OpenBIM Based IVE Ontology: An Ontological Approach to Improve Interoperability for Virtual Reality Applications

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Anne-Solene Dris, Francois Lehericey, Valerie Gouranton, and Bruno Arnaldi

Abstract

In this paper, we propose an ontology improving the use of Building Information Modelling (BIM) models as a virtual interactive environment (IVE) generator. The result is not only the ability to create a bidirectional link between the informed 3D database and the virtual reality application, but to automatically generate object-specific functions and capabilities according to their taxonomy. We present the results based on the Risk-Hunting training application. In this context, the notions of weight, object handles and, scheduling of the construction are essential for the immersion of the future trainee and educational success.

Keywords

Building information modeling (BIM) • Ontology • Virtual and augmented reality • Interoperability

16.1 Introduction

16.1.1 AECO in France, a Sector Highly Exposed to Occupational Accidents

The Architecture, Engineering, Construction and Owner-operated (AECO) industry is the most accident- prone sector in France. In 2014, 145 construction sector employees (excluding temporary workers) died while working in France. The construction industry employed 8.6% of employees and recorded 16.3% of "accidents with stop" and 26% of deaths. As for the causes of accidents, manual handling is by far the most challenged category, accounting for more than half of all work stoppages with a rate of up to 53%. Followings are falling full on foot with 13%, falls from height with 12%, and the use of hand tools with 9%.

An economic approach to the question shows that their cost, globalized with that of occupational diseases, would amount to 1.3% of the national wealth, i.e. the theoretical equivalent of more than ten additional holidays on the calendar. These few figures illustrate the very dangerous nature of the sector and lead to an interest in the problem of accident prevention in construction.

16.1.2 Training, Essential Lever

Various reasons can help to explain the difficulties that prevention poses in this sector of activity: risk factors are of human, technical, organizational, material and often interdependent origins. Statistics show that workers benefiting from reduced

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support in the company, including posted workers, foreigners, temporary workers or apprentices, are most prone to workplace accidents. As an example, mention can be made of the INRS report [1] which stipulates that accident victims of foreign origin (non-European) are three times more numerous in the building and civil engineering sector than in other sectors, the same is true for European foreign employees. These statistics highlight the lack of training and experience of these categories of workers, especially for foreigners, but also the lack of support for temporary workers, who change their job and work environment regularly. Even in large groups such as Vinci, which for many years has been conducting a comprehensive prevention policy with the "zero accident" plan, the difference in frequency rates between employees and temporary workers is still worrying.

One of the difficulties encountered in the management of training is related to temporary workers who do not always benefit from the same level of information and knowledge related to the materials and methods of construction specific to the site on which they intervene. Recent studies demonstrate the benefits of virtual reality training [2] compared to traditional training methods. But the costs involved are still high [3] in the case of virtual reality. In both cases, the training is sequenced and does not allow the real situation, each construction project is unique. However, the work environment has a considerable impact on the perception of risk and therefore on the behavior of employees . The arrival of BIM, a working process commonly used in the construction industry, makes it possible to obtain a virtual double of the act of building.

16.1.3 Goal

The purpose of this study is to present a virtual reality training scenario generation method that allows the trainee to be immersed in the unique configuration of the site he/she is involved in.

16.2 Related Works

Overview Several reasons [?] explain the risky behaviour of the workers: the lack of knowledge of the safety rules, the lack of respect of these rules, a non-conducive environment such as high productivity targets, psychological factors, the pride of "hard leather" in male environments such as construction, lack of training, organization of the site and a sequencing of the tasks to be performed that do not take into account the needs of the workstation.

Traditional training in risk prevention/Training in virtual reality Virtual reality provides a relevant response to the act of training to perform tasks without dangers, train many people from different locations [4] at lower costs, understand abstract concepts or absolve from the language barrier (written or oral), and put into practice.

We also note that traditional training does not allow trainees to adapt to a changing environment [5] so immersion into a risk hunt in virtual reality (VR) can enrich learning.

In the particular case of risk prevention, the hazard reflex is the expected result. According to the work of JB Watson, the reflex can be conditioned by the senses and participates in the acquisition of knowledge in humans. We agree with Sutherland's (1965) view that "the ultimate (virtual reality) device would be an environment in which the computer could control the existence of objects (and our interaction with them). The five senses can therefore be solicited simultaneously [6], which increases the interest and commitment of the participant [7] in his training thus improving the acquisition of knowledge. The limits of VR in relation to Real Education today are of a technical nature related to the use of a new technology: technical and professional skills of the developer, acceptability of interaction techniques by trainees not accustomed to video games, the orientation can be disrupted by the reduction of the field of vision and the movements whose latency can be problematic. We also remember that motion sickness can disrupt immersion in the interactive virtual environment (IVE).

16.2.1 Generate the Virtual World

Costs Building a real-world simulation tool like Risk Hunting is comparable to flight simulators [8]: expensive and long. In the field of construction, using BIM as a support to generate the IVE [9] allows more flexibility and considerable cost reduction.

Ontologies OpenBIM Based IVE, however, has its limits: the interaction and the definition of the objects on which it is possible to interact is not treated by the IFC (Industry Foundation Classes) standard. The development of an ontology meets the needs to enable the reuse [10] of knowledge of a specific area and to share a common structure of information. From the computing point of view, and more particularly knowledge engineering, the most commonly accepted definition is that of [11]: "an ontology is an explicit specification of a conceptualization of a domain". Conceptualization makes it possible to identify by an abstraction process the essential concepts referenced by the terms of the domain and the specification makes explicit the meaning associated with these concepts by associating them with a definition.

Few ontologies have been created for the construction sector; for information processing a complete study of which has been presented by Issa and Mutis [12] in the description of BIM uses and BIM objectives but also in asset management [13] and in the description of the field of action of BIM. All these researches agree on the need for a field that is digitalized to develop these ontologies.

Contribution The interaction needs of VR have not yet been formally addressed and this is the part that our research addresses by proposing a specific domain [14] ontology. Focusing on the Noy & McGuinness Seven-Step method based on Protege software, we offer a common working environment for interactive virtual reality applications whose virtual environment is derived from OpenBIM.

16.3 Proposed Solution and Results

16.3.1 Interoperability of IFC into a Virtual Environment

To interoperate BIM and VR, the first step is to read and write IFC models into a VR framework (in our case Unity3D), this include the geometries of the objects, the properties of the objects and the hierarchical structure. Reading and writing the properties of the objects and the hierarchical structure is trivial, but the geometry cannot be used as-is, we have to convert it from parametric models to triangulated meshes to be able to use it.

Furthermore we need to apply some post-processing to the loaded model to handle the constraints of VR, mainly the real-time constraint for rendering. These post-process, dedicated to VR include:

- Merging meshes: Some IFC object can be decomposed into a high number of meshes, this causes slowdown in the rendering and we merge such meshes.
- Set objects as static: Rendering can be better optimized if we know which objects are static (i.e. never move). We use the semantic of the IFC to select which objects are static (e.g. IfcWall) and which object might move (e.g. IfcDoor).
- Add collider: We need to specify which object have a collider to have physics interaction (such as walking). Having all objects act as colliders would be expensive, instead we filter objects with heir IFC classes.

Additionally, we want to make some of the IFC objects interactive (door, light button,), unfortunately not enough information is present in the IFC file to completely automatize this process. For example, the IFC class for door specify the type of door and its parameters (rotation axis,) but some design software ignore these properties. Moreover, the 3D model is stored in one part and there is no possibility to distinguish the door panel from the door frame or the door handle, this prevent to animate the door automatically. Having the possibility to tag part of the 3D model would solve this problem. To complete this process, we introduced the definition of a specific ontology.

16.3.2 The Creation of Ontologies

Several methodologies have been proposed for the construction of ontologies. These methodologies propose to use different types of information media to start the ontology such as terminology databases, technical documentation, ontologies, interview reports, questionnaires. We can cite inter alia Cyc methods [15] and SENSUS [16], the KACTUS approach [17], METHONTOLOGY methodologies [18] and On-To-Knowledge. The process of building an ontology is composed of several phases such as described in Fig. 16.1 (The life cycle of an ontology [19] (Fig. 16.2).

The Seven Steps Method proposed by Noy & McGuinness breaks down its activities as follows:

i. Determine the domain and the scope of the ontology.
ii. Consider reusing existing ontologies.
iii. Enumerate important terms of the ontology.

Fig. 16.1 Evolution of frequency rate (TF) = (number of accidents in first settlement/hours worked) × 1,000,000

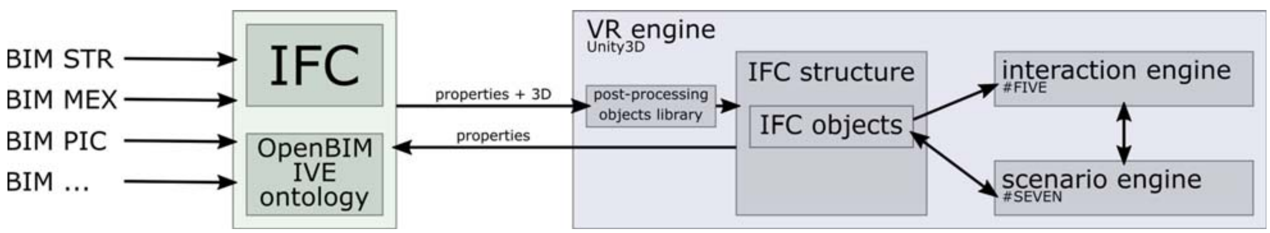

Fig. 16.2 IFC integrator Process—VR Concept Schema

iv. Define the classes and the class hierarchy.
v. Define the properties of classes—slots.
vi. Define the facets of the slots.
vii. Create instances. Steps iv to vii are repeated as many times as necessary in the ontologization process. In view of OpenBIM Based IVE ontology, the addressed domain is that of OpenBIM and interaction in virtual reality. We mainly used IFC ontologies [20] as the basis for project development. Working groups are currently collaborating to use these data and technologies to support their developments such as the buildingSMART Data Dictionary (bSDD). We will therefore evolve the model with the results of their studies. The acquisition of knowledge of the domain is the phase allowing enumeration of the main terms of the domain. For this we have studied the numerous working documents, standards and processes of the various IVE general services as well as the existing Risk Hunting Courses and their specifications.

16.3.3 OpenBIM Based IVE Ontology—Model Used

In the case of the generation of virtual reality applications, and more particularly in the context of design a training scenarios, the ontology presented in the S3PM project, OntoSPM [21] describes the procedures of individual surgery in a formal way, allowing their exploitation in the scenario engine in virtual environment called #Seven with an interaction framework called #Five. In the construction industry, a key aspect is the ability to reuse existing ontologies such as IFC ontology or Conceptual BIM ontology. The OWL family of ontology languages has been developed to unambiguously specify the properties of all ontology constructs.

We therefore implemented an OWL database integrating the concept of user interaction with #Five and #Seven. The current version of OpenBIM Based IVE Ontology contains extracts from the different ontologies used. A preliminary version is available and used in the research projects of Vinci Construction France.

16.3.4 OpenBIM Based IVE Ontology—Generation and Evaluation

The OpenBIM Based IVE has been generated by amending and reusing existing ontologies. The first source of data was IFC ontology as a structural data base of the building. We enriched it with the definition properties of Omniclass and then conceptualized the action models in virtual reality. As a first step, we have drawn up specifications for the construction industry's expectations of virtual reality technology and compared them to BIM processes on a study of twenty-four projects. This analysis allowed us to highlight primary functionalities common to each VR application using the geometric or semantic data of the BIM. These Define the concepts. Secondary features emerge depefinding on the type of application and the level of development of the BIM. As an iterative process, evaluation techniques are put in place not only during the ontology engineering process but also with end users to ensure that the result achieves the objectives set. In particular, we evaluate the number of objects reworked in the virtual environment, comparing whether it is the interaction reason (number of associated variables) or visualization (number of meshes) in order to reduce it as much as possible, goal being to achieve efficient interoperability.

On a same project: an VR application presenting the time laps of the construction, Fig. 16.3 presents the results according to the process evolution. The first study presents the results without the use of ontology, second study has been proceeded with the first version of OpenBIM Based IVE Ontology (V1), followed by version two (V2) and three (V3).

We have chosen to present the case of Risk Hunting in virtual reality since it groups together a majority of the action functionalities described by the ontologies: moving around a building model, moving objects, collaborative work, note taking and exchange with the crane operator. Moreover, it allows a direct evaluation of the ontology. More than 40 training days are conducted each year, based on two scenarios:center training or on-site training. We thus formalized these two scenarios using ontology. The shortcoming is that we have modeled a real training virtually and we envision that future trainees will want to interact differently with virtual reality than they do in a "natural" way. We thus record the unexpected movements and modalities of interaction in order to continue the enrichment process of the ontology.

16.3.5 OpenBIM Based IVE Ontology—Presentation

Four levels are Defined in the OpenBIM Based IVE Ontology:IveConcepts, IveAxiomes, IveAttributes and IveInstances. The Concepts Defines the main functions needed in VR to communicate with OpenBIM: a specific Library, systems of

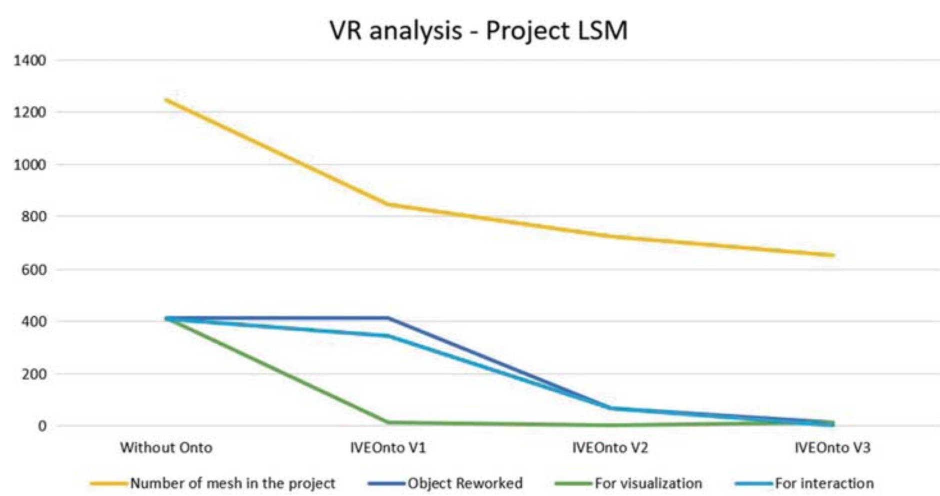

Fig. 16.3 OpenBIM based IVE Onthology—Protege

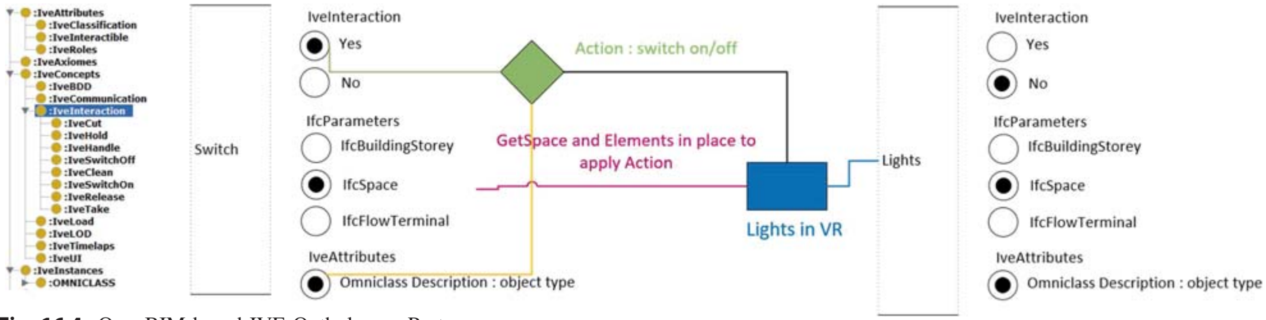

Fig. 16.4 OpenBIM based IVE Onthology—Protege

communications, the loading of les, the level of development used, the time-laps which is crucial in the construction industry and the user interfaces. Three attributes classes were necessary: classification (we used Omniclass as a basis), interaction (boolean allowing any kind of interaction) and the role of the actor in the IVE.

Based on the Omniclass table 35—Tools in order to qualify object classes, we were then able to develop the properties inherent in the interaction such as the ability to grab an object and how it can be manipulated.

Example: the interaction with a switch automatically turns on the lights in the room. These two properties have been developed with the ontology presented here (Fig. 16.4).

The evaluation phase is continued on different virtual reality applications. In our case, we chose the Risk Hunting Course because it seems to us to be one of the most complete VR applications in terms of interaction with the virtual environment: moving around a building model, moving objects, collaborative work, note taking and exchange with the crane operator.

16.3.6 OpenBIM Based IVE Ontology—Broadcasting

Our approach covers applications for visualization, navigation and interaction with building objects. The richness of the ontologies is born from their use, also to generalize our approach to other VR applications integrating perhaps the multi-users or configurators modifying the models, we plan to transpose our results on a Git deposit by getting closer to the groups BuildingSMART.

16.3.7 Design of the Application

BIM models loading. A virtual Risk Hunting Course will be more meaningful to the companions following the training if it is based on the site to which they will be transferred or on which they currently work. Starting from this principle, up to eight BIM models will be used and loaded in the game engine via the integrator.

Scenarized Interactive Environment The trainee is immerged in a virtual environment where he can move and interact (see Fig. 16.5). To address the issue of reusability of the application, we build a model of Virtual Risk Hunting to self-generate randomly possible serious errors based on the integrated IFC. Thus, depefinding on the projects, the scenario adapts to it and proposes a different set of errors for each launch. This is done by abstractly defining errors which look into the IFC ontology to find every possible instantiation of each error. From these random error, the training is guided with a scenario Defined with the #SEVEN model. Each error has a scenario fragment to handle its behaviour, these fragments are combined to make the whole scenario.

Additionally, we use the BIM Collaboration format (BCF) to handle communication between the trainee and the trainer. The trainee can use a virtual camera to take pictures while in immersion. Furthermore, the scenario itself write BCF notes on specific events to keep track of the trainee progress and errors. All these notes can be reviewed by the trainer after the training.

Questionnaire Design During our research on the benefits that virtual reality can bring compared to traditional training methods, we have been faced with the problem of lack of existing studies. The return of the experiments carried out does not make it possible to establish a concrete result. If the finding seems clear about the benefits of this technology during the training, its interest in the long term remains to be proven.

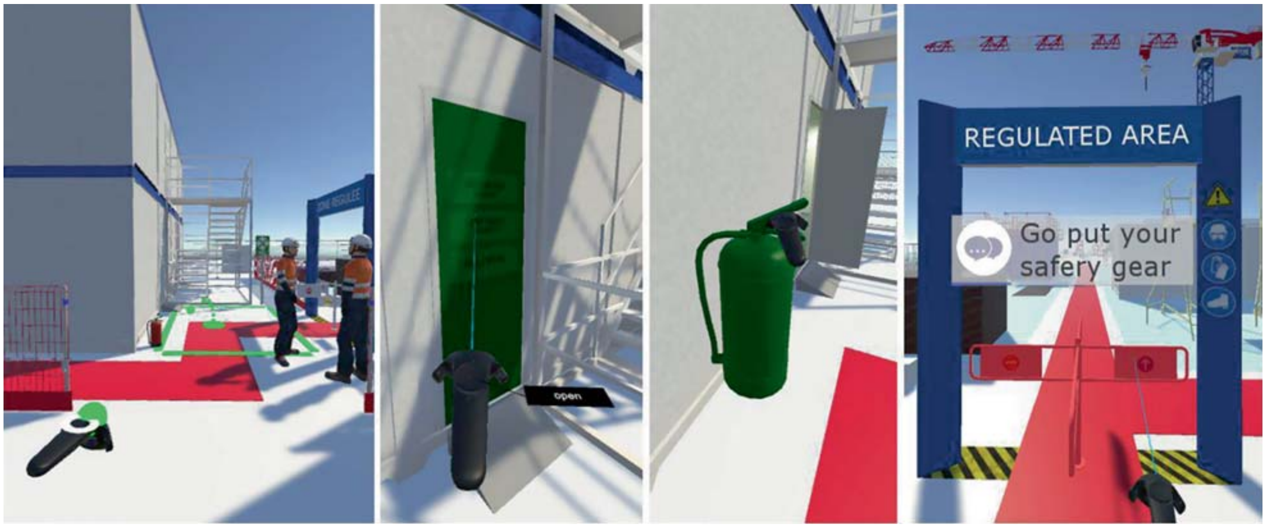

Fig. 16.5 Examples of the different ways to interact with the environment. From left to right: teleporting to a new location, remotely interacting with an object, grabbing an object and getting instructions

We therefore designed a questionnaire system based on three sheets. This test phase will be continued in the coming weeks.

16.4 Conclusion and Future Works

The various areas of AECO industry requiring the formalization of knowledge is still vast but through this study, we propose a solution improving the interoperability between virtual reality and OpenBIM, developing the works of BuildingSmart on the IFC, the bSDD, rankings and BCF in the field of virtual reality.

In the future, it will possible to reiterate the ontology construction process by studying the implementation of the error creation system and the needs of the ontology by studying the actions of trainees during their training. We are also thinking of using it on other virtual reality applications by studying the possibility of co-activity, adding stress levels according to people's roles, and qualifying men's security objects in order to make them more effectives.

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