3D Modelling and Virtual Reality for the Management of Public Buildings

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Key words: Building Information Model (BIM), Virtual Reality (VR), Public Buildings, 3D Visualisation

SUMMARY

Virtual Reality (VR) technologies have become incredibly popular in the era of Industry 4.0, considered to be one step higher than 3D visualisation. VR is described as a computer-generated environment that provides users with the sense of being surrounded by the real world. Visualisation through VR has made it possible to approach a range of issues in the Architecture, Engineering, Construction and Facility Management (AEC/FM) industry, as well as in the real estate domain and urban planning, under a new sustainable perspective. Moreover, as an interactive platform, VR enables smart and sustainable cities to identify and expand their potential by getting smarter. To make VR experience accessible and independent of the device used, the WebVR approach is researched and implemented. This approach mainly relies on the Three.js graphic engine based on Web Graphics Library (WebGL) which has been supported by most of the mainstream web browsers' latest version with no embedded plugin. As a result, some of the barriers obstructing the use of VR have been removed and hence, VR has become more accessible and cheaper.

VR combined with Building Information Modelling (BIM) has the potential to improve collaboration in the AEC/FM industry, offering a supportive environment for conducting analysis and decision-making process. Depending on the scale of each project, the requirements and the budget, the source data that is used to create 3D models to be represented in VR may vary. For instance, for spatial planning projects point clouds can be used; for emergency response and evacuation solutions detailed BIM models are more appropriate, while for representing the indoor reality and navigate through, for example, a museum, 3D image-based models (from 360^{o} images) are commonly used. In this context, VR can be an invaluable tool in the field of urban planning and building management, coupling with BIM projects that are becoming more and more popular, due to the evolution and legal mandate of BIM. Especially for the management of public buildings, a VR solution represents an ideal candidate to deploy for the analysis and synthesis of different layers of information to perform complex scenarios and visualise the results in 3D real time.

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1. INTRODUCTION

1.1 Research background

1.1.1 Building Information Modelling

BIM comprises a variety of benefits, which can be summarised in visualisation, quantity survey, cost estimation, site logistics, phasing and 4D scheduling, building management, as well as option, sustainability, constructability and building performance analysis (Azhar, 2011). Those benefits are assigned to the different stakeholders within a construction project, such as owners, project designers, project constructors and facility managers.

BIM is growing popular both among professionals and public authorities worldwide. National and international BIM standards have been established, such as the National Building Information Modelling Standard-NBIMS (United States) (National Institute of Building Sciences buildingSMARTalliance, 2015), the BS EN ISO 19650-1:2018 (United Kingdom) (National British Specification (NBS), 2018), the HKIBIM BIM Standards (Hong Kong) (Hong Kong Institute of Building Information Modelling, 2018), the Statsbygg BIM Manual (Norway) (Statsbygg, 2011), the AEC (CAN) BIM Protocol (Canada) (CanBIM, 2014), and the ISO/TS 12911/2012.

What is more, BIM starts to become a government mandate for planned constructions in more and more countries (UK, The Netherlands, etc.), as well as for specific projects (i.e. in Germany for transportation projects), resulting in increasingly development of detailed BIM models. Depending on jurisdiction, the development of BIM models may be required for major infrastructures, Public Service projects, or in relation to the area or the value of each project. The contribution of BIM to constructions' planning and management has also been acknowledged by the European Union (EU), which has established a BIM Task Group to encourage the common adoption of BIM in public works, with the common aim of improving value for public money, quality of the public estate and for the sustainable competitiveness of industry (NBS, 2017).

1.1.2 Virtual Reality

A simple "translation" of the term Virtual Reality (VR) according to the Virtual Reality Society (VRS) would derive "from the definitions for both 'virtual' and 'reality'. The definition of 'virtual' is near and reality is what we experience as human beings. So, the term 'virtual reality' basically means 'near-reality'." Augmented Reality (AR) is the evolution of Virtual Reality that

according to Unity3D “is the overlaying of digitally-created content on top of the real world. Augmented reality allows the user to interact with both the real world and digital elements or augmentations”, instead of creating an interactive environment for the user as VR does. Real estate technology is evolving at a rapid speed incorporating means of VR, AR, Artificial Intelligence (AI), Internet of Things (IoT) etc., introducing the concept of Property Technology (PropTech). Specific applications already developed are related to every aspect of Property Management as well as to other Real Estate disciplines such as Development and Marketing.
In the Design Phase of a project, the Architect can communicate his ideas with the potential client using VR instead of just photorealism or 3D modelling to find the best results. During the Development Phase, exploitation of VR facilitates designing, creating, simulating, test, altering and selecting the best of many alternatives to be materialized, within a very brief period of time minimising costs, from within a safe and fully controlled environment. In the Construction Phase all construction workers and supervisors can get a really comprehensive view of the future development, minimizing misconceptions and misunderstandings for each one individually and between crews of different specialties. VR is a valuable tool for documenting “as-built” separate construction phases of the project in order to maintain an archive and to monitor the contractor’s contractual obligations as well. Finally, documentation of buildings’ initial condition is often needed for restoration purposes. Another common area of VR application is Real Estate Marketing and Brokering. Potential buyers can “visit” multiple properties in minimum time and with minimum effort, from their home/office or by just visiting the Realtor of his choice, establishing a clear view of the customers’ needs and preferences, in order to minimize unsuccessful proposals and mutual frustration. Finally, the combination of 360 photos with laser scanning in indoor areas has provided the ability to create highly accurate, metric, VR ready 3D spaces, with infinite possibilities in terms of surveying, documenting, managing, decorating, projecting and advertising properties

Recent research recognises the added value of combining 3D modelling and VR in various applications. To name a few, VR is used for spatial planning projects by using as source data to create a 3D model, point clouds, or -depending on the budget- to build 3D building models with 3D modelling tools (SketchUp, CityEngine, ArchiCAD, Revit, etc.). van Rees (2019) distinguishes two types of VR for such applications: the first is active VR, where the user can walk around and transport himself, and, the second type, is passive AR, which only allows the user to look around while transported automatically. Another application field is emergency response and evacuation, where detailed BIM models are used, while for representing the indoor reality and navigate through spaces (for example, a museum) 3D image-based models (from 360o images) are commonly used.
The rest of the paper is organised as follows: Sub-section 1.2 lists several data sources that are used for creating VR models, as well as the most common data exchanged formats used in this domain. Section 2 presents an overview of BIM and VR combination for public property management. Following, the alternative directions to be followed to design and develop a VR application are presented, supported by relevant application domains, while the last section is devoted to conclusions and proposals for future work.

1.2 Data sources for Virtual Reality models

Data sources and the determination of software and hardware are of high importance for the construction and performance of a VR model. According to Discoe (2005) the "basic steps in creating three-dimensional visualisation of landscape (and in general any digital model) are to acquire raw geographical data, process them into an appropriate form, then use them as inputs to software which will construct the three-dimensional geometry".

Heterogeneous data sources with several data formats and different input technologies are utilized - either physical devices, such as sensor nodes, or third-party software to include GIS, digital drawings (computer-aided designs), multimedia data, and World Wide Web-based VR techniques. - where building information resides (Patti et al., 2017), for the visualization and simulation of urban built environments through interactive 3D virtual models.

More concretely the development of an augmented and virtual reality environment requires the exploitation of physical data from sensors by combining it with an accurate 3D virtual model, which can be developed by using BIM, GIS and LIDAR data. 3D BIM models can be generated from a variety of applications such as ESRI CityEngine, 3ds max studio, Autodesk Revit, Trimble SketchUp, IFCOpenShell. Depending on the type of the data sources different data formats are derived, arguing for a variety of pros and cons regarding certain criteria.

Currently, a number of 3D formats are available in CAD, BIM and GIS related domains for the storage, visualization and transfer of 3D geospatial datasets. Initially, the 3D data models (such as COLLADA, VRML, X3D, etc.) were purely graphical/geometrical representations and mainly used for visualization purposes (Saran et al., 2018). With the inclusion of thematic modules in OGC CityGML and in IFC, the integration of geometry and semantics in a single data model upgraded 3D city models. Apart from 3D models, data sources could be either point clouds, which are produced by Terrestrial Laser Scanning (TLS) or Photogrammetry and LIDAR.

2. BIM AND VR FOR PUBLIC PROPERTY MANAGEMENT

Given this background, BIM is gradually being used in several domains as source for various applications. Namely, the application of BIM in the heritage sector focuses on digital documentation of heritage assets, fueled by technological developments in 3D data capture such as photogrammetry and laser scanning. Applying BIM technology to the historical heritage (HBIM) is an interesting challenge both in the field of 3D modelling and in the management / enhancement of the building architecture and maintenance. The term "HBIM" indicates a new way of modelling existing buildings, using a BIM process that would produce intelligent models containing and managing information (Murphy et al., 2013). Such models are obviously relating to project components and include their geometric and identifying information, and all the physical properties that best describe them.

Research in this domain is carried out to share data and informative models, as historical databases based on the automatic extraction of information previously included in the HBIM modelling and to create an immersive interactive environment (VR and AR) for different types of users (experts, non-experts and tourists) and devices (desktop, mobile, VR headset) (Banfi et al., 2019), as also presented in the figure below.

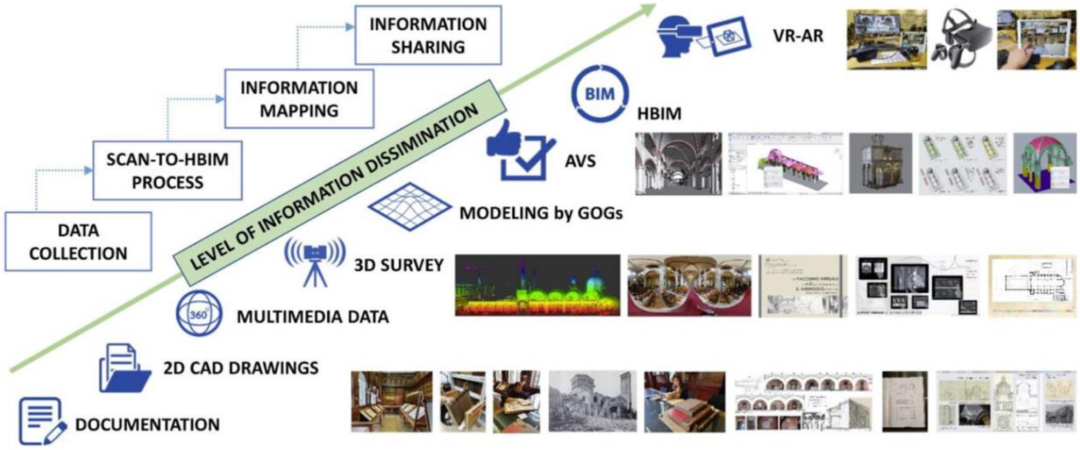

Figure 1. Research method applied to the project (Banfi et al., 2019)

There are numerous examples of heritage assets being documented in this way, and the range of benefits in structural and condition monitoring, education and research for conservation practice, as well as visualisation are becoming well understood (Hull, 2020). Research in this domain, has considered the practical issues of data capture, subsequent 3D parametric modelling from point cloud data, automated data processing, pattern recognition and the creation of object libraries.

Banfi et al. (2019) present a holistic approach, from data collection to AR/VR experience, while within this process, they enriched the BIM model by adding information related to historical and constructive process that the heritage has had over the centuries, in order to disseminate information for non - expert users and construction industry experts.

Moreover, recent research (Lin et al., 2018) proposed a database - supported VR/BIM-based communication and simulation (DVBCS) system integrated with BIM, game engine and VR technologies during the healthcare design process. Hospital construction projects are challenging because of potential disruption to patients and healthcare providers and thus, the aim was to reduce the information communication gap and enhance the design simulation result among the medical staff, stakeholders, for healthcare design in the semi-immersed VR environment, for healthcare projects during the design process. The application also includes the disaster prevention planning and facility management for healthcare of the hospitals in the interactive VR/BIM-based environment.

Figure 2. a) BIM model; b) VR/BIM model; c) DVBCS enabling communication (Lin et al., 2018)

Sampaio (2018) listed several tools that support the combined use of BIM and VR, as well as the use of the combined technologies for real-time supervision of a site. In particular, the data can be visualised, consulted, and even changed while the team and client are inside an apparently construct build. The equipment (e.g. net systems) that cannot be observed because they are hidden over a false ceiling, can be easily visualised using BIM + VR tools, as presented in the figure below. 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 3. VR + BIM application in facilities management (Sampaio, 2018)

In the same direction, Chung et al. (2018), proposed a workflow for smart facility management using AR and mixed reality (MR) in existing maintenance work, thereby increasing maintenance work efficiency and further improving the utilisation of BIM. The information required in BIM is different in each of the phases of design, construction, operation, and maintenance, and there are many pieces of reproduced information, making it difficult for managers to utilise the information. The smart FM is a platform that employs the IoT, cloud, big data, and mobile (ICBM) basis technologies.

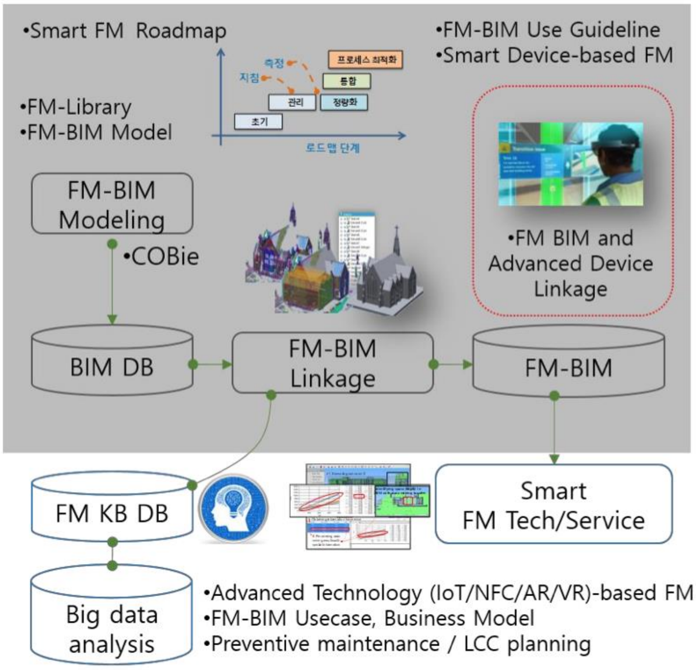

Figure 4. Smart FM technology development for advanced device and data analysis (Chung et al., 2018)

In this context, it appears that the integration of BIM with VR is a winning combination and a topic that requires attention, as its application gains more and more ground. 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. When it comes to the management of public property, VR allows all stakeholders to explore the best possible layouts while keeping costs and specifications under control and when using BIM, all the parts in the project are created and detailed in 3D and thus, misinterpretations become a rarity.

3. METHODOLOGY

Sampaio (2018) notes the contribution of VR to the improvement of BIM methodology, emphasising on walkthrough the 3D model and consulting data, especially those that are associated with parameters that compose the parametric objects used in the modelling process. The growing interest in combining 3D BIM models and VR technology is clear, especially when it comes to complex construction projects (Wang, 2013), serving various purposes. Motamedi et al. (2017), combine BIM and VR to assess the coverage and the visibility of signage systems in public spaces. Within a similar context, Wang et al. (2014), use a BIM-based virtual environment, supported by virtual reality and a serious game engine to address key issues related to building emergency management. Kreutzberg (2015), emphasises on exploiting virtual reality in communicating architectural spaces, by assisting non-architectural specialists to perceive 3D spaces correctly. Virtual Reality, along with Augmented Reality (AR), constitutes a tool that can be used to access parameters such as temperature, humidity or energy consumption, if combined with BIM models and sensor data (Patti et al., 2017).

(Barazzetti & Banfi, 2017), focus on the synergy of Historic BIM (HBIM) and VR, for the development of mobile applications either for preservation, documentation and construction purposes, by specialised users, or to provide historic insight to the public.
However, effective integration of BIM and VR, still faces numerous limitations, especially regarding complex geometries. Kasireddy et al. (2016), according to Du et al. (2017), note several issues related to such integration, such as missing information, slow response and difficulties to integrate building information other than geometry. The lack of efficient data transfer between BIM and VR data, is highlighted by several other researchers (Du et al., 2017; 2018; Johansson et al., 2014). Consequently, investigation of the capacities of current methodological approaches for BIM and VR integration is required, to identify those that minimise the aforementioned limitations, depending on each project's application.
The methodological approach to design and develop a Virtual Reality (VR) application is not unique and depends on various components such as the intended application's scope, data sources, level of detail and interface. The schema of the methodological steps is schematically presented in Figure 5.

Taking into consideration that this paper focuses on the management of public buildings, the data sources pertain various 3D model formats and 360 images. 3D city models may derive from a number of different approaches. Some of the most commonly used 3D city models are the information models such as IFC and CityGML. Additionally, other 3D data formats such as COLLADA, OBJ and X3D significantly facilitate the rendering process using existing visualisation frameworks. However, these types of pure graphics format cannot store rich semantic information. Apart from 3D models, data sources could be either point clouds, which are produced by laser scanning, or 360 images.
Some of the aforementioned data sources are ready-to-use 3D models to be integrated in VR applications. However, in some cases, these data sources should be converted to appropriate 3D model formats, using a variety of applications and libraries such as ESRI CityEngine, 3ds max studio, Autodesk Revit, trimble SketchUp, IFCOpenShell etc.
Depending on the type of the data sources used, the final VR application can be of the following types: image-based VR, 3D-based VR and mixed VR application. The image-based VR application utilises only 360 images, it is possible to be enriched with extra descriptive information and it is used mainly for virtual touring (Figure 6).

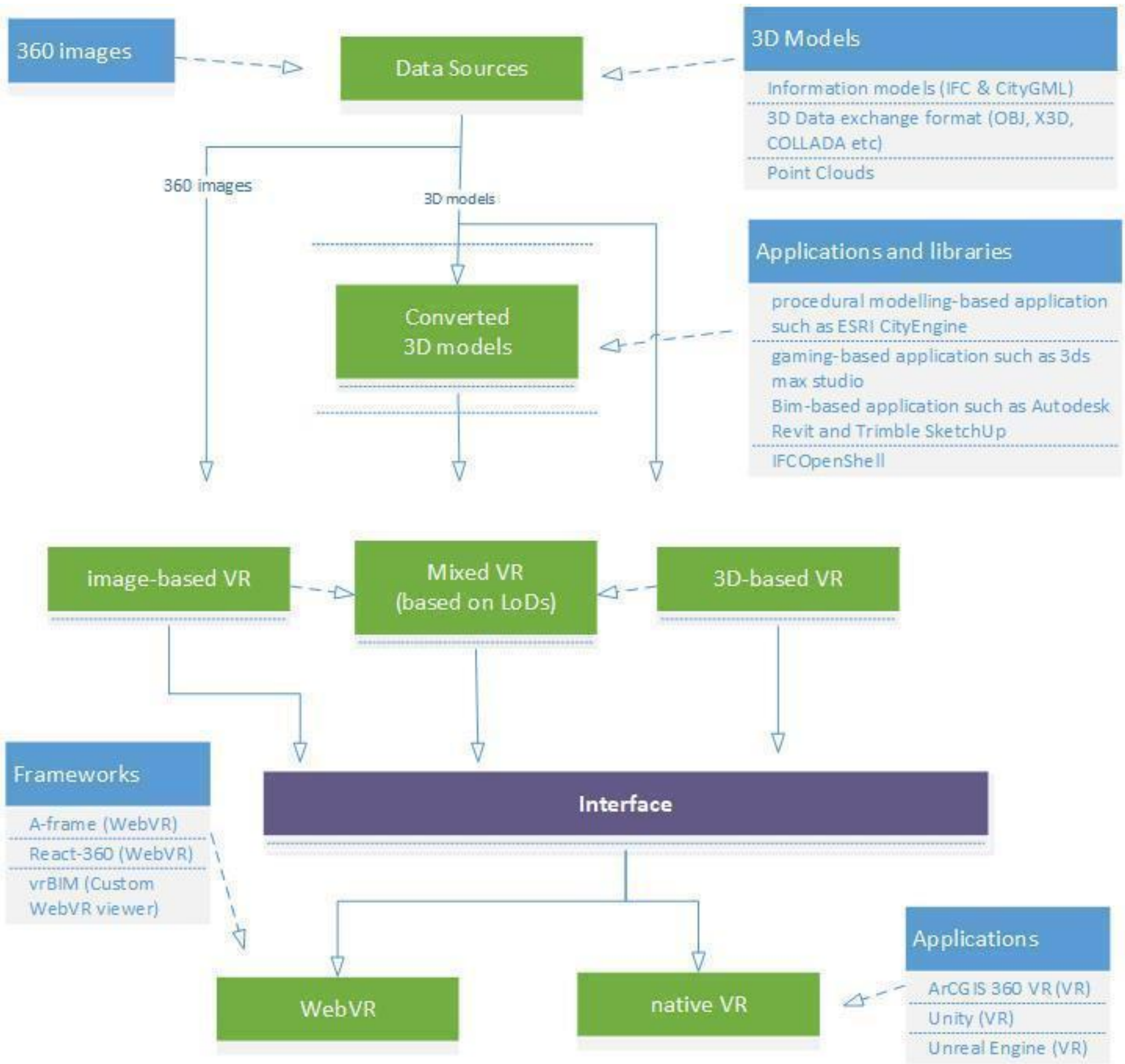

Figure 5. VR methodological schema

The 3D-based VR application only uses 3D models, while the mixed VR application could combine 3D models and 360 images. For instance, the exterior VR of a building could be represented by a 3D model, while the interior could be image-based VR. Additionally, within the context of image-based VR touring some objects, such as furniture, can be represented by 3D objects. The final step to develop a VR application is the interface. Depending on the available interface, there are two technological approaches for the development of a VR experience, namely the WebVR and the native VR.

Figure 6. Interior (a) and exterior (b) Image-based VR

The main advantages of the WebVR approach are that it makes the VR experience accessible and independent of the device used, as well as that it is based on the WebGL which has been supported by most of the mainstream web browsers’ latest versions with no need of embedded plugins. The implementation of the WebVR approach is made accessible using the available VR-based web frameworks such as A-frame and React-360. However, the native VR approach is also widely used due to its relationship with numerous applications that support easy-to-use development of VR experience, such as ESRI CityEngine, Unity and Unreal Engine.
Taking into account the above-mentioned limitations, as well as the generic methodological approach that has been presented in Figure 5, a workflow of developing VR applications, based on CityGML, point cloud, or IFC 3D data formats is presented in Figure 7.

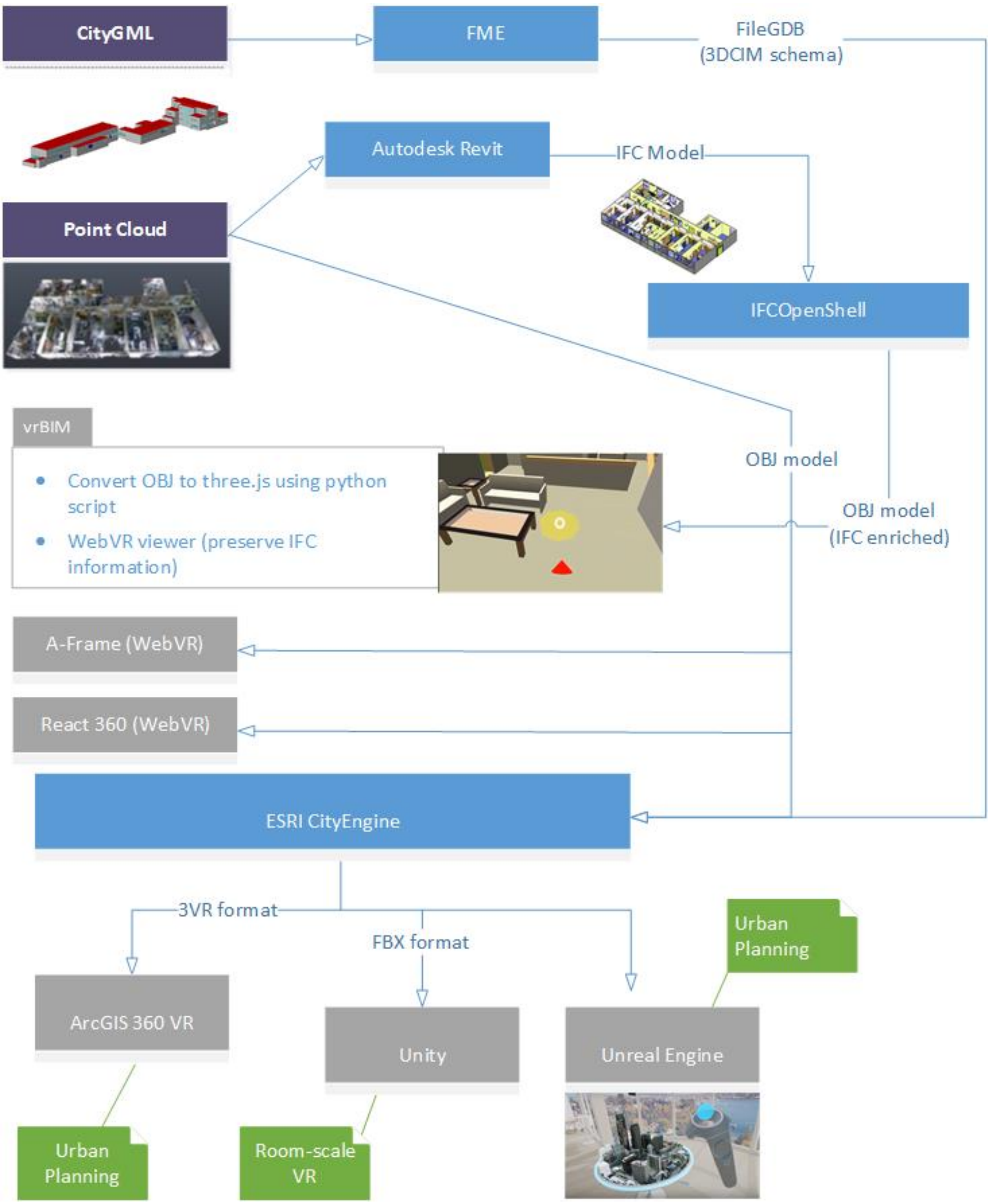

Figure 7. Workflow of developing VR applications, based on CityGML, point cloud and IFC 3D data formats

In the first case, CityGML data is used to develop a VR application. Thus, CityGML data need to be stored in FileGDB, following the 3DCIM schema. The said FIleGDB can then be exported in different file formats, serving different purposes, through ESRI CityEngine software. To this aim, the following options can be distinguished. The first option, is to export 3VR format files using panoramic images, e.g. deriving from ESRI CityEngine scenes, combined with mobile headsets to allow the users to interact with the 3D city model, especially in the case of urban planning applications. Additionally, ESRI CityEngine exports for VR applications may also be in FBX format, which is supported by Unity software, and provides high quality room scale VR solutions. Finally, the data can be exported in Unreal Engine compatible format, providing effective VR solutions for urban-planning-scale applications. In the second case, point cloud data can be used as input for developing a 3D VR application. However, such data cannot be directly used in VR applications, thus it needs to be converted in order to become VR-ready, either in OBJ or CityEngine exportable formats, such as 3VR, FBX or to Unreal Engine, as described previously. The conversion of point cloud data to 3D OBJ models, requires a two-tier data transformation, first to IFC models and then to OBJ models, through the Autodesk Revit software and the IFCOpenShell library respectively. This process allows for the preservation of IFC data, so that it can be directly used for vrBIM applications. However, conversion of point cloud data to 3D OBJ models, can also be achieved directly in case of non vrBIM formats, however, without retaining IFC building information. These OBJ models can be used to develop VR applications utilising WebVR frameworks such as A-Frame and React 360. Also, these models may be converted and imported to ESRI CityEngine software, for the development of native VR applications in 3VR, FXB format or exported to Unreal Engine, as described previously.

4. CONCLUSIONS

Industry 4.0 has led the manufacturing sector to great strides forward, as new technologies continue to create endless possibilities for the industry. As VR becomes more accessible, more projects adopt the technology. BIM benefits greatly from its application, as it offers a semantically rich visualisation method to help users intuitively understand the surrounding environment (Davidson et al., 2019) and this is just the tip of the iceberg (BIMTODAY, 2019).

The research described in this paper, addresses the issue of integrating 3D modelling and especially BIM with VR, which is becoming mainstream and requires attention. The user visualises a virtual world and can interact with it and in this context, VR can be an invaluable tool in the AEC/FM industry, especially for the management of public buildings. Given the recent advances in VR and BIM technology, and that both such technologies are gradually getting open to public use through different methods and formats, the issue of integrating VR capabilities to BIM models holds research interest. Particularly, limitations regarding conversion of IFC data to be compatible with VR are traced, thus restricting reliable modelling capabilities, retaining IFC data. This work challenges an initial report concerning current methods of integrating BIM and VR data, also tracing their advantages and limitations. In the next step of this work, the methodology for the integration of BIM with VR data will be investigated through prototype testing.

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BIOGRAPHICAL NOTES

Ioannis Pispidikis is a Phd candidate in the field of geoinformatics, at the School of Rural and Surveying Engineering, National Technical University of Athens. His PhD research topic is about investigating the optimal solution for semantic retrieval of 3D city data. He holds MSc in Geomatics from NTUA. Since 2002, he is working as an officer at the Hellenic Army and currently he is manager of the Geodatabase subdivision at Hellenic Military Geographical Service.

Dimitrios Kitsakis is a surveyor engineer, graduated from the School of Rural and Surveying Engineering of the National Technical University of Athens. In 2019, he received a PhD Degree from the same institution for his thesis concerning legal requirements for real property stratification. Since 2012, he is working as a freelance surveyor engineer. He is participating in research projects on 3D modelling, and on climate change, while since 2019 he is participating in the cadastral survey for the development of the Hellenic Cadastre. His research interests include 3D Cadastre and Land Administration, 3D Modelling, Public and Land Law.

Eftychia Kalogianni is a PhD candidate in GIS Technology Section, at the Delft University of Technology. Her PhD research topic is about adopting a holistic approach to treat 3D

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Katerina Athanasiou holds an MSc Degree in Geoinformatics from National Technical University of Athens. She graduated from the same institution in 2014. Her bachelor thesis referred to the development of a Marine Administration Model for Greece, based on International Standards, while her MSc thesis was focused on interoperability options for 3D City Modelling.

Anastasios Lampropoulos is a Surveyor Engineer holding a PhD from the National Technical University of Athens, Greece, specializing in Mass Appraisal systems. Currently, he is a member of the Academic Personnel in the School of Rural and Surveying Engineering of the NTUA, where he teaches courses on Property Valuations, GIS & Land Management. His research has focused mostly on Valuation & Mass Appraisal techniques, integrated with Geographic Information Systems and 3D modelling. He is also active in the private sector and is involved as an external consultant on several surveying and valuation projects with major banks and financial institutions in Greece.

Efi Dimopoulou is Professor at the School of Rural and Surveying Engineering, NTUA, in the fields of Cadastre, Spatial Information Management, Land Policy, 3D Cadastres and Cadastral Modelling. She is the Programme Director of the NTUA Inter-Departmental Postgraduate Course «Environment and Development».

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