

Integration of environmental data in BIM tool & Linked Building Data *

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Abstract. Environmental assessment is a critical need to ensure building sustainability. In order to enhance the sustainability of building, involved actors should be able to access and share not only information about the building but also data about products and especially their environmental assessment. Among several approaches that have been proposed to achieve that, semantic web technologies stand out from the crowd by their capabilities to share data and enhance interoperability in between the most heterogeneous systems. This paper presents the implementation of a method in which semantic web technologies and particularly Linked Data have been combined with Building Information Modelling (BIM) tools to foster building sustainability by introducing products with their environmental assessment in building data during the modelling phase. Based on Linked Building Data (LBD) vocabularies and environmental data, several ontologies have been generated in order to make both of them available as Resource Description Framework (RDF) graphs. A database access plugin has been developed and installed in a BIM tool. In that way, the LBD generated from the BIM tool contains, for each product a reference to its environmental assessment which is contained in a triplestore.

Keywords: Linked Building Data(LBD) · Environmental data · Building Information Modelling(BIM).

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1 Introduction

In previous decades, environmental impact control through life cycle analysis has become a hot topic in various fields. In France, the key figures for energy [19] show that the building sector alone consumes around 45% of the energy produced each year. From this last observation emerged the idea to improve the methods hitherto employed in the construction industry, in particular, those related to the exchange of information to facilitate diverse assessment around the facility throughout its life cycle. Among others, the assessment of the environmental impact of the building is one of the most important studies to be conducted and that implies accurate information available and shared between involved actors. Concerning information exchange issues [28], open standards such as Industry Foundation Classes (IFC) [33,18,5] or CityGML [16,11], but also semantic web technologies have been widely used to try to overcome it with some success elsewhere.

However, there are a number of problems that still do not have accomplished solutions. Among other issues highlighted by Pauwels [22], this paper addresses the issue of associating semantic web technologies with environmental databases to increase the flexibility needed to perform and assess the building's environmental impact throughout its life cycle. By implementing our approach based on RDF graphs, this work provides insights on how LBD can be combined with environmental data in the form of RDF graphs in order to improve the environmental impact assessment of a building throughout its life cycle.

In Section 2, we provide the state of the art about LBD and environmental data. It is followed by the research method (Section 3), which has two major parts: making environmental data available as Linked Data (Section 4) and the integration of these data in a BIM tool (Section 5). Section 6 ends the document with a summary of the work, a discussion and highlights possible future works.

2 State of the art

2.1 Environmental data

Life Cycle Assessment (LCA) can be defined as a methodological framework (defined in the DIN ISO 14040/44) to assess environmental impacts associated with all the stages of a product's life from raw material extraction through materials processing, manufacture, distribution, use, repair and maintenance, and disposal or recycling. Results of LCA carried out for a specific product, organized in conformance to the European environmental standard EN 15804, constitute an Environmental Product Declaration (EPD); which thus communicates the environmental performance of the product over its lifetime [17].

An EPD database contains a comprehensive amount of product declarations across one or more countries. Information contained in EPD databases are made to be used by experts in various areas including the agriculture or building sector, to enable the LCA of their final product during its life cycle. In the case of a building, experts face difficulties because they are from many different fields and they need a complementary training to include environmental aspect in their traditional assessment. Moreover, there is a lack of interoperability between the different software systems that might be involved. Anton et al [7,1,2] have highlighted some pros and cons of integration of LCA in a BIM environment. Two approaches were here suggested: based on extracting direct project data from the BIM model to perform LCA, the first approach allows evaluation of the complete construction during its entire life cycle. The second approach is suitable for selecting materials and elements since it is based on the inclusion of LCA-related information in the features of the various BIM objects.

Closer to the second approach of Anton et al [7,1,2], the work in this document is focusing on EPD databases that contain construction products and are usable in France. In France, sanitary information has been added to EPD to form what is called “*Fiche de Déclaration Environnementale et sanitaire*” (FDES) or “Environmental and Health Declaration Sheet”.

2.2 Linked Building Data

Linked Data, also called the Web of Data is data available as RDF graphs, that provides an extension of the Web by enabling sharing and publishing of raw data with the use of open standards [12]: RDF, Uniform Resource Identifier (URI), Simple Protocol and RDF Query Language (SPARQL), etc. Available data are linked into a semantic network of data, in which each property and resource has a web-based URI as an internationally unique identifier. These graphs can subsequently be stored in a triplestore. A triplestore is a purpose-built database that stores semantic facts in the form of RDF graphs, against which queries can be made in SPARQL [20].

LBD is the result of the use of semantic web technologies for the structuring of building data into a set of RDF graphs that can be shared between stakeholders, involved tools and through the Internet. LBD is making use of a set of available vocabularies, including the Building Topology ontology (BOT)[34] as a central reference ontology, with the aim of gathering, using in tools and sharing of building data. Many implementations recently emerged in relation to LBD [30,4,25].

Based on BOT, the IFCToLBD converter by Jyrki Oraskari⁵ converts IFC building data into RDF linked building data (LBD) graphs [4]. In comparison to

⁵ <https://github.com/jyrkioraskari/IFCToLBD>

previous implementations of building data into RDF graphs [24,3,29,31,23,21], data are not in one monolithic and complex graph. Graphs are rather separated into building elements, products and property set definitions, all relying on different partial ontologies. At the time of writing, a product ontology was used inspired by the building elements available in IFC. Properties were output in the instance graph, yet they did not follow a specifically published ontology. Taking advantages of the opportunity of separating product data from others (properties and building elements)[4], environmental RDF data can now easily be integrated to it without increasing the complexity of data querying or browsing.

Since the Building Life Cycle (BLC) includes a huge diversity of domains and disciplines as architecture, project management and many others, there is a serious need to address interoperability issues faced by involved actors when they exchange information [27]. Looking forward to avoid existing solutions, Costa et al.[6] address this issue by applying several transformations on generated data, like mapping between input and target ontologies using SPARQL. Thus, this method is subject to limitations of each particular domain-based format generated. For instance, semantic limitations of IFC as stated by Bonduel et al. [4] will be engaged in the mapping process.

To conclude, in the case of LBD, RDF graphs are generated from IFC files [4] or through a plugin directly available in a BIM tool [34,26] as it is the case in our work.

3 Research methodology

With the aim of enhancing sustainability in building construction, enhancing the way products are chosen during the life cycle of the building is of critical importance. That enhancement could be made through the use of semantic web technologies such as RDF, SPARQL, etc. Pursuing that goal, data were first gathered from EPD databases, then two ontologies were generated. Using the latter, data were translated from their original format (XML) to RDF graphs. To address the issue of accessibility of products and their environmental assessment at the same time by users during the whole BLC and particularly the design phase, we extend an existing BIM tool by adding a plugin to upload products from a triplestore of EPD databases. LBD of each specific building is then generated using our plugin through the user interface (UI) of the BIM tool. The overall method is described in Figure 1.

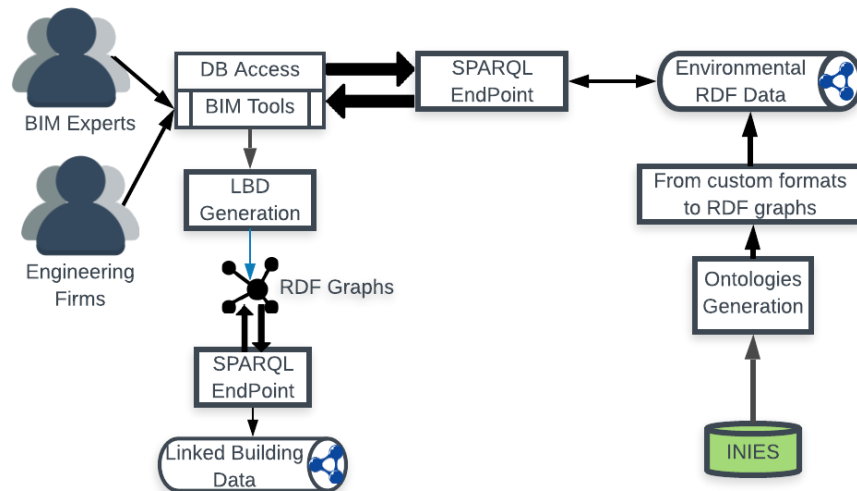


Fig. 1. The method. **Right side:** Using a Java Application Programming Interface (API), ontology derived from environmental data are first generated. Then, environmental data from INIES database are translated from XML to RDF graphs and stored in a triplestore. **Left side:** a plugin is developed and installed in a BIM tool to enable the access to the environmental data. At the end of the modelling phase, users can generate LBD and store them into a triplestore.

4 Making environmental data available as Linked Data

To make environmental data available as RDF graphs, data are first gathered from EPD databases, then using nomenclature data, corresponding ontologies are generated. Nomenclature data contains a classification of construction products. Finally, using generated ontologies, environmental data are translated from their custom formats into RDF graphs. All those functionalities have been developed in one single Java API. The following paragraphs present each step of this process.

4.1 Gathering data from EPD databases

The EPD database chosen to apply our method is INIES⁶. INIES is the “French national reference database on environmental and health declarations of products, equipment and services for the evaluation of the performance of works” [13].

⁶ <http://www.inies.fr/about-the-inies-database/>

It provides Environmental and Sanitary Declaration Sheets (FDES) for construction products. The information in the database is mostly verified by an independent third party in accordance with European regulatory requirements: the NF EN 15804 A1 standard and its French supplement XP P01-0641CN.

An academic license was used to access the INIES web services (IWS) needed to implement the presented method. The round trip of sending requests and receiving responses, using Simple Object Access Protocol (SOAP), allows to gather INIES data in the form of XML files; each file containing the response for each sent request. After the login, the *GetNomenclature* request is sent to gather the entire nomenclature tree used in INIES.

The response of the *GetNomenclature* request consists of a collection of Nomenclature items. Each item includes various properties such as id, a name, the id of its parent, and so on. Each item is identified with an id in the INIES database and can have a parent which is another item. “*Bois massif*” is one of the nomenclature items in the INIES database. Its XML serialization is presented in Listing 1.1.

```

1 <NomenclatureItem>
2   <NomenclatureItemID>153</NomenclatureItemID>
3   <NomenclatureItemName>Bois massif</NomenclatureItemName>
4   <ParentItemID>23</ParentItemID>
5   <TreeLevel>3</TreeLevel>
6   <HasChildren>>false</HasChildren>
7 </NomenclatureItem>

```

Listing 1.1. GetNomenclature response - the 153 Nomenclature Item and its parent with id '23'

4.2 Ontology generation

Using Apache Jena [10] in a Java API, the GetNomenclature XML file was used to generate the Construction Product (CProduct) ontology with the prefix *cproduct* and the URI <http://mindoc.enit.fr/voc/ConstructionProduct>. From each Nomenclature.Item in the GetNomenclature file, a concept with the same “Nomenclature_Item_Name”, “Nomenclature_Item_ID” and “Parent_Item_ID” is created. Depending on the value of “Parent_Item_ID” characteristic of each item, “subClassOf” relationships are created between concepts. Based on INIES documentation and the goal of the CProduct ontology, all necessary annotations are added to the ontology.

In order to generate INIESOnto, GetAllFDESFullDataById request was sent in order to obtain all data contained in each FDES or about a specific product by precisising its id.

```

1 <soap:Envelope xmlns:xsi="http://www.w3.org/2001/XMLSchema-
  instance" xmlns:xsd="http://www.w3.org/2001/XMLSchema"
  xmlns:soap="http://schemas.xmlsoap.org/soap/envelope/">
2 <soap:Body><GetFDESFullDataById xmlns="http://tempuri.org/">
3 <FDES_ID>4156</FDES_ID>
4 <SessionID>ipI7R65GPC</SessionID>
5 </GetFDESFullDataById> </soap:Body> </soap:Envelope>

```

Listing 1.2. GetAllFDESFullDataById request - the 4156 FDES data

As a result of this request for any product (see Listing 1.2 for product with ID=4156), all available data on LCA of the product were obtained and stored in an XML file. This includes a list of constituent products, health data, a set of quantity gauges, etc. Using the latter XML file, another ontology was then generated with our Java API. Depicted in Figure 2, the generated ontology is called INIESOnto as it contains all properties that can be found in each FDES file. Having the URI <http://mindoc.enit.fr/voc/INIESOnto>, INIESOnto has as preferred prefix: *fdes*. Holding only data properties that are specific to INIES, INIESOnto is generated separately from CProduct ontology but imports it. That means INIESOnto contains all concepts and relations from the CProduct ontology.

4.3 From data existing in databases to RDF graphs

Using the CProduct and INIESOnto ontologies, a number of RDF graphs containing environmental data about multiple products were generated with our Java API, as described in Figure 3. Figure 4 presents a part of the generated data.

Once generated, environmental RDF graphs were stored into a Stardog triplestore. Developed in Java, Stardog is a knowledge graph platform that enables the storage of multiple triples with its Stardog server [32]. Using SPARQL, stored data can be queried and updated through desktop, web or command line user interface, as depicted in Figure 5. In addition, APIs like dotNetRDF library [8] have been used to interact directly with the Stardog server once it is launched. dotNetRDF is an open source .NET library to parse, manage, query and write RDF, but also to access RDF triplestores like Stardog or Jena through various user interfaces (UI).

An ontology for the categories of construction product has been generated: the CProduct ontology. Importing CProduct, the INIESOnto hold characteristics of each construction product as described in the INIES database. Using those two ontologies, any XML file resulting from IWS and containing environmental data about a particular construction product can be translated into RDF graphs and stored into a triplestore.

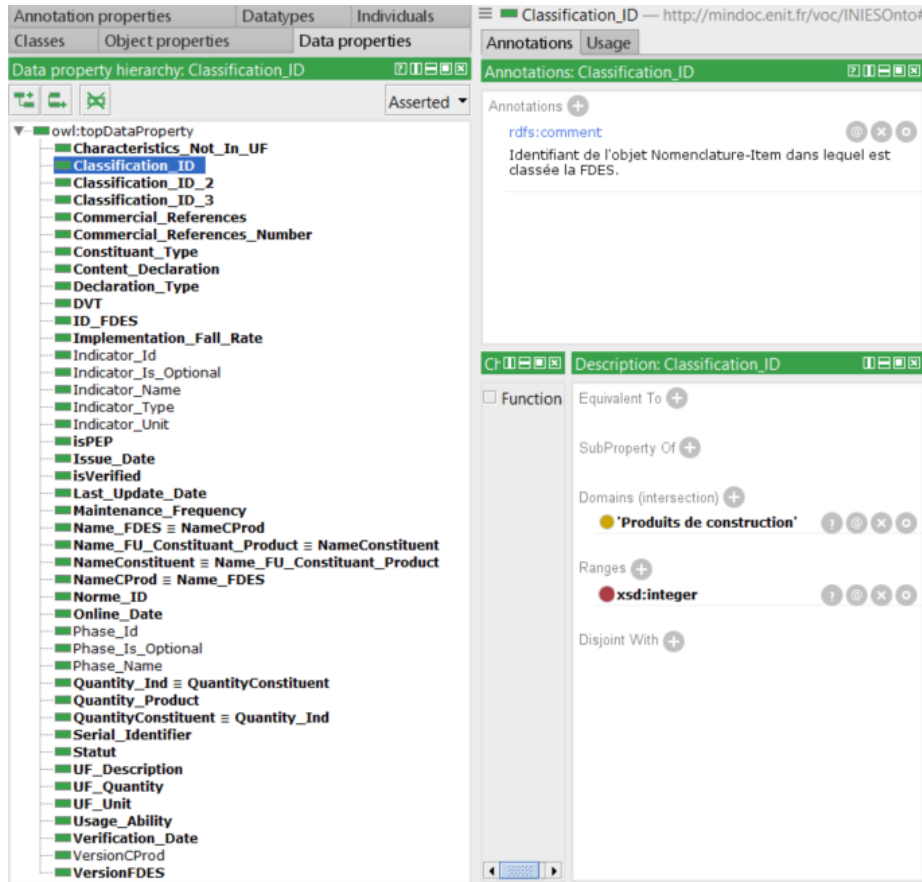


Fig. 2. INIESOnto

5 Integration of environmental data in BIM tool & linked building data

In order to properly do an environmental building assessment by taking advantage of our environmental RDF graphs in a flexible way, we need to give to the user an opportunity to choose products in a practical way and through its usual interface: its preferred BIM tool for example. The objective of the following paragraph is to present the implementation of our method to enable “Linked” EPD database access in a BIM tool and the generation of LBD embedded with environmental data.

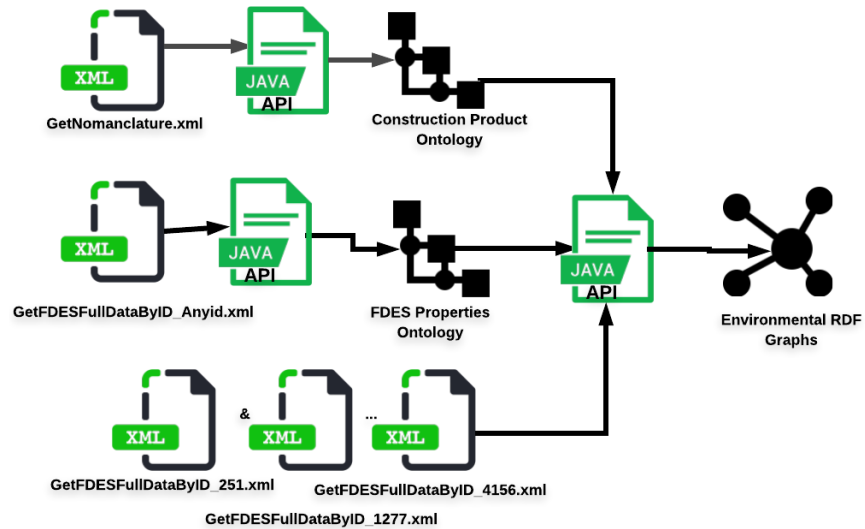


Fig. 3. Generating Environmental RDF Graphs with ontologies & Java API

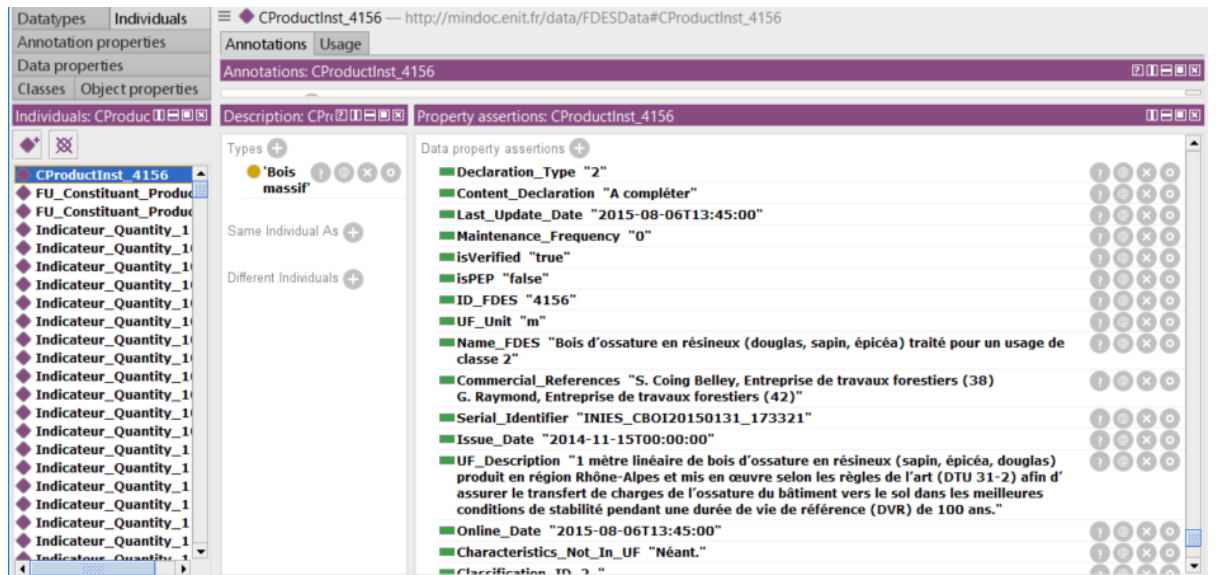


Fig. 4. Translating Environmental data into RDF Graphs with ontologies & Java API.
The URI used is http://mindoc.enit.fr/data/FDESData#CProductInst_4156

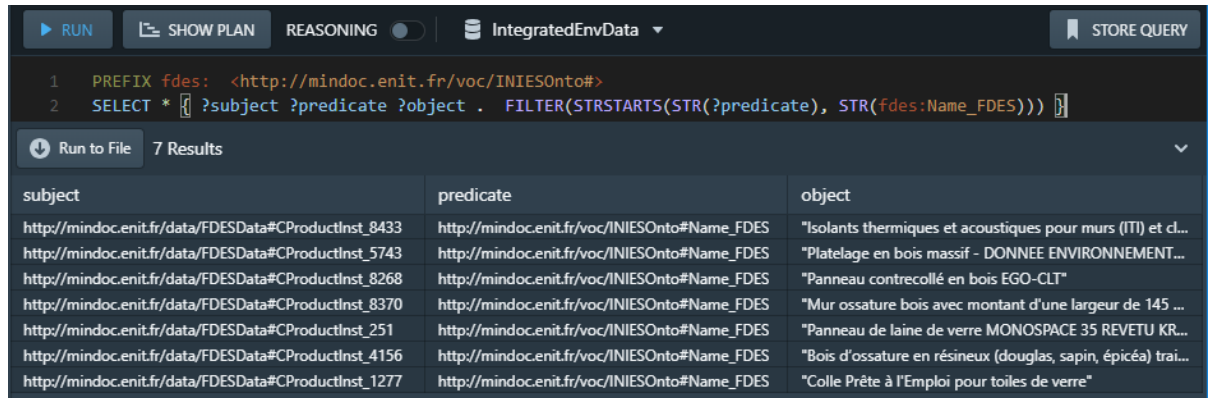


Fig. 5. Environmental RDF graphs are store in a triplestore in Stardog Server and are queried with SPARQL

5.1 Database access

Among many existing BIM tools used in the design phase of the BLC, Revit [14,9] was chosen for our use case. In fact, Rasmussen et al. [26] have developed a plugin to generate and export LBD from Revit. After adding URI and HOST parameters to each Revit project, the program generates a BOT-compliant Turtle file for the building itself, but also Turtle files respectively for properties, product classes and geometries. The URI parameter can be used to store a URI for each construction product in the Revit UI, and the HOST parameter is the base URI of the construction project in Revit.

In order to fulfil our need, we added the parameter named “ProductURI” to each object of the Revit project. The ProductURI parameter is the URI of a corresponding construction product in our triplestore of environmental data. This parameter is added by a brand new plugin which is an extension of the plugin developed by Rasmussen et al. The aim of this parameter is to store the URI of the product chosen by the user so that we can later query all LCA information about each product constituting the building. To enable the user to choose a product from the database, the list of existing products was uploaded in the UI. Behind the scene, the program queries the triplestore named “IntegratedEnvData”, which contains all products with their environmental data and displays understandable labels of all available products in the UI in a combo box, as depicted in Figure 6.

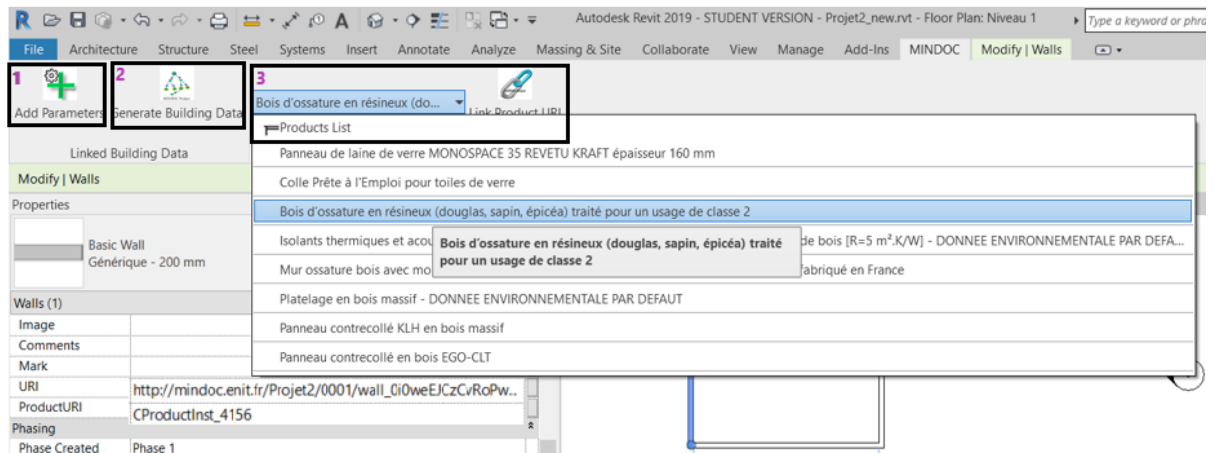


Fig. 6. Product List in Revit UI

5.2 User interaction

A Revit plugin has been developed as an extension of the one developed by Rasmussen et al. That plugin adds a tab named “MINDOC” to Revit UI. The UI of MINDOC tab is divided in three main features: the addition of parameters to the project (see left side of Figure 6), the product selection (see right side of Figure 6) and the generation of LBD. During the modelling, users should click on the button “Add Parameters” in order to add a URI and ProductURI to each element of the project and a HOST parameter to the project itself. Once added, they can assign to them corresponding values adapted to the project needs.

For the product selection, users are required to select an element of the building, and then select the product to which they want to associate it. Finally, they click on the button “Link Product URI” to assign the product URI to the ProductURI parameter of the selected element. Behind the scene, the program finds the URI of the selected product and assigns it the ProductURI parameter of the selected element. Figure 6 (see the drop-down list at the right) shows how products from the triplestore are accessible from the UI.

When the modelling is complete, users click on “Generate Building Data” in order to generate the LBD of their building. Users have the choice to either save data into several Turtle files or to dump data in the designated triplestore; then, the program generates the LBD. For the first choice, LBD is stored in several Turtle files. In the case data are dumped to a triplestore (e.g Stardog), the triplestore is updated with the generated LBD, data can further be queried with SPARQL requests through a web page, the Stardog studio desktop application, any stand-alone (web) application, or the Windows command line UI.

6 Conclusion

The proposed framework has shown that not only making environmental data available as RDF graphs but also integrating them into a BIM tool can severely improve the flexibility of gathering and sharing data during the BLC. By introducing environmental data at early stages of the building project, the latter also fosters the availability of data for conducting the environmental assessment of the building in a flexible way. In the work presented, some refinements are needed, like the event and exception handling in the Revit plugin, design and interaction in the user interface, and scaling of the data infrastructure.

This work is a step toward the goal of enabling the environmental assessment of a building during its whole life cycle. The developed plugin can be extended to any other triplestores compliant with the dotNetRDF library or further if another library is used. The source code will be available on GitHub at the end of the MINDOC project.

As depicted in Figure 1, there is no specific need to generate IFC files in the proposed framework but environmental data can be added to it, using URI and Product_URI parameters, so that other tools can further take advantage of the result. Another future work could be to translate other EPD databases into RDF graphs and integrate all environmental data using the Simple Knowledge Organization System (SKOS) ontology for mapping. The SKOS ontology from Isaac et al. [15] can be further used to link ontologies. For instance `skos:relatedMatch` can be used to express that a particular property in one side is comparable to another property on the other side. This may be useful to link INIESOnto to QuartzOnto, with Quartz being another environmental database.

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References

1. Laura Álvarez Antón and Joaquín Díaz. Integration of lca and bim for sustainable construction. *International Journal of Social, Behavioral, Educational, Economic, Business and Industrial Engineering*, 8(5):1378–1382, 2014.
2. Laura Álvarez Antón and Joaquin Diaz. Integration of life cycle assessment in a bim environment. *Procedia Engineering*, 85:26–32, 2014.
3. Jakob Beetz, Jos Van Leeuwen, and Bauke De Vries. Ifcowl: A case of transforming express schemas into ontologies. *Ai Edam*, 23(1):89–101, 2009.
4. Mathias Bonduel, Jyrki Oraskari, Pieter Pauwels, Maarten Vergauwen, and Ralf Klein. The ifc to linked building data converter-current status. In *6th Linked Data in Architecture and Construction Workshop*, volume 2159, pages 34–43, 2018.
5. Qian Chen, YUNUS EMRE HarmanCI, Yaowen Ou, and BORJA GARCIA De Soto. Robust ifc files to improve information exchange: An application for thermal energy simulation. In *ISEC*, pages 1–6, 2017.
6. Gonçal Costa and Álvaro Sicilia. Methodology for data integration using sparql constructs in the aec industry. In *Proceedings of the 5th Linked Data in Architecture and Construction Workshop (LDAC2017), Dijon, France*, pages 13–15, 2017.
7. Joaquín Díaz and Laura Álvarez Antón. Sustainable construction approach through integration of lca and bim tools. In *Computing in Civil and Building Engineering (2014)*, pages 283–290. 2014.
8. dotNetRDF Project. dotNetRDF an open source .net library for rdf. <https://www.dotnetrdf.org/>, 2018. Accessed: 2019-01-07.
9. FinancesOnline. Best 20 Building Information Modeling (BIM) Software in 2019financesonline.com. <https://financesonline.com/building-information-modeling/>, 2019. Accessed: 2019-01-24.
10. The Apache Software Foundation. Apache Jena apache jena. <https://jena.apache.org/>, 2018. Accessed: 2018-02-17.
11. Gerhard Gröger and Lutz Plümer. Citygml—interoperable semantic 3d city models. *ISPRS Journal of Photogrammetry and Remote Sensing*, 71:12–33, 2012.
12. Tom Heath and Christian Bizer. Linked data: Evolving the web into a global data space. *Synthesis lectures on the semantic web: theory and technology*, 1(1):1–136, 2011.
13. Alliance HQE-GBC. INIES—Les données environnementales et sanitaires de références pour le bâtiment bienvenue sur la base inies. <http://www.inies.fr/accueil/>, 2018. Accessed: 2019-01-22.
14. 2019 Autodesk Inc. Revit—Autodesk free software for students and educators. <https://www.autodesk.com/education/free-software/revit>, 2018. Accessed: 2017-01-07.
15. Antoine Isaac and E Summers. Skos simple knowledge organization system. *Primer, World Wide Web Consortium (W3C)*, page 44, 2009.
16. Thomas H Kolbe. Representing and exchanging 3d city models with citygml. In *3D geo-information sciences*, pages 15–31. Springer, 2009.
17. One Click LCA. Simple guide on Environmental Product Declaration for Green Building a comprehensive guide to environmental product declarations. <https://www.oneclicklca.com/simple-epd-guide/>, 2018. Accessed: 2019-01-22.
18. Yong-Cheol Lee, Charles M Eastman, and Wawan Solihin. An ontology-based approach for developing data exchange requirements and model views of building information modeling. *Advanced Engineering Informatics*, 30(3):354–367, 2016.

19. MINISTÈRE DE LA COHÉSION DES TERRITOIRES ET DES RELATIONS AVEC LES COLLECTIVITÉS TERRITORIALES MINISTÈRE DE LA TRANSITION ÉCOLOGIQUE ET SOLIDAIRE. Chiffres clés de l'énergie - Édition 2018statistiques.developpement-durable.gouv.fr. <https://www.statistiques.developpement-durable.gouv.fr/chiffres-cles-de-lenergie-edition-2018>, 2018. Accessed: 2019-02-04.
20. ontotext.com. What is RDF Triplestore? ontotext. <https://www.ontotext.com/knowledgehub/fundamentals/what-is-rdf-triplestore/>, 2018. Accessed: 2019-01-23.
21. Pieter P. ifcowl ontology file added for ifc4_add1, 2014.
22. Pieter Pauwels. Supporting decision-making in the building life-cycle using linked building data. *Buildings*, 4(3):549–579, 2014.
23. Pieter Pauwels, Thomas Krijnen, Walter Terkaj, and Jakob Beetz. Enhancing the ifcowl ontology with an alternative representation for geometric data. *Automation in Construction*, 80:77–94, 2017.
24. Pieter Pauwels and Anna Roxin. Simplebim: From full ifcowl graphs to simplified building graphs. In *Proceedings of the 11th European Conference on Product and Process Modelling (ECPPM)*, pages 11–18, 2016.
25. Mads Rasmussen, Pieter Pauwels, Maxime Lefrançois, Georg Ferdinand Schneider, Christian Hviid, and Jan Karlshøj. Recent changes in the building topology ontology. In *LDAC2017-5th Linked Data in Architecture and Construction Workshop*, 2017.
26. Mads Holten Rasmussen. MadsHolten/revit-bot-exporter export from autodesk revit to bot-compliant turtle. <https://github.com/MadsHolten/revit-bot-exporter>, 2018. Accessed: 2018-12-17.
27. Fogueu B.K. Magniont C. Abanda F.H. Tchouanguem Djuedja J.F., Karray M.H. Interoperability challenges in building information modelling (bim). In *In: Popplewell K., Thoben KD., Knothe T., Poler R. (eds) Enterprise Interoperability VIII. Proceedings of the I-ESA Conferences, vol 9. Springer, Cham*, 2019.
28. Kamsu-Fogueu B. Magniont C. Tchouanguem J.F., Karray M.H. and Abanda F.H. Interoperability challenges in building information modeling (bim). In *IESA'18 Interoperability for Enterprise Systems and Applications Conference; Berlin, Germany, March 22-23*, 2018.
29. Walter TERKAJ and Pieter PAUWELS. A method to generate a modular ifcowl ontology. In *Proceedings of the 8th International Workshop on Formal Ontologies meet Industry*, 2017.
30. Walter Terkaj, Georg Ferdinand Schneider, and Pieter Pauwels. Reusing domain ontologies in linked building data: the case of building automation and control. In *8th International Workshop on Formal Ontologies meet Industry*, volume 2050, 2017.
31. Walter Terkaj and Aleksandra Šojić. Ontology-based representation of ifc express rules: An enhancement of the ifcowl ontology. *Automation in Construction*, 57:188–201, 2015.
32. Stardog Union. Stardog the enterprise knowledge graph platform. <https://www.stardog.com/>, 2018. Accessed: 2018-12-28.
33. Renaud Vanlande, Christophe Nicolle, and Christophe Cruz. Ifc and building lifecycle management. *Automation in construction*, 18(1):70–78, 2008.
34. W3C-LBD-CG. w3c-lbd-cg/bot building topology ontology. <https://github.com/w3c-lbd-cg/bot>, 2018. Accessed: 2018-09-10.