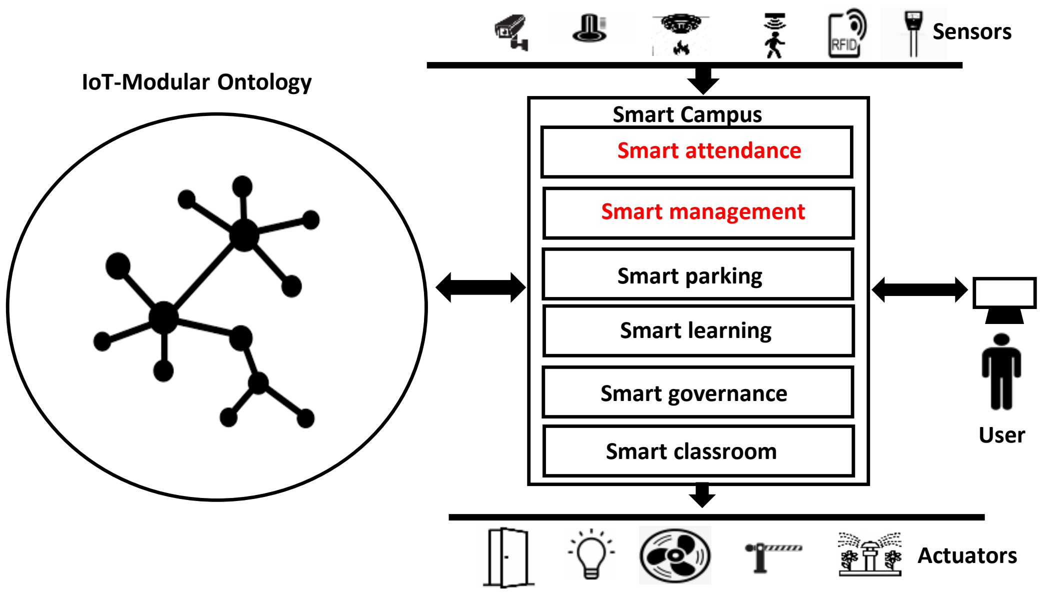

Figure 3: General Structure of the Implementation

We have enhanced our prior work [14], by utilizing the proposed IoT modular ontology for managing the department of computer science. The ontology was applied to better organize and handle different information and processes related to the department's operations. A smart attendance system was implemented. The system utilizes IoT technologies, specifically RFID (Radio Frequency Identification) sensors deployed on each door, to detect movements of lecturers entering or leaving the classrooms.

The implemented system compares the detected movements of lecturers with the schedule of classes. By doing so, it determines whether a lecturer is allowed access to a particular classroom or not. This means that the system checks if a lecturer's presence aligns with their assigned class based on the schedule.

Based on the comparison results, the system accepts or rejects the lecturer's access to the classroom. If the lecturer's presence matches their schedule, access is granted. If there is a mismatch or discrepancy, access is denied.

5. Conclusion

In this work, we have conceptualized, formalized and implemented a new IoT-modular ontology as a semantic model to solve the problem of heterogeneity and to ensure interoperability in the university campus.

The proposed IoT semantic model is flexible and extensible. It is not only capable of expressing concepts and relationships of several sub-domain of the smart campus, but it also allows to unify the representation, the integration and the exchange of information between several IoT-management systems.

The use of the IoT-modular ontology and the implementation of the smart attendance system improved the management and monitoring of the department of computer science, specifically in terms of attendance tracking and access control to classrooms. The system utilized IoT principles and technologies to automate and enhance these processes, providing a more efficient and accurate solution.

Regarding future work, the system can benefit from the implementation of IoT modular ontology and IoT-management systems using an Edge-Fog-Cloud architecture to enhance campus big data analysis and storage.

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