Connecting the Dots between Building Information Modeling, Ontologies and Systems Engineering: Why and What for?

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00 Agenda

01 Introduction

02 Methodology for the literature review

03 Bibliometric Analysis

04 BIM, ontologies, and systems engineering outcomes

05 Conclusion

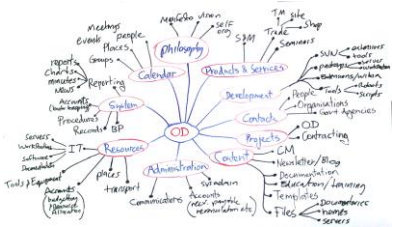
01 Introduction

- The construction sector is characterized by its **economic and social relevance worldwide**, consuming large volumes of goods and services, absorbing unskilled labor, and involving a production chain with **diverse stakeholders**, which implies a considerable degree of **uncertainty and complexity**. So, it's necessary to **develop ontologies and to adopt systems engineering views to improve the management of the complexity in projects**.

- "The need for adopting **a system-of-systems approach for the development of BIM in the construction** sector has been established for instance in (Cerovsek 2011)."

- We got curious about research that would combine **Systems Engineering + Ontologies + BIM**.

- **Project delivery phase**: need for designing a **meta-information-model** (MIM) to be adopted by each actor according to its specific needs (WEF, 2016).



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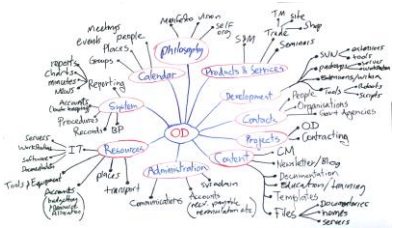
01 Introduction

- **Ontologies + systems engineering**: methodological framework for designing a **MIM** that construction companies could adopt and implement in their activities to benefit from, and contribute to, the overall **BIM process in construction projects**.

- Construction sector is not identified as a **significant contributor to this research effort**.

The objective of this article is to:

"Present a literature review carried out to evaluate to which extent ontologies have been used in the implementation of BIM, in a framework offered by systems engineering."



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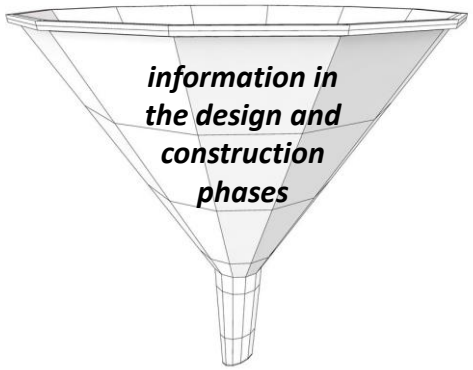
Methodology for the literature review

SSF - Systematic Search Flow (Ferenhof & Fernandes 2016), which is composed of **4 phases and 8 activities**.

- **Phase 1** - **Definition of the research protocol**: **4 databases** were interrogated using the 3 keywords **"BIM" AND "systems engineering" AND "ontology" with no restriction for the publication date**.
  The final portfolio is composed of **22 articles**, all are listed in the article appendix.
- **Phase 2** – **Analysis;**
- **Phase 3** - **Synthesis**: **knowledge matrix** (Ferenhof & Fernandes 2016) to extract and organize the data from the analysis of the articles.
- **Phase 4** - **Writing**.

120 articles



final portfolio
22 articles

Methodology for the literature review

Knowledge matrix:

To read	Authors	Year	Title	Published In	DOI	Citation	Country	Field of Research	Advantages	Issues	Type of ontology language used	Respect of the 4 Linked Data Principles	Commentaries
Fernanda	Tang, S., Shelden, D. R., Eastman, C. M., Pishdad-Bozorgi, P., & Gao, X.	2019	A review of building information modeling (BIM) and the internet of things (IoT) devices integration: Present status and future trends.	Automation in Construction		145	USA	Literature Review; Building Information Modeling (BIM); Internet of Things (IoT) Device; Sensors; Smart building; Smart City; Smart built environment; Integration;	This paper contributes to the body of knowledge by presenting an in-depth review of BIM and IoT devices integration in the AEC industry from domain application perspective and integration methodologies, and by shedding lights on current limitations and prominent areas for future research and development.	Based on the observed limitations, the authors concluded some prominent future research directions for BIM and IoT devices integration. Potential research directions include creating SOA patterns and web services for BIM and IoT integration, establishing information integration & management standards, solving interoperability issue and cloud computing			This paper is very interesting, however, it is a bibliographic review
Leonardo	Lee, Y. C., Eastman, C. M., & Solihin, W.	2016	An ontology-based approach for developing data exchange requirements and model views of building information modeling	Advanced Engineering Informatics,	https://doi.org/10.1016/j.aei.2016.04.008	68	USA	BIM data exchange					this paper looks very good
Fernanda	Geyer, P.	2012	Systems modelling for sustainable building design.	Advanced Engineering Informatics, 26(4), 656-668.	https://doi.org/10.1016/j.aei.2012.04.005	65	Germany	sustainable building design	This paper examines the use of Systems Modelling Language (SysML) to model systems for sustainable building design and develops a method called Parametric Systems Modelling (PSM). This eases the modelling of the physical and technological interdependencies relevant to building performance.	is not mentioned	Systems Modelling Language (SysML)		
Pierre	Dibley, M. J., Li, H., Miles, J. C., & Rezgui, Y.	2011	Towards intelligent agent based software for building related decision support.	Advanced Engineering Informatics, 25(2), 311-329.	https://doi.org/10.1016/j.aei.2010.11.002	45	UK	Multi Agent System ; Facility Management ; BDI (Belief, Desire, Intention) model			IFC for building geometry and construction ; Semantic Web Ontology langage (OWL) + 1st-oder logic ; SWRL = Semantic Web Rule LAnguage		
Pierre / Fernanda	Hiebler, H., & Akeen, D.	2016	Life-cycle information management using open-standard BIM	Engineering, Construction and Architectural Management	https://doi.org/10.1108/ECAM-01-2016-0023	29	Netherlands	Building life-cycle information	Several specific benefits of the suggested approach for life-cycle Information Management are recognized: 1. Information structure: a clear object-based structure in all building information based on the System Engineering breakdowns; 2. Information semantics: semantically rich information by using harmonized libraries and a fully linked-data approach; 3. Information ontology: All information is linked to the Systems Engineering breakdowns providing an ontology. A complete integrated information model is delivered instead of bulks of documents; 4. Standardization: Different projects, actors and phases use the Object Type Library of the asset manager allocated to a supertype library containing standardized items; 5. The right information: IDM and VDI for formal information transactions between actors, addressing the information requirements of actors involved over the life-cycle; 6. No loss of information: Delivery of the BIM containing all building information in its ontology and in an editable format overcomes misinterpretation and a lot of rework; 7. Interoperability: COINS is an open-standard for BIM that everyone can adopt in their discipline or company specific software without having to buy software from a vendor. The interoperability means less rework, errors and other issues for information transactions	Given that this is an innovative approach, a lot of players in the construction industry would still have to learn and adapt to the open-standard of COINS. The more this standard will be used in the future, the higher would be its value for interoperability. In addition, the development of the national Object Type Library CB-NL and harmonization with the existing libraries of actors will increase the benefits of the approach presented. Alongside these developments, research into the existing case studies and new case studies are required to be able to measure the benefits of the approach in terms of failure costs and efficiency of information management over the life-cycle.	The authors do not cite the language, but cite the databases used to generate the ontology: System Breakdown Structure + Object Type Library (OTL)		Pierre: A bit of Systems Engineering. Fernanda:This paper is interesting because they present the implementation of Systems Engineering and BIM in the project and the project team
Pierre	Gómez-Romero, J., Bobillo, F., Ros, M., Molina-Solana, M., Ruiz, M. D., & Martín-Bautista, M. J.	2015	A fuzzy extension of the semantic Building Information Model.	Automation in Construction, 57, 202-212.	https://doi.org/10.1016/j.autcon.2015.04.007	28	Spain	BIM ; Ontologies ; Fuzzy Logic	Fuzzy ontologies can deal with imprecise knowledge representations, imprecise queries (information retrieval), and imprecise parametric modelling	System not efficient in terms of execution time.	EXPRESS, RDF, STEP, OWL, OWL2, ifcOWL (fcRDF, IFC2IQ, protégé, fuzzy OWL Protégé plugin	Work developed within the Linked Building Data initiative	Check whether this kind of appoach had an impact in the community...
Leonardo	Das, M., Cheng, J.C.P., Law, K.H.	2015	An ontology-based web service framework for construction supply chain collaboration and management.	Engineering, Construction and Architectural Management	https://doi.org/10.1108/ECAM-07-2014-0089	27	China	Construction supply chain	Ontology can be used to support heterogeneous data transfer and integration through web services. Distributed data storage facilitates data sharing and enhances data control	problems in channelizing information along CSCs due to data heterogeneity			
Fernanda	Pitz, T., Theiler, M., & Smarsly, K.	2019	A metamodel for cyber-physical systems.	Advanced Engineering Informatics, 41(May), 100930.	https://doi.org/10.1016/j.aei.2019.100930	25	Germany	Structural health monitoring (SHM)	A cyber- physical systems metamodel, capable of describing communication-related information, has been proposed, based on the analysis of three metamodeling approaches that are applied in a broad range of applications, (i) UML and other OMG standards, (ii) the SWIE framework, and (iii) the EXPRESS metamodel	Limitations of the modeling capacities of EXPRESS, of EXPRESS-G, and of the SWE framework have been found with respect to describing communication-related information. In particular, models developed using EXPRESS-G are restricted to descrip- tions of structural semantics.	UML, EXPRESS		This cyber-physical system was tested in the laboratory, it did not have an application on the construction site
Leonardo	Karmu-Figuiem, B., & Abanda, F. H.	2015	Experience modeling with graphs encoded knowledge for construction industry.	Computers in Industry, 70, 79–88.	https://doi.org/10.1016/j.compind.2015.02.004	19	France	Knowledge management for continuous improvement					
Fernanda	Zhai, Y., Chen, K., Zhou, J. X., Cao, J., Lyu, Z., Jin, X., ... Huang, G. Q.	2019	An Internet of Things-enabled BIM platform for modular integrated construction: A case study in Hong Kong.	Advanced Engineering Informatics, 42(October), 100997.	https://doi.org/10.1016/j.aei.2019.100997	18	China	decision support services for prefabrication production, transportation, and on-site assembly processes	Using it to create the necessary items for a bill of quantity that will enable cost estimation to be undertaken for the project	1)The functions of operational hedging decision can also be integrated into the IBIMP for preventing potential risks. 2) the performance and working efficiency of a construction project can be further improved by processing and analyzing the collected data (Big Data can be adopted and integrated to the BIMP). 3) in order to improve and extend the applicability of the IBIMP in other projects and regions, more practical testing should be carried out..	Semantic Web Rule Language (SWRL) and processed by Stanford Protégé		This article is very interesting! He gives the method and tools for integrating the model with the construction site. It may be an initial model to support Leonardo's thesis. It could also be part of the thesis proposal to be developed in the BIM Execution project.
Pierre	Chen, H., & Luo, X.	2019	An automatic literature knowledge graph and reasoning network modeling framework based on ontology and natural language processing.	Advanced Engineering Informatics, 42(May), 100959.	https://doi.org/10.1016/j.aei.2019.100959	14	China	NAtural LAngage Processing (NLP)	NLP technology to extract ontologies	Not exactly for AEC but why not	Ontology-based knowledge graph ; BERT-based ontology elements		
Fernanda	Ao, S., Liu, K., Tang, L. C. M., & Li, W.	2016	A framework for integrating syntax, semantics and pragmatics for computer-aided professional practice: With application of costing in construction industry.	Computers in Industry, 83, 28–45.	https://doi.org/10.1016/j.compind.2016.08.004	13	UK	Costs estimation	This paper intends to establish an innovative means of taking data from the BIM linked to a project, and using it to create the necessary items for a bill of quantity that will enable cost estimation to be undertaken for the project. Three components are necessary to be computerised: the information type which is to be assessed for compatibility (syntax), the definition for the pricing domain (semantics), and the precise implementation environment for the standards being taken into account (pragmatics)				
Leonardo	Eray, E., Sanchez, B., & Haas, C.	2019	Usage of interface management systems in adaptive reuse of buildings	Buildings, 9	https://doi.org/10.3390/buildings9050105	11	Canada	Adaptive Reuse of Buildings					ontology of Interface Management for adaptive reuse projects is defined
Leonardo	Jiang, L., & Leicht, R. M.	2016	Supporting automated Constructability checking for formwork construction: An ontology	Journal of Information Technology in Construction	https://www.itcon.org/paper/2016/28	9	USA	constructability, automated checking	The established constructability ontology underpins the understanding of the constructability concepts for the benefits of integration, and the implementation of these concepts with proactive construction specific design feedback				the current work developed an ontology of constructability review to support automated constructability review through the employment of BIM.
Pierre	Fortineau, V., Paviot, T., & Lamouri, S.	2019	Automated business rules and requirements to enrich product-centric information.	Computers in Industry, 104, 22-33.	https://doi.org/10.1016/j.compind.2018.10.001	8	France	PLM (Product Life Management), BIM, Business How to integrate business rules into a product-centric information system	Business rules contain the memory of decades or centuries of experience		DALTON = DAta Linked Through Occurences Network (can be formalized as aun UML-like class diagram) DALTON-like ontology implemented in Protégé SWRL		Interesting bibliography on automated rul checking and business rules management
Pierre	Hong Lim, K.Y., Zheng, P., Chen C-H., Huang L.	2020	A digital twin-enhanced system for engineering product family design and optimization	Journal of Manufacturing Systems, 57, 82-93	https://doi.org/10.1016/j.jmsy.2020.08.011	8	Singapore	Engineering Products ; Digital Twin Architecture Model	A context-aware DT keeps products/assets compatible with their dynamic environment throughout their lifecycle. Semantic-driven models (knowledge graphs) using ontologies and real-time data acquisition. The system ontology, when coupled with real-time data input, can extract relevant details and infer new relations between entities	Real-time data acquisition on a real site, not in a lab	Labelled directed gaphs using RDF triples. Protégé is used to build a tower crane ontology (OWL-DL syntax for querying) ; reasoning plug-in such as Pellet for knowledge inference		Ontologies created from a learning pedagogy presented in https://doi.org/10.1016/j.promfg.2019.03.055
Fernanda	Perisic, A., Lazic, M., & Perisic, B.	2016	The Extensible Orchestration Framework approach to collaborative design in architectural, urban and construction engineering.	Automation in Construction, 71, 210–225.	https://doi.org/10.1016/j.autcon.2016.08.005	8	Serbia	daylight illumination simulation	In this article is discussed the basic Architectural Design, urban Planning and Construction Engineering domain cooperation aspects and suggest an Extensible Orchestration Framework (ExOF) model that may support them. The authors strongly believe that the ExOF will evolve to a sustainable and applicable hypertool that will support: a dynamic building of an ADUP and CE domain model through framework-based orchestration, extending and integration mechanisms implemented by multiple DSLs (Language Workbench) and the refined multilevel common ontology	.	ExOF, multiple Domain-Specific Language (DSL) (Language Workbench), CityGML, XML	.	very interesting paper, especialy because they show the necessity of a common ontology between Architectural Design, Urban Planning and Construction Engineering
Pierre	Vosseteld, N., & Hartmann, T.	2016	Modeling information for maintenance and safety along the lifecycle of road tunnels	Journal of Computing in Civil Engineering, 30		6	South Africa	Safety					Maintenance phase, PLM. Pierre, we don't have access to this article, could you insert the PDF into Mendeley, please ?!
Pierre	Hore, I. A.	2012	Designing a Framework for Exchanging Partial Sets of BIM Information on a Cloud-Based Service	International Journal of 3-D Information Modelling (IJ3DM)	10.4018/ijdm.2013100102	5	Ireland	BIM data exchange			SPARQL		Data exchange in BIM using Semantic Web technology
Fernanda	Moshtaghian, F., Golabchi, M., & Nasrzai, E.	2020	A framework to dynamic identification of project risks	Smart and Sustainable Built Environment	https://doi.org/10.1108/SASBE-09-2019-0123	5	Iran	Project risk	Findings – Creating an integrated risk identification platform reduced rework and time and cost control and change management, which were positive effects of risk identification at the right time.	Research limitations/implications – In order to identify risks, creating multilateral databases whose information integration enables timely completion of the project and compliance with the planning. There are limitations in this study. (1) This study has only identified the technical risks of the project. However, risks such as inflation or natural disasters also threaten the project. Therefore, in the future expansion of this research, we need to provide a solution for dealing with other risk categories; (2) the API provided is in 4.environment and does not support other BIM-based software.	In this case no ontology was created		Despite being interesting, this article does not propose an ontology. The word "ontology" is mentioned only once in the bibliographic review, saying that another author had proposed the creation of an ontology for risks in BIM projects
Pierre / Fernanda	Sinoh, S. S., Othman, F., & Ibrahim, Z.	2020	Critical success factors for BIM implementation: a Malaysian case study	Engineering, Construction and Architectural Management	https://doi.org/10.1108/ECAM-09-2019-0473	3	Malaysia	AEC Critical success factors for BIM	This paper aimed to identify critical success factors (CSFs) of BIM implementation among AEC firms in Malaysia using quantitative statistical methods. Non-technical factors such as management, leadership and coordination were found to have higher relevance compared to technical factors such as software and hardware. Ranking analysis of the CSFs found internal coordination factors to have more importance compared to external coordination factors.	This study found an interaction between internal and external coordination factors for the implementation of BIM. Future research could explore the dynamics of both intra- and inter-firm coordination, which may create an environment suitable for BIM implementation	In this case no ontology was created		Survey on the success factors for the implementation of BIM in the AEC industry.
Leonardo	Soman, R. K., Molina-Solana, M., & Whyte, J. K.	2020	Linked-Data based Constraint-Checking (LDCC) to support look-ahead planning in construction.	Automation in Construction, 120(July), 103393.	https://doi.org/10.1016/j.autcon.2020.103393	1	UK	Construction planning	Associated ontologies used for supporting LDCC	Previous research has reported that the ifcOWL ontology (used in our software application) is not well suited for linked-data applications [39]. In contrast with ontologies which are light and modular [100], ifcOWL is large, complex and contains unin-tuitive semantic constructs	Shapes Constraint Language (SHACL) : see IfcOWL to capture the model information, LinkOnt (a custom ontology detailed below). LinkOnt is the ontology we propose to support dynamic constraint- checking. This ontology introduces classes that are missing from IfcOWL but are required to do constraint-checking. LinkOnt ontology in-cludes the following classes (Fig. 3): TaskLevel, MainActivity, SubActivity, Sequence, Type, HasResource, Resource, ResourceProp, ResourceType, and OpReqirement.		
Pierre	Wan, H., Daidi, M., & Dengwei, W.		Design of a Multi-Agent System for exploiting the communicating concrete in a SHM/BIM context.	IFAC-PapersOnLine, 53(3), 372–379.	https://doi.org/10.1016/j.ifacol.2020.11.060	0	France	Communicating materials ; Smart products ; IoT ; Multi-Agent System	Distributed data ; Integration in BIM platforms (communication with remote servers) ; Active monitoring	The actual implementation of the IFC standards is not satisfying for Structural HEalth Monitoring use cases. Difficulty for having consistent GUIDs (Globally Unique IDentifiers used to identify ressources in the context of BIM) from one IFC file to another.	No ontology ; IFC BIM standards for communicatino with BIM platform (ISO 16739-1, 2018)		Need for a semantic layer (ontology) to fully benefit from the data stored in smart products?

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Bibliometric analysis

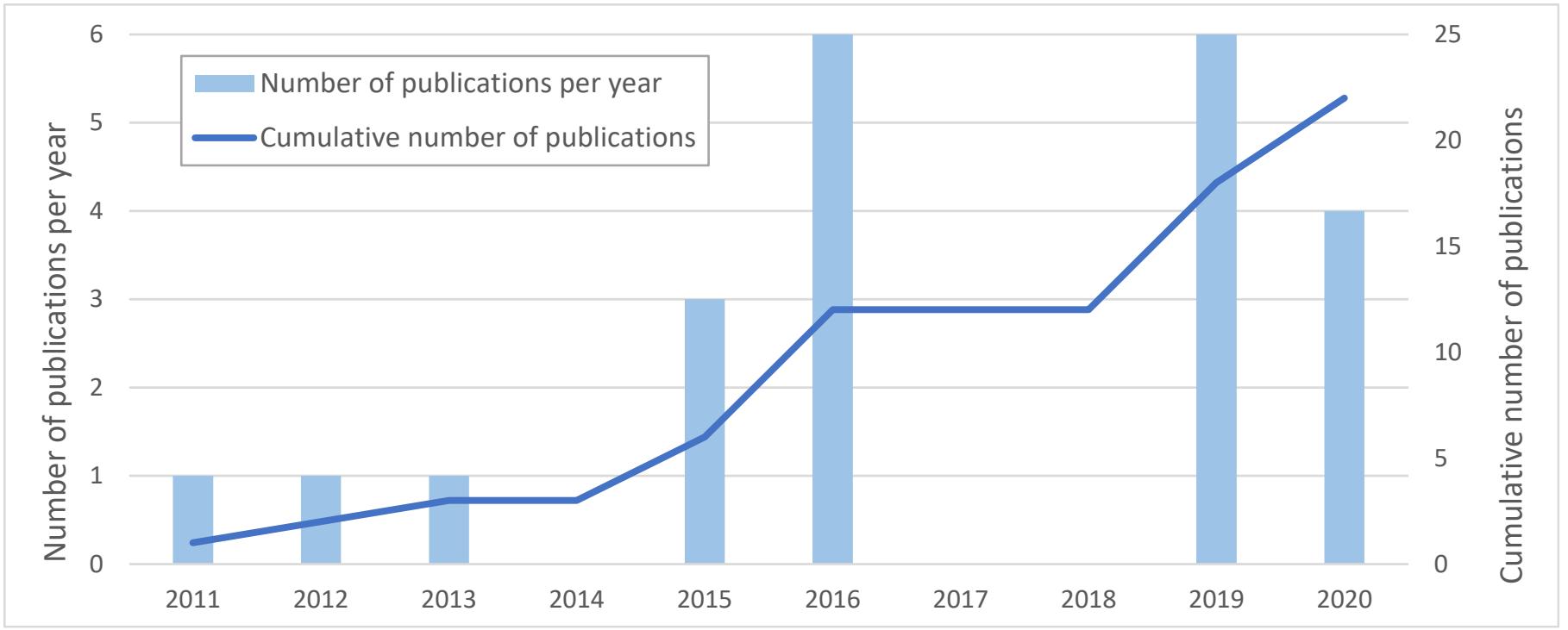


Figure 1. Number of publications per year and cumulative number of publications

Bibliometric analysis

Zone	Journals	No of Articles	%
CORE	Advanced Engineering Informatics	6	27%
RELEVANT	Automation in Construction	4	45%
	Computers in Industry	3	
	Engineering, Construction and Architectural Management	3	
MARGINAL	Buildings	1	27%
	International Journal of 3-D Information Modeling	1	
	Journal of Computing in Civil Engineering	1	
	Journal of Information Technology in Construction	1	
	Journal of Manufacturing Systems	1	
	Smart and Sustainable Built Environment	1	

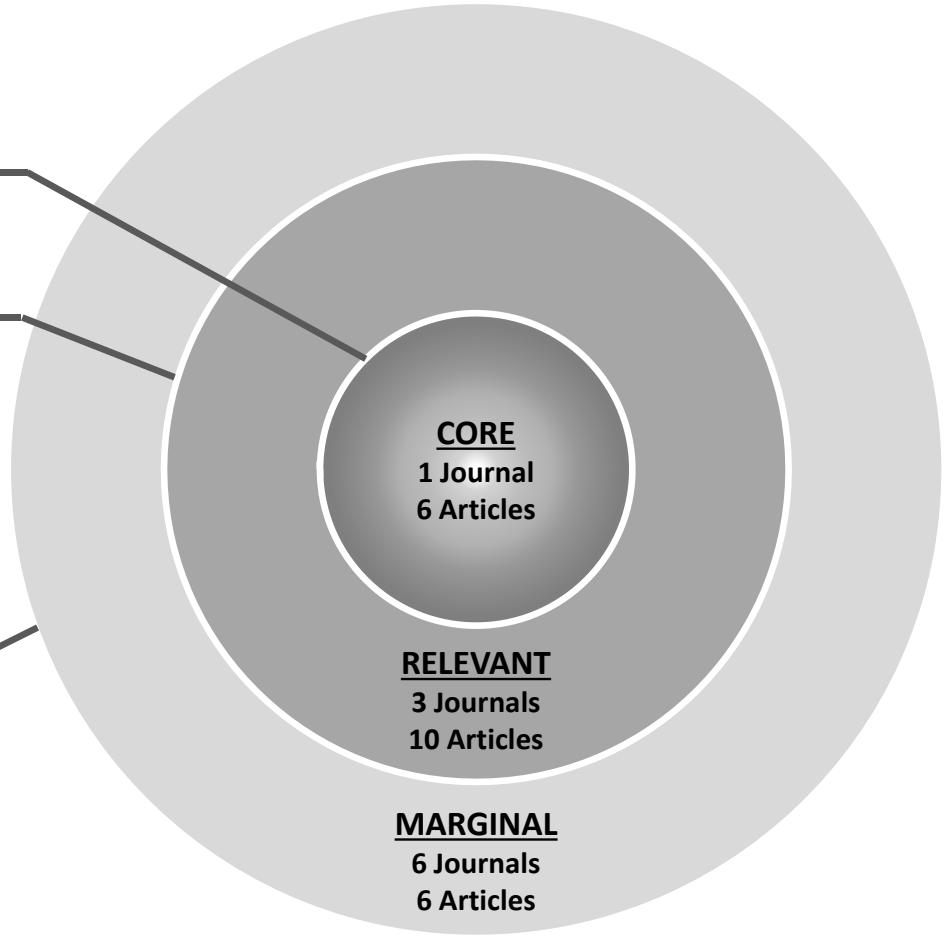
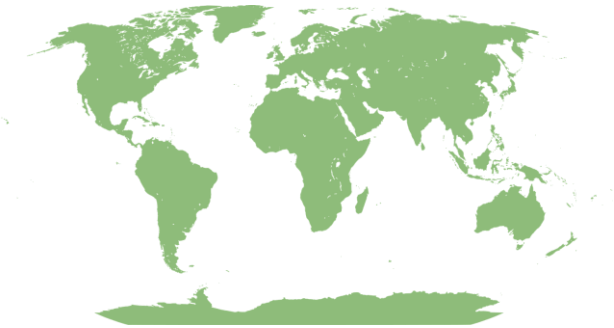


Figure 2. Core, relevant, and marginal journals for the 22 papers selected in this review of the literature

No of Citations	Authors	Year	Title	Published In	Country	Field of Research
145	Tang, S., Shelden, D. R., Eastman, C. M., Pishdad-Bozorgi, P., & Gao, X.	2019	**A review of building information modeling (BIM) and the internet of things (IoT) devices integration: Present status and future trends.**	Automation in Construction	USA	Literature Review: BIM; Internet of Things (IoT) Device; Sensors; Smart building; Smart City; Smart built environment; Integration;
68	Lee, Y. C., Eastman, C. M., & Solihin, W.	2016	**An ontology-based approach for developing data exchange requirements and model views of building information modeling**	Advanced Engineering Informatics	USA	BIM data exchange
65	Geyer, P.	2012	**Systems modelling for sustainable building design.**	Advanced Engineering Informatics	Germany	Sustainable building design
45	Dibley, M. J., Li, H., Miles, J. C., & Rezgui, Y.	2011	**Towards intelligent agent based software for building related decision support.**	Advanced Engineering Informatics	UK	Multi Agent System ; Facility Management ; BDI (Belief, Desire, Intention) model
29	Hoeber, H., & Alsem, D.	2016	**Life-cycle information management using open-standard BIM**	Engineering, Construction and Architectural Management	Netherlands	Building life-cycle information

Figure 3. Most cited articles selected in this work based on Google Scholar

Bibliometric analysis



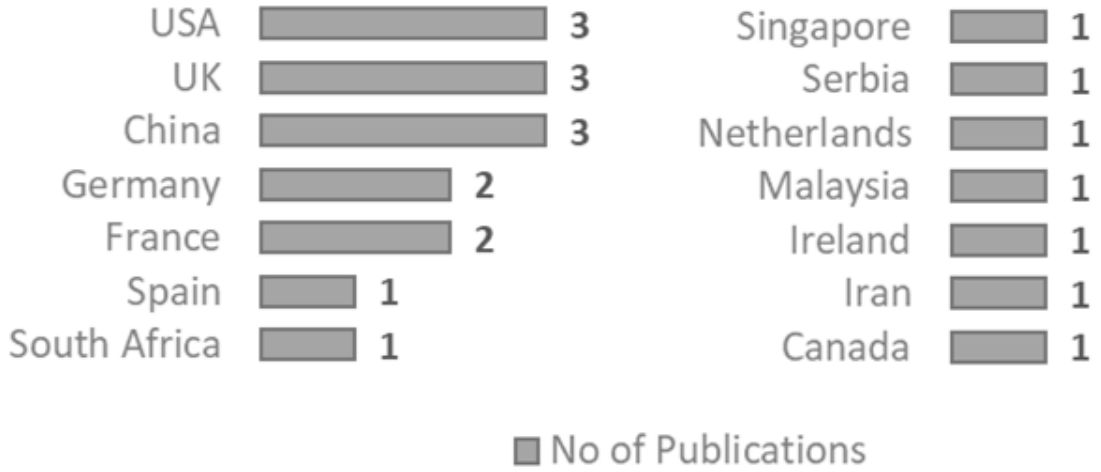


Figure 4. Country of origin of the main authors

Bibliometric analysis

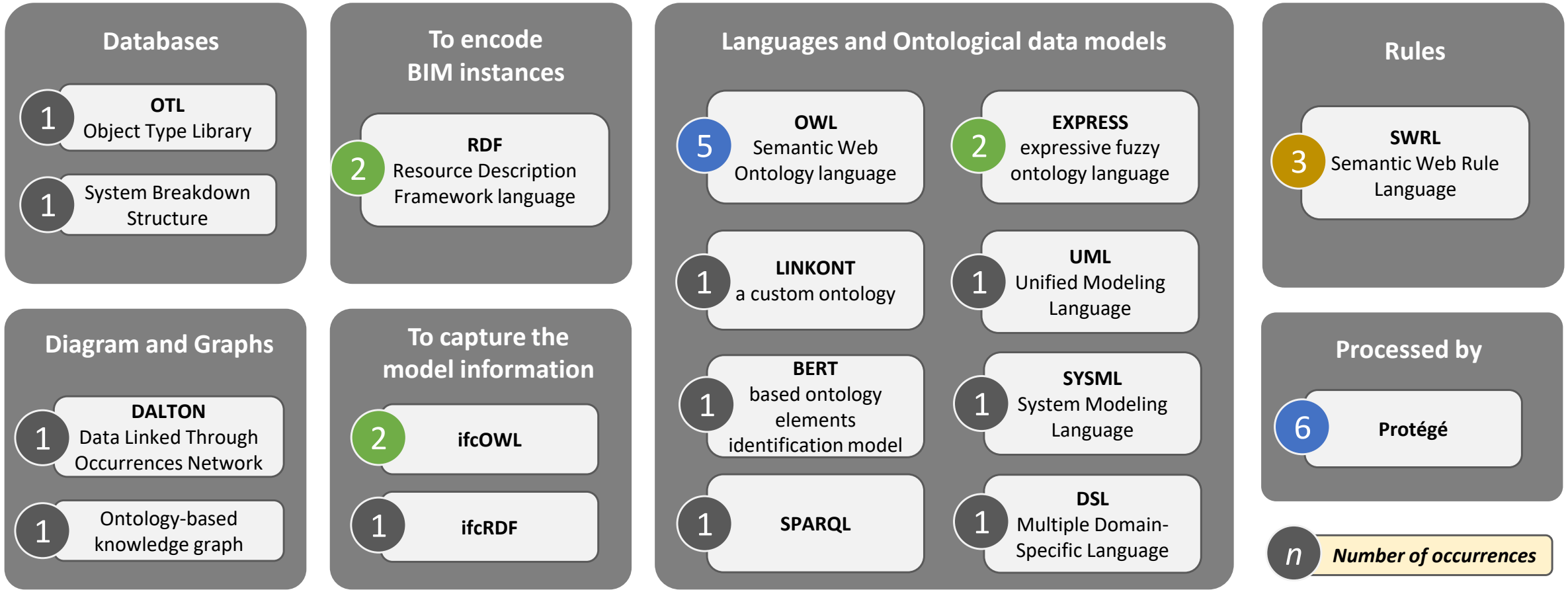


Figure 5. Map and occurrences of the main technological concepts found in the 22 articles analyzed in this work

4.1 Critical factors for BIM adoption

Sinoh et al. 2020: non-technical factors such as management, leadership, and coordination

Lee et al. 2016: no robust standard for construction semantics and data exchange requirements = information lack of consistency

4.2 Design and pre-construction phase

Perisic et al. 2016: common ontology for illumination simulation

Jiang & Leicht 2016: ontology to support automated constructability BIM in reinforced concrete structural elements

Xu et al. 2016: web ontology for automatic cost estimation

[Sinoh, S. S., Othman, F. & Ibrahim, Z. (2020). Critical success factors for BIM implementation: a Malaysian case study. *Engineering, Construction and Architectural Management*]
[Lee, Y. C., Eastman, C. M. & Solihin, W. (2016). An ontology-based approach for developing data exchange requirements and model views of building information modeling. *Advanced Engineering Informatics*, 30(3), 354-367]
[Perisic, A., Lazic, M. & Perisic, B. (2016). The Extensible Orchestration Framework approach to collaborative design in architectural, urban and construction engineering. *Automation in Construction*, 71, 210-225]
[Jiang, L. & Leicht, R. M. (2016). Supporting automated constructability checking for formwork construction: An ontology. *Journal of Information Technology in Construction* (ITcon), 21(28), 456-478]
[Xu, S., Liu, K., Tang, L. C. M. & Li, W. (2016). A framework for integrating syntax, semantics and pragmatics for computer-aided professional practice: With application of costing in construction industry. *Computers in Industry*, 83, 28-45]

4.3 Construction phase

Soman et al. 2020: ontology to to support look-ahead planning in construction

Das et al 2015: construction supply chain, ontology for material and another for purchase order

4.4 Post-construction phase

Eray et al. 2019: ontology to interface management in an adaptive reuse project.

Fitz et al 2019: cyber-physical systems for structural health monitoring and structural control with metamodeling

Hoeber & Alsem 2016: an information structure model that spreads throughout the entire life cycle of a construction project. BIM is used in this case to store object-based information according to the semantics derived from systems engineering methodology and forming the whole ontology of information.

[Soman, R. K., Molina-Solana, M. & Whyte, J. K. (2020). Linked-Data based Constraint-Checking (LDCC) to support look-ahead planning in construction. *Automation in Construction*, 120, 103369]
[Das, M, Cheng, J. C. P. & Law, K. H. (2015). An ontology-based web service framework for construction supply chain collaboration and management. *Engineering, Construction and Architectural Management*]
[Eray, E., Sanchez, B. & Haas, C. (2019). Usage of interface management system in adaptive reuse of buildings. *Buildings*, 9(5), 105]
[Fitz, T., Theiler, M. & Smarsly, K. (2019). A metamodel for cyber-physical systems. *Advanced Engineering Informatics*, 41, 100930]
[Hoeber, H. & Alsem, D. (2016). Life-cycle information management using open-standard BIM. *Engineering, Construction and Architectural Management*]

05 Conclusions

- This review contributes to highlighting relevant studies in this field in the last ten years.
- Despite the fact that BIM is relatively widely studied, **BIM combined with ontologies and systems engineering** appears as emerging and the main outcomes of this combination so far are summarized.
- **Bibliometric information** has been extracted and the main outcomes have been summarized.
- Outcomes have been found in the design, construction, and operation and maintenance phases with **improved interoperability, enhanced capacities for capturing knowledge, automation of various tasks**.

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Thank you!

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