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

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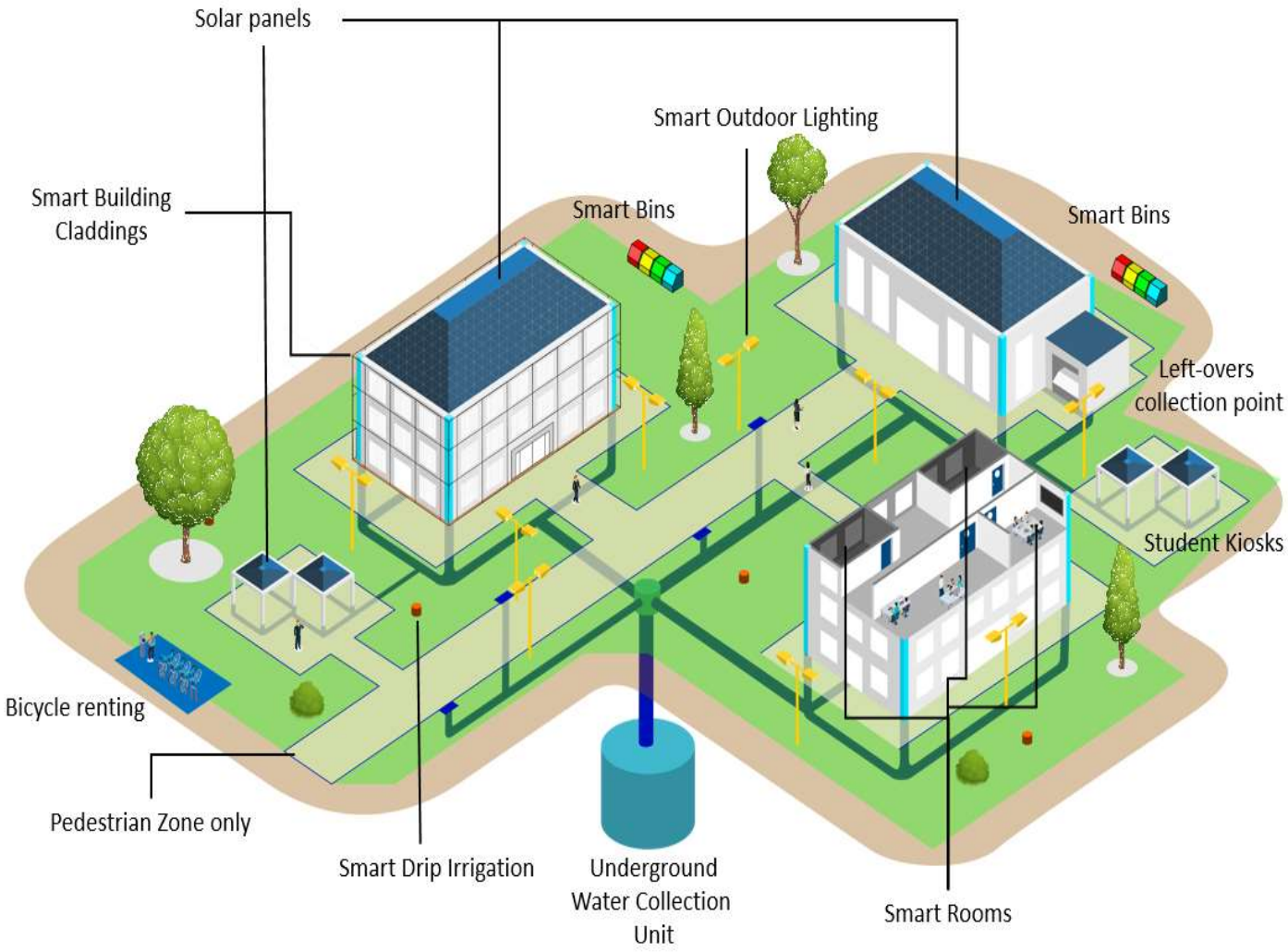
Introduction

- Smart campuses
  - Academic or non-academic institutions where digital infrastructures are in place to support the teaching, learning and research activities
- Internet of Things (IoT)
  - enables the automation of the environment where sensors capture data about the environmental phenomena
  - data are analysed for better resource management and proper decision-making
- Campuses focus on being more sustainable
  - in line with Sustainable Development Goal (SDG) 12 and SDG 13 defined by United Nations Millennium Declaration
- 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

Examples of Smart Green Campuses

- Examples of smart green campuses
  - Themes for smart green campuses namely Smart Learning, Smart Sharing, Smart Buildings and Smart Transport based on best practices for Dutch institutions
  - Green indicators for Malaysian universities for measuring and monitoring green practices in higher education institutions
  - Setup of a sustainability office/centre on campus for Saudi universities to assess campus sustainability
- Sustainability offices or centres are already in place in several campuses around the world
  - ANUgreen Sustainability Office at Australian National University Facilities and Services Division
  - EcoCampus Management Centre set up at the Universiti Malaysia Sabah
  - Aim: to monitor campus activities and operations in order to assess campus sustainability

Fig. 1: Smart Green Campus Example



The need for a Semantic Model

- As shown in Fig. 1, different systems capture data about the environment
  - Systems linked to several domains of a smart campus such as smart building, smart classroom, smart library or smart parking
- Research issue for Smart Campus (analogous to small city)
  - Data interoperability and fusion for monitoring the environment (air, soil, water*)*
- Need for a semantic model
  - To promote sharing and integration of data captured by various IoT systems on the campus
  - To represent data of different domains
  - To enhance interoperability among heterogeneous systems on the campus
  - To promote enhance decision-making on the campus
- Ontology-based models
  - good expressivity
  - good formalization language with logic inference ability

Ontologies for Smart Green Campuses (1)

Ontologies for smart green campuses:

- *SAREF4BLDG* ontology
  - extends the *SAFEF* ontology
  - defines vocabulary for building devices and their location
  - Concepts such as *Building*, *BuildingSpace*, *PhysicalObject*, *TransportElement*, *VibrationIsolator* and *BuildingDevice* have been modelled

- *SmartWater*
  - *IoT-based framework entitled to support smart water monitoring and management*
  - *vocabulary for water zones, storage reservoirs, distribution pipelines, IoT water sensors, smart meters and monitoring hubs for measuring consumption*

- *Waste management (Kultsova et al., 2016)*
  - *Ontology along with rule-based reasoning*
  - *Waste Ontology, Ontology of Waste Management Methods and Ontology of Waste Management Subject have been constructed*

Ontologies for Smart Green Campuses (2)

- *Indoor Environmental Quality (IEQ)* Ontology
  - ontology for indoor monitoring
  - differentiates between pollutant inducing and pollutant reducing activities
  - reused the SSN ontology for sensor modelling

- Conceptual framework for managing sustainability knowledge (Yang et al., 2015)

- Knowledge model for assessing sustainability (Konys, 2018)
  - main concept *Criteria*
  - sub-classes namely *Scope*, *Complexity*, *Type of Approach*, *Issues*, *Domain* and *Indicator*
  - model validation using competency questions

W. Yang, M.C. Mckinnon and W.R. Turner, "Quantifying human well-being for sustainability research and policy", Ecosystem Health and Sustainability, vol. 1(4), pp.1-13. 2015.
A. Konys, "An ontology-based knowledge modelling for a sustainability assessment domain", Sustainability, vol.10 (2), pp.300. 2018

Gap Analysis

- Existence of ontologies
  - different green indicators and specific aspect of green practice management
  - 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
  - smart building or smart waste management systems
  - Limited dissemination of their impact on sustainability
- Limited research
  - How projects are represented and monitored with respect to sustainability frameworks or metrics
- Recommendations
  - development of an integrated framework to facilitate dissemination of sustainability actions and initiatives on a smart campus along with their results
  - need for a semantic model to represent green practice management and monitoring in the smart campus
    - promote sharing of information
    - informed decision making and planning

Proposed Ontology

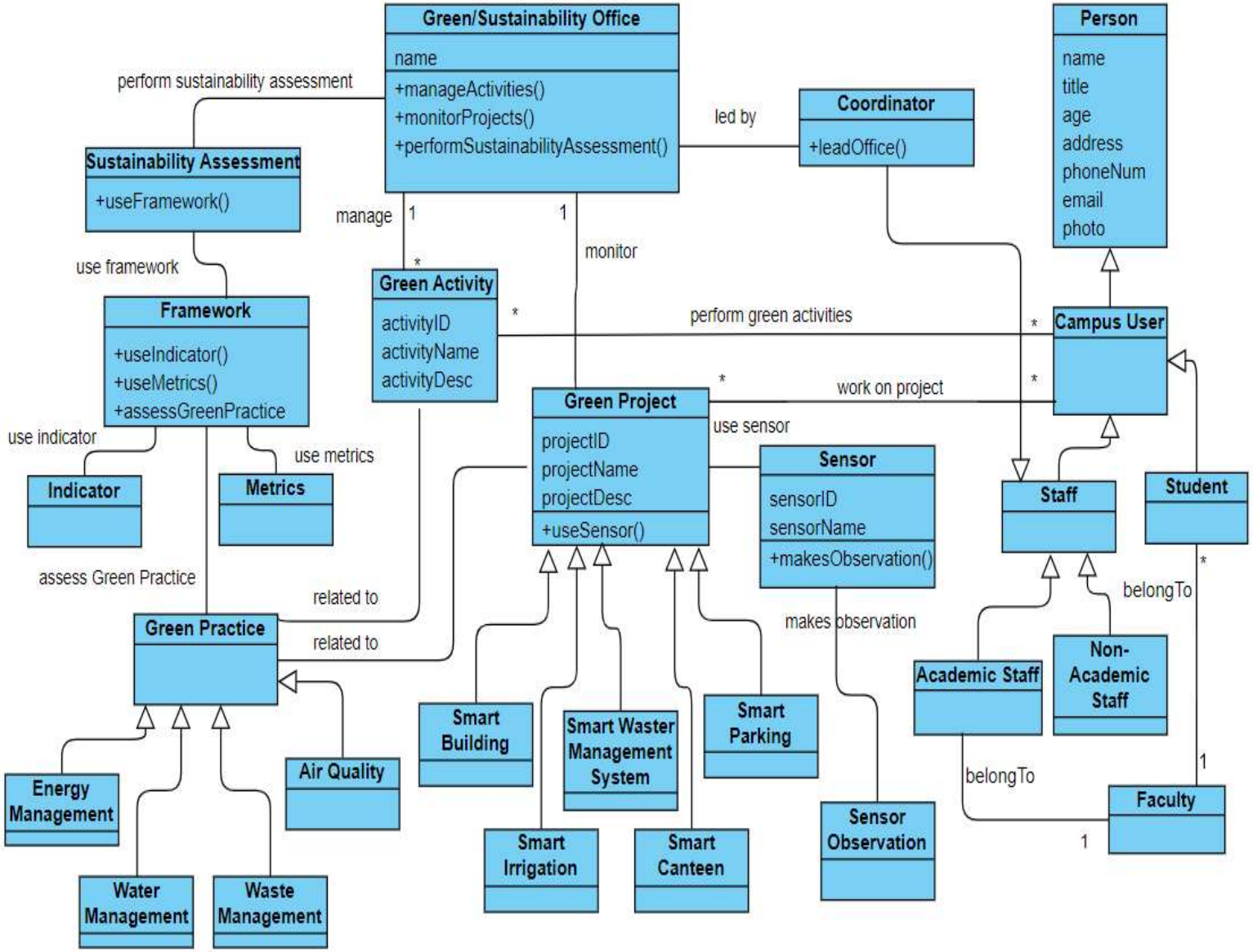
- Methodology
  - The NeOn methodology has been chosen to develop the ontology
    - favors projects with several different domains that are not well understood
    - favors projects where requirements can change during the development process
    - promotes the reuse of ontological and non-ontological resources.

Ontology Requirements Specification Document

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?

Class Diagram



Reuse of Existing Ontologies

- FOAF
  - FOAF stands for Friend-of-a friend
  - Defines vocabulary for a person and consists of several attributes like name, title and age.
- SOSA
  - Provides vocabulary for sensors in terms of capabilities, measurement processes, observations and deployments
- Standards
  - *ISO 37120:2018* is a standard for sustainable cities and communities

Assessment Approach

- Green Office or sustainability office/centre
  - framework for green campus sustainability assessment
  - tool that details guidelines for sustainability evaluation
  - 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 World University Ranking (GM)*
    - evaluates a university performance based on the following criteria: Setting and Infrastructure, Energy and Climate Change, Waste, Water, Transportation and Education and Research
    - used to rank a green campus and its environmental sustainability based on 39 indicators

Additional Concepts

- Green Projects
  - projects undertaken in a smart green campus in order to work towards sustainability
  - examples include Smart Buildings, Smart Drip Irrigation, Smart Waste Management System, Smart Canteen System and Smart Parking
  - dissemination on the impact of these projects on sustainability
- Green Activities
  - fundamental for creating awareness about climate change and SDGs
  - events organized on campus to create awareness
  - programmes developed and integrated in the curriculum to sensitize learners about sustainable development

Conclusion and Future Works

- None of the existing ontologies 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.
  - Ontology reuse: *FOAF* and *SOSA* along with relevant standards such as ISO 37120
  - 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.
  - 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.