Comparing the Capabilities of Virtual Reality Applications for Architecture and Construction

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Since Virtual Reality (VR) entered the consumer market in mid-2016, its uses have been gaining momentum in both architecture and construction firms as well as software developers. While still in the early stage of being widely adopted in the industry, several VR applications for architecture and construction have been developed for commercial uses with Building Information Modeling (BIM). This paper aims to evaluate the capabilities of computer-based VR applications for architecture and construction uses that were available as of mid-2017. Through a literature review and Internet search, eight VR applications were identified and grouped into two categories: a standalone software program or an add-on for another software program. Six VR applications were tested with both Oculus Rift and HTC Vive using the same BIM model, and their VR capabilities were evaluated and compared, including hardware support, navigation, utility, simulation, collaboration, supported file formats, as well as license cost. Recommendations were given on how architecture and construction firms at different levels of interest in VR can apply these applications more effectively. This paper provides first-hand information to architecture and construction firms who are interested in applying the VR technology.

Key Words: Building Information Modeling, Virtual Reality, Applications, Architecture, Construction

Introduction

The consumer market of VR is booming since the arrival of Oculus Rift in mid-2016. Although VR has been commercialized more as a gaming and entertainment tool, its capabilities in the architecture and construction industry have been long recognized. While early practitioners and researchers have started developing and applying VR applications in their projects and studies to investigate and maximize the benefits of VR in architecture and construction uses, the vast majority of the industry are still expecting to see more detailed introduction and review of its uses. Through a comprehensive literature review, it was found that only a handful of available VR applications have been reviewed, while the rest are left behind and their capabilities are thus undetermined.

This paper aims to evaluate the capabilities of computer-based VR applications for architecture and construction uses that were available as of mid-2017. Eight VR applications were identified and six of them were tested with both Oculus Rift and HTC Vive. Their VR capabilities were evaluated and compared, including hardware support, navigation, utility, simulation, collaboration, supported file formats, as well as license cost. Recommendations were given on how architecture and construction firms at different levels of interest in VR can apply these applications more effectively. This paper provides first-hand information to architecture and construction firms who are interested in applying the VR technology.

Background

Due to its unique capacity of visualizing building models, VR has been growing rapidly in the architecture and construction industry since the first modern VR headset, Oculus Rift Development Kit 1, was made available in 2013. Considered as one of the most exciting technologies to hit this industry in years, VR offers its user a sense of scale, depth, and spatial awareness that simply cannot be matched by any rendering pictures, walkthrough videos, or scale models (Corke, 2017). A fully immersive VR experience is able to fool a user’s brain to create a feeling of presence inside the 3D model and provide the freedom to explore how a proposed building will feel and function through inspecting the details, walking across rooms, and teleporting through doors (Corke, 2016; Corke, 2017).

Due to the unique benefits that VR brings to the industry, research efforts have started to investigate its uses in various areas in architecture and construction. Froehlich and Azhar (2016) evaluated the use of Oculus Rift in construction safety training and jobsite management, while Petrova et al. (2017) evaluated such use in end-user involvement in building design. Dayan and Sasks (2017) investigated the enhancement of cognition using Oculus Rift in apartment customization. Ozcelik et al. (2017) and Carneiro and Becerik-Gerber (2017) studied the use of Oculus Rift in understanding occupant-system interactions related to thermal changes and lighting quality, respectively. Soman and Whyte (2017) and Lovreglio et al. (2017) developed a framework with VR visualization for real-time construction progress monitoring and earthquake evacuation, respectively. Asgari and Rahimian (2017) investigated different VR tracking devices for construction process optimization and defect prevention. All of these recent research projects employed VR devices as an effective tool for improving the interaction between human experiences and building environments.

Besides research efforts, software developers have also dedicated to maximizing the potential of VR in architecture and construction. Corke (2016) introduced several software developers that have created VR environments for architecture and construction projects, including TruVision, UE4Arch, IrisVR, ArqVR, by using 3D game engines such as Unreal Engine, Unity, Stingray, and CRYENGINE. Corke (2017) further tested three VR applications with HTC Vive in early 2017, namely Autodesk Live (rebranded to Revit Live), IrisVR Prospect, and Enscape, to demonstrate the process from Revit to VR. These applications are able to convert everything in a Revit file into a VR environment, such as model, sun settings, lighting, materials and entourage, by simply pressing a few buttons without any game engine, and are thus well suited for non-expert BIM users (Corke, 2017). In addition, Revizto and Bentley LumenRT were also briefly reviewed by Corke (2017) but not tested. Other available VR applications for architecture and construction, however, have not been evaluated and their capabilities are thus undetermined.

Methodology

Through a literature review and Internet search, eight computer-based applications were identified to offer VR capabilities for architecture and construction uses, as detailed in Table 1. The eight VR applications were grouped into two categories: 1) a standalone software program that runs independently, including Autodesk Revit Live (previously called Autodesk Live), SimLab Composer VR edition, Fuzor, Revizto, and InsiteVR, and 2) an add-on or plug-in for another software program (typically a 3D modeling program such as Autodesk Revit and Trimble SketchUp), including IrisVR Prospect Pro, Enscape, and Kubity. Besides the standalone applications, Fuzor and Revizto also provide an add-on to synchronize data with Revit or SketchUp. InsiteVR requires an add-on as well, but only for uploading purpose. Its main application is project-specific and needs to be downloaded from its user account website, and it is therefore considered as a standalone application in this study. Out of the eight applications, InsiteVR, Prospect, and Kubity are developed solely for the purpose of VR use, while the rest five applications offer VR capabilities as one feature among many others.

Table 1
Evaluated computer-based VR applications for architecture and construction uses

Developer	Autodesk	SimLab	Kalloc	Vizerra	Vrban	IrisVR	Enscape	Kubity
App name	Revit Live	Composer	Fuzor	Revizto	InsiteVR	Prospect	Enscape	Kubity
App type	Standalone	Standalone	Standalone	Standalone	Standalone	Add-on	Add-on	Add-on
Use of VR	Feature	Feature	Feature	Feature	Purpose	Purpose	Feature	Purpose
Tested	Y	Y			Y	Y	Y	Y

This study tested six out of the eight applications due to the fact that a trial or educational version was not available for Fuzor and Revizto, and contacting the developer was not successful either. As a result, information on Fuzor and Revizto in this paper was solely based on their website, documentation, and video demonstrations. The rest six applications were installed and tested with the same Revit model on two VR-ready workstation computers, each connected with a different VR headset. Hardware support, navigation, utility, simulation, collaboration, supported file formats, as well as license cost were evaluated and compared between these eight VR applications.

Results

Hardware Support

Oculus Rift and HTC Vive, the two most popular computer-based VR headsets at the time this study was carried out, were employed to test the VR applications. In addition, Oculus Touch, the controllers released separately for Oculus Rift, was also used to test the applications. A summary of hardware support of VR applications is presented in Table 2. Seven out of the eight VR applications support Rift with Touch controllers, Vive, as well as mouse/keyboard input. Composer however, does not support Oculus devices.

Table 2
Hardware support of evaluated VR applications

Hardware support	**Standalone**					**Add-on**		
	Revit Live	Composer	Fuzor	Revizto	InsiteVR	Prospect	Enscape	Kubity
Oculus Rift	Y		Y	Y	Y	Y	Y	Y
Oculus Touch	Y		Y	Y	Y	Y	Y	Y
HTC Vive	Y	Y	Y	Y	Y	Y	Y	Y
Mouse/Keyboard	Y	Y	Y	Y	Y	Y	Y	Y

Features

Navigation

Navigation features are a critical part of VR capabilities since the purpose of VR in architecture and construction is to create an immersive experience of a proposed building. Navigation features in VR applications typically include adjusting user height, walking, teleporting, rotating, and scaling. Table 3 details the navigation capabilities that each VR application offers.

Table 3
Navigation features of evaluated VR applications

Navigation features	**Standalone**					**Add-on**		
	Revit Live	Composer	Fuzor	Revizto	InsiteVR	Prospect	Enscape	Kubity
Adjust user height	Y		Y	Y	Y	Y	Y	Y
Walk with button	Y	Y	Y	Y	Y	Y	Y	Y
Walk physically	Y	Y	Y	Y	Y	Y	Y	
Teleport	Y	Y	Y	Y	Y	Y	Y	Y
Teleport to view	Y			Y	Y	Y		
Rotate view	Y	Y	Y	Y		Y	Y	Y
Rotate miniature	Y	Y	Y	Y	Y	Y	Y	
Scale miniature			Y	Y	Y	Y		Y

Adjusting user height allows the VR user to change the eye height at which the VR scene is being observed to match their actual body height. All applications offer this feature except Composer. Movement within the VR scene is achieved by pressing the arrow buttons or rotating a joystick on the controllers. All applications perform the walking function similarly. Since Rift and Vive are both equipped with movement tracking sensors, they are able to track the VR user's body movement and translate it to the VR scene. Such movement allows the VR user to virtually walk in the VR scene while walking in a physical space. Both Rift and Vive are able to display a virtual boundary of the physical movement area to prevent the VR user from colliding with objects in the physical space. All applications expect Kubity allow the VR user to walk virtually in the VR scene.

Teleporting allows the VR user to instantly move to any location in the VR scene without walking. This is typically achieved by displaying a laser beam or projectile indicator from the controllers to identify a location for teleporting. All applications offer the teleporting feature. Some applications also allow the VR user to save a view or location in the VR scene to teleport back to at any time, including Revit Live, Revizto, InsiteVR, and Prospect. Rotating view in the VR scene is achieved simply by rotating the user's head. Most applications also allow the rotation without physically rotating the user's head by using a joystick on the controllers.

All VR applications have the capability to display the building model at a tabletop scale as a miniature to allow the user to observe the model from a "god view" as compared to the immersive view. In addition to physically walking around to observe the miniature from different angles, most VR applications also allow the user to rotate the miniature with the controllers. Some applications provide a scaling feature to allow VR users to zoom in on the miniature for better details at a closer distance from the "god view."

Utility

While the navigation features are more or less in common for all eight VR applications, the utility features make them unique from each other in their uses in architecture and construction. Some typical utilities that VR applications offers include measurement tool, markup tool, snapshot tool, and saving views. More advanced utilities that are usually found only in BIM computer programs include turning layers on/off, inspecting object information, and performing section cut. Table 4 details the utility capabilities that each VR application offers.

Table 4
Utility features of evaluated VR applications

Utility features	**Standalone**					**Add-on**		
	Revit Live	Composer	Fuzor	Revizto	InsiteVR	Prospect	Enscape	Kubity
Measurement			Y	Y		Y		
Markup			Y	Y	Y	Y		
Snapshot					Y	Y	Y	
Saved view	Y			Y	Y	Y		
Layers on/off	Y		Y	Y		Y		
Object information	Y		Y	Y		Y		
Section cut			Y	Y		Y		

The measurement tool allows the user to measure the distance between two points or two objects in the VR scene. This tool is helpful in checking the dimensions of the design in the virtual building. The markup tool allows the user to add annotations and comments to the virtual building in the VR scene for any identified problems during the inspection. The snapshot tool comes handy after the measurement tool and markup tool have been used. With the snapshot tool, the user is able to take a picture of the measured distance or marked area for future reference. Although quite useful, only five VR applications provide these features, and Prospect is the only one that offers all three tools. Besides saving snapshots, some applications allow the user to save the current view or location for revisiting by direct teleportation, as described in the navigation features. This feature can be used for checking the modifications in the marked areas.

Turning layers on/off allows the VR user to change the visibility of objects on the same layer or of the same type, such as hiding the exterior walls, doors, or windows to observe the interior structure without walking into the virtual building. Inspecting object information allows the user to choose a building component in the VR scene and inspect its property information, such as category, type, level, height, area, volume, material, etc., that belongs to the object when created in a modeling program such as Revit and SketchUp. The sectioning tool is able to cut section planes in the miniature mode to allow the VR user inspect the interior structure of the building at different heights or perspectives from the "god view." Only Fuzor, Revizto, and Prospect provide all three advanced utility features, while Revit Live is not able to cut section planes. In addition, it seems that Fuzor and Revizto can perform some of these capabilities only outside of the VR mode with a computer, such as section cut. The user should still be able to observe such effects in the VR scene, and it needs to be further verified when Fuzor and Revizto are available for testing.

Simulation

While the navigation features make the VR applications usable and the utility features make them useful, the simulation features make these applications stand out for visualization purposes. The simulation features provided by the VR applications include the ability to change object materials, move and interact with objects, as well as simulating daylight changes, lighting effects, and object effects. Table 5 details the simulation capabilities that each VR application offers.

Table 5
Simulation features of evaluated VR applications

Simulation	Standalone					Add-on		
features	Revit Live	Composer	Fuzor	Revizto	InsiteVR	Prospect	Enscape	Kubity
Change material		Y	Y	Y				
Move object		Y	Y					
Object interaction	Y	Y	Y					
Daylight simulation	Y	Y	Y	Y	Y	Y	Y	Y
Lighting simulation	Y	Y	Y	Y		Y		
Object simulation	Y	Y	Y					

Changing object material allows the user to apply other materials or colors to selected objects to observe different design options. Moving objects allow the user to pick up selected objects in the VR scene and relocate them to different positions for alternative furniture layouts. Object interaction allows the user to interact with objects that can be operated, such as opening doors, windows, cabinets, and operating kitchen appliances, etc. Only Composer and Fuzor are able to perform all these features while Revit Live allows object interaction (typically doors) and Revizto is able to change materials. Again, it seems that Fuzor and Revizto can perform some of these capabilities only outside of the VR mode, such as changing materials, and it thus needs to be further verified.

Daylight simulation allows the VR user to adjust the time in a day or the sun position to observe the effects of daylight change on the building in the VR scene. This is one of the few features supported by all eight applications for realistic visualization purpose. Lighting simulation allows the user to observe and adjust lighting effects in the VR scene when additional lighting sources have been added in the building model. Lighting simulation is particularly useful when the time of day is set to night and artificial lighting becomes the main lighting source. Object simulation allows the user to observe the dynamic effects of certain objects in the VR scene, such as flames, waves, smoke, moving leaves, spinning fans, television contents, etc. Only Revit Live, Composer, and Fuzor support both lighting simulation and object simulation while Revizto and Prospect can only perform lighting simulation.

Collaboration

Collaboration has become an increasingly important feature for VR applications to overcome the fact that a VR scene usually can be viewed only by the user who wears the specific VR headset. The collaboration feature allows multiple VR users, each wearing his/her own VR headset, to view the same VR scene at the same time, and all users can observe the presence of each other in the scene. The collaboration setting will either allow each user to walk freely in the scene by displaying avatars to represent everyone's position, or assign one user as the presenter and all other users as audience to follow the presenter's view. In addition, all users in the same VR scene will present a laser beam to indicate the focus point at which they are looking at so that in a team discussion, the entire project team will be able to focus on particular objects in the virtual building that cannot be physically pointed or touched.

As an advanced feature, collaboration is only offered by Fuzor, Revizto, and InsiteVR, as presented in Table 6. Fuzor allows collaboration either through a host server or a host computer on the Internet by inputting the host IP address, or through a local area network (LAN) by searching active local collaboration sessions. Revizto should work in a similar way to Fuzor and more details need to be further verified. InsiteVR uses its user account website to provide a shared link for collaboration purpose. IrisVR announced multi-user collaboration support in Prospect early 2017 and it is expected that collaboration will be included in Prospect soon.

Table 6
Collaboration feature of evaluated VR applications

Collaboration feature	Standalone					Add-on		
	Revit Live	Composer	Fuzor	Revizto	InsiteVR	Prospect	Enscape	Kubity
Collaboration			Y	Y	Y	Soon[1]		

1. Multiuser Beta available since November 2017.

Supported File Formats

The eight VR applications support different types of file formats, as detailed in Table 7. As the most popular computer modeling software, Revit files are supported by the all eight applications. Except for Revit Live, the rest seven applications also support SketchUp files. Unlike Autodesk, Trimble does not have its own computer-based VR application for SketchUp, but it provides SketchUp Viewer, a Mixed Reality application for Microsoft HoloLens. Some commonly supported file formats also include Navisworks, ArchiCAD, Rhino, 3ds Max, and FBX, each supported by three to four applications. Other file formats supported by one to two applications include AutoCAD, SolidWorks, Solid Edge, and Grasshopper.

Table 7
Supported file formats of evaluated VR applications

Supported file formats	Standalone					Add-on		
	Revit Live	Composer	Fuzor	Revizto	InsiteVR	Prospect	Enscape	Kubity
Revit	Y	Y	Y	Y	Y	Y	Y	Y
SketchUp		Y	Y	Y	Y	Y	Y	Y
Navisworks			Y	Y	Y			
ArchiCAD			Y	Y	Y			
Rhino		Y	Y	Y		Y		
3ds Max			Y		Y	Y		
AutoCAD				Y		Y		
SolidWorks		Y						
Solid Edge		Y						
Grasshopper						Y		
FBX		Y	Y	Y	Y			

License Cost

The license cost varies among the eight VR applications depending their capabilities and license type, as detailed in Table 8. Five applications offer monthly subscription with Revit Live, Enscape, and Kubity at a low cost range between $20-45 per month while Fuzor and Prospect at a higher cost range between $200-300 per month. All eight applications provide annual subscriptions for either a standalone license or network floating license. Revit Live, Composer, and Kubity are again at the low cost range between $199-250 per year. Revitzto and Enscape cost in the mid-range between $449-679 per year, while Fuzor and Prospect are at the higher cost range between $2,000-2,500 per year. InsiteVR only provides floating licenses due to the fact that the project models are hosted in its user account website for multi-user access and its pricing is based on the number of hosted projects. The cost of InsiteVR starts at $99 a month for one project model, billed annually.

In addition to subscriptions, Composer also offers perpetual licenses at $399 for a standalone license and $799 for a floating license. A perpetual license will help to reduce subscription cost each year but will result in additional costs when upgrading to a newer version of the application. Revit Live and Prospect offer a free version of the application with limited features. Revit Live Viewer does not have the capability to communicate directly with a Revit file and can only open files created by Revit Live Editor, the paid version. Prospect Basic does not include any utility or simulation features and only allows basic navigation. Both free versions of the applications do provide the VR viewing experience. In addition, most of the eight applications offer a free trial for 14 to 45 days as well as a free educational version from 6 months up to 2 years.

Table 8
License cost of evaluated VR applications

License	**Standalone**					**Add-on**		
cost	Revit Live	Composer	Fuzor	Revizto	InsiteVR	Prospect	Enscape	Kubity
Monthly								
Standalone	$30		$200			$300	$45	$20
Floating			$250					
Yearly								
Standalone	$250	$199	$2,000	$500		$2,400	$449	$199
Floating			$2,500		$1,188		$679	
Perpetual								
Standalone	Viewer	$399				Basic		
Floating	free[1]	$799				free[2]		
Trial	30 days	21 days			14 days	45 days	14 days	14 days
Educational		2 yr free	Contact	Contact	Contact	1 yr free	6 mo free	1 yr free

1. No longer available since November 2017.
2. $75/month and $600/year since November 2017.

Discussion and Recommendations

The eight VR applications evaluated in this study offer a wide variety of options for architecture and construction firms at different interest levels of applying VR in their projects, from as early as trying it out, gaining the VR experience, all the way to a comprehensive integration in their design and project rendering.

For VR headsets, although Oculus Rift with Touch and HTC Vive provide a very similar VR experience, Vive provides better tracking for the headset as well as the controllers for a larger movement area due to its two wireless wall-mounted sensors. Rift can support up to four sensors for better tracking, but each sensor has to be connected to the same computer and additional costs will occur for the extra two sensors. In addition, due to its bulkier design, Vive has more room within the headset to accommodate eyeglasses, providing a more comfortable wearing experience for glasses wearers but at a cost of heavier weight. From the cost aspect, Oculus currently offers a bundle price for Rift and Touch at $399 while Vive costs $599, both with two tracking sensors and two controllers.

For architecture and construction firms who just want to try VR out in their projects, it is always beneficial to take advantage of the trial of each application. After the trial, the free Prospect Basic is a good starting point since Revit Live Viewer cannot be used alone with Revit. Even for firms who would only like to view their projects in VR, Prospect Basic provides full navigation features to satisfy the basic needs of inspecting the architectural designs in a VR scene that have to be paid for in other applications. When project needs grow towards the utility features in VR, Prospect is still a great choice but at a high cost. Depending what features are desired, Revit Live, Fuzor, Revizto, and InsiteVR can play different roles. Revizto seems to be a very competitive choice for its utility capabilities at a relatively low cost. Again, some of its features need to be further verified to be able to use in the VR mode.

When simulation in VR is a firm's priority, Revit Live, Composer, and Fuzor become the top candidates. Composer offers full simulation features at a very competitive cost, while Revit Live is able to render most simulation effects within a close price range. Fuzor also provides all simulation features, but on the other side, costs much more than its counterparts do. As collaboration between the project team becomes more valuable, the need of collaboration in VR can be achieved by using Fuzor, Revizto, and InsiteVR. Revizto again seems to be the most economical choice while Fuzor and InsiteVR may offer additional collaboration features at a higher cost.

Finally, in addition to the VR capabilities evaluated in this study, Composer, Fuzor, Revizto, and Enscape also provide many other BIM-related features that architecture and construction firms can take advantage of. While Enscape specializes in real-time rendering for Revit and SketchUp, Composer itself is a 3D modeling program with rendering, animation, and file-converting capabilities. Fuzor and Revizto is a full platform for BIM operations and analyses, including project interoperability, clash management, 2D drawing export, 4D scheduling (3D models attached to a schedule), team collaboration, etc. Furthermore, if an architecture and construction firm uses specific file formats, such as ArchiCAD, Rhino, and 3ds Max, the VR applications then must be carefully selected according to Table 7.

Conclusions

While BIM benefits the delivery of buildings by providing greater efficiencies at all stages of a project lifecycle, VR offers the possibility to explore the human elements of architecture, the form, space and aesthetics of buildings, through an immersive experience (Corke, 2016). Although still in its early days, VR has shown extensive benefits to bring to the architecture and construction industry, from functional and aesthetic evaluation of projects to daylight and lighting studies as well as client collaboration and communication (Corke, 2017).

Through a literature review, it was found that only a handful of available VR applications for architecture and construction uses have been reviewed. To provide more comprehensive and detailed information on such uses, this paper evaluated the capabilities of computer-based VR applications for architecture and construction that were available as of mid-2017. Eight VR applications were identified and six of them were tested with both Oculus Rift and HTC Vive. Their VR capabilities were evaluated and compared, including hardware support, navigation, utility, simulation, collaboration, supported file formats, as well as license cost. Recommendations were given on how architecture and construction firms at different levels of interest in VR can apply these applications more effectively. This paper provides first-hand information to architecture and construction firms who are interested in applying the VR technology.

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