Modelling Sustainability for an IoT-enabled Smart Green Campus using an Ontology-based Approach

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Abstract

Sustainability is a key concern for smart campuses. Several campuses around the world are changing their environmental culture to achieve sustainability. Much emphasis is laid on green practice initiatives to ensure proper usage of resources such as efficient waste management, effective water management and energy management among others. Sustainability offices and centres have been set up on campuses to manage, monitor and assess campus activities related to sustainability. Several of the activities in smart green campuses adopt IoT-based systems to capture data about environmental factors. Data captured about the environment are often shared among heterogeneous systems in the campus for insightful assessments. One major challenge for sharing and integrating data among several systems is data interoperability. Knowledge-based approaches are seen as an effective and promising way to promote semantic interoperability. This paper thus presents a semantic model for green practice management and monitoring in the smart campus. The proposed model will eventually empower management for taking decisive actions.

Keywords

Sustainability, Smart Campus, Internet of Things, Green Campus, Ontology

1. Introduction

Smart campuses refer to academic or non-academic institutions where digital infrastructures are in place to support the teaching, learning and research activities [1]. They are often considered as small cities where enhancements with respect to management, governance, sustainability and learning activities are of paramount importance [2]. Such developments improve the environment where learning takes place and hence contribute positively towards student learning process. The advent of technologies such as Internet of Things (IoT) has enabled the automation of the environment where sensors capture data about the environmental phenomena and these data are analysed for better resource management and proper decision-making. The environment is thus turned into an intelligent one where there is better coexistence between the campus community with its surroundings [3]. One such example is automatic turning on of light when someone enters a room and turning off when nobody is in the room [4].

Apart from being smarter, campuses are also focusing on being more sustainable to be in line with Sustainable Development Goal (SDG) 12 and SDG 13 defined by United Nations Millennium Declaration. These SDG goals focus on environmental sustainability, laying emphasis on proper usage of resources such as energy consumption and reduction of carbon dioxide. Such initiatives have given

Proceedings WOP 2023: 14th Workshop on Ontology Design and Patterns, in conjunction with ISWC 2023, November 6–7, 2023, Athens, Greece
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rise to smart green campuses whereby sustainable and eco-friendly practices are integrated in the campus environment [5]. A smart green campus thus aims to use natural resources such as energy and water efficiently to promote healthy living on the campus both indoors and outdoors with the help of technologies.

Several examples of smart green campuses exist where the environmental culture has been reinvented to achieve sustainability. Ravesteyn et al. [6] suggested four themes for smart green campuses namely Smart Learning, Smart Sharing, Smart Buildings and Smart Transport. A framework was thus proposed based on these four themes and on best practices for Dutch institutions. Anthony Jnr [7] has proposed several green indicators for Malaysian universities. These indicators can be used as measures for measuring and monitoring green practices in higher education institutions. Abubakar et al. [8] have recommended the setup of a sustainability office/centre on campus for Saudi universities to assess campus sustainability, that is, the extent to which the university is moving towards sustainability goals. Sustainability offices or centres are already in place in several campuses around the world. One example is ANUgreen Sustainability Office at Australian National University Facilities and Services Division [9]. Another example is the EcoCampus Management Centre set up at the Universiti Malaysia Sabah [10]. These offices aim to monitor campus activities and operations in order to assess campus sustainability.

Su et al. [11] highlight that one of the pre-requirements for setting up a smart city is to construct wireless infrastructures such as smart urban management, smart transport, smart medical treatment among others. Similarly, smart green campuses, being analogous to a small city [2], adopt wireless automation systems to support sustainability initiatives such as energy management or efficient waste management with the aim to improve quality of life of the campus population. These systems capture data about the environment and are linked to several domains of a smart campus such as smart building, smart classroom, smart library or smart parking [4]. De Nicola and Villani [12] identify "*data interoperability and fusion for monitoring the environment (air, soil, water)*" as one of the research issue for smart city.

To promote sharing and integration of data captured by various IoT systems on the campus, there is the need for a semantic model. A semantic model will represent data of different domains and will enhance interoperability among heterogeneous systems on the campus. Among different semantic models that exist such as key-value, markup scheme, graphical models such as UML, object oriented models, logic based and ontology based models, ontology-based models provide good expressivity and good formalization language with logic inference ability [13]. Gruber defines an ontology as an ''*explicit specification of a conceptualization''* [14]. Ontologies "*provide a common understanding of specific domains that can be communicated between people and application systems"* [15]. An ontology consists of a number of components such as Concepts, Individuals and Relationships [16]. Concepts also known as classes represent the entities of a specific domain. A concept may be a subconcept of another concept. Individuals represent instances that describe the entities of interest. Relationships describe how individuals are related to each other. Each class and relation (property) in the ontology must have a unique Uniform Resource Identifier (URI). A URI encompasses of Uniform Resource Locator (URL), Uniform Resource Name (URN), and other ways to indicate a resource. An ontology is best suited to solve interoperability problems [13].

This paper thus aims to create an ontology for green practice management and monitoring in the smart campus. The rest of the paper is structured as follows: Related works on existing ontologies related to green practices are presented in section 2. The motivation scenario behind the proposal of the ontology along with the Ontology Requirements Specification Document (ORSD) are presented in section 3. The proposed semantic model for smart green campus is discussed in section 4. Section 5 concludes the paper and highlights future works in progress.

2. Related Works

Anthony Jnr [7] have identified several green indicators for green practice management in a smart campus namely energy management and conservation, CO_2 emission management, rainwater harvesting and management and food waste management among others. Several ontologies have been developed to represent knowledge for these green indicators. Some of them, which are relevant to the context of smart green campus are described as follows.

2.1. Energy Management

Managing energy is of paramount importance in a smart campus as it leads to cost reduction and contributes towards sustainability. This section describes some ontologies in the domain.

Hu et al. [17] have developed a conceptual framework for representing cross-domain knowledge regarding building information and energy performance assessment in buildings. Several ontologies were considered for the framework namely *ifcOWL*, *SSN*, performance ontology, Think-home ontology, *iCalendar* ontology and *DB* schema ontology. A set of rules was defined to allow meaningful energy performance assessment of buildings.

SAREF4BLDG ontology extends the *SAFEF* ontology, which is a reference model for smart homes [18]. *SAREF4BLDG* ontology defines vocabulary for building devices and their location. Several concepts such as *Building*, *BuildingSpace*, *PhysicalObject*, *TransportElement*, *VibrationIsolator* and *BuildingDevice* have been modelled.

Degha et al. [19] have modelled knowledge in the form of an ontology entitled Onto-SB for smart building with much emphasis laid on user profile concepts. This ontology aims to save energy by promoting a change in user behavior. The ontology defines vocabulary for concepts like *Health State*, *Psychological State*, *Behaviors* and *Abilities* among others.

2.2. Water Management

Water management is a green practice initiative for a smart campus. Mezni et al. [20] have developed an IoT-based framework entitled *SmartWater* to support smart water monitoring and management. The framework includes a knowledge graph, which defines vocabulary for water zones, storage reservoirs, distribution pipelines, IoT water sensors, smart meters and monitoring hubs for measuring consumption among others.

2.3. Waste Management

Effective waste management contributes towards sustainability in a green campus. Sinha and Coderc [21] have developed an ontology to sort smart waste management items for recycling purposes. The ontology models smart bins in terms of *GlassBin*, *MetalBin* and *PaperBin.* Smart waste items are tagged with RFID, which store information about the percentage contents of the various recyclable materials. An RFID reader is used to read the RFID tags to detect the smart waste items along with their content.

Kultsova et al. [22] have used ontology along with rule-based reasoning in the domain of waste management. Three ontologies namely Waste Ontology, Ontology of Waste Management Methods and Ontology of Waste Management Subject have been constructed. The Waste ontology represents the waste types of different nature, aggregate states, origins and hazard degrees. Ontology of Waste Management Methods defines the waste management methods, their economic costs and the degree of the negative impact on the environment. Ontology of Waste Management Subject describes the state of the subject, which has geographic coordinates, the budget, its own waste and the waste management methods.

Kalpana et al. [23] have proposed an ontology for waste management system. Classes such as *Area*, *location_type*, *Waste_disposal_methods* and *waste_type* have been modelled which represent area, location, recycling methods and type of waste respectively. Four methods for managing waste have been defined by the *Waste_disposal_methods* class namely *Landfills*, *Incineration*, *Composting* and *Recycling*.

Sosunova et al. [24] came up with Smart Waste Management Presentation and Recommendation system that adopts an ontology entitled *Waste Management Ontology* for IoT-enabled smart waste management. The ontology defines vocabulary for regions, routes, smart garbage bins, trucks, waste dumps and waste processing companies among others.

2.4. Air Pollution

One of the initiatives of green campuses towards sustainability is to reduce air pollution and achieve low carbon emission. Oprea [25] has modelled an ontology for air pollution entitled *AIR_POLLUTION_Onto.* Concepts such as *Pollutant*, *Pollutant Source*, *Meteorological Factor* have been defined. The ontology has been used in several systems for air pollution monitoring and control.

Adeleke and Moodley [26] have developed an ontology entitled *Indoor Environmental Quality (IEQ)* Ontology for indoor monitoring. The ontology differentiates between pollutant inducing and pollutant reducing activities. The ontology has reused the SSN ontology for sensor modelling. Ghorbani and Zamanifar [27] have developed an ontology for indoor air quality, which models key concepts associated with air and air pollutants.

Ajami and Mcheick [28] have developed an environment ontology that models environmental factors such as ambient air, weather and air pollution, which are potential risk factors for Chronic Obstructive Pulmonary Disease (COPD). Several indoor pollutants and outdoor pollutants have been modelled.

2.5. Sustainability Assessment

There is a growing interest to use knowledge-based approaches to promote sustainability. Yang et al. [29] have proposed a conceptual framework for managing sustainability knowledge. Konys [15] has developed a knowledge model for assessing sustainability of a particular domain in OWL. The main concept of the knowledge model is the class *Criteria*. This class consists of several sub-classes namely *Scope*, *Complexity*, *Type of Approach*, *Issues*, *Domain* and *Indicator*. The model has been validated using competency questions.

2.6. Discussion

While a number of ontologies exist to model different green indicators and specific aspect of green practice management along with sustainability assessment for a particular domain, none have focused on green practice management and monitoring in an IoT-enabled smart green campus. Several projects to achieve sustainability are carried out in different campuses around the world such as smart building or smart waste management systems. However, Amaral et al. [30] highlight that there is limited dissemination of their impact on sustainability. Additionally, limited research exists on how the knowledge about these projects are represented and monitored with respect to sustainability frameworks or metrics. Amaral et al. [30] recommend the development of an integrated framework to facilitate dissemination of sustainability actions and initiatives on a smart campus along with their results. To build an integrated framework, there is, first of all, the need for a semantic model to represent green practice management and monitoring in the smart campus. Such a model will promote sharing of information so that the latter can be reused by different instances for informed decision making and planning. This paper thus aims to come up with an ontology that represents environmental sustainability for a smart green campus.

3. Methodology

It is of paramount importance to follow a proper methodology for developing an ontology. Several such methodologies exist such as TOVE Methodology [31], METHONTOLOGY methodological framework [32], Ushold and King methodology [33], Noy and McGuinness methodology [34] and NeOn Methodology [35] amongst others. For this research work, the NeOn methodology has been shortlisted. This methodology caters for several scenarios that may arise during ontology development [36]. Each possible scenario is well detail so that it is understandable by ontology practitioners. Furthermore, the methodology supports projects with domains that are not well understood and where requirements will possibly change in the future [35]. One strong point supported by this methodology is the reuse of both ontological and non-ontological resources. As part of the methodology, a motivation scenario justifying the need for the ontology and the Ontology Requirements Specification Document (ORSD), are presented in this section.

3.1. Motivation Scenario

Green Office or sustainability office/centre plays an important role towards sustainable development on university campus. It monitors the campus activities and operations in order to assess campus sustainability. The office is led by a coordinator who performs planning and execute projects [37]. The projects are executed by students belonging to a faculty and staff on the campus. The staff comprises of academic staff posted to a faculty and non-academic staff. The office is allocated a budget, an office space and a mandate [37]. In an IoT-enabled smart green campus, environmental factors are captured by IoT devices [4], [38]. A survey carried out by Filho et al. [37] reports that the green office handles several aspects such as energy efficiency, renewable energy, water management, waste management, sustainable education, sustainable procurement, mobility and sustainable reporting among others. Figure 1 provides an illustration of a smart green campus, which comprises of different projects contributing towards green practice management. Sensors are used to capture relevant data in several domains of a green campus.

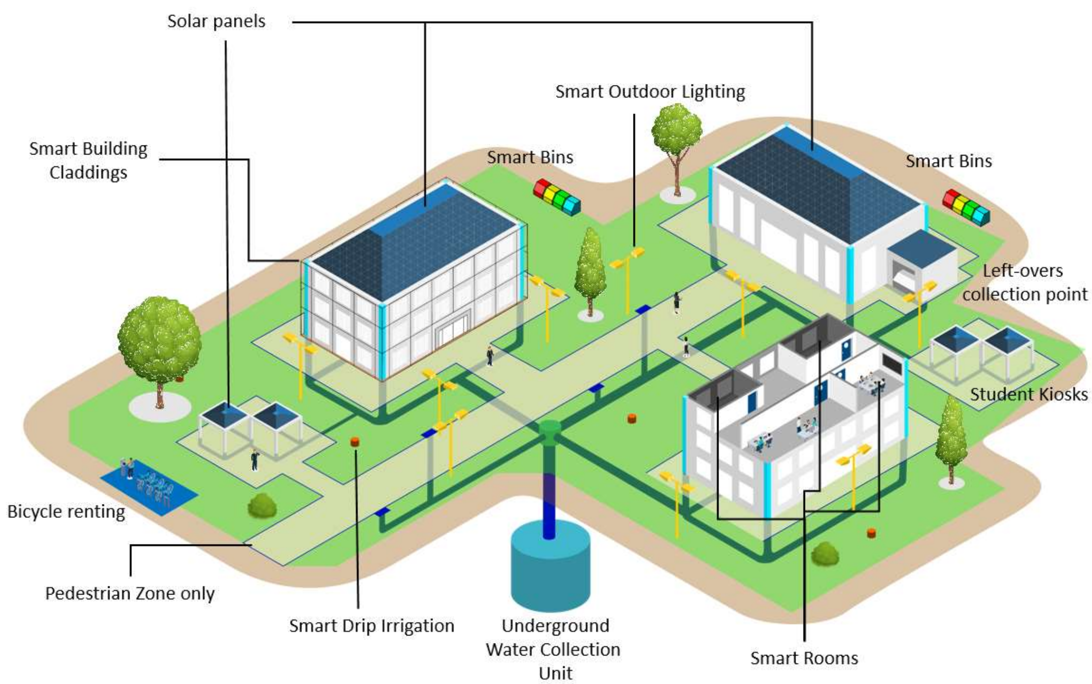

Figure 1: Green Practice Management on a Smart Green Campus

3.1.1 Energy efficiency

As shown in Figure 1, solar panels are present on roofs and they rely on green energy. Smart building cladding that operates flaps and openings are used to regulate building temperature by following wind currents and sun movement. In smart rooms, sensors are used for detecting human presence to decide whether to switch on lights and air conditioning. Smart outdoor lightings are carefully positioned for optimum clarity during night time. They can synchronise themselves to output light with varying lumens.

3.1.2 Water management

In an IoT-enabled green campus, water collected from rain or other sources of unpurified water, can be filtered and be used in irrigation of the campus lawns and plants. Rainwater harvesting system is used on buildings and kiosks in the campus and are routed to water tanks around the campus. Rain sensors can be used to capture data about the amount of water available. Smart drip irrigation system senses soil humidity to know when to sprinkle water on the lawn. Soil moisture sensor can additionally be used to learn about information regarding soil. Such information is important in drought period.

3.1.3 Waste management

Smart bins strategically located throughout campus notify their levels with concerned departments. Colour coded bins are used for different types of waste. Organic waste can be sent for composting. Compost can be used to enrich the campus soil. Smart bins can be equipped with ultrasonic sensor positioned inside the bin's lid. By sending a high frequency sound wave through the bin and capturing it back, the bin's filled level is calculated. A PIR sensor can be used to detect the presence of people around the bin. When someone approaches the smart bin, the PIR sensor can trigger a servo motor to open the bin's lid. An RFID sensor can be placed on the side of a bin to allow an employee to unlock the bin.

3.1.4 Food safety and quality

Smart food monitoring systems are important on campus to ensure that food of good quality is consumed by campus users. In a smart canteen, MQ-2 gas sensor and DHT11 temperature and humidity sensor can be used to measure the air surrounding the food to determine food quality [39]. Canteen application notifies people on campus about leftovers that can be sold or distributed freely to reduce wastage.

3.1.5 Air Quality

To measure the air pollution level in a smart green campus, air quality sensor, MQ-135, could be used. To reduce pollution, it would be interesting to convert the campus zone into pedestrian zone. Students can rent smart bikes to move around. Smart parking system on campus can also reduce pollution level by allocating a parking slot to a user in advance. The user will not travel unnecessarily to find a parking spot and thus leading to reduction of fuel consumption and carbon footprints in the atmosphere [40].

3.2. Ontology Requirements Specification Document (ORSD)

The proposed semantic model will be in the form of an ontology. Table 1 presents the ORSD, which outlines the different aspects regarding the development of the proposed semantic model such as the purpose, the scope, users and uses of the ontology along with the ontology requirements.

Table 1
ORSD

Ontology Requirements Specification Document	
Purpose	The purpose of developing the ontology is to represent knowledge with respect to monitoring and management of green practices by the Green Office in a smart campus.
Scope	The ontology will tackle several green indicators regarding a smart campus. The level of granularity is directly related to the competency questions and terms identified.

Implementation Language	The ontology has to be implemented in OWL 2.
Intended End-Users	The relevant users of the semantic model would be students, academic staff and non-academic staff of a smart campus.
Non-Functional Requirements	The ontology should be based on standards for green practice management and sustainability for smart campuses
Functional Requirements: Groups of Competency Questions	1. Who are the members of the Green/Sustainability office? 2. Do the members belong to a particular faculty? If yes, which faculty? 3. Which green practice is being tackled by the Green/Sustainability office? 4. Which green projects are monitored by the Green/Sustainability office? 5. Which green activities are monitored by the Green/Sustainability office? 6. Which projects fall under which green practice? 7. Who is working on which green project? 8. Who is working on which green activity? 9. Which metrics assess which green practice?

4. Semantic Model for IoT-Enabled Smart Green Campus

This section describes the proposed ontology entitled *SmartGreenCampOnto* for sustainability for an IoT-enabled green campus based on the motivation scenario and the ORSD described in the previous section. The proposed ontology aims to capture information regarding green projects and activities carried out in a smart campus. These projects and activities are monitored and assessed by frameworks.

4.1. Reuse of ontological/non-ontological resources

Rather than developing an ontology from scratch, several resources whether ontological or non-ontological can be reused. This practice is supported by the NeOn methodology. Examples of resources to be reused are described as follows:

4.1.1 FOAF

The Friend-of-a-Friend (*FOAF*[2]) ontology is used to define vocabulary for an individual. The ontology describes several elements for a person such as name, age, title as well as relationships with other individuals. To model the members of the sustainability office such as staff and students, this ontology is deemed appropriate.

4.1.2 SOSA

In an IoT-enabled smart green campus, environmental factors are captured using sensors. The *SOSA*[3] ontology, will be suitable for modelling sensors, observations, samples and actuators in such an environment. *SOSA* is a lightweight ontology, grounded on *SSN*.

4.1.3 Standards

[2] http://xmlns.com/foaf/spec/#sec-intro

[3] http://www.w3.org/ns/sosa/

ISO 37120:2018[4] is a standard for sustainable cities and communities. This standard defines several indicators for measuring the performance of services and quality of life smart cities and communities such as education, energy, solid waste among others.

4.1.4 Assessment Approaches

Green Office or sustainability office/centre uses a framework for green campus sustainability assessment [15]. A framework is considered as a tool that details guidelines for sustainability evaluation. It may adopt indicators or metrics for measuring progress towards sustainability. Several frameworks have been set up for sustainability evaluation in the context of a university. One example is *UI GreenMetric*[5] *World University Ranking (GM).* The UI GreenMetric evaluates a university performance based on the following criteria: Setting and Infrastructure, Energy and Climate Change, Waste, Water, Transportation and Education and Research. It is used to rank a green campus and its environmental sustainability based on 39 indicators.

4.1.5 Modular Approach

A modular approach will be used to represent each green practice such as energy efficiency, renewable energy, water management, waste management, sustainable education, sustainable procurement, mobility and sustainable reporting. Such an approach is essential to generalize concepts into separate ontologies to promote reusability and maintainability [15]. Existing ontologies related to each green practice can be integrated with *SmartGreenCampOnto.*

4.1.6 Green Project

Universities play an integral role to combat climate change. Several universities around the world are working towards initiatives and novel ideas on how to achieve sustainability in a campus environment. Several green projects have been undertaken in a smart green campus in order to work towards this objective. Some examples include Smart Buildings, Smart Drip Irrigation, Smart Waste Management System, Smart Canteen System and Smart Parking. Though these projects have been implemented in campus environment, Amaral et al. [30] highlight little effort has been laid on the dissemination on the impact of these projects on sustainability. The proposed ontology in this paper thus aims to fulfil this gap by representing knowledge of the green projects and their impact on sustainability.

4.1.7 Green Activity

Green activities are fundamental for creating awareness about climate change and SDGs. Several events are organized on campus to create awareness. Additionally, a number of programmes have been developed and integrated in the curriculum to sensitize learners about sustainable development.

4.2. Conceptual Modelling

Based on the motivation scenario and ORSD described in section 3, a conceptual model, illustrated in a class view, is shown in Figure 2. The concept model describes each concept/class, the properties elaborating details on the concept and the binary relationships between the concepts of the proposed ontology. The class Green/SustainabilityOffice is responsible for monitoring *GreenActivity* and *GreenProject*. The *Green/SustainabilityOffice* is led by the *Coordinator. CampusUser* consists of *Academic Staff* and *Student* belonging to a *Faculty* along with non-academic staff. *CampusUser*

[4] https://www.iso.org/standard/68498.html
[5] http://greenmetric.ui.ac.id

performs *GreenActivity* and *GreenProject* related to *GreenPractice*. *GreenProject* uses *Sensor* to capture environmental data. *Green/SustainabilityOffice* performs *SustainabilityAssessment* where *Framework* consisting of *Indicator* and *Metrics* are used to assess *GreenPractice* on the campus.

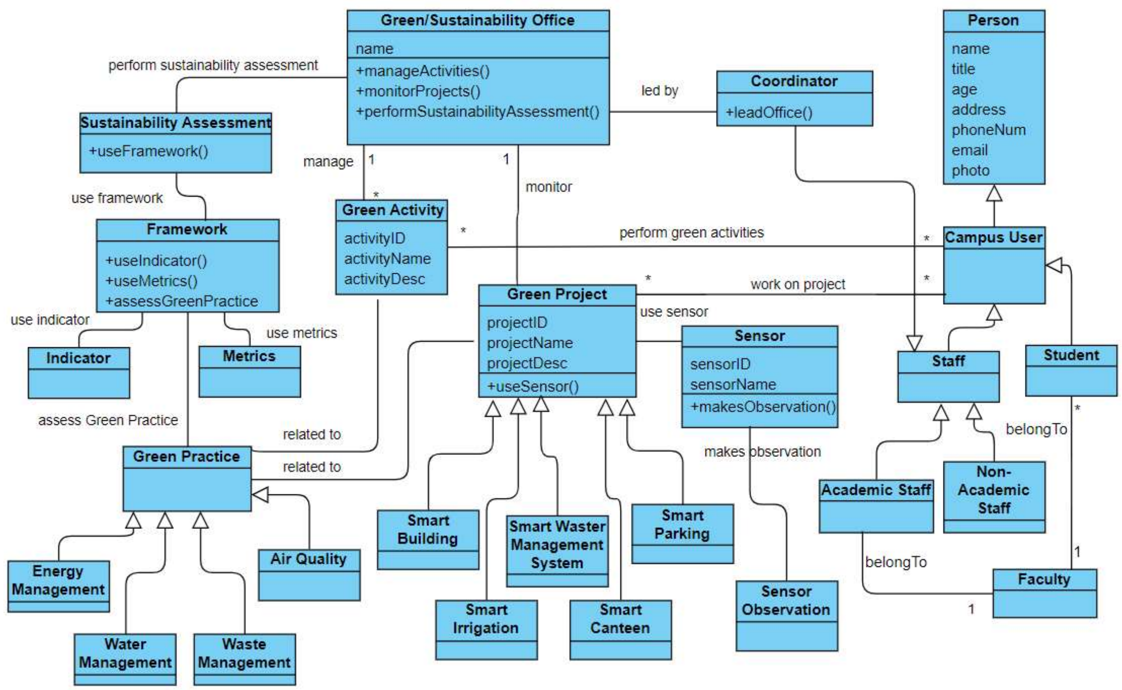

Figure 2: Conceptual model of *SmartGreenCampOnto*

Table 2 further details the different concepts shown in the conceptual model and suggests components that can be reused from existing resources.

Table 2
List of Concepts for *SmartGreenCampOnto*

Concept	Description	Ontology Reuse
Sustainability Office/Centre	Refers to a centre or office responsible for carrying out sustainability activities and projects and for assessing sustainability on a campus	
Green Practice	Refers to an action which protects the environment in order to achieve sustainability	
Sustainability Assessment	Refers to sustainability assessment based on a particular approach	
Green Project	Refers to a project undergone to achieve sustainability	
Green Activity	Refers to an activity undergone to achieve sustainability	
Sensor	Refers to the sensor used for capturing environmental data	sosa:Sensor
SensorObservation	Refers to a particular output of a sensor at a particular time	sosa:SensorOutput
Energy Management	Refers to a green practice which aims at managing and reducing energy consumption	Energy ISO 37120:2018
Water Management	Refers to a green practice which aims at managing water resources	Water ISO 37120:2018

Air Quality Efficiency	Refers to a green practice which aims at reducing air pollution and achieve low carbon emission	Environment and Climate Change ISO 37120:2018
Waste Management	Refers to a green practice which contributes towards effective waste management	Waste ISO 37120:2018
Framework	Refers to a tool used for assessing sustainability	[15]
Indicator	Refers to a qualitative, quantitative or descriptive measure for evaluating sustainability	ISO 37120:2018, [15]
Metric	Refers to a qualitative or quantitative measure for evaluating sustainability	[15]
Campus User	Refers to an individual who makes use of the campus services	
Staff	Refers to a staff employed by the university	
Academic Staff	Refers to an individual employed in academia by the university	[41]
Non-academic Staff	Refers to an individual employed by the university who is not an academic	[41]
Coordinator	Refers to a staff who leads the sustainability office	[37]
Student	Refers to a student registered at the university	
Faculty	Refers to a group of departments in a university	

5. Conclusion and Future Works

This paper presents a semantic model, in the form of an ontology, for a smart green campus where emphasis is laid mainly on green practices and sustainability. While several ontologies exist in the field, none have focused on the management and monitoring aspects of green practices in a smart campus environment. Knowledge regarding green projects and activities has not been represented formally, hindering reuse and sharing of information. The proposed ontology, *SmartGreenCampOnto* caters for several aspects like IoT, green projects, green activities and sustainability assessment in a smart campus environment based on frameworks. The proposed ontology reuses several existing ontologies such as *FOAF* and *SOSA* along with relevant standards such as ISO 37120. Such an ontology will provide a common understanding of the domain to allow university management personnel to take informed decisions towards achieving sustainability goals. In future, the proposed ontology will be developed using Protégé Ontology Editor[6]. Semantic Web Rule Language (SWRL) will be used to define inference rules that will perform semantic reasoning. SPARQL queries will be used to evaluate the competency questions defined in the ORSD. Furthermore, the proposed ontology will be evaluated using appropriate metrics such as accuracy, adaptability, clarity, completeness, conciseness and consistency. Domain expert feedback will also be gathered to improve the proposed ontology.

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