



HAL
open science

Integration concept and model of Industry Foundation Classes (IFC) for interactive virtual environments

Anne-Solène Dris, Valérie Gouranton, Bruno Arnaldi

► **To cite this version:**

Anne-Solène Dris, Valérie Gouranton, Bruno Arnaldi. Integration concept and model of Industry Foundation Classes (IFC) for interactive virtual environments. 33rd CIB W78 Conference, 2016, Brisbane, Australia. hal-01391786

HAL Id: hal-01391786

<https://hal.science/hal-01391786>

Submitted on 3 Nov 2016

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Integration concept and model of Industry Foundation Classes (IFC) for interactive virtual environments

Anne-Solène Dris, anne-solene.dris-kerdreux@irisa.fr

Vinci Construction, IRISA / Inria, France

Valérie Gouranton, valerie.gouranton@irisa.fr

INSA de Rennes / IRISA / Inria, France

Bruno Arnaldi, bruno.arnaldi@irisa.fr

INSA de Rennes / IRISA / Inria, France

Abstract

The intention of this paper is to provide a concept of Building Information Modeling (BIM) and an integration model in the Virtual Environment (VE) that provide 3D model rich of information used for applications by increasing the level of abstraction of this process. The IFC model provides a definition of building objects, geometry, relation between objects, and other attributes such as layers, systems, link to planning, construction method, materials, domain (HVAC, Electrical, Architectural, Structure...) and quantities. We propose to explore and define how to create a BIM to insure IFC interoperability to use this information in the aim of creating an informed and interactive VE, thus reducing the costs of applications' development. The presented analysis will conduct to define a BIM modeling methodology extending the IFC interoperability to the interactive mixed reality environment.

Keywords: Virtual reality, Building Information Modelling, Data Management, Standardization

1 Introduction

The objective of this research is to propose a link between BIM and Augmented Reality and Virtual Reality (AR/VR) based on an Open-BIM integration creating an IVE (Interactive VE). No single computer application can support all of the tasks associated with building design and production. Interoperability (Eastman et al 2011) depicts the need to pass data between applications, allowing multiple types of experts and applications to contribute to the work at hand. Interoperability is a well-known problem in AEC Industry and the generated issues produce significant cost (GCR 2004). It has been a very long time that IFC are recognized as the international standard but two major issues are slowing its adoption by users: the first one is economic and rely on BIM software editor (some business model is to impose the proprietary format as a standard, thus rejecting the promotion of IFC) the second one is bound to the lack of standard in terms of modelling methodology: an exterior wall composed of masonry, insulation and finishing can be modeled as a single wall composed of three layers or three walls in different layers but the consequent IFC export will undoubtedly not be the same. Data loss is inevitable. As there is no modelling methodology, the experience means the rule and BIM managers are trying to improve the interoperability by organizing processes for the different softwares used to ensure the client needs. This experience of interoperability in BIM and Open-BIM project is now reproducing with VR/AR applications: each application designer have his own method importing IFC, depending on the needs.

In import, as in export, we know the format (IFC) but we still have to write the modelling methodology and the protocol of import for the IFC to be used as an IVE. To ensure these tasks, a deep study of the actually used BIM guidelines was conducted and should provide the best change management in the integration of the proposed methodology.

2 Related Works

An OpenBIM based IVE guideline for standard and use can be seen as a bridge between two important research domains: computer science and construction. In this section, we examine this knowledge separation through the vocabulary and techniques analysis in both domains of research which are converging with the use of Building Information Models as environments for Virtual or Augmented Reality applications.

We will discuss the two points of view:

- Virtual Reality viewed by the Construction side
- BIM used by VR domain specialists

2.1 Virtuality in Construction

As defined by The National Building Information Model Standard Project Committee, Building Information Modelling (BIM) is a numeric construction (BuildingSmart, Accessed: 30/06/2016) of a facility.

2.1.1 BIM

BIM is based on a 3D model enriched with information about the facility, 3D is bearing a huge amount of data characterizing the facility or a part of it. For example, a wall is defined with length, height and thickness and can be informed with the type of concrete, the tests results, day to be built or physical characteristics.

BIM does not only mean 3D - visualisation but improving workflows and processes. Specific workflows using these IT Tools are being described such as installation verification, clash detection, project management, sequencing and estimating.

In fact, 3D Intelligent and photo-realistic BIM for Space planning enables clear and interactive navigation and visualisation of the existing layouts and proposed requirements. We can quickly visualize multiple options of layouts before making any decisions or moving any furniture. We can also review alternate cost-plan options in a minute to ensure the best options are assessed and communicated rapidly. Everybody can get a tactile perspective of his proposed design with a physical 3D model and order data from multi-discipline models.

2.1.2 Virtual Construction

BIM is shared by the different crafts involved in the process of construction from the design stage to the facility management and even sometimes the deconstruction. During the construction period, a group of specialists is in charge of studying the movements of materials, humans and equipments to optimize the workspaces (Kassem et al 2015).

This group is called the process engineering and is a crucial department of a contractor: many urban construction sites are facing a lack of space impacting work progress (Clayton et al 2002) and safety. The scientific and technical IT domain of research attempting to develop new interactive tools for planners is called Workspace Management (Waly & Thabet 2003).

Linking the 3D Building model to a construction schedule (4D model) gives planners the ability to improve construction sequences, identify and resolve schedule conflicts, track and manage workers and resources such as formwork, scaffolding, and cranes, to make sure they are all applied effectively and do not conflict. In the literature, Virtual Construction (Dawood et al 2005) refers to a digital representation of the construction, a 3D modelling and Virtual Construction Environment (VCE) is a special tool for planning.

2.1.3 BIM Modeller

Talking about the new roles that are emerging in the Architecture, Engineering, Construction and Owner-Operated (AECO) Industry, the BIM technology increased the skills of many functions such as the former draftsman. With the broad use of BIM, draftsman is disappearing, sloughing in a higher skilled function called the BIM modeller.

A BIM modeller is attached to the production of deliverables and models, respecting the guidelines written in by the BIM manager (Barison et al 2014) for a specific project and controlled by the BIM coordinator.

2.1.4 Interactions in BIM work

Interactions are important in virtual building simulations, between the final BIM modellers, the decision makers and the final owners. As the final project is made of a composed BIM

models, the number of interactions (Grilo & Jardim-Goncalves 2010) during the lifecycle of BIM, from early stage design to deconstruction is understood as a scheduling of rights and administrations of them drew by the BIM execution plan.

2.2 BIM in Virtual Reality

2.2.1 General definition

"The virtual reality is a scientific and technical domain operating information technology (IT) and behavior interfaces to simulate a virtual world, the behavior of 3D entities that interacts in real time between them and with one or more users in pseudo-natural immersion via sensory-motor channels" (Arnaldi et al 2006).

In the field of Augmented Reality and Virtual Reality (AR/VR), the Virtual Environment (VE) (Barfield & Furness 1995), is defined as a computer representation of an object (Bellotti et al., 2009), a database or a physical property which can:

- be represented within different level of realism, from abstraction to hyper-realism (Bridges and Charitos, 1997)
- be manipulated (Barfield and Furness 1995) by the virtual participant
- be felt as a "container"(Steuer 1992) by the virtual participant

2.2.2 BIM-based VE

Traditionally, VR systems use a 3D modeller to create the VE and interactive rendering tools such as game engine, in real-time (Chen 1995). Virtual Reality affords new medium that we will call VR application to support and improve industries' tasks in the real world. The 3D modeling process is a hard manual task costing a lot of time to realize a VR application.

BIM is recognized as an approach that could help reduce the time spent modeling the VE as a model able to provide realistic and detailed 3D virtual environments with graphical and non-graphical data that represent key properties for end-users. The support of "BIM export file format (especially FBX)" is clearly announced (Shen et al 2012) and can be a good basis for the 3D part of the BIM. An IFC methodology is proposed for a low-cost VE (Hilfert & Konig 2015) for engineering and construction but the Software Architecture import geometry to the game engine used and did not use the metadata stores in the IFC for the scenarios. The loss of the huge amount of information supported by the 3D BIM objects has to be repaired to afford interoperability to the AECO users.

To enable a level of data transfer between tools there are three main approaches (Moloney & Amor 2003):

- a bespoke converter
- a standard building file transfer
- an integrated project database

Currently, the BIM-VE works with Revit and a specific data format (e.g., FBX) to transfer building information from BIM to game engine with a Revit API (bespoke converter), which limits its proliferation to work with other BIM software packages.

An integrated project database could be a key work for collaborative design or when the IFC were in previous version (from IFC1.0 to IFC 2x2). Our interest will be focus on the realization phase application for a BIM-IVE. The major concern in this phase is responsibility. Each enterprises supplying a BIM enriches the global model with its own details of fabrication, the execution drawings are extracted from the BIM and no one is then allowed to modify what has been agreed in the building process. VR applications can be a great help in the realization phases and as IFC has been promoted as the de facto standard for data and process interoperability in the AECO industry, we will consider that the IFC is the database and the only transmission vector, implementing the IFC interface that research is missing (Wang et al 2014) to build a universal data component adopting different BIM packages.

But an IFC interface is not enough to create interoperability as it would need too many configuration and adaptation from the designer of the application due to the lack of standard in terms of modeling and in terms of IFC translating from the BIM software. It has to go with a Modelling Methodology Guide for OpenBIM-based IVE.

2.2.3 Modeller-Computer Science Definition

In 3D computer graphics, 3D modelling is the process of developing a mathematical representation (Suppa et al 2007) of any three-dimensional surface of an object (either inanimate or living) via specialized software. The product is called a 3D model. It can be displayed as a two-dimensional image through a process called 3D rendering or used in a computer simulation of physical phenomena. The software used for modelling is called the 3D modeller.

2.2.4 Interaction with the VE

In the VR technology field, interaction covers the notion of being able to transform the VE, to become an actor (Fuchs et al 2006) of the virtual world, making change and getting response from it. The interaction is then defined by the interplay actions performed by the VE participants and the VE. Interaction concerns the direct movement of the participants, physical controls and virtual controls (menu). These kind of actions can be done using mouse, haptic interfaces, gesture (Mine et al 1995) and voice. But in the Virtual Reality research domain, the interaction is also related to the sense (Mine et al 1997) of the VE for the VE participant: movement, localization, volume, haptic and texture.

In the communication with multiple users, interaction abilities and the numerous data treated, VR and AR applications afford great answers to save time from the construction actors. Regrettably, no research (Wang et al 2013) was closely conducted with industrials in the AECO field. The systems developed have not been tested on real world project and that explains the gap that has to be overcome between academia - industry and AECO - IT.

3 Method and Analysis

As this research is conducted with a BIM manager from an international construction company, model and systems developed will be tested on real world project.

Supposing the VR technology has reached a significant degree of maturity (Choi et al 2015), the development of standard for the application designer and the dynamic integration of IFC is now required. In this section we want to propose an interoperable BIM-based integration protocol for the creation of virtual environment. The protocol definition first started with a large study of the applications attended from AR/VR to the AECO Industry. This first part will give us the "what we want", then a second part will present "what we have", related to the IFC and the different manners of creating IFC to finally conduct to a guideline for the BIM drawers to be able to implement a usable BIM in the VE to answer the question "how doing?".

3.1 Application needs – What we want

We want here to list the AR/VR applications (Abboud 2014) that could be a priority to be confronted in practical project. They have been chosen for two type of reason: either the actual functionality described exists with a huge time spent and need interoperability to be usable or the VR/AR offers an innovative and expected ability.

3.1.1 VR Applications for AECO

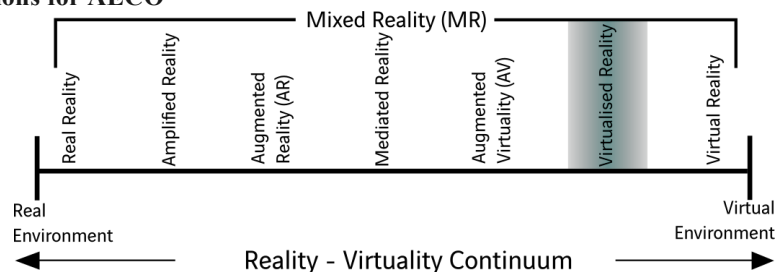


Figure 1 VR Application in the Mixed Reality Domain, diagram inspired by the Simplified representation of "virtuality continuum"(Milgram and Kishino, 1994)

1. Building virtual visit to help the client validate some proposals without being on-site
2. Construction scenario for a better comprehension of the installation, the process and security proposed, the pedestrian and vehicles traffic

3. Accommodation configurator
4. Site quality control
5. Interactive general plan of site installations
6. Workspace management during the rough-in phase
7. Team rotation during the finished phase
8. Site management (quantities needed, consumed, time spent...)
9. Warm-up and training of building workers
10. As-built document management and interactive reading in the IVE
11. Operating method explanation
12. Accessibility validation (Disabled paths)

3.1.2 AR Application for AECO

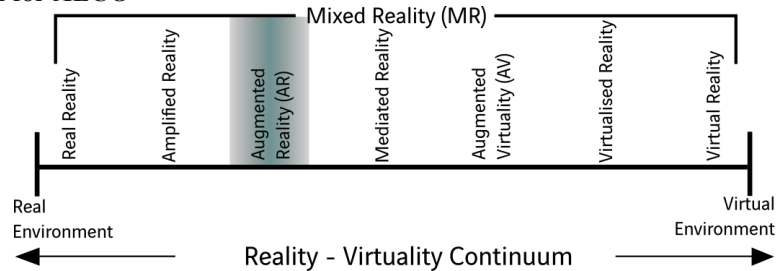


Figure 2 AR VR Application in the Mixed Reality Domain, diagram inspired by the Simplified representation of "virtuality continuum"(Milgram and Kishino, 1994)

1. Visit historical site as they used to be in their golden age
2. View a future project in its real projected environment: AR landscape integration
3. Augmenting physical presentation media
4. Validation of conception or furnishing propositions on Site like facing panels as well as sun-screens for example
5. Visualizing subsurface utilities before excavation work
6. Control of holes dimensions and positions
7. Help to the box position in metal concrete form panel or in slabs
8. Exploring mechanical systems behind existing walls for FM
9. Find ways to guide a final user in infrastructures such as hospitals, airport, universities and colleges, libraries.

3.2 Interoperability and Actual possibilities of development – What we have

Interoperability is the ability of hardware, software or different protocols to operate together and share information without a hard human treatment. The extraction of industrial domain knowledge (Wang 2009), creating a database usable for AR/VR applications in a reasonable time spent is possible with OpenBIM. Interoperability in AR/VR applications from OpenBIM means that the application designer will use all the BIM information, making the applications works with any IFC file as data input.

To ensure this task, we first analyze the previous goals to extract the IFC data's implementation, and in a second time, we will describe the guidelines for any BIM software to fit the IFC needs for an OpenBIM-based IVE.

The first need is quite evident: all items listed need to have the 3D imported with object's name, colors, scale, and placement origin.

VR items 1, 4, 5 and AR items 1, 2, 3, 4, 5 are BIM representation and visualization applications. They need 3D high quality graphics with the free and guided navigation function for the final user. They use the 3D objects as a game object to be displayed or not.

VR item 2, 6 et 7 adds the notion of time and scenario. They will need the user's property set for the time line or the creation and demolition data field, depending on the software used, being able to act on the building and level's object membership and the layers used in the BIM software would also help to act on the objects used for security. These applications add the needs for volume impact and clash detection function.

VR items 8, 10, 12 and AR items 6, 7, 8 and 9 will need all the properties used in the BIM to save time from data changing: object type, name, dimensions, layers, dates, manufacturer, model, FM ID... all the standard IFC properties and the special one's defined in the BIM Execution Plan.

VR items 3 add the possibility to configure an object. Such application needs the IFC standard import with the possibility to modify some field's result and write these changes directly in the file, using the standard as the OpenBIM database.

VR items 9 and 11 would perform with equipment recognized as "ready to act on" objects, materializing the weight for pseudo-haptic returns.

4 Results

We propose a new approach in order to make interoperable the integration of BIM in VE: an OpenBIM-based IVE model.

4.1 Integration Model – How doing

In addition to the previous requirements, and to ensure the best user's interaction with the VE, we append the possibility to sort the only displayed datas. It can be a filter by building, levels or element. As IFC specification is developed as the AECO's "Data Standard", it is then not a surprise that the IFC hierarchy structure fits the needs of an OpenBIM-based IVE.

This IFC hierarchy structure in the game engine is quite essential for the layered abstractions selection based on a building typology and contribute to the interoperability. The OpenBIM-based IVE's hierarchy has to be directed as we can see in figure 3:

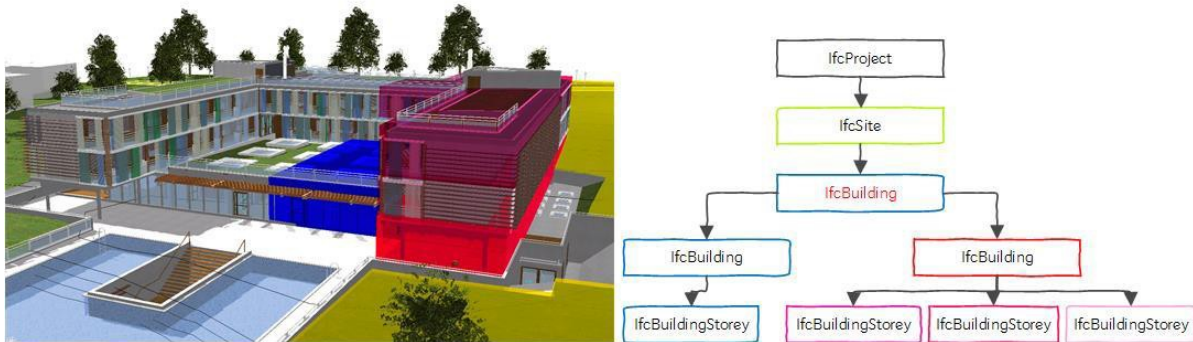


Figure 3 IFC Spatial Structure Use Definition from BuildingSmart

In each *IfcBuildingStorey*, corresponding to the building's levels, all *IfcBuildingElement* of the project must be gathered under their object's type. The Property set for Objects, Quantity Sets (unmodifiable) and Material have to be readable, and modifiable (except quantities) directly in the IFC database.

Properties (attached to the Game Engine Material) have to be gathered and fill in a special subset called "IFC Properties". When the listing is created, we create a filter function selecting the object completing conditions that can be made on the properties' values.

This selection filter affords a higher level of abstraction using the BIM objects as intelligent entities for the application designer instead of graphical object selection. The implementation of the IFC Integration is still in progress. The OpenBIM-based VE thereby described is independent from the CAD software used, in the limit IFC export is well written.

If the format is now recognized as a standard in the AEC/FM industry, there are still great issues of interoperability as the way the BIM is modelled impact the way softwares export and import the IFC. However the modelling techniques needs to be precisely described in a drawing international guideline depending on the software used and the goal pursued. The next section will present the BIM modelling rules to respect to ensure a usable IFC, results of many years of practice and exchange with IFC.

4.2 Modelling rules

Nowadays, there are four BIM softwares among the most ones used: Autodesk edits Revit, Nemetschek Group edits Allplan and Archicad, and Trimble edits Tekla Structures. The first three of them can be used by Architects as they support multilayer walls. Revit, Allplan and Tekla Structures can be used by Engineers and Revit is the only one cited that can fit the MEP (Mechanical Electrical Plumbing) needs.

4.2.1 General

The following recommendations are common for the four softwares.

Always use the right tool for the building element type. As we need to gather elements with their object's type, a column must be modelled with the column tools and not the free tool's one that could be done for reason of ease. Even a corresponding table cannot fix that error.

Cut each element in a define level with its exact height, do not use the attach function because the IFC export will use the defined height and not always the attached one to ensure the quantity is set properly in the IVE.

Pay a particular attention to the junctions: model the building element as they will be constructed in the real world to ensure the limitations of the navigation and volume interaction in the IVE.

Separate the structural elements and the architectural ones. If your software uses the concept of layer, take special attention to the creation of the layer structure. Each function of a material or object of the building must be informed and we constructed the minimum list.

Any objects and materials in the case of systems must be linked to its layer.

Do not let empty the field "Name of materials" of each element, whether structural, architectural or fluids. Ideally, the codification to meet has to follow the standard such as Omniclass table 23 codification or the BIM convention and at the minimum a representative name. The material's name is used as a basic for the texture's IVE representation.

A particularity of the IFC is that a multilayer element does not have the parent notion with another one. That means for example that a multilayer wall will be traduced in IFC in one single wall, storing the information that it used to be multiple. Because some application may need to focus on the structural part of the wall, the finishing or the covering, we need to have a particular attention to the multilayer element description and ensure a proper export with each part individually treated.

4.2.2 Methodology applied to Walls

The application for which is destined the IVE can need to simulate the construction sequence (VR item 2), thus the IVE would need the structural part of the wall, the day each wall is constructed and the construction method used. The IFC export from BIM software being one IFC object per BIM object, it means that we need to have a wall per construction task. That let us understand how important is the following rule: model as you build.

To ensure that the IfcWall will be settled at the right level in the hierarchy, wall modelling must be done from floor to floor, and not continuously over several floors. In addition, wall modelling can be done in three different cases depending on its location, namely:

- Facade walls have to be modelled from the upper face of the bottom floor to the upper face of the top floor (upper to upper leveled)
- The interior walls have to be modelled from the upper face of the bottom floor to the under face of the top floor (upper to lower leveled) or under the beams. In the context of mobile partitions, the latter must be modeled over the floor;
- The hopper walls (elevator shafts, stairwells) need to be modeled in the same way as building facades that is to say from the top of the bottom floor to the top of the upper floor (upper leveled at top).

Because the application for which is destined the IVE can need to act on the finishing layer (VR item 3), the OpenBIM-based IVE needs have each layers of the wall as a different wall, sharing the same properties.

We studied the different options to fit that need. Depending on the software used, a multilayer wall will be defined by layers (in Archicad or Allplan) or by material (Revit). The layer ordering allows the software to export only the activated one's, permitting the user to create

IFC by type of object: interior, exterior, structural. In Archicad or Allplan, you could work modeling BIM with multilayers element but using Revit, there is no possibility to export only one part. In the aim to divide the IFC in as many walls as they are layers the only possibility in Revit is to model as many walls as you would need to act in the IVE and at the minimum: the structural one, the interior complex and the exterior complex.

To ensure interoperability and interaction from different software's IFC in the IVE, this scientific approach was carried out on each IFCElementType.

5 Conclusions and future work

The methodology guidelines outlined in this paper are presented as minimum requirements. The next stage of this project is the evaluation of the effectiveness of the guidelines in the complete implementation of the OpenBIM-based IVE integrator and practical experimentation on the priority VR items 2 and 8.

The following research challenges (Wingrave & LaViola, 2010) should be addressed:

- Incorporate standard BIM design (natural representation) already used in design to improve interaction and accessibility of the AR/VR technology, regardless the BIM software or the game engine used: Open- BIM based model of integration for IVE.
- To meet the ambitious challenge of using the Open-BIM based IVE for the AR/VR applications in terms of usability, a layered abstraction has to be described, providing input to the IFC integrator protocol.
- Finally, a model, natural and layered will describe the AR/VR systems for AECO.

Acknowledgements

The authors would like to acknowledge the support of Vinci Construction France Ouest as this research was partly conducted on their projects and construction sites.

References

- Abboud, R. (2014). *Architecture in an Age of Augmented Reality*. NAWIC International Womens Day Scholarship Recipient 2013.
- Arnaldi, B, Tisseau, J. & Fuchs, F. (2006). *TRAITE DE LA REALITE VIRTUELLE*. Ed. by Les Presses de l'Ecole des Mines de Paris.
- Barfield, W. & Furness, TA. (1995). *Virtual environments and advanced interface design*. Oxford University Press.
- Barison, MB. & Santos ET. (2010). *An overview of BIM specialists*. Computing in Civil and Building Engineering, *Proceedings of the ICCCB2010*, p. 141.
- BuildingSMART. The worldwide authority driving transformation of the built asset economy through creation & adoption of open, international standards. Accessed : 30/06/2016. BuildingSMART url: <http://buildingsmart.org>.
- Chen, SE. (1995). *Quicktime VR: An image-based approach to virtual environment navigation*. *Proceedings of the 22nd annual conference on Computer graphics and interactive techniques*. ACM, pp. 29–38.
- Choi, SS., Jung K. & Do Noh S. (2015). *Virtual reality applications in manufacturing industries: Past research, present findings, and future directions*. Concurrent Engineering 23. Sage Publications, pp. 40–63.
- Clayton, MJ., Warden, RB. & Parker, TW. (2002). *Virtual construction of architecture using 3D CAD and simulation*. *Automation in Construction* 11.2, pp. 227–235.
- Dawood, NN., Scott, SM., Sriprasert, E., & Mallasi, Z. (2005). *The virtual construction site (VIRCON) tools: An industrial evaluation*. Electronic Journal of Information Technology in Construction.
- Eastman, CM., Teicholz, P., & Sacks, R. (2011). *BIM handbook: A guide to building information modeling for owners, managers, designers, engineers and contractors*. John Wiley & Sons.
- GCR, NIST (2004). *Cost analysis of inadequate interoperability in the US capital facilities industry*. National Institute of Standards and Technology (NIST).
- Grilo, A. & Jardim-Goncalves, R. (2010). *Value proposition on interoperability of BIM and collaborative working environments*. *Automation in Construction* 19.5, pp. 522–530.

- Hilfert, T. & König, M. (2015). *LOW-COST VIRTUAL REALITY ENVIRONMENT FOR ENGINEERING AND CONSTRUCTION. Visualization in Engineering.*
- Kassem, M., Dawood, N. & Chavada, R. (2015). *Construction workspace management within an Industry Foundation Class-Compliant 4D tool. Automation in Construction* 52, pp. 42–58.
- Mine, MR., Brooks Jr, FP., & Sequin, CH. (1997). *Moving objects in space: exploiting proprioception in virtual-environment interaction. Proceedings of the 24th annual conference on Computer graphics and interactive techniques.* ACM Press/Addison-Wesley Publishing Co., pp. 19–26.
- Mine, M. et al. (1995). *Virtual environment interaction techniques. UNC Chapel Hill computer science technical report TR95-018*, pp. 507248–2.
- Moloney, J. & Amor, R. (2003). *StringCVE: Advances in a game engine-based collaborative virtual environment for architectural design. Proceedings of the International Conference on Applications of Virtual Reality*, Blacksburg. Citeseer, pp. 156–168.
- Shen, Z., Jiang, L., Grosskopf, K. & Berryman, C. (2012). *Creating 3D web-based game environment using BIM models for virtual on-site visiting of building HVAC systems.* Construction Research Congress, ASCE, Reston, VA, pp. 1212–1221.
- Steuer, J. (1992). *Defining virtual reality: Dimensions determining telepresence. Journal of communication* 42.4, pp. 73–93.
- Suppa, M., Kielhofer, S., Langwald, J., Hacker, F., Strobl, KH., & Hirzinger, G. (2007). *The 3d-modeller: A multi-purpose vision platform. Proceedings 2007 IEEE International Conference on Robotics and Automation.* IEEE, pp. 781–787.
- Waly, AF., & Thabet, WY. (2003). *A virtual construction environment for preconstruction planning. Automation in construction* 12.2, pp. 139–154.
- Wang, B., Li, H., Rezgui, Y., Bradley, A., & Ong, HN. (2014). *BIM based virtual environment for fire emergency evacuation. The Scientific World Journal* 2014.
- Wang, X. (2009). *Augmented reality in architecture and design: potentials and challenges for application. International Journal of Architectural Computing* 7.
- Wang, X., Kim, MJ., Love, PED., & Kang, SC. (2013). *Augmented Reality in built environment: Classification and implications for future research. Automation in Construction* 32. Publisher : Elsevier, pp. 1–03.
- Wingrave, CA. & LaViola, JJ. (2010). *Reflecting on the design and implementation issues of virtual environments. Presence* 19.2. Publisher : MIT Press, pp. 179–195.