36 Workflow in Virtual Reality Tool Development for AEC Industry

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Abstract

The relatively low cost and intuitive user interface of modern virtual reality devices offer many possibilities for it to be adopted in various industry. One characteristic that is offered by virtual reality is its ability to enhance user's perception by making the user immersed in the virtual world. As such, the system has a potential to be used in the Architecture, Engineering, and Construction (AEC) industry, especially during the design and pre-construction phase. Some AEC firms, including architects and general contractors, had implemented this technology into their projects. However, there is little known on how the firms integrated the technology. Previous researches have been studying the impact of this technology but did not analyze the workflow of its implementation. Therefore, the novelty of this study is in the analysis of the workflow. Semi-structured interviews were conducted on AEC firm to develop the workflow and identify several challenges in VR integration into project. The study found that most AEC firms utilize VR technology mostly for building walkthrough. There are several software solutions that were used to build the walkthrough. Depending on the complexity and time constraints, the AEC firms utilize either a one-click solution or develop the walk-through in-house. The study found that latest software solutions allow for quick deployment of VR for visualization purpose. However, AEC firms still must develop their own solution for some other purposes such as model annotation and multi-user environment.

Keywords

Virtual reality • Workflow • Organization

36.1 Introduction

The relatively lower cost and intuitive user interface of virtual reality offers many possibilities for it to be adopted in various industry. One characteristic that makes virtual reality promising is its ability to immerse the user in the virtual environment. As such, the system has a potential to be used in the AEC industry, especially during the design phase.

Several AEC firms, not limited to just architects but also general contractors, have begun incorporating virtual reality system in their projects. The firms use the technology as an alternative to physical mockups that takes time to build. Some benefits offered by the use of virtual reality are the "environment fidelity" and the "interface fidelity" that closely resemble those that are encountered in real-life [4]. With the help of the technology, architects are able to visualize and immerse themselves in their designs and achieve much clearer understanding of both qualitative and quantitative nature of the space they are designing [2].

The creation of virtual reality content has been made easier with the releases of tools that offer one-click solution. Despite offering the benefit of accelerating the project, these tools are specialized and has little customizability. Therefore, certain companies develop their own workflow of developing their own VR environment with interactions that are required to support the project.

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Different studies had outlined a workflow of VR assets conversion for AEC firms and presented challenges associated with the conversion based on a case study. However, the organizational structure of the development team was not outlined. By investigating the organizational structure, it is expected the general practice of VR development by AEC firms could be identified.

36.2 Background

36.2.1 Organizational Structure in Developing Virtual Reality Content

Since virtual reality is some form of interactive content, it would be best to draw its similarities to interactive entertainment industry before going further into VR development for AEC industry. Interactive content development requires a multitude of specialties. The number of individuals involved in a project varies depending on the scope of the project they are working, aside from the size of the company. In a typical development, there are several roles involved in a project [6]. The first role is the designer who decides which direction the application is going to take. This responsibility also covers the decision on what software to use and what interaction is required to achieve the desired result.

The second role which takes a large work responsibility during the development. To the programmers, the product is seen as line of codes which they have to create. They develop many aspects such as graphics, interaction, network, or physics through coding language. The coding language used by the programmer would be determined by their own language specialties and the language the software primary uses. The programmer could build the product from the ground up, which would take a significant amount of development time, or use a specific software which could significantly reduce the workload of the programmer.

The third role is the artist which designs the visual aspects of the application. This role is assigned to design objects, environment, interface, and visual presentation. In designing these aspects, the artist can use several approaches such as hand drawing, sculpting, or digital drawing. Artists also model the assets to be used in the interaction.

36.2.2 Asset Creation and Optimization in Virtual Reality

Unlike pre-rendered 3D design practice commonly found in design firm practices, virtual reality is identical with real-time representation of model in 3D. Real-time representation in 3D means that the viewer is given a certain degree of freedom to interact with the 3D environment, usually in the form of movement. This requires the computer to rapidly update the displayed image to give a sense that the user is moving. The rapidly updated images are measured in frame per second. Interactive 3D simulation would require between 30-60 fps to be an enjoyable experience.

This standard applies to virtual reality, whereas most virtual reality headsets available on the market today could render a maximum of 90 fps, with each display on each eye rendering the image sequence in 45fps.

Because of the higher resource demand for rendering in virtual reality, developers must develop their own optimization methods. Some of these methods are already implemented for real-time rendering application, especially in the development of videogames. The process of optimization allows artists or modeler to create a good 3D model without impacting much of the performance.

The 3D artists, the people who work in the game industry, must have both a good sense of aesthetics and understanding of how the tool used to develop the real-time simulation works. These knowledges are mandatory because they allow the artists to make a good use of the limitation of the hardware.

Polycount used to be the main driver that determines the graphical load of a real-time 3D rendering. It is the number of polygon that defines an object in 3D and often associated with the amount detail on the object. Developers used to keep the numbers as low as possible to maintain the real-time rendering's performance. The low detail was hidden by applying details on the model's textures. However, as the rendering technology advances, additional factors are beginning to surface such as post-processing effects and shaders. Nowadays, it has grown the point where developers think it is faster to add more polygon instead of applying additional texture maps.

Polycount optimization is about reducing the amount of polygon of an object. Because the amount of polygon determines how the shape would look like. Therefore, when it comes to the polycount optimization it is important to maintain the shape and general looks of the geometries while reducing the polycount. Applying additional details to texture maps can also be considered because it reduces the polycount. However, this process would require additional development time.

Graphical Processing Units, from herein referenced as GPUs, are capable of rendering polygons at a fast rate. However, it needs to receive a data that instruct it to draw those polygons from the relatively slower CPU. The data that contains those instructions is called draw calls. Whenever a new mesh or material needs to be rendered, the CPU will issue a draw call.

Optimization of the draw call for real-time rendering is very important, especially when the rendering will be used to represent a virtual reality environment. The optimization can be done by geometry instancing or combining meshes into a single mesh.

In optimization, model or mesh reusability is important because it can be created multiple times with minimum impact on the resources' memory. This method is also known instancing. The key here is to maintain the balance between reused meshes and non-reused meshes. When designing an environment, it is not preferable to build it from a big, combined meshes because it reduces the reusability. Likewise, having too many small meshes to be placed individually on the scene is not preferable either because it would inflate the development time [7].

A research conducted at Sodertorn University attempted to observe the performance difference between a scene that implemented optimization strategies and another scene that did not implement any optimization. In the study, the researchers created two scenes in Unreal Development Kit.

The first scene in the study didn't use models with reduced polygons. Instead of using texture mapping technique, the researchers modeled the detail using polygons. This resulted in many of the models in the scene to be high-poly models. Meanwhile, most of the models used different instanced materials instead of reusing the materials.

On the other hand, the second scene was an optimized version of the first scene. The models used in this scene were low-poly models and used more normal mapping technique to give the impression of high detail. The low-poly models were the result of polycount optimization based on the high-poly models in the first scene. Geometries that were obscured from player's view were deleted, this process is called culling. Additionally, materials on the scene were instanced from two master materials and had lower resolutions than the materials in the first scene.

From the results, the study found that the optimization strategies used in the second scene were able to increase the performance from 6.1 fps to 10.21 fps. The researchers were also managed to reduce the memory usage by 42.9%. These results indicated that optimization of 3D models could positively impact the performance, especially in improving the framerates and reducing the memory usage.

In general, the performance aspect of real-time 3D simulation is important. Developers of real-time visualization experience would take different approach by limiting the amount polygon displayed on-screen. Other optimization approaches are also taken such as simplifying the textures and lighting. In virtual reality development, the performance aspect is more important because a person's perception is more sensitive in virtual reality environment. A variability in performance would cause discomfort for the user.

36.2.3 Assets Optimization for Virtual Reality

Unlike the videogame industry, architectural and structural models used in construction projects are designed using CAD tools specifically developed for the AEC industry. Pre-rendered models are more preferred because the design will be printed on paper. However, with the adoption of BIM, the industry is seeing more applications of real-time rendering in tools such as Revit.

Realtime visualization in Revit is relatively different than realtime visualization in VR. In Revit, the users are not concerned with framerate because the tool is used for design and the model's photorealism is not the focus. Meanwhile, in VR environment, the performance becomes important the users because low performance would have side effects on the users themselves. For instance, a virtual reality environment with low performance would induce motion sickness.

Therefore, when creating a visualization of a building design in virtual reality the optimization process becomes important again. With the amount of works that the optimization take, there should be a solution to automate the process. Researchers at Chalmers University of Technology from Sweden developed a Revit plugin for viewing the geometries through virtual reality headsets [5]. The developers utilized effective culling methods in which the software only renders object that are within visibility range. The plug-ins were capable of extracting 3D geometry data through Revit C# API into Oculus Rift HMD.

The developers optimized memory usage through geometry instancing. Basically, it is an optimization method where identical components share the same geometrical representation. Through this method, the memory usage for duplicate instances of an identical object can be minimized. The challenge that developers faced during the development of this plug-in was the difference of language used by Revit API and the Oculus API. Revit uses C# language while Oculus uses C++ language. The developers had to connect the different software components through a C++/CLI bridge. The developers also faced difficulties of displaying Revit's material in the plug-in's visualization prior to the 2014 update of the Revit's API. Fortunately, subsequent update addressed that, and the developers could extract material and texture's data directly from Revit.

Based on the practice done by previous studies, conversion process from BIM/IFC model to videogame engine follows the following pattern

1. Assuring the compatibility of the BIM model with videogame engine.
2. Generating meshes based on the information received from the original model.
3. Realigning the UV mapping.

Additional parameter associated with the original model are usually ignored. But it is possible to implement the information retrieved from parameters into the programming logic in the videogame engine. Two most popular videogame engine (Unity3D and Unreal) are capable with injecting the information through each engine's programming language. In Unity 3D, this can be achieved through the scripting component attached to the geometry. Meanwhile, in Unreal Engine, the information can be embedded in its visual scripting tool.

Optimization is important for maintaining the comfort level of the virtual reality environment. As discussed in the previous segment, there are several ways to optimize a model. Some of these optimization strategies can also be implemented for BIM model conversion:

1. Mesh Decimation
   This strategy can be done in external 3D modeling tool such as 3Ds Max or Blender as both tools have scripting capabilities that allows for polygon optimization. This method reduces the number of polygon on the mesh without significantly altering the appearance of the object. Further optimization can be done manually by the user.
2. Texture baking
   Baking the texture could have several benefits. For one, it could help reducing the number of model's polygons. Aside from reducing the polygon, it also reduces the requirement for dynamic lighting which requires heavy computational power. Baking the lighting into the texture will give the impression that the texture is "lit" by the lighting while it is just the color of the texture that was made lighter.
3. Culling
   For heavily-detailed BIM models, it is possible to gain significant performance improvement through culling. Culling is essentially an automated process that hides any meshes within a certain distance from the viewer. For BIM, there are several ways we can implement this strategy: (1) Hiding interior geometries while the viewer is outside the building model and (2) Preserving the geometry of the room the viewer is currently located at while hiding the rest of the geometry.

Based on prior studies, asset optimization is an important aspect when developing a virtual reality asset. Geometries that were extracted from BIM models often contain details that would significantly impact the real-time performance. Compared to other Virtual Reality experience development workflow, developing a VR product for AEC presents more challenges because the available assets might not be appropriate for VR visualization. Therefore, additional steps might be required to deliver a VR-ready asset. This study investigated how AEC firms minimize performance impact when using the BIM models as the virtual reality assets.

36.2.4 Related Studies

Adams et al. [1] addressed the general workflow of VR implementation for general contractors [1]. However, this research only covered one specific project within a general contractor at a time when there was a limited selection in VR systems. With the current state of VR technology, the authors felt the need to improve update a review of VR implementation by gathering more data from several firms that also implemented VR technology into their project workflow with the current array of hardware and software.

In prior research the first author documented difficulties in bringing CAD design files into virtual environment. He found that:

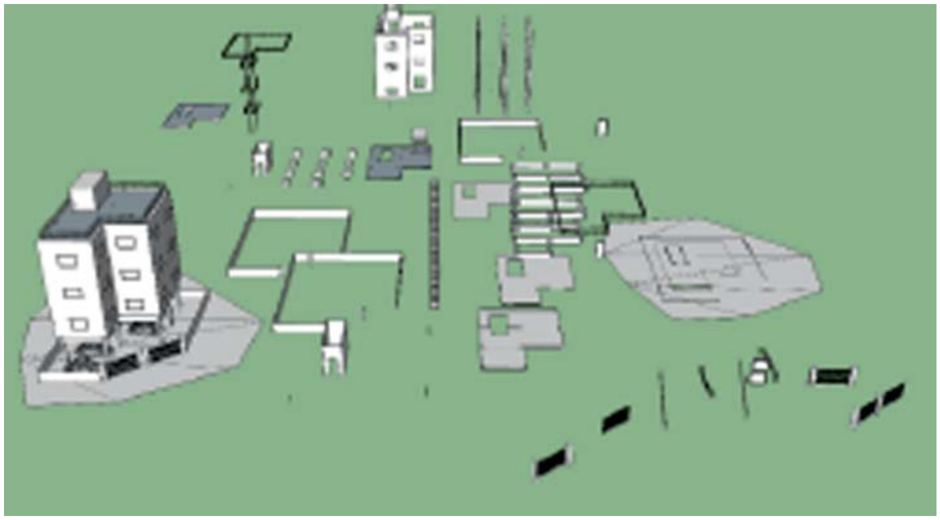

Fig. 36.1 Revit model broken down into smaller parts [9]

1. Directly converting the whole CAD model resulted in the creation of only one single building geometry in the software. For the 4D model simulation, the building model must consist of smaller geometries.
2. Materials/textures from CAD models were not converted properly. As a result, the geometries were either missing textures or displaying incomplete textures. The software used to develop the virtual reality model only recognize certain texture format.
3. Typical materials imported from CAD models were flat textures. Displaying the texture without any modification resulted in the model incorrectly showing its lighting properties.

The study attempted to convert a 3D model created in Revit to simulate a construction schedule similar to 4D models in Navisworks. Conversion of the Revit model required additional process in other modeling software such as 3DSMax, especially because the purpose of the model was not simply to represent the completed building in virtual reality. The model had to be manually subdivided into individual building components and the materials had to be remade due to the loss of information during the conversion process. In addition to modifying the models, important information that was embedded in the model such as information on Revit family of each component did not carry over into the program used to create the virtual reality model [9] (Fig. 36.1).

Rather than focusing on the impact of VR in the construction project, this study would break down how AEC firms implement and organize the team to utilize the technology.

This study aims to achieve several goals:

1. Identify how AEC firms organize a team when incorporating virtual reality technology to their projects.
2. Identify the technical aspects of optimization approach done by AEC firms to provide a good virtual reality user experience.

36.3 Research Methodology

To identify the workflow, the author decided to approach the study using qualitative method using semi-structured interview as its primary tool for obtaining data. The interviews were conducted concurrently with literature reviews. The semi-structured interview that used open questions allowed the researcher to gather as much information as possible with a limited time. From the interviewee's standpoint, semi-structured interviews allowed the respondents to express their own answers in their own way. However, this can be a challenge for the researcher because the response need to be analyzed thoroughly.

During this study, interviews were recorded through audio and field notes. Both approach had to be made because of the open questions. Relying solely on the field notes for open questions could be difficult and time-consuming. In this qualitative approach, records of the interviews were transcribed and coded to help with the data analysis. From these record, observations about the VR development workflow were identified. This methodology is deemed to be useful when there is little knowledge of an area, especially when the area is relatively new. All related aspects and observation would be thoroughly explored to build a new theoretical explanation of the area [3].

36.3.1 Study Population

Respondents from four AEC firms were invited to participate in this study. All participants have experience working on projects that utilizes the virtual reality technology. Participants, ranging from architects to general contractors, were interviewed either in person or through phone interview.

36.3.2 Interview Questions

The interview questions were formulated to identify elements of the virtual reality workflow: (1) organizational, (2) technical, and (3) execution.

Purpose	Interview questions
Background information and team structures	• How have you been involved in VR development? • Tell me about your background regarding VR development • When showcasing the Virtual Reality, does the company provide a dedicated infrastructure for it? If yes, could you elaborate on what kind of facility does the company provide? • For what purpose does your company use VR? • How VR has helped your company's business? • In a typical development, how many people are involved in the team? • How is the VR team structured? • Is there anyone outside of your team that provides feedback on the quality of the VR experience?
Identifying the conversion process	• In developing the VR, how do you develop the assets? Do you use an existing BIM/3D model? • What software do you usually use for model optimization? • What kind of optimization strategies do you usually incorporate when putting the assets into the tool used to develop VR? • What are your goals in doing the optimization process? • What elements from the original model do you usually keep during the optimization process? • What kind of lighting method do you use? Do you bake the lighting into the texture?
Other questions: desired output from VR, interaction, involvement of third party software or plugins	• In the final product what kind of output/feedback do you typically receive? • What kind of interaction do you typically add to the model? • What kind of external plugin or script do you typically use? • Are there other issues that you would like to discuss that we have not covered yet?

36.4 Interview Results

36.4.1 Organizational Structures in Content Development

Team Structures in AEC Firms

Based on the interview conducted with several AEC firms, it was found that AEC firms typically designate only a handful of people specifically for VR content development. All three AEC firms use models that are already built instead of developing the model from zero.

AEC firm #1, which identified itself as a general contractor, formed its own division called Immersive Technology team. This team is consisted of 2 staffs, would develop virtual reality tool for a project the company is working on. The team consists of a person with construction management background and another member with architectural background. In the team, one member would do the programming while the other would mainly be working on the assets creation and optimization.

In AEC Firm #1, The decision to use the technology is made after the team proposed it to the client. Insofar, the company has yet to receive a new request to use virtual reality because the client asked for it. If there is any, it is usually a request from the repeat client.

AEC firm #2, an architectural firm, also designates an employee to handle virtual reality projects. The employee, who has a two years' experience in VR development, would lead the VR project and collaborate with other division. The model used for the VR development is a model that is already developed and used in the design document. The employee would then proceed to add details not present in the existing model. Feedbacks would be received at the end of the development when the VR environment is demonstrated in front of the client. The feedback would be used mainly for altering the designs.

Similar to AEC firm #1, the virtual reality is only incorporated after the firm pitched the idea of using this technology the client. The firm also designate a specific space for demonstrating the technology to the client.

AEC firm #3, also an architectural firm, does not have a specific division for VR content creation. When asked about how the team is usually structured, the source said, "We have individual with VR capability that we can deploy to the team to provide whatever resources they required".

AEC firm #4, a general contractor, stated that the firm allocated funds for research and development for XR. In terms of organizational approach, the team size and structures vary by needs. Usually, the team is formed from a collaboration between integrated design engineer and project team. In certain circumstances, the team enlisted help from a VR company that specializes in AEC content creation. The firm also stressed that they do not develop apps, but instead utilizing existing resources that the company has. This company has incorporated VR/AR in various purposes, including constructability review, clash detection, estimating, and quality control.

It can be inferred from AEC firm #1 and AEC firm #2 that the VR core team consists of roles similar to the designer and programmer. Artist roles are usually taken by the people with architecture background who designed the building model and they are not part of the core team. Firm #4 is slightly different with the incorporation of design engineer in the team, but their roles are mostly similar to those in firm #1 and #2.

36.4.2 Technical Aspects

AEC Firm #1 mentioned that the team usually develop their virtual reality tool in-house using videogame engine such as Unity. The team would first determine what kind of application the virtual reality environment will be used for. After the goal has been set, the team then decides what level of interactivity needs to be incorporated:

1. Model walk-through that allows the user to navigate through the model.
2. Interface that allows user to swap between several design alternatives.
3. Networked environment that support several users in one session.

In developing the virtual model, the division would take a completed model, usually a BIM model, and begin their development by adding details to the model. The VR division of this firm is open to using third-party plugins or script because of the time-saving factor.

AEC Firm #2 has similar workflow in general, except the person working on the VR initially used Unreal Engine because of its visual scripting system. The VR division of this firm develop the script in-house and seems reluctant to use third-party plugins. When asked on the reason, the respondent replied that by developing their own script, it gave them opportunity to improve their understanding on the engine. An example of script that the team developed is a spline tool system that can be used to place fences or railings.

Unlike the others, AEC firm #3 would rather use already available VR plugin or application. The respondent also addressed the VR contents as outputs rather than tools. According to the firm, it would save the company a lot of development time compared to using videogame engine such as Unity because there are already software and plugins that fulfill what the company needs for a VR application. The firm argued that even if the company would develop a specific tool in-house, they prefer to collaborate with a video game developer rather than spending development time on in-house tools.

The company also prefers using mobile/phone-based VR because it is more practical to use, especially during meeting with clients.

Since AEC firm #4 have their own research and development budget allocated for VR and AR development, they prefer the product that they developed in-house. The company also did not limit their approach to one kind of software suite, although for in-house developed content they prefer to use video game engine as their primary VR development tool. The firm also used custom-made scripts and plugins to work on features that are not available yet.

From the interview this far, it can be concluded that there are two general models of workflow based on the tool used:

1. Develop the virtual reality content in-house.
2. Use existing software to produce a ready-to-use virtual reality content.

36.4.3 Optimization Approach Taken by AEC Firms

AEC Firm #1 mentioned that the team would take 3D models from the architectural rendering to be optimized. At the beginning of the workflow, the team would decimate the mesh by reducing the number of polygons in Rhino. Interestingly, the team would add more details to the model because they perceive 3D models, especially those extracted from BIM, do not contain enough details or even missing details. The extracted model usually looks like primitive objects and does not look good when put in a virtual environment. Optimization was also done through grouping the geometries into categories. The categorization allows the team to rapidly modify the model should any design changes occur during the review.

AEC Firm #2 uses similar approach, including mesh decimation, lighting and shadow baking. The respondent also mentioned a type of geometry instancing method developed by their own team. Additionally, additional technique such as culling was used in some projects.

AEC Firm #3 does not do much optimization because the process had already been taken care of by the third-party plugins or tools they are using.

AEC Firm #4 does optimization to achieve smooth VR/AR integration and gamification of certain tasks, which are primarily focused for illustrating how the completed construction would feel and operate once it is completed. In achieving the goals, the team relies on displaying the highly detailed objects and visual effects within the operator's field of view. Whenever the object is out of range of view, the system would show either a low-detailed model or completely hide it to save system resources.

AEC firms #1, 2, and 4 all approached the optimization process similarly. They also mentioned a specific commercial software that could automate the optimization. Using the tool, the project team can generate several models of a same object but with different Levels of Detail (LOD). It should be noted that the term LOD used in the optimization process is the term that is used in real-time graphics application, in which the model's detail is determined by how much polygon is used to build the model. Despite being able to cut the majority of the optimization process, it could increase the cost of the project since the model that is generated by the tool can only be accessed as long as the user is subscribed to the service.

36.4.4 Challenges in Assets Conversion

In a study conducted by NYU researchers to identify challenges in Building Information models into virtual worlds, it is found that geometry models tend to lose all of its attributes during the process. At the end of the conversion, all data that is left is the geometry [8].

AEC Firm #1 and AEC Firm #2 stated that they find difficulties particularly in texture conversion for the process. BIM models extracted from Revit do not contain enough texture detail to be presented in VR environment. As a result, the team must develop new textures before assigning those textures as material for the geometries.

Additionally, none of the firms retrieves semantic data from the BIM. Semantic data could contain attributes for the geometries such as weight, material, room information, and cost. Should the project need any attributes from the semantic data be included, the team had to inject the information manually by referencing the original BIM.

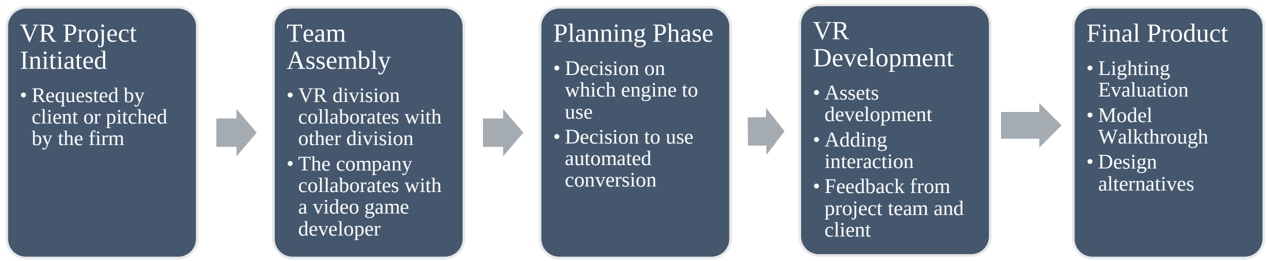

Fig. 36.2 VR development workflow

36.5 The Workflow

From the interviews, it can be summarized that the general VR development workflow is initiated when the project receives a request to use virtual reality technology. Afterwards, the VR development team/individual will be assigned to the project. The virtual reality environment would be developed either in-house or using a commercial software. At then the product is showcased to the client. During this process, the client would generally provide feedback on the design, not the virtual reality experience itself (Fig. 36.2).

From the assets creation and optimization, there are two types of workflow based on the current practices identified from the AEC firms:

1. Manual Conversion of 3D Models into Virtual Reality Environment (Fig. 36.3)
2. Automated Conversion using Plugin and Software (Fig. 36.4).

The second workflow skipped the format conversion and model optimization in the previous workflow using a 3rd party software or plugin. This workflow also skips the optimization because they are already created during the conversion process. Because most of the conversion process lie in the optimization, this workflow type could greatly save the amount of development time. The downsides of this workflow are:

1. The tools used for conversion are not free and require the user to pay subscription fees.
2. The tools are specialized for certain development software packages. One tool even requires the user to be connected to the authorization server in order to display the optimized model.
3. Most tools can not do subdivision of the models. This type would not be efficient if the user would like to use the model for something other than model walkthrough.

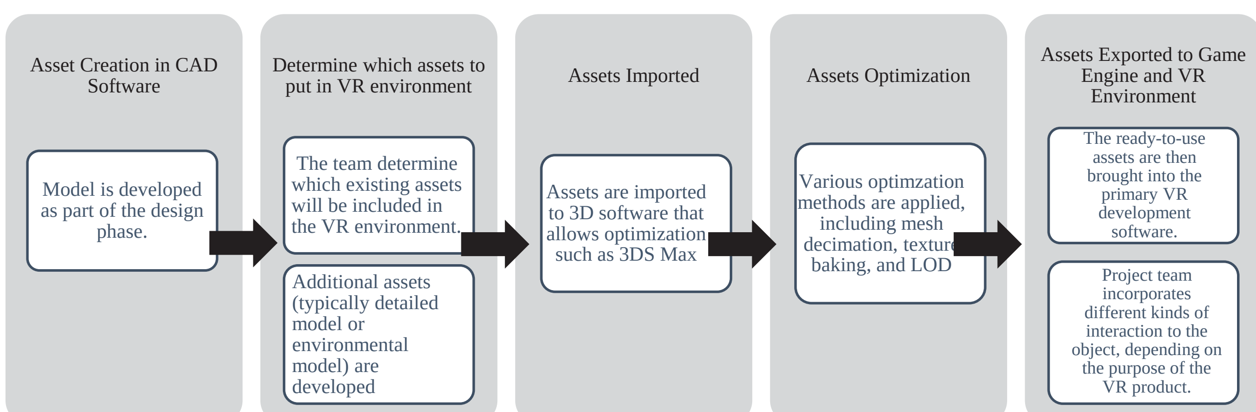

Fig. 36.3 Manual assets creation

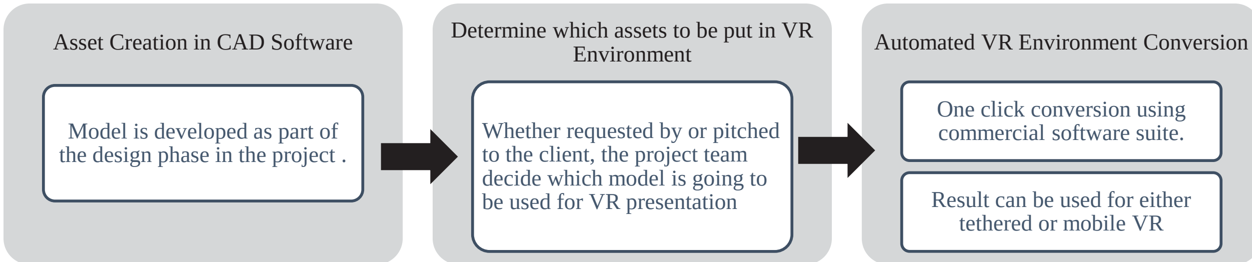

Fig. 36.4 Automated conversion

36.6 Conclusion and Suggestions

From the study, it can be concluded that:

1. Virtual reality division, if any, in AEC firms plays a relatively minor role in the whole project. The core team would consist of only one or two members who, depending on the scope of the project, would collaborate with other division.
2. The minor role and the very specific skillset required for this field which are removed from the skillset desired by many AEC firms can be a barrier to implementing VR in AEC firms. Therefore, it would be logical for the company to use a commercial software for the VR environment creation.
3. For a very specific need, the firms would rather develop the tool using video game engine. Aside from natively supporting off the shelf headsets such as HTC Vive and Oculus Rift, the development team would have more freedom in programming the interaction.
4. Mesh decimation, shadow and light baking are the most prominent approach to optimization in VR development. These approaches are common because the process can be automated in 3D modeling software.
5. In order to improve the workflow, VR should not be considered as a "novelty" but rather an integral part of the project.
6. There are commercial software suites that could greatly streamline the optimization process. However, further study about the cost/benefit ratio of the software needs to be conducted.
7. There are more potential uses of VR than simply a design visualization tool. Since currently VR software suite tailored for AEC industry is quite limited, AEC firms could use this opportunity to develop their own VR tool to leverage their company.

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