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Enhancing BIM Methodology with VR Technology

Alc nia Zita Sampaio

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Abstract

Building information modeling (BIM) is defined as the process of generating, storing, managing, exchanging, and sharing building information. In the construction industry, the processes and technologies that support BIM are constantly evolving, making the BIM even more attractive. A current topic that requires attention is the integration of BIM with virtual reality (VR) where the user visualizes a virtual world and can interact with it. 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. The objective of this chapter is to report the improvement of BIM uses with the addition of interactive capacities allowed by VR technology. A bibliographic and software research was made to support the study.

Keywords: BIM, VR, VR devices, VR + BIM applications, construction, facility management

1. Introduction

Building information modeling (BIM) methodology enables project stakeholders to create information-rich virtual models that help better to visualize building projects. There is currently a shift in the AEC (Architecture, Engineering, and Construction) industry to embrace BIM as a tool that can assist in integrating the fragmented industry by eliminating inefficiencies and redundancies, improving collaboration and communication, and enhancing overall productivity [1]. 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 [2]. BIM concerns the process of development of a computer-generated model representing all disciplines of a building design, and its use in several tasks as design simulation, construction planning, or facilities management. The resulting product,

a Building Information Model, is a data-rich, intelligent and parametric digital representation of the building project. So, as a first perspective, the result of BIM methodology can not only be considered as a virtual representation of a building, an object-oriented three-dimensional (3D) model, but is also a repository of project data [3]. The BIM data-model can be easily accessed, facilitating interoperability and exchange of project data with related software applications.

An actual BIM subject that requires research, practical application and software adaptation, is the integration of BIM with virtual reality (VR) technology. Current VR devices allow the user to visualize a virtual world and to interact with the virtual space and its components. The main objective, that has been reported, concerns the use of VR system combined with plugins in order to support BIM multiuse throughout the building lifecycle. As so, the VR environment integrates information systems and immersive environments. For that, VR requires devices for interaction with the virtual environment of the building and the construction space. The current target, concerning integrating VR and BIM, is the study of how to use or adapt those VR devices and how to establish links for the presentation of information contained in a BIM model. This is bringing BIM data into a VR environment. Visualizing virtual worlds and interacting with it, is essentially a VR aspect, and creating and manipulating design data, is the essence of BIM, so the link of these two strong capacities should be known and explored. Following this 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. Unlimited extension of the use of BIM information combines BIM-based software with other advanced technologies [4]. 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. The present reflection involves the link of BIM to VR.

Concerning BIM training, the school has an important role in the education of young entrants in the industry and to equip them with BIM skills, including the additional knowledge about VR + BIM. Regarding current digital 3D modeling technologies, added to design information and provided in mobile equipment, students and professionals can use advanced capabilities of interaction like VR technology, improving the use BIM methodology. The objective of this text is to report some of the most important enhances of BIM uses, when interactive capacity allowed by VR technology is added. A research concerning technologic advances in VR software, as a complement to improve BIM environment's management, was made.

2. nD/BIM models

BIM methodology can generate and maintain information produced during the whole lifecycle of a building project, from design to maintenance, in a centralized model, the BIM model. As so, the BIM data-rich model supports the application of the rich-data in various fields [5]. The model allows views and data, appropriate to various users' needs. Distinct type of data can be extracted from the model, analyzed, and applied to generate new information. The data-rich model supports decisions making and improves the process of developing and delivering the design. Due to the consistency of design data with quality data and construction modeling process with value control, the potential of BIM implementation in improving management lies

in its ability to present multi-dimensional data concerning design data. The use of BIM data in the development of several tasks is considered for the generation of nD/BIM applications [6].

- 3D/BIM model concerns the modeling process of all disciplines (architecture, structures and MEP - mechanical, electrical, and piping) and as it is based in parametric objects, the relationships (spatial geometry) and the properties (physical and mechanic);
- 4D/BIM model refers to the construction planning supporting the visual simulation of the building construction and its control. The 4D application links 3D elements, organized in sets, to the correspondent time schedule, allowing the comparison between the real work and the planned sequence of the process (supports eventual changes and allows a permanent actualization of schedules, estimates, and logistic site management) [7];
- 5D/BIM model is associated with cost estimation (control of the financing plan based on take-off material quantities in each constructive step) [8];
- 6D/BIM model supports the performance of energy and sustainability studies (energy consumption estimate along the project and subsequent monitoring, measurement and verification of consumption during the occupation of the building) [9];
- 7D/BIM model is generated to support the maintenance activity and distinct management facilities needed in the building during its occupancy [10].

The use of design data, centralized in a BIM model, in several activities allows a high level of communication among the team members, but to achieve an adequate collaborative work it is required an efficient interoperability between specific BIM tools. As per the reports, companies began seeing faster project approvals, increased positive team interactions, and higher product quality [11]. Unlimited extension of the use of BIM information combines BIM-based software with other advanced technologies, such as VR for quality defect management [12]. In the context of linking VR with BIM, the application of VR tools seems to be the next natural step for BIM as it can seamlessly blend into the design process, ultimately improving architecture and engineers and the entire built environment [13].

The VR field is interrelated with other domains 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. As such, it is expected to be further explored in the near future. This text reports the main improvement of BIM uses when interactive capacities allowed by VR technology are added. The focus is how to explore BIM data in an interactive VR environment. As so, the study analyses the degree of achievements allowed by the actual software to perform several tasks combining BIM and VR, mainly in two important applications: 4D model supporting construction activity and 7D model concerning maintenance.

3. VR and BIM capacities

Virtual reality (VR) technology leads to a better communication for key players across the building sector, based on greater design visualization, contributing to a better understanding of the

project [14]. The knowledge about the different type of data that can be associated to the set of parameters that identifies each parametric object, base of the BIM modeling process, is of great importance when the team members wants to analyze problems and to discuss alternative solutions. Interacting with the BIM model, in order to visualize the geometry of the elements and to consult the parametric data, is an improvement in the development of a collaborative project.

The acceptance of VR use in construction field has been growing. VR enables the user to fully immerse himself in a 1:1-scale, 3D/BIM model which can be manipulated, providing an immersive accurate sense of presence in a space that is yet to be built [15]. Architectural, engineering, and construction management professionals recognize that VR applications are making it easier for clients to visualize designs earlier, shaving material costs off budgets and reducing the amount of workers needed for projects. For instance, a VR tour can be applied over a BIM model in order to check, from a facility management perspective, the maintenance schedule (7D/BIM model), or from a project team view, the constructability review (4D/BIM model), supporting decisions making. VR technology can improve BIM methodology, as it allows interaction with 3D/BIM models in two essential ways:

- **Walkthrough** is the most popular as the user can view the 3D model in a virtual environment in real time from multiple perspectives of the building, from inside or outside;
- **Consulting data** concerns the possibility to retrieve information centralized in a BIM model, namely, data associated with parameters that compose the parametric objects used in the modeling process.

3.1. Walkthrough

Virtual reality can improve the development and analyses of any detail of the project, along distinct design steps, as it easily involves all team and a justifiable decision can be worked out concerning alternative solutions or problems resolution. The viability of a building could be tested through scale digital models and human judgment, but these models cannot completely simulate the environmental factors that a building is subjected to and human analyses can be inaccurate. VR offers more realistic possibilities as the final model can be rendered in 3D and the team member can experience and explore the space as a real space.

VR technology allows the user to observe artificial world, by walking through outside and inside and see everything around, and also reach out touching objects in real time. To create an immersive VR environment computer graphics technology and a selective equipment with advanced viewing and interaction capabilities are needed [16]. The 3D virtual world used to support the distinct aspects of the construction activity is permanently increasing nowadays. The current perspective, reported in research works and in commercial web sites, is the use of VR applied over the BIM model, as a positive and an innovative contribute, to improve the construction industry efficiency. VR technology has seen developments in recent years and has been applied in architectural, engineering, and construction fields. The checklist can be prepared smoothly so as to save valuable time and money for the company as well as the client.

Currently architects, engineers, and other construction specialists are already exploring the length and breadth of the joint RV + BIM technology (**Figure 1**). There are almost 50+ VR



Figure 1. Virtual reality tour inside and outside a BIM model and supporting a collaborative meeting.

software and hardware tools available right now that can redefine the way BIM is implemented and interpreted [17].

Experience VR content can be non-immersive, by using just a desktop or tablet PC, or immersive, by using a head-mounted display (HMD) like Gear VR or Oculus Rift. VR head-mounted displays have the capacity to improve the way designers communicate before buildings are built. HMD device allows the user to be immersed in the project model supporting to understand and assess new design concepts and alternatives created with BIM modeler tools. Currently, there are various applications of virtual reality tools that can be applied in the construction activity as a support to engineers' and architects' work:

- **Samsung Gear VR** is a virtual reality device that allows exploring virtual worlds at the construction site or during meetings (**Figure 2**). To accomplish virtual reality by utilizing Gear VR during facility management purposes, a BIM model is needed and also construction site pictures are needed to follow construction phases [18]. The user should be familiar with BIM software, such as Revit for visualizing, and 3ds Max for rendering. In order to navigate inside and outside the BIM model in a virtual world, the use of game engines like Unity3D with Android Studio are necessary and regarding exploring panorama pictures, equipment for panoramic photographs and editing tools that will help convert those photos to the 3D world will be required as well [19];
- **Oculus Rift** is a real-time viewer application with interactive capacities, developed by the Oculus Company, and can be implemented as a plugin in Revit [20]. With the right technical know-how, Oculus can be used to represent an entire building and give a better perspective of the actual scale of the project, which is not allowed so realistically using just traditional monitor oriented systems. It offers a wide viewing angle of up to 110°. These VR glasses are handling to visualize and experience 3D model, 360° panorama picture, and virtual mock-up over a BIM model [21]. For Oculus Rift, the minimum interactivity demands are typically higher, as physical interaction and display update becomes much more integrated. The device provides stereoscopic 3D view and includes a gyroscope, an accelerometer, and a magnetometer to determine the orientation of the user's head in the real world. In the case of the Rift, the stereoscopic 3D view is implemented by means of split-screen rendering, where the left half of the screen corresponds to the left eye, and vice versa (**Figure 3**);

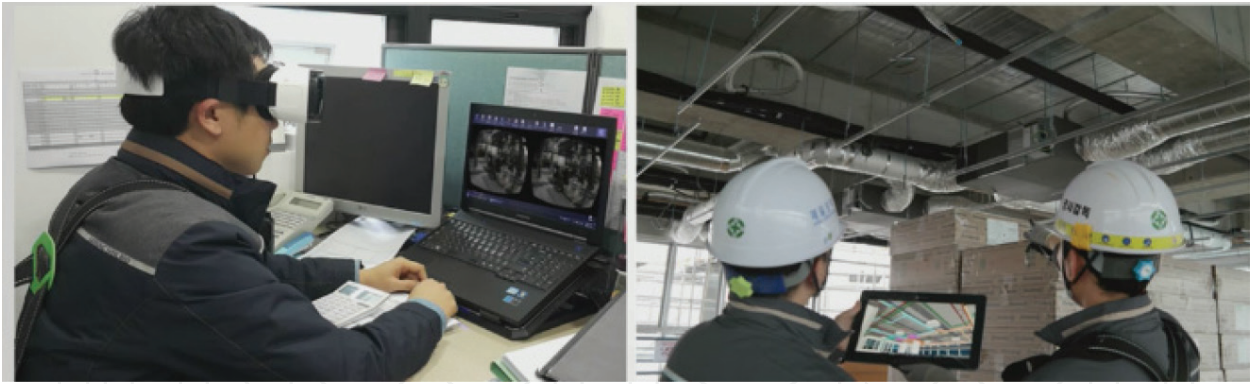


Figure 2. Improving BIM with gear VR glasses in a desktop and in a work place [18].

- The rapid advancement in engineering brings VR to expand vision capacities. The use of **hologram projections** in the construction activity, enables the end user to experience different textures or choose from a variety of in-built texture formats the required aspect for the project [22] (**Figure 4**). The Revit model can be manipulated using hologram projections supporting a building collaborative design;
- With the **Enscape** Revit plugin, the user is able to quickly explore different design options and present projects to clients and so it has become a standard application in projects worldwide [23]. A walkthrough using Enscape usually runs alongside Revit or SketchUp, reflecting all the perspectives, geometric details, and eventual adjustments to the project. Additionally, in a real time rendering in SketchUp, available by Enscape, a programmed walkthrough can be programmed, allowing the creation of a series of walkthrough movies, which can be exported as a stand-alone executable file to be distributed to clients or colleagues. Using Enscape for real-time visualization and rendering enables the project team to accurately communicate with engineering design, clients, and stakeholders, improving the collaborative design. The ability to walkthrough inside BIM models and to regenerate design changes without leaving Revit is of a great importance and time saver. So Enscape add a significant value to communication in a team, as a real-time rendered walkthroughs, is able to be generated straight from Revit models. In this immersive and highly realistic way, consultants or designers better understand the project, as they can judge not just the technical aspect but also the realistic visual impact (**Figure 5**);



Figure 3. Left and right half of the screen corresponds to each eye [20].



Figure 4. Touchable holograms [22].

- **Smart Reality** app brings a new realism of tools to interact with clients, engineers, contractors, and other professionals in the building industry [24]. The user is instantly immersed in a true 3D environment that gives a sense of scale, depth, and spatial awareness adding a more realistic perspective of the model and its environment. The VR mobile app was developed for builders and combines 2D plans and 3D project models for an enhanced, mobile visualization of construction projects. The VR capacity of this app is beginning to introduce a new level of certainty for the design and construction process as well, helping stakeholders to get a more full experience of the BIM model, offering an unobstructed, real-world perspective of projects for planning, design, and construction management (Figure 6). It is designed for the AEC sector and works with BIM tools like Autodesk's Revit. As the design process is slow, Smart Reality can be used to help the owner or architect to get a better feel of spatial recognition of the intended product in advance of construction beginning. The Smart Reality app can be downloaded for iOS and Android and used to check and analyze distinct aspects of the project in any place and with any member of the team, in an easy and collaborative way. The viewing experience can further be enhanced by using VR headsets like Oculus Rift and Epson's Moverio BT-200 smart glasses [25];
- The **Visidraft** app actually builds a 3D world around the user. Visidraft instantly converts 2D elevations as well plans into corresponding 3D projections (when viewed through a mobile camera). When the user places virtual objects into the environment, the app automatically calculates the relative distances of all items present in that room allowing the



Figure 5. Walkthrough capacity using Enscape Revit plugin [23].

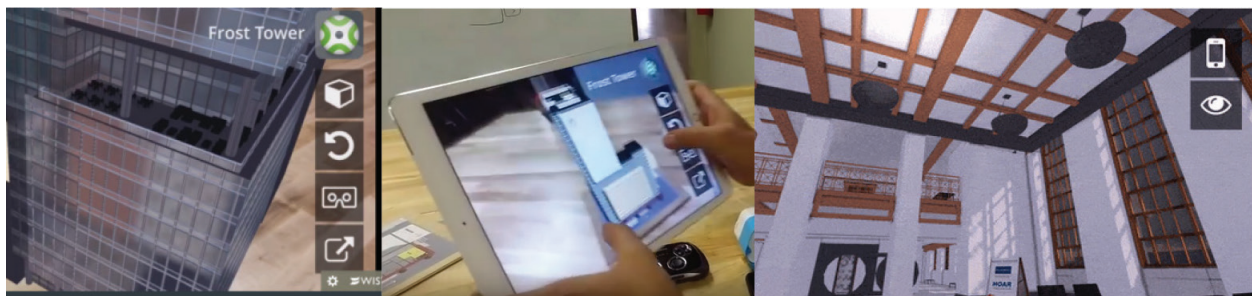


Figure 6. Smart reality application [20].

user to walk around the room physically with the device and visualize and re-arrange the items conveniently (Figure 7). The app comes out with Revit, ArchiCAD, and Nemetschek Vectorworks plugins [26];

- **PrioVR** is a real-time motion capture system for virtual reality that can be also used in construction (Figure 8). The motion capture device PrioVR helps the user to experience a VR environment through natural body movements instead of using a keyboard and a mouse [22]. PrioVR can be used for virtually opening doors, switch the lights on and off and reposition objects, and also change materials such as wall paper and flooring and experiment with all kinds of environmental elements such as lighting, weather, and surroundings in real time. The device works via body sensors that transmit information about the body's movements back to the VR software. The user is equipped with a full body suit, which has 12 internal sensors attached to it, or just with an upper body, tracking with 8 sensors. To create a VR environment of a construction place and to allow a useful interaction with the design components, the Prio VR sensors must adequately be calibrated. This adjustment allows user to capture accurately movements and modeled objects in the VR world. It allows a 360° viewing angle around the virtual place;
- **CAVE** (Cave Automatic Virtual Environment) platforms have been developed for immersive VR experience as they track user's head and control stick usually with 6 degrees of freedom, to navigate inside the virtual environment and interact with the contents of a 3D model including a 3D BIM model [27]. A CAVE takes normally the form of a cube-like space in which images are displayed by a series of projectors. Due to its immersive experience and intuitive manipulation capability, it quickly gained popularity in both research and construction industry community. The sense of presence is overawed and the



Figure 7. Visualizing, in mobile device, a 3D model using Visidraft app [26].



Figure 8. PrioVR capture system applied in construction [22].

sensation of the user being immersed in a real place is the most convincing. As the team member better communicate between them and the client better understand spatial relationships and scale of the project. VR can induce a quit realist analyses as the physical construction seems to be present. VR plays an important role at all stages of the design-to-construction process. Igloo BIM cave has space constraints; there are limitations on where an environment can be placed and how easy it is to bring people to it (**Figure 9**).

3.2. Consulting data

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. This is the concept of walkthrough, but BIM contains data and it is convenient to explore BIM data while walking inside a virtual model. VR 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. Fully interactive VR software has extremely high performance demands, during a tour, but additional technology capacities concerning model-data retrieving is required when bringing BIM data into a VR environment.

Collaboration for BIM tools is designed to help project teams overcome the barriers of corporate firewalls and physical location by enabling centralized access to BIM models. Team members in

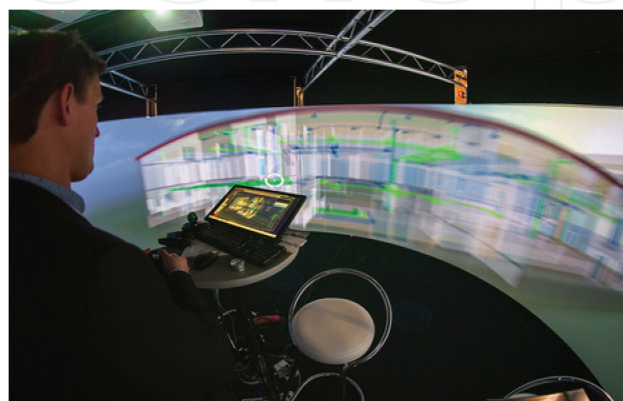


Figure 9. An igloo BIM cave [27].

all disciplines from multiple companies or sites worldwide are able to access and work in models hosted on cloud servers. The model is centrally hosted and access to project data is permissions based, and it can be accessed by project teams anywhere. So, when collaborative projects are discussed between firms, they consult BIM data in models hosted on clouds. In addition, the capacity of consulting BIM data can be improved with VR devices applied directly over the BIM model.

Concerning a 7D/BIM application, a VR tour can be applied, from a facility management or maintenance perspective to support decision making. Combining VR devices applied over the BIM model and the real inspection in the place, it offers a new perspective for facility management professionals. VR has the capacity to improve how managers and construction workers access virtual information of the established project. All data-rich virtual information is available from the BIM model, and can be retrieved, consulted, and analyzed during the real inspection to the site. Construction issues can be addressed in real-time and internal assets can be illustrated to facilitate installation and layout, saving time, and resources. Several plugins or BIM viewer allows consulting data from the 3D/BIM model and now there is a new class of mobile apps available that let project teams experience building plans in 3D:

- **Autodesk 360** allows the integration of the team in collaborative projects, as every modification in a BIM model is displayed in a handy timeline for everyone to see [28]. Autodesk produces a complete web-based solution for reviewing BIM content. To work with it, all Autodesk 360 involved members must be invited to the project and so every members will be able to see and download files uploaded in their project discipline. Along with showing the 3D model, Autodesk 360 displays every sheet embedded in the uploaded Revit model (**Figure 10**). The 3D viewer allows users to isolate elements by categories and display every elements property. So all data can be consulted, analyzed, and changed, refining the project in a collaborative environment;
- To support an integrated design environment, the Autodesk Revit allows a **viewer Revit plugin** [28]. In Revit the user initializes the Add-Ins tab and a 3D visualization representation results visible in a new window (**Figure 11**). The user can navigate over the model, retrieving the desired data in a desktop using mouse and keyboard, or improving the VR experience connecting with an Oculus HMD device. The immersion in the model exposes the user to the entire underlying BIM database initializing a data consulting process. The model is visualized in an overlapped window, where the user can interact as a VR user,

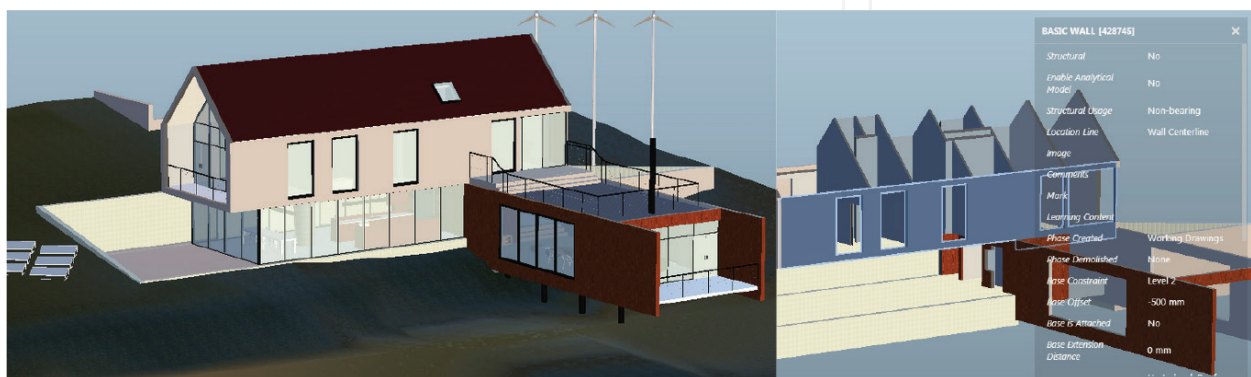


Figure 10. Using Autodesk 360 in a collaborative project [28].

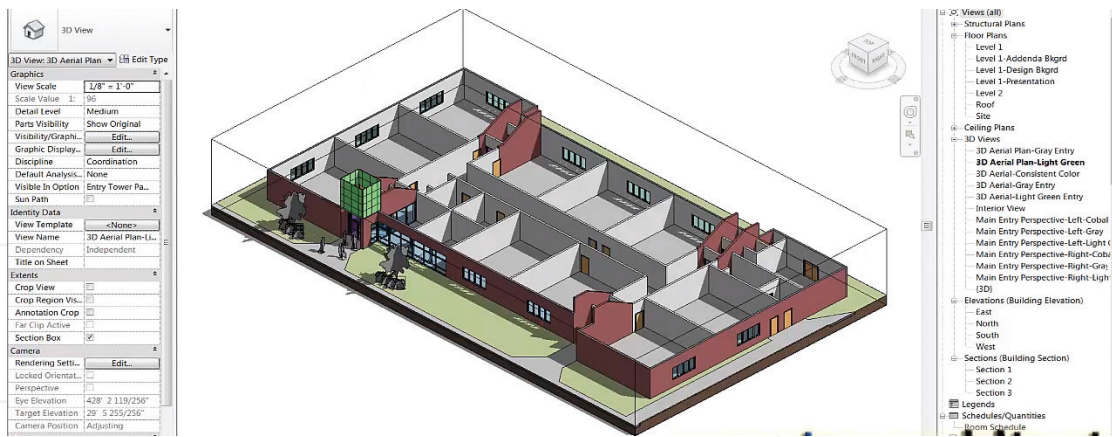


Figure 11. The viewer plugin interface in Revit [28].

and in addition, with the Revit open the user can consult the database of the model or the parametric object used in the modeling process. Every time a unique geometric representation is encountered for the first time, all of its data can be retrieved;

- An accessible high end visualization and virtual reality of a BIM model is obtain using the VR plugin of Revit, the **Enscape** [23]. It was previously mentioned just the walkthrough capacity, but Enscape also allows, together with Revit, to consult data. Inside Revit is possible to access the plugin Enscape and the user can observe both models in Revit and in Enscape (**Figure 12**). In Revit, the user can consult the rich-data incorporated in the 3D/BIM model and in Enscape, can interact in a virtual space. So, all changes in Revit are immediately available to evaluate in Enscape. As the Revit allows the user to work over the model, it is possible to retrieve the information linked to each parametric object used in the BIM model. In a 7D/BIM domain (**Figure 12**), 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, using Revit interface. 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. 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. With Enscape, the user is able to quickly explore different design



Figure 12. Enscape plugin of Revit to access data [23].

options supporting a collaborative project team. Enscape will immediately show the alternative solutions or changes in the design, the designer makes in the project, using Revit;

- **Augment** is augmented reality (AR) software that allows user to view the 3D/BIM model in a realist environment and can be downloaded in a smartphone or tablet [29]. AR plus BIM technologies allow a real-time tour inside the building and also to consult BIM information. Augment allows the visualization of a 3D construct space from a set of 2D drawings of the project (**Figure 13**). The design team can upload the 2D design to the Augment app's website, and the client can view the 2D drawing in a 3D way, improving the understanding of the project details. In addition, AutoCAD, Revit, and SolidWorks software are compatible with Augment app. In Revit, the user can consult data and in augment the user can interact in a VR environment.
- **Autodesk Stingray** allows the user, by clicking over objects of a Revit model, to view the underlying attribute information [30]. The VR device allows the user to create high-quality, interactive estimates, and schedules in VR by linking external BIM data sources into Autodesk's Stingray interactive engine. For that BIM data is exported from Revit software into an external data source, to be organized and sorted, and then this information is used in Stingray in various configurations to create interactive, immersive environments (**Figure 14**). So, clients can visualize different design, cost, and scheduling options in VR. Members' team will be able to visualize 4D site logistics plans and 5D estimates, and so, to choose from various design and material options and see the costs associated with them. In addition, BIM information can be easily exported from Stingray to an external data source. Benefits of estimating and scheduling in VR include realistic design visualization and real-time decision;
- Since BIM software is normally run on single workstations, the potential for direct collaboration is somehow limited. The focus of research conducted by Kieferle and Woessner [12] was to provide a platform for the development and optimization by combining BIM and VR, based in linking Revit with **Covise**, VR software [31]. They have been able to implement a range of interactions but however they detected some limitation in the process. The project 3D model and the associated data can be visualized and consulted using Covise, improving collaboration even in remote team conferences situation. When changes are made in Revit, they directly reflected in Covise software and vice versa. This new approach as the capacity to promote bidirectional data exchange between the systems. Compared to other software this can be considered an advance in VR + BIM technology (**Figure 15**).

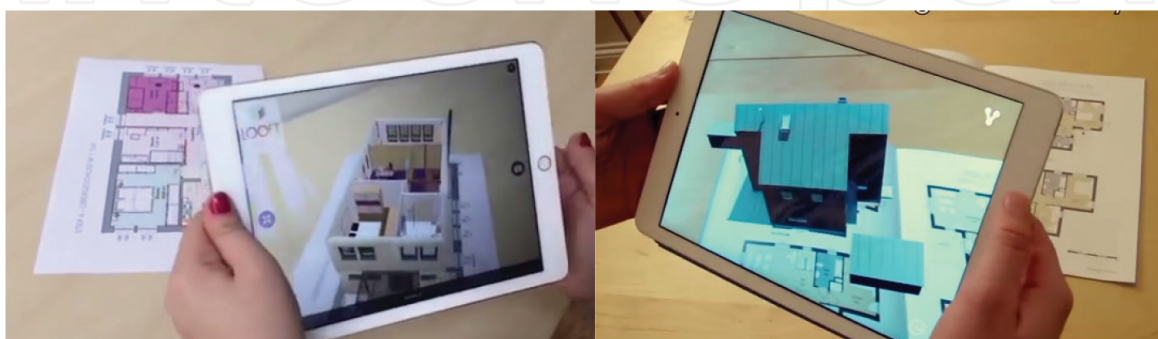


Figure 13. Consulting data to support maintenance using augment [29].



Figure 14. Interacting with Autodesk stingray [30].

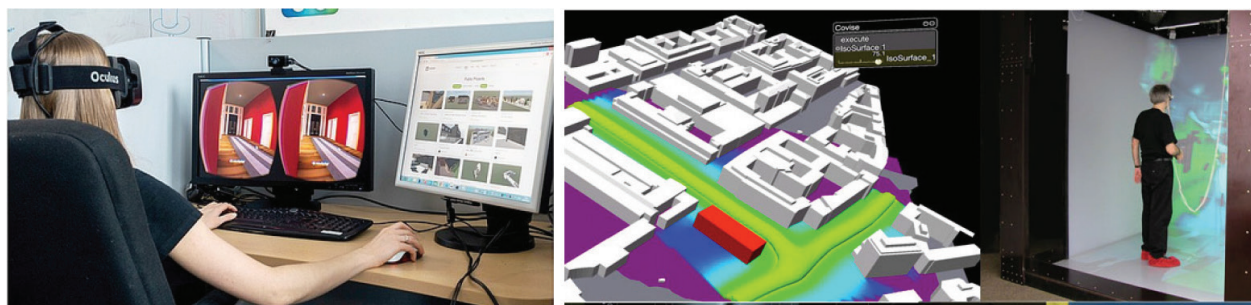


Figure 15. Interacting with Covise software [31].

- Some progress has been made on VR techniques but only recently the link to BIM methodology has being made. A VR system should be combined with in-use applications to support multi-disciplinary users throughout construction lifecycle. Jiao et al. [14] presents a pilot cloud framework regarding an environment utilizing **web3D**, **BIM**, and **BSNS** (Business Social Networking Services). Web3D can be applied in several BIM that uses supporting the AEC industry, namely, in system coordination and constructability review tasks (**Figure 16**). So 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.

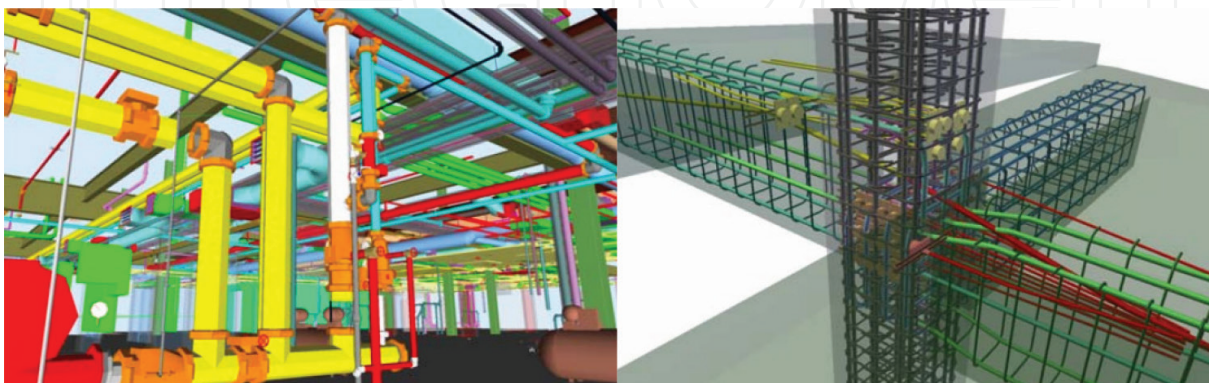


Figure 16. System coordination and constructability review using Web3D [1].

Some VR + BIM tools were described in order to present the state-of-the-art and the main progress concerning the current topic involving BIM tendency. Next items regard two nD tasks where the use of VR over BIM has been applied.

4. 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 [32]. 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, and 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. Two examples of 4D models are listed, using used only VR technology and the second model uses BIM tools without VR capacities (Figure 17):

- Sampaio et al. [33] 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 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;
- Sampaio and Mota [7] created a 4D/BIM model using Revit, MS Project, and Navisworks. The Navisworks software allows the interconnections among the 3D models, grouped in sets, and the related task following the activity sequence for the construction, established in MS Project. The created 4D model adds the time factor to 3D/BIM set components, allowing the visual simulation of the construction work. The ability to navigate through the model allows to analyze each corner and each location of the model, and to obtain quantities take-off of materials over each wanted construction step. Navisworks also has the potential to provide support in the analysis and detection of conflicts among the specialty projects;

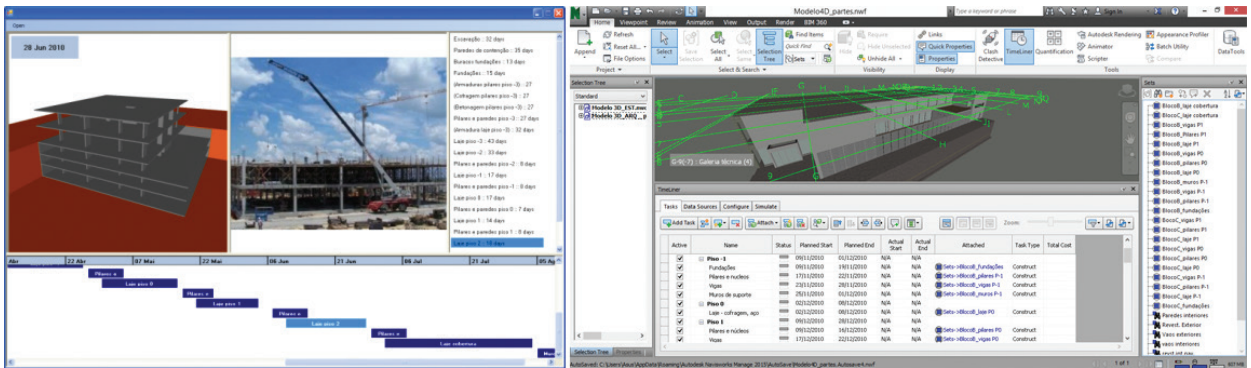


Figure 17. Interfaces of 4D/VR model and of 4D/BIM model.

In the modeling BIM process some elements, that were created as a unique object (but composed of several layers of materials), for a 4D/BIM model propose, must be decomposed in their essential elements. For that it is important that the BIM modeling software in use, can allows dividing elements, like a wall or floor, as needed to support the 4D construction modeling workflows. In an inverse way, it must also be able to assemble elements. In this context, two Revit categories were designed to support construction modeling workflows [28]:

- It allows **dividing** a model element into discrete parts that can be independently scheduled, tagged, filtered, and exported;
- It allows selecting any number of element instances to create an **assembly** and then the assembly can be manipulated as a single unit, which can be independently scheduled, tagged, and filtered.

A part can be divided into smaller parts and each one is automatically updated to reflect any changes to the element from which it is derived. So modifying a part has no effect on the original element. So each part, for instance, the finishing layer of a floor or a wall system (Figure 18), can be linked to the respective MS Project activity. This capacity allowed by the BIM tool is important, as normally the construction of a wall or a floor needs to be defined in a sequence of operations corresponding to distinct periods of time in a construction schedule planning. These two capacities, diving and assembling, allowed by the BIM modeling software can be improved with the use of a VR software that can operate over a 4D/BIM model. In the construction planning stage, VR and BIM can improve building design and construction management, as the boundary-pushing concepts can be tested and refined at an interactive virtual world, before committing to real-world construction.

Normally, concrete conflicts became a reality in the construction site, when the construction process is in progress. At that moment any eventual error reverts in additional cost and time delay. A 4D/BIM following each construction step helps the team to analyze each eventual conflict and over the BIM model, it is possible to do the necessary corrections. By adding VR capacities the analyses performance in of BIM models can be improved. So, BIM + VR applications can contribute to reduce costs due to the construction of a real work, and to avoid mistakes on site that generates material wastes.

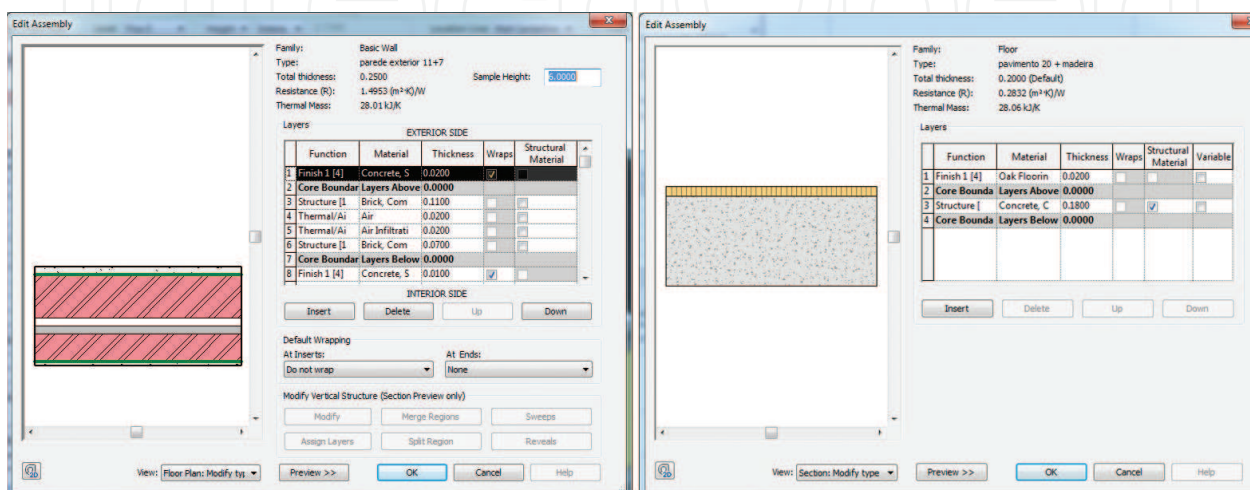


Figure 18. Parametric objects of a wall solution and a floor system [6].

Recent developments in VR have encouraged the utilization of interactive visualization in the construction of building BIM projects. Du [5] finds 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 [11]. The multiplayer virtual walk allows real-time interactions of remotely located project stakeholders in the same environment, with a shared immersive walkthrough experience (**Figure 19**).



Figure 19. Screen shots of 4D/VR/BIM simulation processes.

BIM supports 4D analysis, where activities from the project schedule can be simulated and studied to optimize the sequence of construction. A 4D model allows users to visualize the schedule and to optimize sequencing on the construction site. BIM can also be integrated with the cost factor, to generate a 5D/BIM simulation, in any stage of the building construction. The BIM is used to facilitate a quantity survey of building materials and components, and these quantities are linked directly to cost databases.

As mentioned, VR combines a device for interaction creating virtual environment and following that perspective, software houses have been developing advanced BIM/VR products applied also to improve 4D/BIM models. Some of the discussed VR software is also applied in construction planning:

- **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 [23]. 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. Enscape has become an useful construction planning support;
- 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 user visualize the correspondent building 4D/BIM step and consult all the information the user needs in order to compare the progress building stage and the delay or the advance realized in the construction place;
- Using **Augment** software, data-rich virtual information is available on site, through connected devices, like smartphone or tablet, in real time. It allows the user to follow the real construction evolution of the work, from multiple perspectives, and to compare it to the

planned 4D/BIM model. BIM with VR enables project stakeholders to analyze information-rich virtual models that help better visualize the building construction project [34]. Nowadays, it is essential to build trust between project parties and give the owners and users the possibility to analyze and give feedback of the construction process plans, and using BIM with VR this intention is easily achieved (**Figure 20**).

- 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 (**Figure 21**). The EON Icube provides users a realistic aspect of the interior of the building namely concerning lighting and texture of wall materials. EON Icube is compatible with several VR devices (data-gloves, joysticks, or motion tracking systems) [35].

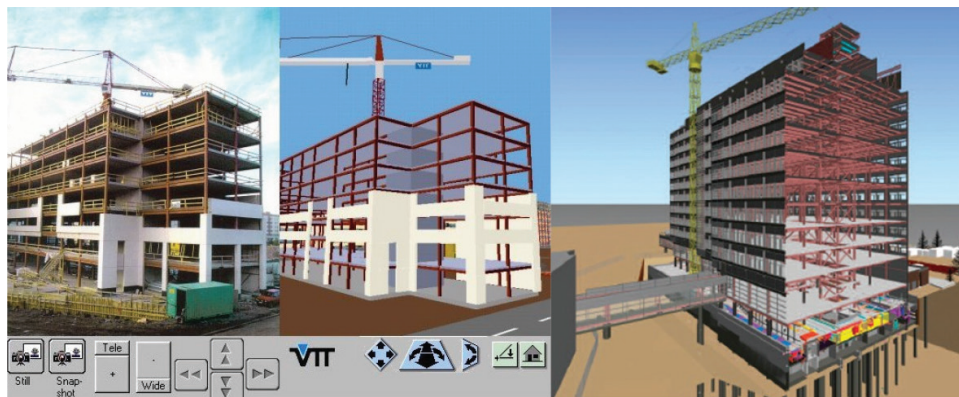


Figure 20. Screen shots of augment software [34].



Figure 21. EON Icube environment [35].

5. 7D/VR/model: management and maintenance

Combining BIM with VR is predictable to improve efficient collaboration, as the data can be visualized, consulted, and even changed while the team and client are inside an apparently construct build. In a real place, the equipment that cannot be observed because they are hidden over a false ceiling, such as HVAC devices or net systems (electrical, water, or gas supply or elements of acoustic protection), can be easily visualized using BIM + VR tools. So the management and maintenance facilities can be facilitated in a 7D/VR + BIM/model context. VR will enable the engineer to carry out a physical survey of the property or the building site (**Figure 22**). The VR technology applied to BIM tools has been enhancing a high level of integration but it is still necessary to do more in order to obtain an even more real platform, in a retrieving data perspective. As so, the importance of adding VR benefits should be a constant research point [36].



Figure 22. Screen shots of 7D/VR/BIM applications.

The maintenance aspect needs the user to free consult all components of the real place through the correspondent BIM model. The model can include several parameters concerning a wall, roof and floor composition (layers of material and respective physical proprieties) and can also include maintenance plans, information on the date of replacement of equipment, certifications, and guaranties. This information should be able to be consulted from the model, and the access to this information could be easily provided. Any BIM tool allows the consult of BIM data and so it support management and maintenance within a collaborative team.

6. Conclusions

VR + BIM enable architects and designers to better communicate design within the team members and with the client. In construction activity, the use of VR capacities brings interesting potentials. Presenting BIM models of projects in VR environment redefines communication and collaboration in the field and in the office. The advantage to 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 and the distinct discipline projects. The BIM + 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 analyze and explore BIM models within virtual environments.

BIM technology and VR have the ability to innovate the building industry. At a first perspective, many feel the benefits of using a BIM model with VR are only for improving the 3D model for visual aids, but taking a second perception at a BIM model it reveals diverse reasons to adopt BIM with VR. Collaboration in VR can be the future of VR BIM. The text follows the principal technological advances that have been achieved so far. The so appealing 50 + RV tools applied in construction become from the entertainment world, but its application is almost in the perspective of visualizing stunning immersive, namely: head-mounted display (Gear VR, Oculus Rift); hologram projections; Enscape Revit plugin; Smart Reality and Visidraft apps; PrioVR full or upper body suit; and CAVE platform. The construction field needs an additional and a very important complement, concerning the aim of BIM, which is retrieving, using, manipulating, and incrementing information. To cover this perspective, just a few VR software combined with BIM modeler tools, were found: Autodesk

360; viewer Revit plugin; Enscape Revit plugin; Augment; Stingray; Covise; web3D; EON Icube. From the analyses of the applicability of each tool, the two most relevant combinations of tools are Enscape and EON Icube that operate over Revit. With these tools the user can visualize the building, with more or less immersive capacity, and can consult data in a Revit environment. So, the user sees final aspect of building in Enscape and EON and, in addition, retrieve the correspondent Revit component (with materials constitution and mechanic-physic parameters).

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. 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.

Author details

Alc nia Zita Sampaio

Address all correspondence to: zita@civil.ist.utl.pt

Department of Civil Engineering, University of Lisbon, Portugal

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