v. 3, n. 10, 2023

Journal of
Engineering
Research

ONTOLOGY, INTERNET OF THINGS AND *BUILDING INFORMATION MODELING* (BIM): EXPLORATORY STUDY

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Abstract: The article analyzes connections between ontologies, internet of things (IoT) and BIM (Building Information Modeling) technology in civil engineering. For this, a non-exhaustive literature review was carried out with a search for publications in the CAPES portal databases, revealing: the term "ontolog*" appears in 402,047 articles, which confirms the maturity and interest of the theme; "Internet of Things" at 16,023 and "Building Information Modeling" at 4,878. This research aims to be a starting point for the application of the ontology with the scope of the internet of things for civil construction processes in a Brazilian university. To achieve the objective, a 3D simulation proposal is presented using modeling (BIM) in all its components, organized in an IoT framework ontologically structured and dynamically monitored.

INTRODUCTION

The presence of new information technologies in civil construction and in the work of engineers and architects has required changes in thinking and producing various architectural objects. These changes involve the entire life cycle of a construction, going through the work itself and reaching the monitoring of use and monitoring of its performance in society.

The use of equipment, such as computers and *smartphones,* expands people's access to the internet. A new generation of originally isolated equipment – refrigerators, washing machines, coffee makers, video cameras, household appliances in general, as well as other devices such as microphones and sensors – are connected to the online world. This phenomenon is called "*smart building*", within the scope of what has become known as the *Internet of Things* (IoT). In this dynamic context, controlled vocabularies, such as ontologies, emerge as promising solutions for knowledge representation in the modeling phase.

This article brings together three seemingly unconnected themes: ontologies, used in the creation of machine-readable vocabulary; systems and platforms for the Internet of Things (IoT), involving devices and the data they generate; and BIM technology (*Building Information Modeling)* for the design, production and management of buildings in the Architecture, Engineering and Construction (AEC) industry.

The research investigates the scientific production that associates ontologies, IoT and BIM technology in civil construction, analyzing the relationship between the themes and their insertion in the management of buildings in the AEC industry. An exploratory research was carried out based on a non-exhaustive literature review in pioneering articles on the subject in the CAPES/MEC/BRASIL Journal Portal, with the descriptors "*Ontolog**", "*Internet of Things*" and "*Building Information Modeling*". The relationship between the themes is emphasized here, contributing to the identification, selection, evaluation and synthesis of evidence of the relationship between them.

The rest of the article is organized as follows: section 2 presents a brief *background* of the three themes cited; section 3 describes the methodology adopted in the research; section 4 analyzes and discusses results and section 6 brings final considerations.

BACKGROUND

This section briefly covers the issues involved, providing the minimum background for perceiving the advantages of integrating the three technologies.

The subject "ontology" has been studied in several areas of knowledge, including research in the fields of philosophy, computer science and information science, and with

applications in medicine, biology and engineering. In this context, ontology here refers to a representation of part of a given domain, in a machine-readable format, for the purposes of computational representation and information retrieval, with possibilities for automatic inference.

Table 1 summarizes the types essential for managing data and metadata for IoT purposes in healthcare facilities such as hospitals, medical centers and clinics. This is the kind of controlled vocabulary that an ontology can provide, emphasizing here data quality control, specifically, the quality aspects of accuracy, consistency and reliability. The definitions are based on notions of high and medium level ontologies such as the *Basic Formal Ontology* (Arp & Smith, 2015), *Ontology for General Medical Science* (OGMS), (Scheuermann, Ceusters & Smith, 2009), *Adverse Events Ontology* of ReMINE [10] and *Ontology of Biomedical Investigations* (OBI) (Jensen et al, 2014). Capitalized terms are classes defined in the mentioned ontologies.

Type	Definition (or elucidation)
TEST	(E) PROCESS designed to produce information about a MATERIAL ENTITY through physical examination.
BODY COMPONENT	CORPORAL QUALITY or CORPORAL PROCESS. HUMAN BEING in which the ROLE OF CAREER is inherent.
DEVICE	OBJECT that manifests causal unity through the projected assembly of components and instances of a type which are maximal with respect to this criterion of causal unity.
INTERPRETATIVE PROCESS	COGNITIVE PROCESS that creates, sustains or destroys COGNITIVE REPRESENTATIONS based on an OBSERVATION.
IOT for health	AGGREGATE OF OBJECTS that is part of the IoT and is composed of DEVICES and other OBJECTS that generate or analyze OBSERVATIONS in a PATIENT community.
SENSOR	DEVICE in which the FUNCTIONS for carrying out TESTS and generating OBSERVATIONS are inherent.
SITE	three-dimensional IMMATERIAL ENTITY that is bounded by a MATERIAL ENTITY or is an immaterial part of it.
PATIENT	A HUMAN BEING who receives ACTS OF CARE.
OBSERVATION	REPRESENTATION resulting from a TEST.
REPRESENTATION	QUALITY that is about or intends to be about a PART OF REALITY.

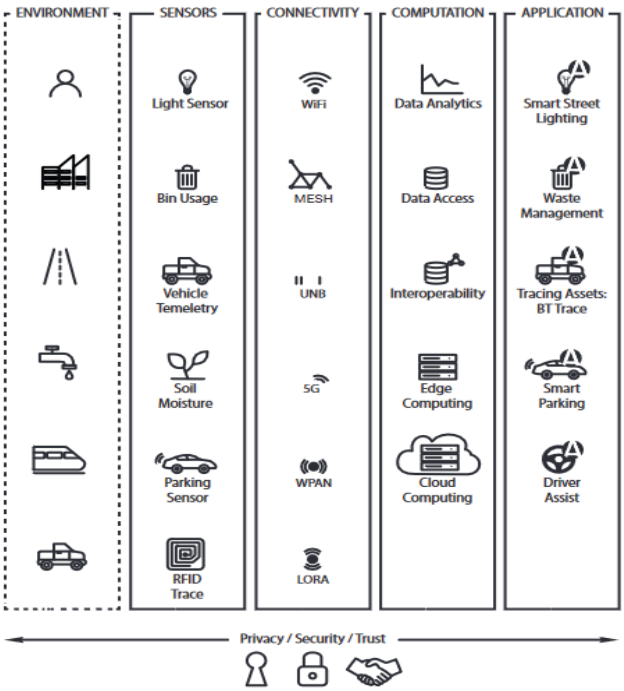
Table 1: Examples of ontology terms for the health unit

Source: adapted from Ceusters, W.; Bona, J. (2016)

The expression Internet of Things or *Internet of Things* (IoT), created in 1999 by Kevin Ashton, director of the Auto-ID Center at the Massachusetts Institute of Technology (MIT), has been used as a reference to a new generation of pervasive computing, representing the omnipresence of computing resources in consumer products and everyday people (Yang, Liu & Liang, 2010). Traditional industrial equipment and products such as automobiles, telephones, televisions, refrigerators, cameras and sensors now have built-in connection, communication and internet access capabilities, presenting several new possibilities of use such as remote control, personalization, automation and performance analyses. Through sensors, physical objects become capable of processing and, therefore, can "exchange, request, provide, delegate, manage and exchange data.

According to Davies & Fortuna (2020), IoT

has gone through a rapid development cycle from the beginning to the present, where the perspective of its massive adoption tends to increase the volume of data generated by society, and, consequently, the complexity for its management and exchange. For the authors, three phases are clearly identifiable in this evolutionary cycle: i) Technologies RFID: use of tiny identification tags with built-in RFID-type microchips (*Radio Frequency Identification*) for collecting and storing data about objects in common use for transmission and processing in a computational unit; ii) Omnipresent sensors: ubiquitous deployment of connected sensors in digital networks, in view of the advances in communication technologies obtained in the early 21st century and; iii) Security and Data Integrity: Currently, the focus of interest in IoT projects rests on aspects of data collection, processing and security due to concerns about security, privacy and trust in their contents. In image 1, real examples of IoT technology applications in different sectors, identified by the authors, are illustrated.



Souce: Davies & Fortuna (2020, p.2).

Another relevant feature when it comes to the development of IoT technologies refers to the multiplicity of actors participating in such projects and the relationships that occur between them, called by Davies & Fortuna (2020) as the IoT Ecosystem. An IoT ecosystem is composed of at least seven types of actors, playing specific roles, namely: sensor providers, connectivity providers, information providers, application developers, analytics service providers, platform providers, and information end users. and applications.

The technology BIM (*Building Information Modeling*) emerges as a concept of designing, planning and monitoring built works (Eastman et al. 2008). The process proposes profound changes in relation to the traditional model. The conception of a work presents many problems related to lack of communication and exchange of information between different stages, processes and, mainly, professionals. The proposal is to use BIM for project development, construction monitoring, as *built* and maintenance of a sustainable building.

BIM technology employs parametric objects and their relationships to build a virtual model of a building. However, a true ontological commitment is not identified there, which would be very welcome both from the point of view of representing reality around BIM and IoT technologies and promoting the semantic interoperability of interchangeable data between both. There is a need to understand the approximation between ontology and BIM in recent studies and research. The use of semantics in BIM is related to the use of ontology for the representation and management of information in architectural models in civil construction. The approximation between BIM and IoT presents itself as a possibility of exchanging information between existing objects and equipment in the real building

and the virtual model.

The three technologies have a fundamental principle in common: they go beyond a structure or a simple organization of objects or actors that they represent, but, above all, they emphasize the relationships between them and with an effort in the resolution of conflicts. In ontologies, the objective is to go beyond the description of what exists and the characterization of entities, explaining the possible relationships at different levels. In IoT, the importance of being aware of your state and others, the exchange of information and the sharing of actions between actors also demonstrate the emphasis on the relationships between things. And in BIM technology, the building is modeled with its elements parametrically, but, above all, representing the relationships between these components, avoiding, for example, compatibility errors.

Considering ontology as a way of representing the field of civil construction, the relationship between elements is fundamental for data organization and analysis. In turn, the IoT is directly linked to the construction of space for the identification and location of objects, the interconnection between them and the modeling of information. BIM, in addition to the direct proposal of developing the project and assisting the construction, has a fundamental role of modeling the entire building in 3D, with all the constructive elements and has the proposal of the relationship between the built elements (Lee et al. 2006).

METHODS

This research aims to map the research that encompasses the themes discussed above and their interrelationships through research carried out and the study of published literature. This research used the CAPES/MEC Journal Portal as the basis for the review protocol. This option was based on the availability of joint access to several databases, such as SCIELO, SCOPUS, WEB OF SCIENCE, PROQUEST, SCIENCEDIRECT AND IBICT. Publications were researched that had as their subject the use of ontologies, at the same time that these are employed with the Internet of Things and BIM technology. As an excerpt, the specific relationship between ontology, IoT and BIM models in civil construction was sought.

The articles identified by the search strategy were evaluated according to the inclusion criteria: availability of access to the full text, via the CAPES portal, and formally declared use of ontologies, IoT and BIM technology, simultaneously. As the objective is the relationship between these three subjects, the first inclusion criterion consisted of the text dealing together with the three themes.

To carry out the primary studies, the advanced search was used, through access to the CAPES Periodicals Portal, combined with the Boolean operator AND, the following were used in the specific search fields: i) in the first selection box of the specific search – by subject, author or title – any option was selected; ii) in the second checkbox, in the choice of the comparison constraint – contains, is (exact) or starts with – used: in the first line contains Ontolog* AND "Internet of Things" and in the second line is (exact) " Building Information Modeling".

Any contains ontolog * AND "Internet of Things"

Any is (exact) "Building Information Modeling"

The objective was to retrieve articles according to the keywords: "Ontolog*" AND "Internet of Things" AND "Building Information Modeling". No refinement was used in the search. Material Type: All Items; Language: Any language; Start date: undefined; End date: undefined.

As this search resulted in only one work, a second search was carried out with the

same operators, only replacing the expression "Building Information Modeling" with "Building". The objective was to access works that related ontologies and IoT not necessarily with the use of BIM technology, but expanding to the building and construction.

RESULTS

A quick search on the CAPES Journal Portal with the term "ontolog*" resulted in 402,047 papers, 222,871 of which were peer-reviewed journals, a large volume of texts which demonstrates the maturity of the area and interest in the subject. A search for the expression "Internet of Things" yielded 16,023 works, 5,023 of which were peer-reviewed, a much smaller number. But if one considers the fact that it is a more recent term, there is a very expressive number. With a search for the expression "Building Information Modeling", the result showed 4,878 works, 1,671 peer-reviewed, a much lower number than the previous ones, expected because it is a more specific subject of a certain area.

The research with the sum of the three expressions – "Ontolog*", "Internet of Things" and "Building Information Modeling" resulted in only one work by Howell, Rezgui and Beach (2017), article received on 28/jun/2016, revised on Dec/20/2016 and accepted for publication on Feb/26/2017, with the title *Integrating building and urban semantics to empower smart water solutions* (Integration of building and urban semantics to enable smart water solutions). This work proposes an ontology for the domain that describes smart homes, smart metering, telemetry and geographic information systems, along with social concepts. Four themes used in research on water in cities are presented: the use of smart sensors, integration between systems, proactive users and data management through advanced analytics.

The work by Howell, Rezgui and Beach (2017) presents a semantic knowledge management service and domain ontology for urban-scale domestic water systems. Implements a demand-optimized management use case, demonstrating the interoperability of smart home applications. It aims to integrate previously isolated systems, as well as supply and demand interventions, to improve system performance. Semantic web and IoT technologies can merge to bring together data models with dynamic flows, with the aim of supporting applications in the operational phase of systems for the built environment.

The search with the sum of the three expressions - "Ontolog*", "Internet of Things" and "Building" resulted in 57 papers, 49 of which were peer-reviewed journals. However, only two works deal with Building as Building or Civil Construction, the one already mentioned above and the text by Wang, Huang, Zhong, Huang, Han and Zhang (2015), entitled: *An Intelligent Monitoring System for the Safety of Building Structure under the W2T Framework* (An Intelligent Monitoring System for Building Structure Safety under the W2T Framework), published in 2015.

FINAL CONSIDERATIONS

This work analyzed the scientific production that associates ontology, Internet of Things and BIM technology in the AEC environment. An exploratory literature review was carried out in order to increase familiarity with the three themes. The research was carried out on the basis of the CAPES portal, verifying that the volume of published studies is very low, when compared to other works on ontologies, IoT or BIM separately.

An opportunity for research was identified in the bibliography and a bibliographical survey was carried out, which suggests the lack of consolidated research relating the themes. It is believed that there are fruitful research possibilities in this intersection,

since BIM deals with spaces and objects and the ontology theory is space-time.

The CAPES Portal brings together reputable databases and is a national reference. The result of this research of finding only one article on the subject draws our attention to the need for expansion, the originality and the contribution of this theme. In Exact Sciences, a larger number of publications are easily accessible via a simple search in conferences. However, in the area of Information Science, conferences are not considered and scientific communication is only done via journals.

In addition to the design and construction process of buildings, one can consider a building, or broadening the horizons, all the buildings in a city, simulated three-dimensional modeling (BIM) on all its components, organized in a structured way (ontology) and dynamically monitored (IoT). The union of these concepts will bring innovations to the process and the need for theoretical research and practical applications.

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