Semantic approach to formalize knowledge from building renovation domain: application to the IsoBIM project

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Abstract. The introduction of semantic technologies to the construction field is a concept that has been explored many times over the last few years. However, building renovation tends to be overlooked when talking about advancements in construction. Even if, Renovation projects consists 57% of construction activities, the renovation field is still the least developed. Information exchange between the project's different actors is still a persistent problem. Therefore, this paper proposes a semantic approach that aims to formalize knowledge from the renovation domain, using BIM as the information source, to design a dynamic digital representation of a renovation project (construction digital twin). In this context, and to highlight the remaining scientific questions, a case study of a renovation project is used to assess the current state of the renovation process and to test the ontology under development.

Keywords: semantic web, building renovation, digital twin.

1 Introduction

Buildings in Europe are responsible for about 36% of all CO2 emissions, 55% of the electricity consumption and 40% of the total energy consumption [1]. Thus, building renovation[1] rate in Europe is expected to increase in the near future in an attempt to soften the impact on the environment. Till today, the renovation field relies heavily on manual labor, which is reflecting on the current renovation rate, since less than 2.5% of

[1] This paper deals with the renovation of the exteriors of buildings. Hence, the term "building renovation" refers to "renovation of the external envelope of buildings using external insulation".

existing buildings are renovated each year[2]. Information technology is expected to play a considerable part in enhancing the progress of renovation projects. However, the construction sector suffers from specificities preventing its introduction. Indeed, since more than 93% of the construction companies regroups less than 10 employees, most of these companies do not have the resources required to adopt and deploy computer tools to automate their processes. Moreover, the strong fragmentation of the sector leads to interoperability issues and therefore information exchange problems, that also need sufficient resources and expertise to be solved. Consequently, problems arise regarding collaboration between actors, planning updates, respect of deadlines, strongly disturbing the evolution of the construction project. This observation is even more correct for the renovation domain.

As a result, the ANR ISOBIM project[3] , summarized in figure 1, aims to speed up the renovation process by providing low-cost and fully integrated computer tools to companies of the renovation sector. Based on the Lean and BIM paradigms, the IsoBIM platform ought to cover the entire process of renovation of buildings, from the identification of the constructive solution, through the development of configuration and layout models to the development of models for planning and monitoring construction projects. In this context, one of the objectives is to be able to ensure the management of all project information in a formal and integrated repository capable of covering the design, layout, planning and monitoring phases which this research will attempt to achieve.

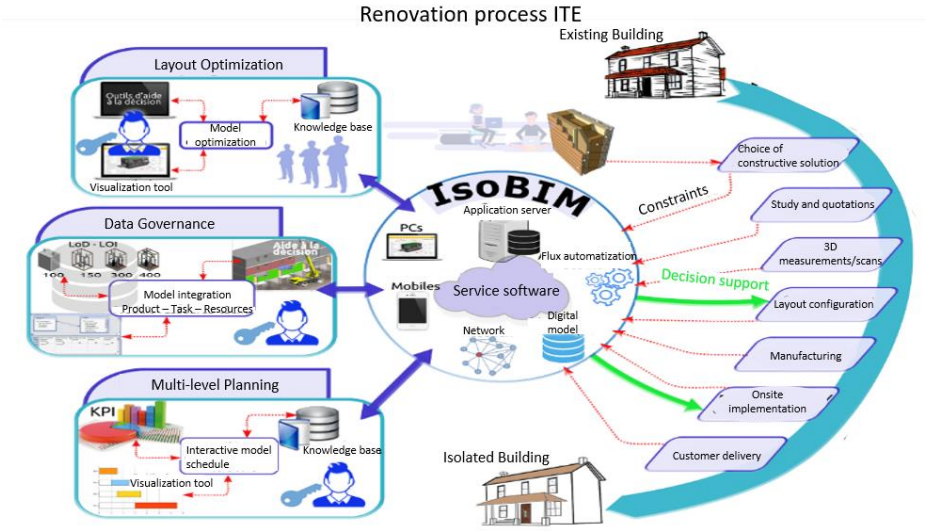

Fig. 1. IsoBIM project overview

[2] www.europarl.europa.eu

[3] ANR ISOBIM project website: http://isobim.cran.univ-lorraine.fr

The IsoBIM platform manages two different representations of the construction project: the first one is a static view of the renovated building, composed of the old building on which external insulation panels are plugged. The data involved here is data related to the building dimensions and geometry plus some information regarding the panels (sizes, materials, required handling resources, …). The second one is a dynamic view, related to the renovation process itself, that will be monitored and managed through the platform. The construction digital twin as a system able to monitor a physical asset, improve its operational efficiency and to enable predictive maintenance. This digital twin uses real-time data generated via sensors or manual entries to record and analyse the real-time structural and environmental parameters of a physical asset and to improve the building's interaction with the environment and with users [2]. As a result, the IsoBIM platform can be considered as a digital mock-up of the renovated building coupled with a digital twin of the renovation project.

In this paper, the question that we will attempt to answer is how to formalize the information required for a renovation project? Indeed, this paper propose a framework that enables the management of a renovation project data through a formal repository, using a dedicated renovation ontology. This paper is organized as follow: In section 2, a quick look is done on the state of the art of semantic technologies in the construction industry. Section 3 presents the general envisaged framework and its current state of deployment. In section 4, a case study featuring the ontology under development is presented. Finally, the last section is reserved for conclusions and future works.

2 Use of BIM and semantic technologies in the construction field

Conducting a review of the construction industry, till today this industry suffers from lack of research and development and poor technology advancements. Building renovation seems to be even more neglected in this area [3]. From the renovation perspective, introducing automation requires the availability of certain information related to aspects such as building geometry, planning, scheduling and the implementation on site monitoring, in an ideal case where a BIM model would be accessible. The digital twin paradigm aims to enhance existing construction processes and BIM models, with their underpinning semantics, within the context of a cyber-physical synchronicity, where digital models reflect the construction physical assets at any given moment in time [4]. Furthermore, based on a review of the usage of semantic web technologies in AEC (Architecture, Engineering and Construction) industry, there is a noticeable interest in the use of semantics in the construction field [5]. These technologies are mainly used as complementary to existing BIM models, in order to overcome interoperability issues. The goal is to be able to serialize a BIM model to a common data model so that it can automatically be parsed into a different data structure.

Mainly, when talking about automation in the construction industry, two approaches arise: data-driven and knowledge-driven approaches. The meaning of data-driven is the practice of collecting and analyzing data to derive insights and solutions. A data-driven

approach facilitates predicting the future by using past and current information. However, data-driven approaches rely on extensive information which require the existence of a knowledge base. Without the availability of good quality data, the risk of making false assumptions increases [6]. Whereas knowledge-based approaches are less reliant on data, it recognizes the importance of creating a knowledge environment, this is to enhance the quality of decision making through the development process, as well as to re-use and share the knowledge in order to address the different problems that may occur throughout the project.

Thus, a review of various methodologies of BIM usage and semantic web technologies in AEC domain, specifically in renovation applications, is necessary for a better understanding of the construction data managing.

2.1 Data-driven approaches

A novel approach combining Building Information Modelling (BIM), lean project production systems, automated data acquisition from construction sites and supply chains, and artificial intelligence to generate a data-driven planning and control workflow for the design and construction of buildings while benefiting from digital twin information systems is presented [7].

The authors identify two types of information, virtual and physical. Physical information is found in building, components and their relationships, resources and their

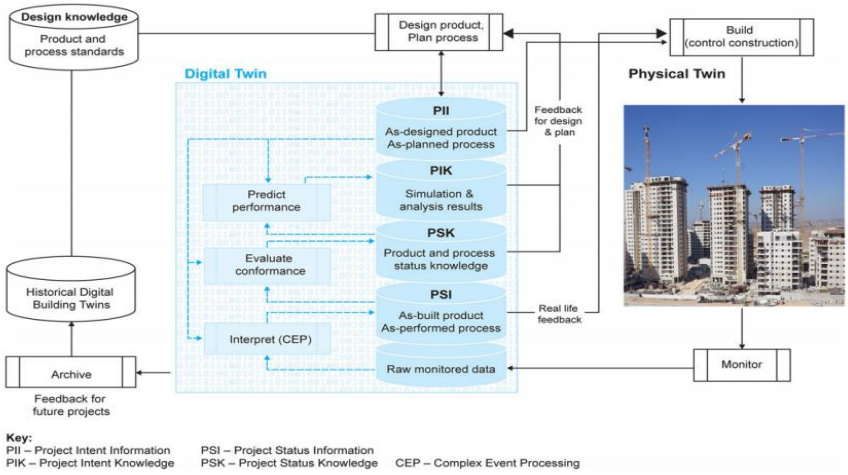

Fig. 2. DTC workflow process

actions. These can be measured and monitored resulting in digital copies which are the virtual information, the virtual information is used to build the digital twin which will represent both the construction product and process as shown in figure 2. The digital twin must contain all the virtual information. However, the information used to build the digital twin may change through time, hence two states are taken into consideration, the future state which is referred to as Project Intent Information (PII) and the past state

defined as Project Status Information (PSI). At the start of a construction project, designers generate a planning, which is used to create the PII. Once the construction phase begins, monitoring the physical building begins as well, the accumulated data generating the PSI. Contractors then use the PII to guide and control the construction process. A specialized function compares the PII and PSI to detect the degree of deviation and check if it is acceptable or requires an intervention. In the latter case, designers are set to interfere and update the planning which is added to the PII. The updated version of the PII guides the project and the cycle continues until completion. All the data gathered throughout the lifecycle of the project is then archived.

This approach is still mainly theoretical given that the implementation of DTC requires some advancements in areas such as: data fusion, data storage mechanisms, and algorithms for maintaining consistency among diverse digital twins; data science methods and algorithms for monitoring, interpretation, simulation, and optimization.

Even though the implementation of the digital twin in the construction industry is trending, when reviewing the digital twin application in the construction industry in 2021, it was found that there is no research on implementing this technology in renovation applications [6].

2.2 Knowledge-driven approaches

When gathering different information from various sources, miscommunication and lack of shared understanding is bound to happen, which can lead to complications that can disrupt the work progress. The desire of overcoming the interoperability issues among software tools and improving data exchange in general, motivated the usage of semantic web technologies and especially ontologies [5].

A renovation project ontology which formally models knowledge from the renovation field, while considering the different requirements, constraints and also taking into accounts the installation of common renovation products such as windows and thermal insulation panels is presented [8]. At the beginning, data regarding the planning of the project and other complementary documents is collected, then verified based on the ontology requirements. Once the project begins, it is divided by RenovationProduct which has Component and InstallationActivity and is linked to a BuildingInterface. The installation activities for each renovation product require specific MaterialsAndResources, Workforce, and ToolsAndEquipment. The installation activities are subjected to certain constraints found in the class Constraint (figure 3).

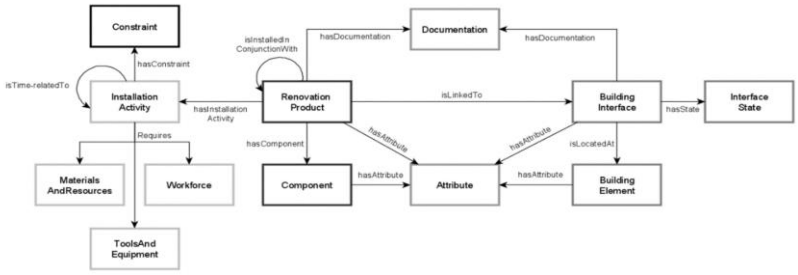

Fig. 3. Reno-Inst ontology overview

This approach is verified and validated by experts in the field through multiple workshops then the model is implemented in a case study. However, this approach presents some limitations: only three renovation products are taken into consideration, the available ontological resources are not used in this approach, and no link to the BIM or IFC is established.

A semantic approach that aims to automate the safety checking of a construction project is proposed [9]. The proposed framework shown in figure 4 consists of four modules. The first, the ontology development module, aims to create a standardized format for the heterogenous information regarding the construction safety checking, through semantically linking four ontologies. The second module creates a set of rules for safety checking, in which SPARQL-based safety checking rules are automated. The third module handles the safety risk factors data extraction from BIM models and sensors. The extracted data is then converted into ontology instances. The last module is where the rule-based safety checking takes place, ontology instances that do not meet the constraints are filtered and the safety checking results are exported.

This approach is validated through a case study, which proved the feasibility and the efficiency of the model. However, some limitations arise, the approach cannot extract information directly from BIM models or sensors.

2.3 Challenges and Problem statement

Till today, not one efficient approach is developed to support the renovation domain. The traditional ways of renovating buildings by relying on manual labour are incredibly time consuming and complicated. There is a need for information collection, and multiple studies are developed to assess the methodologies of building digitalization.

Moreover, semantic web technologies are leveraged in an attempt to formalize and organize all the information required for renovation. Many approaches are developed; however, they all present some limitations. Plus, after reviewing the literature, not enough studies are conducted regarding the renovation phase, renovation is rarely talked about, even though the construction industry is one of the largest industries and renovation projects consist 57% of all construction projects [8].

Till today, no approach successfully offers the knowledge formalization of a renovation process that covers the lifecycle of the whole project from the design phase till

the implementation phase. Most of the data driven approaches are dedicated to construction in general and do not offer solutions to the renovation domain, meanwhile in the knowledge driven approaches the renovation was addressed, however the offered solutions are limited to static data management, the only approach found that utilizes the ontology for the dynamic management is addressing the issue of safety checking of a construction project. Therefore, the aim of this paper is to present a novel framework that aims to automate building renovation by formalizing the information gathered from BIM in a renovation ontology.

3 A new framework for knowledge formalization in building renovation sector

This section presents the framework that is currently under development. Given the complexity and individuality of renovation projects, having a fully automated process is unrealistic, however, once the process is broken down into tasks, some of them can be automated. When talking about automation, having an information management system that will serve as a database for the project and ensure the information exchange between different parties is very helpful, hence the concept behind the previously discussed repository. The benefit of having such a robust database is summarized by paving the way for the successful implementation of the digital twin in the renovation industry. The chosen approach for this repository is the ontological one. The aim of the ontology in development is to formalize the knowledge required for building renovation domain. The appeal in building such ontology is to help project managers to organize the planning and the execution of a renovation project. The renovation ontology will be designed to represent all the concepts related to requirements, planning, scheduling, installation, and execution of a renovation project. Moreover, it will encompass concepts and properties regarding the tasks required for the installation of thermal insulation panels on buildings with various geometric complexities.

Normally, in a renovation project, different actors are responsible for different parts of the project, usually information will be a side effect to the progression of their work. The interest behind this approach is the development of a common knowledge base that will organize the information generated throughout the entire project.

Ontologies are very powerful when it comes to mapping, representing and retrieving knowledge which is exactly why it is the core of the proposed approach [10]. The ambition of the project is to develop a collaborative and semi-automatic process for the renovation of buildings. A SaaS (Software as a Service) solution also currently in development by different colleagues, is required to bring together the multi-level layout, as well as a renovation ontology that organizes and collects information while offering a knowledge base that can be utilized at different stages of the project. To achieve the highest level of automation, the passage from a model, generated by one of the actors of a renovation project, to another model must be done via an automatic transformation method. Such a solution will establish a semantic and procedural link between all the actors.

The framework is presented in figure 5. The main interest in this framework is the ontology development, the renovation ontology consists of four ontologies handling different information. In order to get a clear idea regarding the renovation process and to help guide the ontology development multiple experts in the domain were interviewed. The experts consisted of two main categories: construction companies that conduct renovation projects and research laboratories specialized in the renovation field. Experts were asked to provide a clear idea of the renovation process and the challenges they face when handling complex projects. Special attention is given to their suggestions on how to improve the proposed approach based on their needs. They were also questioned about the execution phase, once the on-site implementation begins, what kind of information were they interested in collecting. After comparing the answers, a common ground between all the experts is found. When dealing with a renovation project, the building need to be divided into facades, where each façade needs to located using longitude, latitude and altitude. Several elements can belong to a façade, the elements could be on the inside or the outside of the building: doors, windows, cross-walls and floor-ends. Each of these elements is assigned information regarding the type, location, material properties and dimensions.

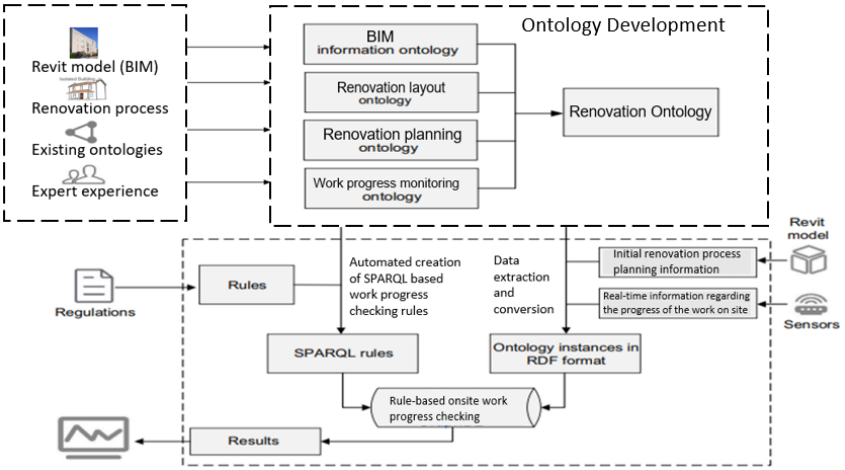

Fig. 4. Novel framework overview, (X. Li et al., 2022)

When talking about renovation, the project in question is related to an existing building, usually an old building, which will result in an absence of a BIM model, most of the time, finding 2D drawings could be complicated. Hence, at the beginning of the project the first step is to conduct a series of 3D scans to generate the BIM model of the building. Once the BIM model is available, the BIM information ontology can be enriched by the information provided by the BIM model regarding the existing building. The next step is the layout generation, a software that is under development, will enable the automatic renovation layout generation. The output of the software is a json file offering the required information for the renovation layout ontology. This layout can easily serve as the basis for the preliminary project planning. The renovation planning ontology is built based on the initial planning generated based on the renovation

layout, and the fourth and final ontology is the work progress monitoring ontology, one of the many benefits of using an ontology is the manageability of new information. The Revit model combined with the initial planning will be compared to the real state of the site collected by sensors in real time, any deviation from the planning will be detected automatically using SPARQL rules.

3.1 Ontology development methodology:

There is no one "best" way or methodology for developing ontologies. Many approaches can be followed to build an ontology, such as the iterative approach which is the best fitted path to building the ontology given the resources currently available. The iterative approach consists of beginning with a rough first pass at the ontology, then revising and refining the evolving ontology and filling in the details [11]. After having a clear idea on what kind of information needed to be provided by the experts, several meetings are organized with experts in the renovation field, to help understand what kind of information they need [11].

4 Case Study

The case study taken into consideration in this paper is an actual building, located in Nancy, France. The renovation process envisioned for this building consists of installing thermal insulation panels to envelope the whole building. Multiple visits were organized to collect as much data as possible, the documents that were transferred: technical files, energy bills and maintenance costs for the years 2018 to 2020, floor plans of the ground floor and a current floor of the building, façade plans.

Some scans of the outside of the building were also conducted to retrieve the exterior

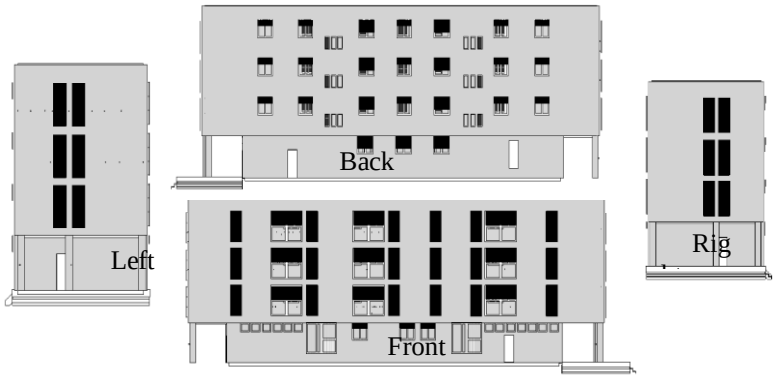

Fig. 5. Jarville building 3D model

geometry and, after eliminating the noise from the scans, the point clouds were obtained

and the 3D model of the building was generated (figure 6), and enriched by the information regarding the interior design and thermal properties of the building.

Thus, a first draft of the ontology shown in figure 7 is built based on the available information. The main classes of the ontology aim at representing a general view of diverse aspects related to the domain of renovation projects, requirements, constraints, and the installation of renovation products. A class hierarchy is created with the main concepts identified during the conducted interviews. Class properties between the concepts are established to represent their relationships. The ontology has two main classes: facade and facade_components which defines all the elements belonging to a building. The facade_components class consists of construction entities with a characteristic technical function, form or position. These entities possess certain data properties necessary for the renovation layout generation. Each facade-components has a height, width, x_dim, y_dim and mechanical_resistance, which are crucial information for renovation. Moreover, the facade_components are located in a facade which belongs to a building.

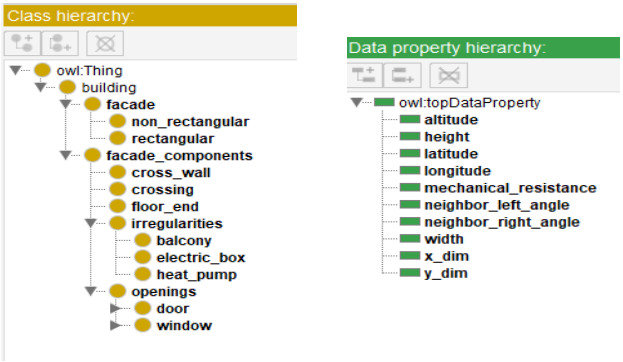

Fig. 6. ontology hierarchy

For deeper look in the ontology as presented in figure 8, each building will be linked to facade and facade_componnents, facade_components consist of architectural elements such as cross_walls, floor_ends and openings which can be door or window. As mentioned previously each element will have data properties describing the dimensions and the location with respect to the facade that it is linked to. Other properties such as neighbor_right_angle are necessary for locating the facade with respect to each other. Up until this moment, building elements, their properties and their relationships with each other are defined, however constraints are not addressed yet.

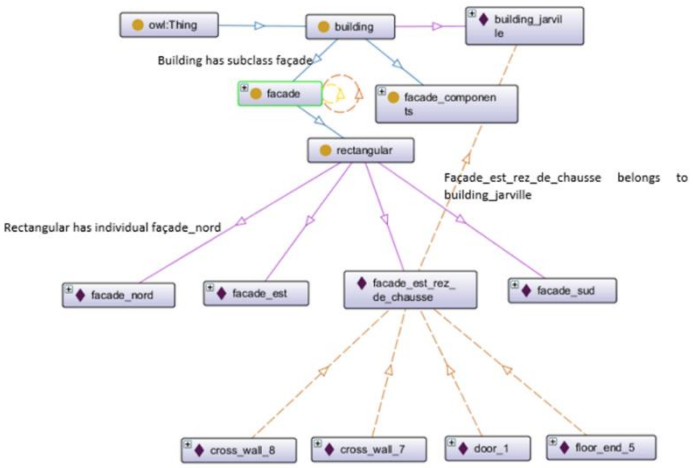

Fig. 7. ontology overview

5 Conclusion and Perspectives

Over the past few years, the construction field started witnessing digitalization and automation, even semantics approaches were explored, and while renovation projects take up to 57% of all construction activities [8], it seems to be neglected, hence, the need for an ontology to facilitate and delegate the information management of the different phases of a renovation project.

In this paper, a framework in development that ensures the mapping, representation and retrieval of information through a renovation ontology is presented, as well as a developed case study to test the ontology.

Given that this approach is still in the development phase, it will be beneficial to do a systematic literature review. The idea is to enrich what already exists instead of redefining concepts since renovation ontologies already exist.

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