LBD server

LBD server: Visualising Building Graphs in web-based environments using semantic graphs and glTF-models

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ABSTRACT

Over the last years, Building Information Modelling (BIM) has been increasingly adopted in building projects for its benefits to collaboration and associated risk mitigation. Recent work is trying to make this data available over the web (web-based BIM applications). Most notable in making building data web-ready is the Linked Building Data (LBD) initiative. This group has worked on a number of vocabularies and ontologies, thereby starting from a linked data approach (RDF graphs), aiming at representing building data on the web. Yet, a platform is needed that allows to manage the available linked building data, including 3D geometric visualisation, which is the topic of this article: a LBD server. The LBD server is a web-based application which allows users to upload building data and visualise their geometric representation in a graphical user interface, thereby also enabling to link to this data.

Key words: *Linked Building Data, IfcOWL, Web-based BIM, Xeogl*

1 INTRODUCTION

Over the last decade, new advancements in software technologies have enabled the Architecture, Engineering & Construction (AEC) industry to become increasingly more digitised (Pauwels , P. & Petrova, E. 2018). Such developments, commonly identified as ‘Building Information Modelling/Management’ (BIM) technologies, encompass many different aspects of the building industry, such as digital visualisation techniques, information exchange, innovative formal design or collaboration processes. Overall, BIM has been characterised by the shift from interpretative information of two-dimensional plans and paper documents to fully integrated models that incorporate digital building data. Even though there are still several obstacles to overcome before BIM gets fully adopted into the professional scene and building data becomes fully digitised, the building industry reports economic incentives due to the benefits to collaboration and associated risk mitigation that BIM already brings to the sector at this stage (Eastman, C. et al. 2011).

Building Information Models improve interoperability and efficient exchange between stakeholders through utilizing central vendor-neutral formats for building information. Most of these open standards used throughout BIM processes are developed and maintained by BuildingSMART international. The most notable format for AEC information is the IFC or "Industry Foundation Classes", which aims to describe all architectural construction data in the Building lifecycle. The IFC remains legible across all specialised software, facilitating collaboration between project partners (BuildingSMART 2020). Yet, it remains primarily a data exchange format.

Recent work is trying to make this data available over the web (web-based BIM applications). Having building data available on the web opens up the possibility to exchange building data more openly. Being able to display and share geometric as well as non-geometric building data over accessible web servers and browsers will greatly improve communication between project participants. Furthermore, data can in such case be directly linked to alternative geometric representations (point clouds, different kinds of meshes, simplified CSG models), and to related semantic data (e.g. facility management data, heritage data, geospatial data) in a web-friendly manner, thereby scaling up the usability of building data significantly.

This highlights the importance of fully digitised and integrated building data. This would not only allow stakeholders to exchange their building data without loss of information, but also allow developers to interact more effectively with the building data, extending the functionalities of BIM using innovative techniques such as machine learning, semantic inference, or querying (Zadeh, P.A. 2018). In other words, the potential that BIM could offer remains partially untapped as long as we are unable to work with fully interchangeable building data.

The Linked Building Data (LBD) initiative, that started in the W3C LBD Community Group, has focused heavily on making this kind of building data web-ready. This group has worked on a number of vocabularies and ontologies, thereby starting from a linked data approach (RDF graphs), aiming at representing building data on the web. This approach diverges away from the use of IFC as a file-based exchange format. Yet, a platform is needed that allows to manage the available linked building data, including 3D geometric visualisation.

Therefore, this paper describes the Linked Building Data server (LBD server), a web-based building data platform that incorporates (semantic) web technologies, which attempts to remedy the aforementioned problems. The LBD server is a web-based application which allows users to upload building data and visualise their geometric representation in a graphical user interface. At the moment, building data is mainly uploaded in the IFC file format, after which the loaded IFC model is converted to Collada using the IfcConvert application from IfcOpenShell (IfcOpenShell 2019). This in turn is converted into a GL Transmission Format (glTF) using COLLADA2GLTF (KhronosGroup 2019). These glTF streams are rendered into full 3D scenes of our architectural projects using Xeogl, an open source JavaScript library from Xeolabs for 3D model visualization on WebGL, supported by most modern web browsers (Xeolabs 2019).

In this article, we will first give an overview of the state of the art in representing building data on the web. Then, the LBD server project is presented, including a number of first implementations and tests. The article ends with an overview of conclusions and a list of next steps, which mainly includes a need for an investigation of user interactions with the data and interface.

2 SERVING BUILDING DATA ONLINE

2.1 Linked Data

The semantic web (Berners-Lee et al. 2001) can be regarded as an extension of the world wide web, enabling users of the web to connect various pieces of digital data in semantic graphs, as a novel alternative to document-based approaches. This method of publishing and connecting data is called "Linked Data", referring to the interconnectivity of the data definitions. It utilises the open standardised data model called the "Resource Description Framework" (RDF[1]). In such an RDF framework, information is organised in the form of 'triples', each time consisting of three data concepts (subject-predicate-object) in which the subject shares a relationship, defined by the predicate, to a certain object. This means that the information stored in graphs can be enriched without limit and remains dereferenceable over the web. This is a significant advantage in comparison to conventional relational databases in the case of highly interconnected data and a very broad scope. Each of these data concepts can be identified separately through a globally unique Uniform Resource Identifier (URI[2]), which keeps similar data concepts distinguishable from one another. The design of the URI also allows the information resource to be semantically enriched with additional data, regardless of discipline. This means that information becomes modular and boundlessly expandable, opening up new possibilities for interdisciplinary communication and collaboration.

[1] https://www.w3.org/RDF/

[2] https://www.w3.org/wiki/URI

This interconnectivity is made possible through the use of semantic schemas that define specific real-world concepts. Inside these schemas, called 'ontologies'[3], abstract data concepts are coherently defined and may refer to other ontologies or definitions inside the same ontology to define it, similar to a dictionary, see Fig. 1. By combining different definitions and relationships, an abstract concept can become fully described and comprehended. By publishing these definitions of data concept openly on the web, digital applications are able to navigate from one concept to another using their URI. Therefore, the RDF representation of data remains structured and legible to computing (Berners-Lee, T. 2009), allowing for semantic reasoning and interpretation of the data as well as advanced rule checking or inference of the data schemas. These benefits, in turn make the RDF framework an effective format that can be interpreted and used inside digital applications.

Figure 1 The definition for ifcBuildingStorey in the ifcOWL ontology (Pauwels & Terkaj 2015)

2.2 Linked Building Data

An increasing amount of building data is being published as RDF graphs and AEC industry specific ontologies are being developed (Pauwels, P. et al. 2017c). The benefits of structuring building data using semantic web technologies is the improved interoperability, linking across domains and additional logical inference and proofs (Pauwels, P. et al. 2017a) which coincide with many of the ambitions of the building industry such as lossless information exchange and complete interoperability. By defining ontologies and data definitions for different disciplines within the AEC-sector, a connected and comprehensively legible interdisciplinary practice becomes possible. Furthermore, the utilised ontologies do not need to be limited to the AEC-sector alone, instead building data can be enriched by connecting it to other linked open data from disciplines outside the building industry, further improving the quality and interdisciplinary nature of our building data.

Several Web Ontology Languages (OWL[4]) have been introduced to the building industry that expand upon the existing open standards such as the ones developed by BuildingSMART. IfcOWL[5] is a Web Ontology Language representation of the EXPRESS-based IFC schema into a RDF-based schema for Linked Data (Beetz, J. et al. 2009, Pauwels, P. et al. 2017b). By translating IFC to RDF through the use of ontologies, building information becomes available as an RDF graph while remaining in the structure of the widely used standard of IFC (see Fig. 2).

[3] https://www.w3.org/standards/semanticweb/ontology/

[4] https://www.w3.org/OWL/

[5] https://github.com/buildingSMART/ifcOWL

Figure 2 Building project visualised in ifcOWL using IFC definitions (Pauwels & Roxin 2016)

However, it is clear that ifcOWL alone will be unable to cover the full dictionary that the AEC sector needs. Rather, the IFC schema is best used as an exchangeable and interoperable format for communicating general information, and therefore serves its purpose as a vendor-neutral exchange format, but not as a fully integrated and all-inclusive description of a project. Fortunately, due to the nature of the semantic web, building data does not need limit itself to a single ontology and can be expanded by multiple, smaller and modular ontologies that are easier to wield or are able to cover specific areas not included in the IFC schema (Rasmussen et al., 2017).

Notable ontologies of this sort include the Building Topology Ontology (BOT[6]) and the Building Product Ontology (BPO[7]). BOT is an ontology that simplifies element relationships in construction to more efficiently visualise projects in RDF (Rasmussen, M., H., et al. 2019). The latter, BPO allows users to freely define building element properties while adhering to a semantic web structure. This makes it easier for manufacturers to define their products and still reap the benefits from the semantic web in regards to accessibility and modularity (Wagner, A., Rüppel, U. 2019).

3 PROPOSAL FOR AN LBD SERVER APPROACH

While the benefits of the semantic web technology for the building industry have been made clear, the actual applications on the market today remain limited. This is partially because semantic technologies and applications are characterised by a steep learning curve (Verborgh, R. 2018), but also because the building industry is still catching up with the digital revolution and BIM. Current developments are bringing BIM closer to open platforms to improve interoperability and efficiency of exchange.

There is an opportunity for developers to combine the innovative Linked Data technologies with BIM visualisation in order to bring the semantic data closer to the user. Giving industry stakeholders an interface to visualise and manipulate Linked Building data without the required semantic web experience will significantly flatten the learning curve of Linked Data management and can motivate new developments to take place in the field of construction industry semantics. At the same time, if Linked Building Data can be attached to existing BIM models and visualised in web-based clients, the platform for collaboration and exchange of information can shift from standalone vendor software towards open web-based applications (often termed Digital Twins now). This would facilitate lossless information exchange and interdisciplinary communication between stakeholders as the data is more readily available.

[6] www.w3c-lbd-cg.github.io/bot/

[7] www.github.com/w3c-lbd-cg/product

Common Data Environments (CDE[8]) for visualising and managing BIM models for collaboration exist in various forms. the most widely used are vendor-proprietary software such as Autodesk BIM360[9] or Graphisoft's Bimcloud[10]. These act foremost as BIM repositories and collaboration platforms, complete with organisational and design tools (Chong, H. et al. 2014). Although these kinds of software offer many features to manipulate the building data, they remain closed source and use proprietary models locked behind paywalls. More importantly, they are typically file-oriented and much less amenable to a Linked Building Data approach to building data management. More promising alternatives are web-based applications such as BIMServer[11].

These allow to upload and visualise BIM models inside a web-browser and are open source. BIMserver in particular enables users to open up their own BIM server for file sharing.

Imported IFC data for each project is stored as objects in a specific database, which allows for analysis of the IFC data. Open source initiatives such as these give developers the opportunity to create additional plugins and tools that expand the application's initial features.

Even though BIMserver permits management and visualisation of BIM data to a large extent, it is unable to cover all aspects of AEC-industry related information. Also the recent graph-oriented approaches towards building data management are missing, let alone that a fully web-based modular linked data approach is followed. Therefore, it Is difficult to enable specific tasks such as managing non-geometric data, linking to external data or computing and analysis can be delivered through modular web applications. Such modular web applications, called BIM bots (Berlo, L. 2015), each provide a single specialised task that admit an input in order to produce a certain output. They need full transactional and web-based data exchange, which is best supported using a linked building data approach.

The other option is for current web-based applications to integrate semantic web technologies in order to accommodate for complex building data and at the same time allow interconnectivity with data from other fields, not typically included in the AEC-sector.

4 THE LBD SERVER

4.1 Outline and purpose

This section of the paper describes the Linked Building Data server (LBD server), a proposed web-based building data server that incorporates semantic web technologies, currently in development at the University of Ghent, Belgium. The LBD server is a web-based server which allows users to upload building data (e.g. IFC data) and visualise their geometric representation in a graphical user interface, as well as view Linked Building Data attached to the project. By combining BIM visualisation techniques with semantics, the LBD server attempts to bring Linked Building Data closer to the professional scene and improve communication between project stakeholders. Assimilating semantic web technologies in this application for IFC visualisation has its own merits, as hinted at before.

Linked Building Data can be enriched boundlessly through the use of semantic web ontologies. The semantic data initially imported in the server upon user upload can be enriched with multiple other data sets in alternative vocabularies in order to improve the quality of the data. Linked Building Data Graphs can be interconnected, starting from a single or multiple LBD server nodes, forming a large knowledge network that is able to span across different industries and disciplines. Additionally,

[8] https://www.iso.org/obp/ui/#iso:std:iso:19650:-1:ed-1:v1:en

[9] https://www.autodesk.com/bim-360/

[10] https://www.graphisoft.com/downloads/bimcloud/

[11] https://github.com/opensourceBIM/BIMserver

managing building data in Linked Data Graphs provides the possibility of advanced rule checking against rulesets, semantic inference and querying possibilities.

Thus, the LBD server acts as an interface (Fig. 3) to upload BIM models and attach relevant Linked Data to parts of the project and allow users to peruse this Linked Building Data, while still adhering to visually recognisable geometry of the model for navigation. Using semantic web technologies as complementary descriptors of the building data inside a web-based visualisation application will bring the model closer to a complete rendition of the project.

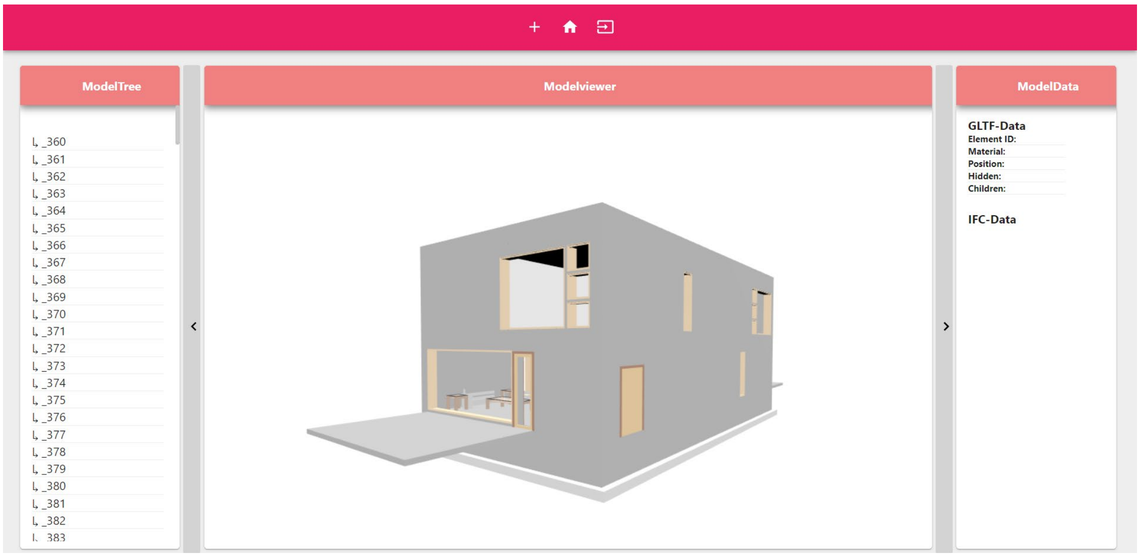

Figure 3 The LBD server viewer interface

4.2 Implementation approach

The LBD server is being developed as a JavaScript web application which connects a web GUI with multiple databases that are each optimised for serving specific data (RDF triples, geometry, images). Even though this application promotes the use of graph Databases, more conventional types of database management systems still remain useful, and can be included because of its modular and web-based system architecture. While RDF Graph databases allow for a much larger flexibility for storing highly interconnected building data, conventional document-based databases can be used for storing non-textual documents and files such as images or the IFC model geometry.

Currently the LBD server makes use of a Cloud based document store to store building data and relevant documents. As of this writing, IFC models and accompanied IFC data are utilised as a use case for development of the LBD server.

4.3 Geometric data

Visualisation of the building geometry inside the browser occurs in a similar fashion to most IFC viewer applications. Namely, the geometry is made available into an available standard geometry representation for the web, namely glTF. One can obtain glTF in multiple ways, yet we document below how this glTF representation can be obtained when starting from an IFC file.

First the loaded IFC model is converted to the "COLLAborative Design Activity"-format (COLLADA[12]), developed and maintained by the industry consortium KhronosGroup. COLLADA is a standard XML-based schema to make it easy to transport 3D assets between applications, and used as an intermediary

[12] https://www.khronos.org/collada/

format (KhronosGroup 2019). The conversion from IFC to COLLADA utilises the IfcConvert[13] application from the open source software library ifcOpenShell, yet standardised COLLADA files can easily be obtained directly from any 3D editor program. The COLLADA file is afterwards converted into a GL Transmission Format (glTF[14]) using the COLLADA2GLTF convertor (KhronosGroup 2019). The glTF format utilises JavaScript Object Notation (JSON[15]) schema to organise the geometric information of the model. JSON allows the glTF format *'to be cross-platform and web-friendly ; and to hold geometry and texture assets in binary blobs for future expandability of asset types that may include streaming and compression*' (KhronosGroup 2013). By using these DAE and glTF standards, the LBD server aspires to rely as much as possible on available standards for the representation of data, thereby enabling wide adoption and re-use of embedded data. Also the JSON and RDF formats play a very important role in this regard. The glTF utilises JSON to divide the 3D model into mesh-objects, which include texture information and matrix location. The LBD server allows to upload an IFC file inside a project, after which it automatically goes through the above-mentioned string of conversions, finally to be stored as glTF data. After upload, the IFC file can be discarded, as data exchange is complete.

These glTF streams can be rendered in any openGL-enabled browser. To render the converted glTF streams into 3D scenes, the LBD server utilises Xeogl[16], an open source JavaScript library from xeolabs for 3D model visualization on WebGL, which is a specification supported by most modern web browsers (Xeolabs 2019). The xeogl tool is able to differentiate between the geometries of the various elements present in the converted model.

4.4 Non-Geometric data

Of course, the geometric data needs to be linked to the available semantic Linked Building Data. When starting from IFC data and converting this data using IfcConvert, the mesh objects in the glTF file also includes meta-data from the IFC format; namely an encoded version of the IFC Global Identifier (GlobalId) that remains present in the glTF file. The encoded IFC GlobalId is attached to every mesh-object inside the glTF file. This GlobalId can be used as a connection between the geometries inside the xeogl viewer and the original IFC data schema, as a unique identifier to locate specific IFC elements of the model. Any Linked Building Data cloud typically relies on the full UUIDs that is also used in the glTF data.

So, links between data can be made by relying on identical IDs. When relying fully on a linked data approach, it is best to create meaningful links between geometry and semantics, ideally relying on the 'bot:hasComplexGeometry' and/or 'omg:hasGeometry' predicate, instead of using 'sameAs' links.

Currently, however, the LBD server aims to utilise this GlobalId as an identifier that connects the geometry to the respective RDF graph (Fig. 4). Links between models are now made directly in the API middleware. This makes it possible to summon Linked Building Data relevant to the selected geometry inside the LBD server user interface.

[13] http://ifcopenshell.org/ifcconvert

[14] https://www.khronos.org/gltf/

[15] https://www.json.org/json-en.html

[16] https://xeogl.org/

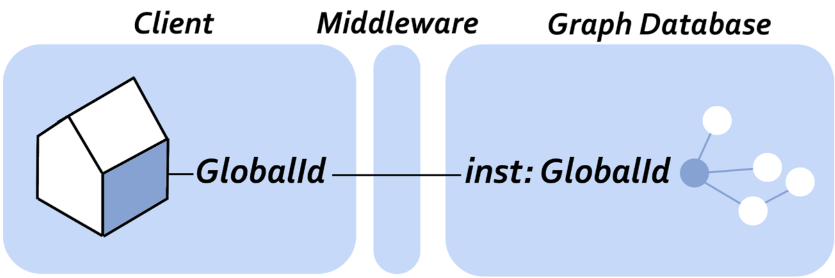

Figure 4 Schema of connectivity between glTF mesh geometry and graph data

4.5 User interaction and interface

The user is able to navigate the 3D model by interacting with the xeogl viewer component or by sifting through the 'ModelTree'-tab, depicted in Fig. 3. Clicking on a single element inside the viewer component or inside the ModelTree will highlight the selected element as well as zoom in on the element inside the viewer. Relevant Linked Building Data is queried for and appears inside the 'ModelData'-tab for the selected element. More advanced use cases are currently under development, thereby aiming particularly at enabling BIM Bots that connect directly to the API middleware.

5 CONCLUSION

This paper proposes the increased combination of semantic web technologies to web-based BIM applications in order to improve integrity and quality of building data. The transition from conventional document based database systems to semantic graph databases allows rule checking, inference and reasoning capabilities to assist users in managing their Linked Building Data more effectively.

The concept for the LBD server has been described. The main goal is to allow its users to interact with Linked Building Data very intuitively. By utilising BIM visualisation techniques in combination with semantic web technologies, the LBD server can make it possible to navigate the Linked Building Data in an intuitive manner. The LBD server will be useful for collaboration platforms that necessitate visualisation and communication of building data between project participants. By allowing users to interact more easily with Linked Building Data, web-based BIM applications and semantic AEC technology gain more credence, bringing us closer to an open, web-based and transactional BIM practice.

Several topics for future work remain of interest. First, in the LBD server, the goal is to link building data (RDF nodes) to other RDF graphs to make it possible to enrich the model with additional information. As of this writing, the LBD server viewer displays limited amounts of information about selected elements. Making the attached Linked Building Data readily available in the interface is an important milestone for the LBD server that is not yet reached.

Second, there is a vast amount of building information that is not bound to building geometry or is not meant to be navigated in 3D space or lists. The LBD server project will need to decide how such information such as project data, labour, time,… should be taken into account, if at all.

Lastly, an important topic not yet covered by the LBD server in its current state is the manipulation of semantic data attached to the model. The interface does not yet allow the user to interact with the Linked Building Data found in the graph database. Building an appropriate user interface that displays the semantic data needs to be developed, and likely depends on particular use cases.

REFERENCES

Beetz, J., van Berlo, L., de Laat, R., & van den Helm, P. (2010). BIMserver.org–An open source IFC model server. Proceedings of the 27th CIB W78 Conference on Information Technology in Construction, 8.

Beetz, J., Van Leeuwen, J. & de Vries, B., (2009) IfcOWL: a case of transforming EXPRESS schemas into ontologies, Artificial Intelligence for Engineering Design, Analysis and Manufacturing 23. pp. 89 101. http://dx.doi.org/10.1017/ S0890060409000122.

Berlo, L. (2015). Automate your work with BIM bots. Available online: https://www.slideshare.net/berlotti/bim-bots, Consulted March 2020.

Berners-Lee, T. (2009). Linked Data. Available online: https://www.w3.org/DesignIssues/LinkedData.html, Consulted November 2019.

Berners-Lee, T., Hendler, J. Lassila, O. (2001). The semantic web. Scientific american, 284(5). pp. 34-43.

BuildingSMART. (2020) "Industry Foundation Classes (IFC) - An Introduction." Available online: https://technical.buildingsmart.org/standards/ifc/ Consulted January 2020.

Chong, H., Wong, J.S. & Wang, X., (2014). An explanatory case study on cloud computing applications in the built environment. Automation in Construction 44, pp. 152–162.

Eastman, C., Teicholz, P., Sacks, R. & Liston, K. (2011). BIM handbook : a guide to building information modeling for owners, managers, designers, engineers and contractors. 2nd edition. ISBN 978-0-470-54137-1

Heath, T. (2009). An introduction to Linked Data. Available online: http://tomheath.com/slides/2009-02 austin-linkeddata-tutorial.pdf, Consulted November 2019.

ISO. (2018). ISO 16739-1:2018 Industry Foundation Classes (IFC) for data sharing in the construction and facility management industries -- preview. 1st edition.

Kiviniemi, A., Fischer, M. & Bazjanac, V., (2005). Integration of multiple product models: Ifc model servers as a potential solution, in: Proc. of the 22nd CIB-W78 Conference on Information Technology in Construction

KhronosGroup. (2013) "Khronos COLLADA now recognized as ISO Standard" Available online: https://www.khronos.org/news/press/khronos-collada-now-recognized-as-iso-standard, Consulted March 2020

KhronosGroup. (2019) "Collada2gltf." "Collada:3D asset exchange schema" Available online: https://github.com/KhronosGroup/COLLADA2GLTF and https://www.khronos.org/collada/, Consulted January 2020

Logothetis, S., Karachaliou, E., Valari, E. & Stylianidis, E.. (2018). OPEN SOURCE CLOUD-BASED TECHNOLOGIES FOR BIM. ISPRS - International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences. XLII-2. 607-614. 10.5194/isprs-archives-XLII-2-607 2018.

Mohammad, A., Changali, S., Van Nieuwland, M. (2015). The construction productivity imperative. Available online: https://www.mckinsey.com/industries/capital-projects-and infrastructure/our-insights/theconstruction-productivity-imperative, Consulted November 2019

Pauwels, P., Krijnen, T., Terkaj, W. Beetz, J. (2017a). Enhancing the ifcOWL ontology with an alternative representation for geometric data. Automation in Construction 80, pp. 77-94.

Pauwels, P., Petrova, E. (2018). Information in Construction.

Pauwels, P. & Terkaj, W. (2017b) “ifcOWL ontology (IFC4x1_RC3).” Available online: https://users.ugent.be/~pipauwel/ontologies/ifc/20170101/IFC4x1_RC3/, Consulted February 2020

Pauwels, P., & Terkaj, W. (2016). EXPRESS to OWL for Construction Industry: Towards a recommendable and usable ifcOWL Ontology. Automation in Construction, 63, 100.

Pauwels, P., Van Deursen, D., Verstraeten, R., De Roo, J., De Meyer, R., Van de Walle, R. & Van Campenhout, J., (2011). A semantic rule checking environment for building performance checking. Automation in Construction 20, 506–518

Pauwels, P., Zhang, S., & Lee, Y.-C. (2017c). Semantic Web Technologies in AEC Industry: A Literature Overview. Automation in Construction, 73, 145.

Rasmussen, M.H., Pauwels, P., Hviid, C.A. & Karlshøj, J. (2017) “Proposal of a central AEC ontology for domain specific extensions.” Proceedings of the joint conference on computing in construction, no. 1, pp.237-244. Greece:Heraklion.

Rasmussen, M.H., Pauwels, P., Lefrançois, M. & Schneider, G.F. (2019) “Building Topology Ontology Draft Community Group report 07 january 2019.” Available online: https://w3c-lbd-cg.github.io/bot/# Consulted January 2020.

Törmä, S. (2013). Semantic Linking of Building Information Models. 2013 IEEE Seventh International Conference on Semantic Computing, 412. IEEE.

Wagner, A., Rüppel, U. (2019). BPO: The Building Product Ontology for Assembled Products. Proceedings of the 7th Linked Data in Architecture and Construction Workshop - LDAC2019

Xeolabs. (2019) “Xeogl.” Available online: http://xeogl.org/, Consulted January 2020.

Zadeh, P.A. (2018). Introduction to Machine Learning in Construction. Conference on Construction Management Seminar at UBC

Short bio

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