The Indoor Air Quality Domain Ontology for the Development of COPD Self-Management System

Ramsha Ali†, Raluca Lefticaru, Marian Gheorghe
University of Bradford
Bradford, United Kingdom
†rali51@bradford.ac.uk

Abstract–Indoor Air Quality is the main concern for many individuals, specifically since the Covid'19 outbreaks. Internet of Things (IoT) devices or sensors detect and monitor indoor air pollutants. Indoor air pollution has a direct effect on human health in terms of respiratory conditions, cardiovascular problems, and endocrine disorders. There is a recognized need for providing a self-management system for patients affected by respiratory infections and indoor air pollutants. There has been substantial research undertaken on the role of indoor air quality monitoring systems. Previous research has indicated a potential association between indoor air quality and human respiratory health conditions such as Chronic Obstructive Pulmonary Disease (COPD). COPD is estimated to be the world's third leading cause of death. However, the effect of indoor air quality on COPD patients has yet to be understood. The principal finding of this research is the development of an indoor air quality ontology domain model based on the ontology engineering methodology that is Human-Centered Ontology Engineering Methodology (HCOME), which will be helpful in the development of a COPD self-management system.

I. INTRODUCTION & MOTIVATION

Recent years have witnessed a growing academic interest in Indoor Air Quality monitoring systems (IAQ). While previously, academic, and industrial research was more focused on Wireless Sensor Network (WSN) based monitoring systems, research in recent years is increasingly concerned with the development of IoT-based Indoor Air Quality Systems [1].

In a recent review of literature on IoT based Indoor Air Quality Monitoring, Saini J. et al. [1] identified the noxious effects of indoor air pollution. It was suggested that this pollution may have contributed to up to 2 million premature deaths annually. Among the leading causes of deaths were lung cancer (2%), Chronic Obstructive Pulmonary Disease (54%) and pneumonia (44%). Determining the impact of Indoor Air Quality on respiratory conditions such as COPD is critical for the future of declining the rate of premature deaths and high morbidity and exacerbations in patients.

Indoor Air Pollution and COPD [2] are increasingly recognized as a serious, worldwide public health concern because most of the people spend their time indoors especially in the winter season. It is significant to develop a self-management system that cope not only with the IAQ domain but provide some sort of solutions to the patients getting affected by COPD during their stay indoors.

The major problem is unavailability of COPD data and its correlation with the Indoor pollutants. However it has been identified in literature that IAQ is linked to respiratory morbidity and mortality [3].

The ontology plays a significant role in gathering and manipulating data related to the IAQ and COPD because it will contain the complete knowledge of the domain in the form of entities, relationships, and properties. An ontology provides a better way of query formation and information retrieval than the traditional databases. A knowledge base differs from a database in that a database's expressive power is constrained and it is primarily used to store facts. For example, dealing with data variability, expressing the meaning of the data, or performing AI reasoning over the data are difficult, if not impossible, without extra tools.

Semantic technology solutions are better suited for storing knowledge because they get around the drawbacks of traditional database technology, allowing for more flexible information structuring, the expression of information semantics, and support for more sophisticated querying techniques and AI reasoning. It is possible to create knowledge bases manually or automatically [4]. That's why Indoor air quality domain ontology will play a vital role in the development of COPD self-management system.

It is believed that there is a need for building a separate domain model that captures the concepts and relationships and characterize the indoor air quality which helps in the development of COPD [2] self-management system to manage the exacerbations and comorbidities of COPD affected patients. This is an ongoing research work. This research addresses the significance of Indoor Air Quality domain model based on the HCOME [5] methodology for the development of COPD [2] self-management system. The research question that is being targeted in this research is: ***"How to build a domain model that captures concepts and relationships that characterize Indoor Air Quality, and can be used for developing an ontology-based information system?"***

Recent evidence suggests that there have already been numerous IAQ monitoring systems and clinical systems developed but few have followed and highlighted the methodology they used to develop the ontology domain model of Indoor Air Quality systems and clinical expert/decision support systems. It has been evident that there is no occurrence of Indoor Air Quality domain model found in the ***shared ontology libraries*** *such as* **Manchester OWL Repositories (NCBO BioPortal / OBO Foundry / Protégé ontology library)**. It is vital to follow an ontology engineering methodology (OEM) to develop an ontology domain model because it helps in making the ontology domain model capable of being shared, live and reused by other researchers in the development of various clinical support systems or multi-agent systems.

The expected benefits of developing an indoor air quality ontology are to:

- Make an efficient and accurate information retrieval with the query formulation and information integration from a mass of information and get an answer as precise and relevant as possible.
- The IAQ domain ontology will be able to predict and help in improving the indoor environment for adapting a better lifestyle within residential, institutional, and healthcare settings. (The data based on the domain ontology will help data analyst and data engineers to identify the correlations between the meteorological factors, source of pollutants and the activities which are causing poor indoor environment. The data analysis and visualization outcome will help in making decisions for improving the indoor environment.)
- This domain ontology will be helping database designers and software developers to use the domain model as a reference point in the software development of domain ontology-based intelligent information systems and multi-agent applications because all the classes, relationships and properties are defined and tested.

This paper comprises of five sections. Section I addresses the introduction, motivation and the problem statement. Section II addresses a brief literature review of the topic. Section III discusses the methodology and related work done in this research. A brief overview of proposed COPD self-management system is discussed in Section IV and finally the conclusion and future directions are discussed in Section V.

II. Literature Review

Marques G. et al. [6] have reviewed the status of IAQ monitoring systems for 10 different countries since 2014 - 2019. According to the findings, 57 percent of the systems are Arduino-based, while 53 percent use Internet of Things technology. Hybrid IoT/WSN architectures were used in 14 percent of the systems. Wi-Fi communication technology was the most popular method of connecting to the Internet. For getting the data related to the enhanced thermal comfort, temperature, humidity and light sensors were incorporated. Health professionals must evaluate air quality data to aid in the decision-making process in medical diagnostics. It may also be possible to link the diseases of patients to their surroundings. It is critical to incorporate mobile device notifications to alert building occupants or city managers in a timely manner. Sun S. et al. [7] have proposed a monitoring system in which managers can take measures to improve indoor working conditions. Authors [7] also proposed to apply one basic green plant (discovered by NASA), an "***Areaca palm (Chrysaidocarpus lutescens)"*** to remove CO_2 efficiently. The limitation of this research is the accuracy of IoT based measurements related data. Marques G. and Pitarma R. [8] proposed the AirPlus real-time IEQ monitoring system offers a number of benefits, including scalability, flexibility, modularity, and ease of installation and configuration. It's a piece of mobile computing software that allows you to consult data and receive notifications. Validation is required to improve system calibration and accuracy, which is a limitation of this system. Adeleke et al. [9] created an ontology model for "indoor environmental quality (IEQ) monitoring and control". They followed the "Methontology [10]" ontology engineering methodology (OEM) for the development of IEQ domain model. The purpose of IEQ ontology was ontological reasoning that results in the automatic monitoring of the "IAQ index and a thermal comfort index". Marques G. and Pitarma R. [8] highlighted some issues related to IAQ and children's respiratory health. They also highlighted those laboratories in most universities have a large number of polluting sources. In [11], Kotis et al. stresses the importance of choosing well-structured ontology engineering methodologies. Kotis et al. argues in favor of collaborative methodologies as they allow ontology evolution and reuse. For live ontologies to stay live and reusable, they must follow widely accepted standards. The author backs the HCOME methodology by doing a comparative analysis with other ontology engineering methodologies (OEM)[12]. Several ontologies tailored via different OEMs were gathered and compared. Ajami H. and Mcheick H. in their paper [13] describes a remote COPD healthcare solution that uses an ontology-based system to provide real-time assistance to patients and efficient decision-making support to healthcare professionals. They further stated that the environmental factors are also a COPD trigger, with dangerous elements such as excessive "humidity or temperature, air pollutants, or abnormal oxygen concentrations" in the atmosphere that endangers the patient's lungs. COPD patients are protected from environmental hazards both indoors and outdoors by inevitably enabling spatial sensor nodes based on geographical location. For COPD patients, assessing daily activity is an important feature that can help them avoid potentially dangerous situations. Ajami H. and Mcheick H. [13] in their work developed a COPDology (Chronic Obstructive Pulmonary Disease Ontology[13]), which represents a particular medical domain based on information gathered from numerous research articles and relevant provisions, as well as data gathered from pneumologists who were interviewed and questioned about COPD treatment options. The disease, environment, equipment, patient data (personal information, symptoms, risk factors, and clinical test results), and treatment are all covered in this ontology. Protégé (https://protege.stanford.edu/) ontology development tool was used to implement the ontology in OWL[14] format. The ontologies they created to support the necessary health surveillance of COPD patients include patient, clinical findings, gadgets, activities, eco system, facilities, place, and disease. Camus-Garcia E. et al. [15] suggested in their work that although outdoor and indoor air pollution is the leading cause throughout many countries, it is obviously linked to the prevalence of drug smoking. Self-management interventions (SMIs) have been shown in the literature to support clinical outcomes including COPD, health, and wellbeing, and the cost of chronic medical conditions. The indoor pollutants such as NO_2 concentrations may have adverse effect on the patients having obstructive airway disease [16].

Ajami H., Mcheick H. and Mustapha K. validated the rule-based ontology framework as they proposed in [17] for COPD patients. An intelligent monitoring platform is included in the proposed system, which keeps records of a patient's overall status, makes recommendations, and delivers interventions on time. The limitations of this system is its complexity because it deals with the large ontologies and RDBMS simultaneously that is reducing the computing performance with respect to response time. For considering and solving the major issue of complexity and reducing the response time, two separate systems are being proposed (see figure 3.) that are integrated together that is COPD self-management system based on IAQ monitoring system.

III. Methodology & Related Work

This research is based on HCOME (Table I.) such that it is a collaborative ontology engineering methodology [12] as it supports active user involvement and iterative processing as the agile development methodology does. The HCOME works like a funnel that's why it is proposed to be named as the HCOME Funnel as depicted in the Fig. 1.

The first iteration of HCOME Specification and Conceptualization is accomplished as follows:

Defined Aim & Scope → Competency Questionnaire (CQ) → Competency Questionnaire Analysis → Identified Entities & Classes → Identified Relationships and Properties → Developed the IAQ ontology in Protégé

TABLE I. HCOME Life Cycle Phases (Kotis [5])

Ontology Life Cycle Phases	Goals
Specification	Define aim/scope/requirements /teams
Conceptualization	Acquire knowledge Develop and maintain ontology
Exploitation	Use ontology Evaluate ontology

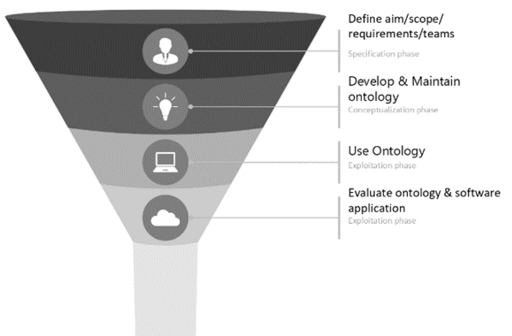

Fig. 1. The HCOME Funnel

Firstly, some competency questions based on the literature review studied were created for gathering requirements from domain engineers. A questionnaire was built on Microsoft Forms and shared the link with the domain engineers and knowledge workers. Upon receiving their responses, analysis phase was initiated in which the answers were analysed. Later on, an Excel sheet was created for segregating Entities, Classes and Individuals w.r.t their relationships in CQ Requirements Matrix (see Fig. 2). For instance, see the CQ1.1 in the Fig. 2, which says, "Does mold cause emissions? what are they?" From this question, one can easily identify an individual "**mold**" which is an instance of a **Particulate Matter** class. A Particulate Matter is a **Type of Pollutant**. Hence **Pollutant** is the main/root class, **Type of Pollutant** is a subclass of Pollutant and Particulate Matter is the subclass of Type of Pollutant.

1	Question on getting the emission rate of a pollutant within an indoor environment setting? For example, which pollutant has what emission rate in presence of a person or group of persons living within a room or a house performing any household activity?	1. Does mould cause emissions? what are they? 2. Does a gas cooker cause emission, of what? 3. how much difference does an extractor make?

Fig. 2. An extract from competency questions gathered

S.Nos	Competency Questions	Entity/Individual	Entity/Class	Relationship	Exisitng class	Existing Relationship
1	CQ1.1	Mould(Particulate Matter)	Pollutant	emission		
2	CQ1.2	Gas cooker (HouseholdAppliance)	Product_Used		1.1	1.1
3	CQ1.3	Extractor Fan (HouseholdAppliance)			1.2	1.1

Fig. 3. An extract from CQ Requirements Matrix

For identifying relationships among these classes, let us consider the CQ1.1 again. "Does mold cause emissions? What are they?" In this question, the **emission** is the relationship between an individual **mold** and a class **Particulate Matter**. Similarly, as Particulate Matter is a subclass of Type of Pollutant, it is clearly stated that every **Pollutant** causes emission must have a kind of **source of emission** and **rate of emission.** Hence the source of emission and rate of emission are the attributes of a class Pollutant, which will be inherited by all **Types of Pollutant**.

Protégé is adapted for the development of IAQ ontology. The IAQ ontology metrics are shown in the Fig. 4:

Ontology metrics:

Metrics

Axiom	407
Logical axiom count	199
Declaration axioms count	104
Class count	34
Object property count	15
Data property count	28
Individual count	30
Annotation Property count	1

Fig. 4. IAQ Ontology Metrics in Protégé.

The complete IAQ ontology is shown in figure 5. In the IAQ ontology, the imported ontologies are PLANT, SSN (IoT), Country and COPD. The relationship between some of the classes are stated as under and shown in Fig. 6. The classes are written in bold.

- IndoorAir and OutdoorAir is associated with the EnvironmentAir.
- A **Building** has an influence of **IndoorAir** and **OutdoorAir**.
- A building is associated with some **RegionalZones** of a **Country**.
- A building has an influence of MeteorologicalFactor.
- A **Building** is occupied by some **Person**.
- An **Activity** is performed by a Person.
- An **Activity** has certain types (**ActivtyType**).
- A Pollutant has certain types such as Gaseous, Odour, ParticulateMatter, VolatileOrganicCompunds and WaterVapour.

The evaluation of IAQ ontology is in progress that is why queries are not being shared in this short paper. This paper discusses the requirements engineering of the indoor air quality domain ontology.

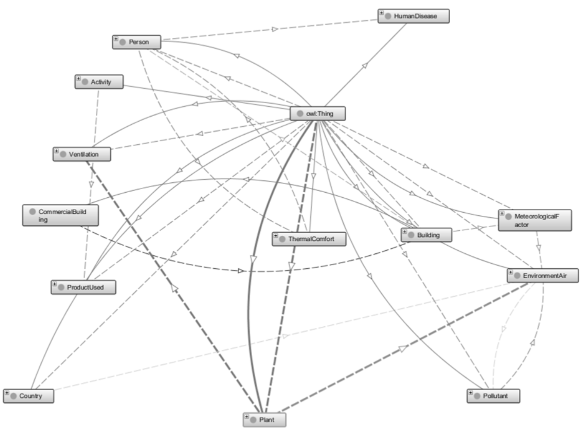

Fig. 5. IAQ Ontology

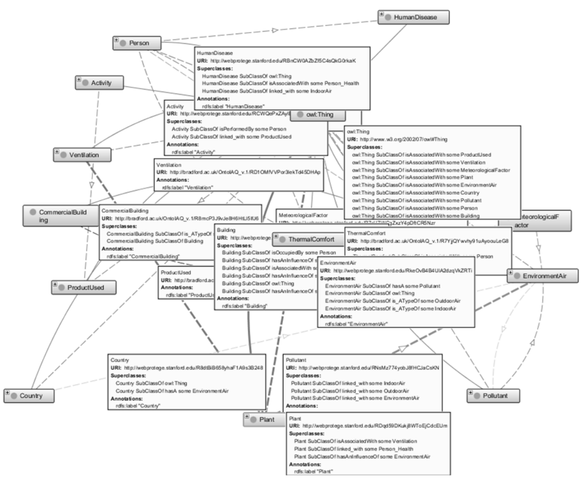

Fig. 6. IAQ Ontology with some details

IV. COPD SELF-MANAGEMENT SYSTEM

An ontology-based self-management system for COPD patients is being proposed in this research that can get the Indoor Air Pollutants data through environment sensor and then notify a patient about the significance of that pollutant. Upon receiving notification regarding the frequency of Indoor Air pollutant that could be affecting the health conditions of COPD patient, a patient would be capable of adapting possible measures to reduce the frequency of that indoor pollutant such as by opening the windows for ventilation or turning on the Air Purifier for managing their health condition while staying at home. The significance of IAQ ontology and monitoring is shown in figure 7.

The knowledge base consisting of IAQ ontology and other ontologies such as IoT(SSN) ontology, Plant, Country, COPD ontology will be helpful in assisting personalized COPD self-management reasoning. In addition to the personalized COPD self-management reasoning, the ontology-driven knowledge base can effectively support other applications such as COPD Decision Support System in hospitals.

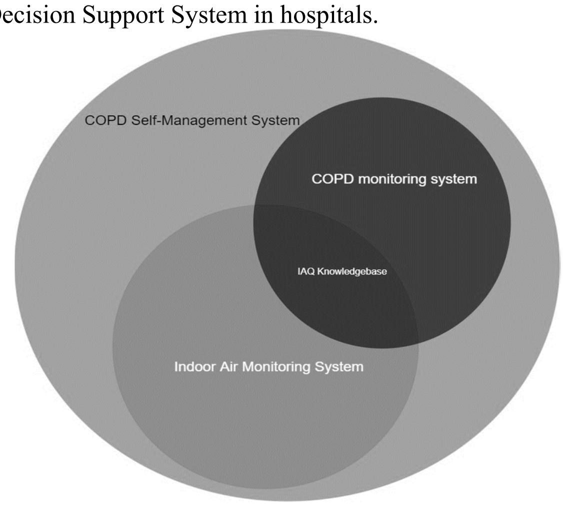

Fig. 7. Venn Diagram of COPD Self-Management System

V. FUTURE IMPLICATIONS & CONCLUSION

As future implications, it is much needed to evaluate the IAQ domain model in order to publicly shared on the shared ontology libraries such as Manchester OWL Repositories (NCBO BioPortal / OBO Foundry / Protégé ontology library). Thus, it is concluded that there is a significant need of developing a robust, scalable and reliable indoor air quality (IAQ) ontology domain model that plays an imminent role not only in the development of IAQ monitoring systems but also acts as an ingredient in the COPD self-management system. The emphasis on the development of IAQ domain model is due to making an efficient and accurate information retrieval with the query formulation and information integration from a mass of information and get an answer as precise and relevant as possible. The IAQ ontology is helpful not only in improving the indoor environment for adapting a better lifestyle within residential, institutional and healthcare settings but also can be used with the integration of clinical information systems to support health practitioners, consultants and patients. The benefit of domain ontology is helping database designers and software developers to use the domain model as a reference point in the software development ontology-based intelligent information systems and multi-agent applications because all the classes, relationships and properties are well-defined and tested.

ACKNOWLEDGMENTS

The first and the foremost thanks to Hujjat-ibnil-Hasan a.s. The authors thank Leena Aamir, BSc (Biomedical Science) – University of Bradford, Mr. Syed Nasir-ul-Hassan Naqvi (R.Ali's husband), Jawad Mustafa (Associate Software Engineer – 10 Pearls, Karachi, Pakistan), Dr. Saman Zehra Rizvi (Visiting Researcher at Cambridge University and Research Scientist at Raspberry Pi Foundation), Ågot Watne (PhD - Swedish Environmental Research Institute - Environmental intelligence), Sally Jones (Monitoring and Evaluation Manager, Clean Air Programme- City of Bradford Metropolitan District Council, Bradford, UK) for their invaluable contribution.

REFERENCES

[1] J. Saini, M. Dutta, and G. Marques, "Indoor air quality prediction using optimizers: A comparative study," (in English), *Journal of Intelligent & Fuzzy Systems,* Article vol. 39, no. 5, pp. 7053-7069, 2020 2020, doi: 10.3233/JIFS-200259.

[2] D. Singh, A. Agusti, A. Anzueto, P. J. Barnes, J. Bourbeau, B. R. Celli, G. J. Criner et al. "Global strategy for the diagnosis, management, and prevention of chronic obstructive lung disease: the GOLD science committee report 2019." *European Respiratory Journal* 53, no. 5 (2019).

[3] A. M. Senerat, S. M. Manemann, N. S. Clements, R. D. Brook, L. C. Hassett, and V. L. Roger, "Biomarkers and indoor air quality: A translational research review," *Journal of clinical and translational science,* vol. 5, no. 1, 2021.

[4] A. Sanctorum *et al.*, "End-user engineering of ontology-based knowledge bases," *Behaviour & Information Technology,* pp. 1-19, 2022.

[5] K. Kotis and G. Vouros, "Human-centered ontology engineering: The HCOME methodology," (in English), *Knowledge and Information Systems,* Article vol. 10, no. 1, pp. 109-131, JUL 2006, 2006, Doi: 10.1007/s10115-005-0227-4

[6] G. Marques, J. Saini, M. Dutta, P. Singh, and W. Hong, "Indoor Air Quality Monitoring Systems for Enhanced Living Environments: A Review Toward Sustainable Smart Cities," *Sustainability,* Review vol. 12, no. 10, MAY 2020, 2020, Art no. ARTN 4024, Doi: 10.3390/su12104024.

[7] S. Sun, X. Zheng, J. Villalba-Diez, and J. Ordieres-Mere, "Indoor Air-Quality Data-Monitoring System: Long-Term Monitoring Benefits," (in English), *Sensors,* Article vol. 19, no. 19, OCT 2019 2019, Art no. ARTN 4157, Doi: 10.3390/s19194157.

[8] G. Marques and R. Pitarma, "mHealth: indoor environmental quality measuring system for enhanced health and well-being based on internet of things," *Journal of Sensor and Actuator Networks,* vol. 8, no. 3, p. 43, 2019.

[9] J. A. Adeleke, D. Moodley, "An Ontology for Proactive Indoor Environmental Quality Monitoring and Control," SAICSIT '15: Proceedings of the 2015 Annual Research Conference on South African Institute of Computer Scientists and Information Technologists, South Africa, 28 September 2015, 2015, 2.

[10] M. F. López, A. Gómez-Pérez, J. P. Sierra, and A. P. Sierra, "Building a chemical ontology using methontology and the ontology design environment," *IEEE Intelligent Systems and their applications,* vol. 14, no. 1, pp. 37-46, 1999.

[11] K. Kotis, G. Vouros, and D. Spiliotopoulos, "Ontology engineering methodologies for the evolution of living and reused ontologies: status, trends, findings and recommendations," *Knowledge Engineering Review,* Review vol. 35, 2020 2020, Art no. ARTN e4|PII S0269888920000065, doi: 10.1017/S0269888920000065.

[12] Y. Sure, S. Staab, and R. Studer, "Ontology engineering methodology," in *Handbook on ontologies*: Springer, 2009, pp. 135-152.

[13] H. Ajami and H. Mcheick, "Ontology-based model to support ubiquitous healthcare systems for COPD patients," *Electronics,* vol. 7, no. 12, p. 371, 2018.

[14] S. Bechhofer *et al.*, "OWL web ontology language reference," *W3C recommendation,* vol. 10, no. 2, pp. 1-53, 2004.

[15] E. Camus-García *et al.*, "Self-management interventions for adults living with Chronic Obstructive Pulmonary Disease (COPD): The development of a Core Outcome Set for COMPAR-EU project," *PloS one,* vol. 16, no. 3, p. e0247522, 2021.

[16] N. N. Hansel, M. C. McCormack, and V. Kim, "The effects of air pollution and temperature on COPD," *COPD: Journal of Chronic Obstructive Pulmonary Disease,* vol. 13, no. 3, pp. 372-379, 2016.

[17] H. Ajami, H. Mcheick, and K. Mustapha, "A pervasive healthcare system for COPD patients," *Diagnostics,* vol. 9, no. 4, p. 135, 2019.