

EDUCATION IN ENGINEERING: BIM AND VR TECHNOLOGIES IMPROVING COLLABORATIVE PROJECTS

ALCÍNIA Z. SAMPAIO

University of Lisbon, IST, Dep. Civil Engineering
Av. Rovisco Pais, 1049-001 Lisbon, Portugal
zita@civil.ist.utl.pt

Key words: Education; BIM methodology; VR technology; Construction; Maintenance.

Abstract. Building Information Modelling (BIM) is defined as the process of generating, storing, managing, exchanging, and sharing building information. The potential of BIM methodology to support a transformation of the processes of design and construction has been evident in the construction industry. A current topic that requires attention is the integration of BIM with Virtual Reality (VR) where the user visualizes a virtual world through interactive devices or a total immersion. VR combines several devices for interaction, creating virtual environment, and this must followed by studies concerning how to use devices or how to establish links for the presentation of information contained in a BIM model. By adding VR, the BIM solution can address retrieving and presenting information and increasing efficiency on communication and problem solving in an interactive and collaborative project. BIM + VR allow two main capacities: walkthrough and consulting data, and currently BIM tools allow links to VR plugins in order to achieve both capacities. As such, it is expected to be further explored in the near future. The text presents a review of actual perspective of the VR use applied over 3D/BIM models to supports multi-dimensional BIM applications, namely, 4D/BIM and 7D/BIM models. The objective of the study is to report the improvement of BIM uses with the addition of interactive capacities allowed by VR technology. Being the school the main actor in the formation of new engineers, it has the mission prepare students for the professional activity, giving the most advanced technology knowhow allowing them to make a difference in the job market.

1 INTRODUCTION

Building Information Modelling (BIM) methodology enables project stakeholders to create information-rich virtual models that help better visualize building projects. BIM is defined as the process of creating building information, stored in a centralized virtual model, that can be managed allowing exchanging, and sharing building data in an interoperable and reusable way [1] (Azhar et al., 2008). BIM provides an opportunity to analyze a model namely for:

constructability conflicts; ways to reduce energy usage; validating energy reducing design ideas; or improving life safety. BIM represents the procedure of development and use of a computer generated model to simulate the planning, design, construction and operation of a facility [2] (Eadie, et al., 2013). The resulting product, a centralized BIM model, is a data-rich, intelligent and parametric digital representation of the building project. So, BIM can first be considered as a digital representation of a building, an object-oriented three-dimensional (3D) model, but also a repository of project information to facilitate interoperability and exchange of information with related software applications. Therefore, BIM data-rich model allows views and data, appropriate to various users' needs. BIM data can be extracted and analysed to generate information that can be used to make decisions and to improve the process of delivering the project or the facility.

BIM can generate and maintain information produced during the whole lifecycle of a building project, from design to maintenance, and can be applied to various fields [3] (Chen and Luo, 2014). Due to the consistency of design data, with quality data and construction process with quality control process, the potential of BIM implementation in quality management lies in its ability to present multi-dimensional data including design data and time sequence. BIM and its applications in project management are considered nD/BIM models, namely [4] (Sampaio, 2017):

- 3D/BIM model refers to all 3D building components (architectural, structural, mechanical, electrical. . ., etc.) and it incorporates all the building aspects, including geometry, spatial relationships, properties and quantities;
- 4D/BIM model concerns the construction process that can be visualized by building the 3D product model through time according to the critical path network (the model supports dynamic construction site safety management, preparation of schedules and estimates, tracking and managing changes, and managing site logistics) [5] (Sampaio and Mota, 2016);
- 5D/BIM model is related with costs (take-off material quantities, cost planning and estimating, safety checking integration for dynamic safety analysis);
- 6D/BIM model is associated to support management facilities and maintenance along the post occupation lifecycle of the building;
- 7D/BIM model is created to support management facilities and maintenance along the post occupation lifecycle of the building [6] (Sampaio and Simoes, 2017).

The nD directions of BIM use must be based in an adequate relationship between the team members improving an adequate collaborative project, supported in an efficient interoperability of specific software. As per the reports, companies began seeing faster project approvals, increased positive team interactions and higher product quality. Unlimited extension of the use of BIM information combines BIM-based software with other advanced technologies. These advanced technologies link the digital to the physical entities and research has already been conducted to investigate the combination of BIM and other technologies such as Virtual Reality (VR) for quality defect management.

The objective of this text is to report the improvement of BIM uses with the addition of interactive capacities allowed by VR technology. The text analyses the degree of achievement allowed by the actual software to perform each aspect combining BIM and VR, mainly in two important applications: 4D model supporting construction activity; 7D model concerning maintenance. A bibliographic and software research was made to support the study.

2 VR AND BIM CAPACITIES

Virtual Reality (VR) technology has been improving BIM allowing interaction with 3D/BIM models in two essential ways:

- The **walkthrough** is the most popular as the user can view the 3D model in a virtual environment in real time from multiple perspectives, from inside or outside of the building;
- The **consulting data** focus concerns the possibility to consult the information centralized in a BIM model.

The VR context is interrelated with other fields that can make use of the visualization allowed by the BIM model, such as facilities management related with the visualization of data included in a BIM model, in real time following the interaction made possible by VR technology.

2.1 Walkthrough

Currently there are various applications of virtual reality tour applied in the field of construction. Revit files as *fbx* format can be imported into 3ds Max, and render with appropriate materials and settings for virtual space can be applied. An experience VR content can be non-immersive, by using just a desktop or tablet PC, or immersive, by using a head-mounted display like Gear VR [7] (Rho, 2015) (Figure 1) or Oculus Rift [8] (Rift, 2017).



Figure 1: Improving BIM with Gear VR glasses in a desktop and in a work place.

- **Oculus** can be used to replicate an entire building and give a better perspective of the actual scale of the project, which is impossible using traditional monitor oriented systems and offers a wide viewing angle of up to 110° [7] (Rho, 2015). VR glasses are handling to visualize and experience 3D model, 360-degree panorama picture, and virtual mock-up over a BIM model. Currently architects, engineers and other construction specialists are already exploring the length and breadth of this joint technology (Figure 2);
- **CAVE-like platforms** have been developed for immersive VR experience as they track user's head and control wand usually with 6 degrees of freedom, to navigate inside the virtual environment and interact with the contents. Due to its immersive experience and intuitive manipulation capability, it quickly gained popularity in both research and industry community [9] (Du *et al*, 2016). VR can evoke a quit realist response in exactly the same way that physical architecture can play an important

role at all stages of the design-to-construction process, from evaluating design options and showcasing proposals, to designing out errors and ironing out construction and serviceability issues before breaking ground on site.



Figure 2: Virtual reality tour inside and outside a BIM model and supporting a collaborative meeting.

In construction activity the use of VR capacities brings great potentials. Presenting BIM models of projects in VR environment redefines communication and collaboration in the field and in the office. BIM technology and VR have the ability to innovate the building industry. At a first glance, many feel the benefits of using a BIM model with VR are purely for marketing leveraging the 3D model for visual aids, but taking a deeper look at a BIM model it will reveal many practical reasons to adopt BIM with VR. Collaboration in VR can be the future of BIM.

2.2 Consulting Data

The basic concept of BIM is a consistent 3D model of buildings containing all main data as base for collaboration for all disciplines. Compared to dedicated AEC design review software like Navisworks or Tekla BIMsight, equivalent tools inside a VR environment are still very much in their beginning. This is particularly true of game engine VR experiences, where the onus tends to be on presenting a polished vision of a proposed building, rather than delivering practical tools for solving real world design and construction problems. When moving from Revit to Autodesk Stingray [10] (Stingray, 2017), data is not only retained, but users can click on objects and view the underlying attribute information. In VR mode, users can click on an object to view information, including metadata.

Fully interactive VR software also has extremely high performance demands, so some form of model optimisation is required when bringing BIM data into a VR environment. This is one area where specialist VR consultancies earn their keep with finely tuned processes for tasks like simplifying geometry, adding lighting, fixing gaps in the model and culling objects that will not be visible in the scene. Once the model is inside the VR environment, things like materials, lighting, furniture and other small details that make the VR experience feel real are added:

- An accessible high end visualisation and virtual reality of a BIM model is obtain using the VR plugin of Revit, the **Enscape** [11] (Enscape, 2017). Enscape is a VR and real-time rendering plugin for Revit. Inside Revit is possible to access the plugin Enscape and start to walk through the fully rendered project, without uploading to cloud or exporting to other programs. The user can observe both models in Revit and

in Enscape (Figure 4). So, all changes in Revit are immediately available to evaluate in Enscape. With Enscape, the user is able to quickly explore different design options supporting a collaborative project team. As the Revit allows the user can work over the model applying all the capacities of modelling, consulting the information linked to the parametric objects used in the model process, and obtain cuts over perspectives allowing the analyses of the composition of all elements of the BIM model. So the aspect of linking the consulting capacity and the VR ability of walking around is a very important improvement in the use of BIM methodology. To improve VR experience Enscape can also be used together with Oculus Rift;

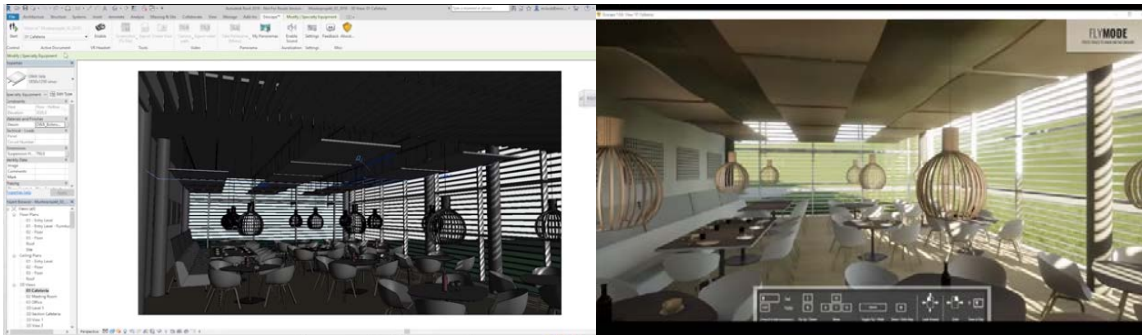


Figure 3: Enscape plugin of Revit.

- Some progress has been made on VR techniques such as registration on tracking and display hardware, but only recently the link to BIM methodology have being made. However, a VR system should be more convenient and combined with in-use applications to support multi-disciplinary users throughout construction lifecycle. Jiao et al. [12] (2013) presents a pilot cloud framework regarding an environment utilizing **web3D**, BIM and **BSNS** (Business Social Networking Services). Technical solutions to key issues such as authoring, publishing, and composition are designed. The proposed environment is seamlessly integrated into in-use information systems and therefore enjoys greater usability.

3 4D/VR/BIM MODEL – CONSTRUCTION PLANNING

4D CAD models, that integrate physical 3D elements with time, have been used to visualize construction processes in several projects worldwide [13] (Mahalingam et al., 2010). 4D models have been used during the construction phase and have been shown to have benefits over processes that span the entire lifecycle of a project such as collaboration with stakeholders, making design decisions, assessing project constructability, identifying spatial conflicts in construction. Concerning the creation of 4D applications, as a support to follow construction planning, several studies can be found, linking VR technology to 3D geometric models and reports related with the generation of 4D/BIM models (Figure 5):

- Sampaio et al. [14] (Sampaio et al., 2012) implemented a prototype based on VR technology applied on construction planning. The geometrical AutoCAD 3D model of distinct steps of the construction activity is linked to the construction planning schedule, defining a 4D model. VR technology allows the visualization of different

stages of the construction, and the interaction with the construction activity, resulting in a valuable asset in monitoring the development of the construction activity. The prototype makes use of MS Project, AutoCAD and EON Studio a VR software. The 4D/VR application clearly shows the constructive process, avoiding inaccuracies and building errors, and so improving the communication between partners in the construction process;

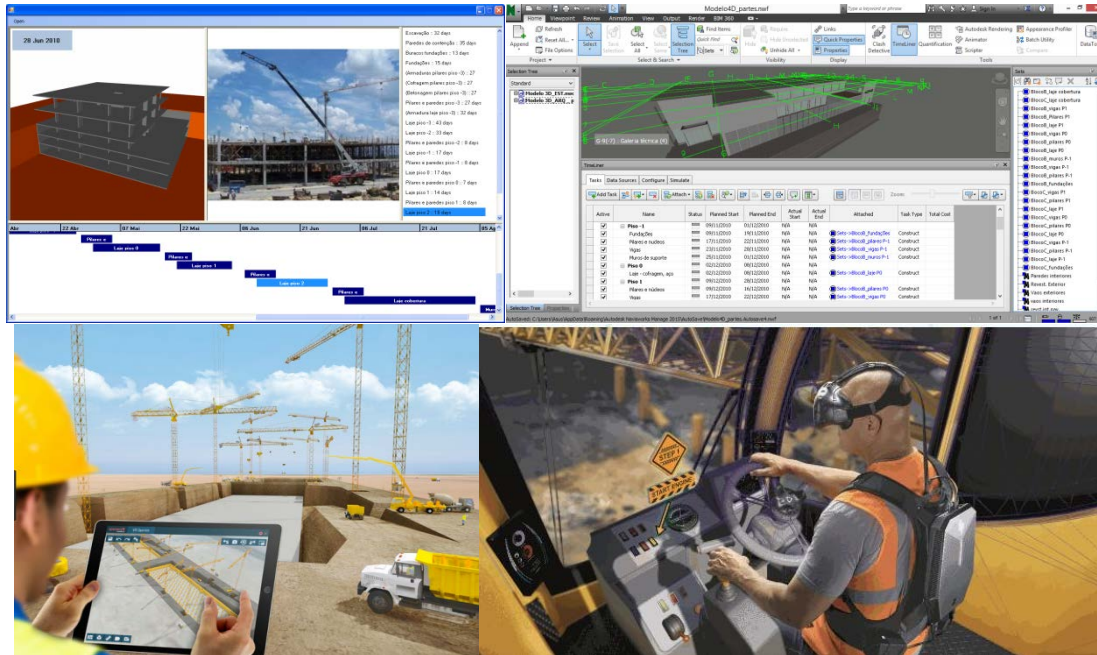


Figure 4: Screen shots of 4D/VR/BIM simulation processes.

- Sampaio and Mota [5] (Sampaio and Mota, 2016) created a 4D/BIM model using Autodesk software (Revit and Navisworks) and MS Project. The 4D model allows the addition of time associations to the 3D elements, grouped in sets related with each task, allowing the visualizations and analysis of the activity sequence for the construction. The Navisworks software allowed the interconnections amongst the 3D models created in the planning where this solution built the interconnection of 3D models with planning in MS Project. The ability to navigate through the model allows analyzing each corner and each location of the model. Navisworks also has the potential to provide support in the analysis and detection of conflicts amongst the specialty projects.

Recent developments in VR have encouraged the utilization of interactive architectural visualization in the design, construction and facility management of building BIM projects. Du (2016) [9] find that the interpersonal interaction in the VR environment is more critical to the effective communication in a building project, as it creates a shared immersive experience, and developed a BIM-enabled VR environment to realize multiplayer walkthrough in virtual buildings. The multiplayer virtual walk allows real time interactions of remotely located project stakeholders in the same environment, with a shared immersive walkthrough experience [15] (Gu and London, 2010).

VR combines a device for interaction creating virtual environment and the current aim is study how to use device or establish links for the presentation of information contained in a BIM models. Following that perspective, commercial software houses have been developing advanced BIM/VR products. The use of BIM technology on construction projects has the potential to improve the process by allowing all team members to collaborate in an accurate and efficient way. Some of the VR software adapted to BIM and the main capacities are listed below:

- **Enscape** is Revit plugin that creates a VR walkthrough with one click, based on BIM data and can be also used in a 4D context [11] (Enscape, 2017). There is no need to download or learn how to operate additional software. All materials, geometry and entourage come from the Revit construction project and can be changed during the VR simulation. This flexibility allows spontaneous presentations with a real-time rendering quality within the construction design workflow;
- Combined with the **Oculus Rift**, customers can virtually walk through the Enscape project and experience it as if it were already built. In the construction process the engineered visualise the correspondent building 4D/BIM step and consult all the information the user need to compare the progress building stage, the delay or the advance realized in the construction place. Enscape has become a standard application in projects worldwide namely as a construction planning support;
- **Augment** is software that can be used in smartphone or tablet allowing the user to view the 3D model in the real environment in real time from multiple perspectives. BIM with VR enables project stakeholders to create information-rich virtual models that help better visualize building projects. Data-rich virtual information is available on site through connected devices in real time. Site managers can overlay the BIM model on the project site. Construction issues can be addressed in real time, saving time and resources [16] (Augment, 2017) (Figure 6);
- **Samsung Gear VR** is a virtual reality device that allows exploring virtual worlds at the construction site or during meetings. To use Gear VR during construction phases and facility management purposes two paths are needed: BIM model and construction site picture based, and users must be familiarized with Revit software and 3ds Max software for visualizing and rendering, or to navigate inside game engines like Unity3D with Android Studio are need [7] (Rho, 2015).

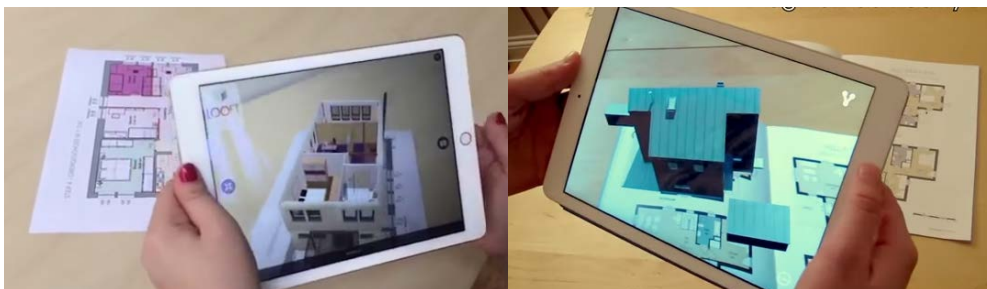


Figure 5: Screen shots of Augment software.

4 7D/VR/MODEL - MANAGEMENT AND MAINTENANCE

Combining BIM with VR is expected to envision efficient collaboration, improved data integrity, intelligent documentation, distributed access and retrieval of building data and high quality project outcome through enhanced performance analysis, as well as multidisciplinary planning and coordination. VR research considers not only the technological development; a very important part of the research also concerns the application of the technologies and their adoption by the practices. In BIM, while the potential benefits of the technologies may seem evident, the industry adoption rate of BIM varies and now the importance of adding VR benefits must be a research point [17] (Advenser, 2016).

The BIM includes semantics into the construction process (e.g., structure, air conditioning/ventilation, mechanical, electrical, plumbing, etc.) and data for simulation (materials/structure resistance, energy consumption, thermal calculations, lighting, acoustic simulations, etc.). These issues must be addressed throughout the construction project but mainly, at the beginning during the design phase to fulfil the customer's requirements, during the construction work to anticipate technical constraints on site, and during the maintenance phase to control the building;

The acceptance and expansion of VR has been growing exponentially in the construction field. A VR tour can be applied, from a facility management perspective, in the maintenance control (7D/BIM model), or from a project team view, to review constructability (4D/BIM model) and to support decision making (Figure 7):

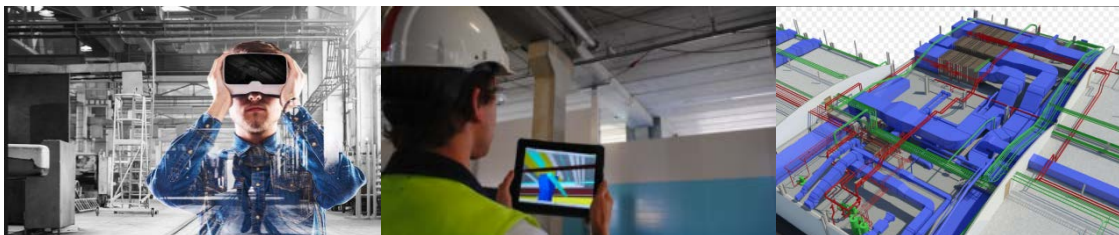


Figure 6: Screen shots of 7D/VR/BIM applications.

- A virtual tour together with **Enscape** allows the facility manager to look around the facility and check the conditions of equipment and obtain relevant information from the BIM model. For instances, visualizing the BIM model of a MEP system, in a virtual tour and using on a tablet PC, helps the facility manager to understand what is installed behind the ceiling tile. Augment tool can also be used to view and consult the 3D model data, in the real environment and in real time, to facilitate installation and layout;
- The traditional **EON software** has been used in 4D/VR models to support the construction activity. Currently the EON Icube is a multi-walled system where the user is completely surrounded by images and sound. The EON Icube uses light-enhancing rigid wall material, provides users with an impressive speed of immersive content creation and deployment, and has built-in collaborative capabilities. EON Icube is compatible with most Virtual Reality peripherals, such as data-gloves, Xbox controllers, joysticks, or motion tracking systems. EON maintains a virtual reality library that already has many sample AEC environments built [18] (Eon, 2017);

- The **Autodesk LIVE** allows users to transform Revit models and step inside their own designs to share and present. AEC professionals can upload BIM models to the cloud with just one click and interactive visualizations that can be published to mobile. This gives collaborators a better sense of the design early on so changes can be made with minimal disruption or delay. It allows the consult of BIM data and so it support management and maintenance within a collaborative team.

5 CONCLUSIONS

For architects and designers, VR+BIM enable them to better communicate design intent. A challenge for architects is that of communicating concepts and visions for buildings. The advantage in using VR is in the communication of ideas, concepts and the vision for the building. This enables all the parties to more quickly reach a full appreciation of the building plan. When everyone shares a common understanding of the design, the project is executed more efficiently from the outset. This current BIM with VR topic require dissemination; application in real cases and pointed out, in reports, achievements and limitation; following the technologic advances that supports the BIM use and the visualization of data, in real time while the interacting with the model made possible by VR technology. BIM + VR provide an opportunity to analyse and explore BIM models within virtual environments.

Introducing VR interactive capabilities into 3D/BIM models in the construction process is a main way to test virtually and correct a construction project before the realization, as the walkthrough is available as well the visualization of data linked to each parametric object, improving the necessity collaboration within the design team. So, BIM/VR applications can contribute to reduce costs due to the construction of a real mock-up, and to avoid mistakes on site that generates material wastes.

Software houses have been demanding the integration of BIM with VR plugins in order to support the development of nD/BIM tasks. The fundamental base of BIM+VR concerns the collaboration as a first step, but the possibility of consult data while walking through the building, improves significantly the use of BIM in design, construction, maintenance and management.

REFERENCES

- [1] S. Azhar, M. Hein, and B. Sketo, “*Building information modeling (BIM): benefits, risks and challenges*”, <http://ascpro.ascweb.org/chair/paper/CPGT182002008.pdf> 2008
- [2] R. Eadie, M. Browne, H. Odeyinka, C. McKeown and S. McNiff, “*BIM implementation throughout the UK construction project lifecycle: An analysis*”, *Automation in Construction* 36 (2013) 145–151. <http://dx.doi.org/10.1016/j.autcon.2013.09.001>
- [3] A.Z. Sampaio “*Building Information Modelling: nD/BIM models*” (in portuguese), FUNDEC Workshop, University of Lisbon, Lisbon, Portugal, Apr 2017.
- [4] L.J. Chen and H. Luo, “*A BIM-based construction quality management model and its applications*”, *Automation in Construction* 46 (2014) 64–73 <http://dx.doi.org/10.1016/j.autcon.2014.05.009>
- [5] A.Z. Sampaio and C. Mota, “*BIM model of structures used in construction planning*”, *Proceedings of the National meeting of Structural Concrete*, Coimbra, Portugal, 2 - 4 November 2016. ID: 4, 10 pgs, <http://be2016.dec.uc.pt/>

- [6] A.Z. Sampaio and D. Simes, “*Maintenance of buildings supported on BIM methodology*”, Proceedings of XIV DBMC - Durability of Building Materials and Components, Ghent, Belgian, May 2017, e-ISBN: 978-2-35158-159-9
- [7] J. Rho, “*CS10427: Virtual-Augmented Reality for Construction, Utilizing Gear VR*”, Autodesk University <http://au.autodesk.com/au-online/classes-on-demand/class-catalog/2015/revit-for-architects/cs10427#chapter=0>
- [8] Rift, 2017 Oculus Rift, <https://www.oculus.com/experiences/rift/>
- [9] J. Du and Y. Shi, “*Communication by Interaction: A Multiplayer VR Environment for Building Walkthroughs*”. Proceedings of Construction Research Congress, 2016: 2281-2290. DOI: 10.1061/9780784479827.227
- [10] Stingray, 2017. <https://knowledge.autodesk.com/support/stingray/getting-started?sort=score>
- [11] Enscape 2017, <https://enscape3d.com/>
- [12] Y. Jiao, S. Zhang, Y. Wang and B-M Yang, “*Towards cloud Augmented Reality for construction application by BIM and SNS integration*”, Automation in Construction 33 (2013) 37–47. <http://dx.doi.org/10.1016/j.autcon.2012.09.018>
- [13] A. Mahalingam, R. Kash and c. Mahajan, “*An evaluation of the applicability of 4D CAD on construction projects*”, Automation in Construction 19 (2010) 148–159. <http://dx.doi.org/10.1016/j.autcon.2009.11.015>
- [14] A.Z. Sampaio, J. Prata, A.R. Gomes and D. Rosrio, “*Construction and maintenance planning supported on virtual environments*”, Book: Virtual Reality - Human Computer Interaction, Ed. Xin-Xing Tang, Publisher: InTech, ISBN 978-953-51-0721-7, DOI: 10.5772/46409, ch. 07, 125 – 152, <http://www.intechopen.com/articles/show/title/construction-and-maintenance-planning-supported-on-virtual-environments>
- [15] N. Gu and K. London, “*Understanding and facilitating BIM adoption in the AEC industry*”, Automation in Construction 19 (2010) 988–999. <http://dx.doi.org/10.1016/j.autcon.2010.09.002>
- [16] Augment, 2017, <http://www.augment.com/blog/enhancing-bim-with-augmented-reality/>
- [17] Advenser, 2016. Integrating BIM and Virtual Reality – The Next Big Thing?, <https://www.advenser.com/2016/11/23/integrating-bim-and-virtual-reality-the-next-big-thing/>
- [18] EON icube 2017 <https://www.eonreality.com/eon-icube/>