THE ACCEPTABLE VISUAL QUALITY OF STEREOSCOPIC VIRTUAL REALITY ARCHITECTURAL VISUALISATION

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Abstract. The realism of VR visualisation is diminished when images look pixelated or forms are faceted instead of smooth. What constitutes acceptable visual quality by viewers? This paper presents the survey results of what is the acceptable visual quality of triangle complexity and texture resolution for full-size VR visualisation on a large screen and serves as a guide to create VR models more efficiently.

Keywords. Virtual Reality, Stereoscopic, Visualisation, User perception

1. Introduction

Stereoscopic virtual reality (VR) architectural visualisation on large screen provides depth and close to real world scale to experience architectural spaces. Large screen refers to screen height of at least 2m where objects can be projected at full-size. Real-time navigation through a model is the strength of VR as it allows viewers to experience moving through the space. The more complex a model is, the slower the navigation is in real-time. When there is a lagging of frame rate on the screen, the effect of real-time is lost.

Research has been done to identify the variables that affect efficient real-time walkthrough of architectural models and how each variable affects frame rate (Tan BK & Hii JC, 2007). It was found that triangles count affect the frame rate most followed by the number of geometry (objects) that made up the model. These are the quantitative variables that affect real-time VR visualisation. However, the effect of VR visualisation is also dependent on users' acceptance of the visual quality of the visualisation. The effect of VR visualisation is diminished if viewers see pixelated texture (i.e. poor texture resolution) on the screen.

There are also research done on colour and material impact to human perception in 3D scenes (Chan CS, 2007), wayfinding in VR (Darken and Sibert 1996) and feeling of presence in VR simulation (Morie et. al., 2003, Chan C and Weng CH, 2005) but none on acceptable visual quality of VR presentation especially for large screen.

Creating models with textures for as realistic a presentation as possible is often a time consuming and tedious process.
The challenge of a good VR visualisation is balancing the viewer’s demand of what looks acceptable and real with what hardware and manpower resources are available to create and run a complex model in real-time.

This paper aims to find out what is the acceptable visual quality of basic elements in VR visualisations on large screen projections so that VR projects can be done more efficiently without wasting resources on creating what are unnecessary. For example, in a restaurant scene where there are many chairs, if optimising a chair of 50,000 triangles to 25,000 triangles is visually acceptable to a viewer, then it means saving 50% in geometry, thus improving the frame rate of real-time navigation. The same applies to texture resolution. If 1024 x 1024 pixels texture mapping is adequate for flat surfaces, there is no point using a 4096-pixel texture map that taxes computer resources. By optimizing the basics, hardware resources can be freed to support other advanced features that add to realism.

2. Method & Scope

The scope of this paper deals with forms and textures common in architecture visualisation for exteriors and interiors and focuses on large screen projection. Two variables were tested – triangle complexity and texture resolution. Curve surfaces were represented by objects with 2-directional and 3-directional curves. Common textures in buildings such as wood grain, stone slabs and rough texture were used. They were applied on a flat surface (representative of a floor or wall), a curved surface (representative of a curved wall in a building) and an organic form (stone or rock).

2.1 PROCEDURE

A survey was conducted for 59 subjects of different gender, age and educational disciplines to gather their preferences for two variables — triangle complexity and texture resolution. For each variable, participants were shown one model at a time on a screen, ranging from the best to the worst visual quality and asked to pick the one that is not acceptable. There were a total of 7 models. The participants were given a questionnaire with questions “From which object onwards is the quality not acceptable to you? Please circle your answer”. All 3D models used in the experiment are projected at least to full size on a large screen of 4.5m x 2.5m when displayed to the participants i.e. the chair height measured on the screen is an actual chair height.

Figure 1. Large screen setup

This is to ensure that it is as close as possible to real world size and is realistic for evaluation. The participants are requested to sit at a distance of approximately 2.5 metres from the screen. This is a comfortable distance where their cone of vision can take in the entire object. The simulations are in stereoscopic mode and the participants view them with the stereoscopic glasses.

580
The choices are displayed one at a time from the best quality to the worst quality from A to G. When a participant indicates that he has seen the 3D model long enough, the person who controls the display will pan to the next model and announce the alphabet. After displaying all the 7 choices, the participants were asked if they would like to view any 3D models once again.

2.2 SURVEY PARTICIPANTS

The suitable subjects for the survey are people from all kinds of background and discipline. The argument here is that the potential audience who will view virtual reality visualisation projects could be developers, quantity surveyors, engineers, scientists, accountants, businessmen and many other professions other than just architects. Therefore, the survey is targeted at the community inside and outside the university campus. Those who attended the survey included undergraduate students, postgraduate students as well as alumni who are already working professionals. They consisted of 42 males and 17 females and were from diverse departments including architecture, industrial design, real estate, building, electrical engineering, chemical engineering, civil engineering, sociology, general arts and social sciences, mathematics, computing and business. The possible audience for virtual reality presentations is people from any possible backgrounds and thus this coverage of diversified fields represents that. Virtual reality presentations have been used in so many different industries and it will be crucial to understand the requirements and needs of people from all those different industries.

2.3 TRIANGLES COMPLEXITY TEST

All CAD models are formed from triangles. For curve shapes, the more triangles there are, the smoother the shape. Most CAD softwares have optimising algorithms to reduce the number of triangles. However, if a curve form is optimised into too few triangles, it will look jagged. In the triangles complexity test two non-linear objects, a chair (of 3-directional curves) and a sink (of 2-directional curves), were shown using different compression levels.

In this test, the choices of A to G are for objects that are not optimized to those optimized to 5%. The non optimized chair and sink were modeled with default segment settings common to most software. The compression algorithm with the best visual appearance was used. The choices are 100% (A), 55% (B), 45% (C), 35% (D), 25% (E), 15% (F) and 5% (G). The original chair has 69,854 triangles (100%). It is optimized to 38,179 triangles (55%), 31,218 triangles (45%), 24,214 triangles (35%), 17,237 triangles (25%), 10,263 triangles (15%) and 3,304 triangles (5%).

The sink originally consists of 69,482 triangles (100%). It is optimized to 38,056 triangles (55%), 31,021 triangles (45%), 23,978 triangles (35%), 16,970 triangles (25%), 10,060 triangles (15%) and 3,163 triangles (5%).
2.4 Texture Resolution Test

The texture resolution test is done with the objective of finding out participants’ acceptance of the limits of texture resolution quality applied on three different types of surfaces. The surfaces are representative of those used in buildings i.e. flat surface, curve wall and organic forms. The texture used are all the DDS DirectDraw Surface) format in 72dpi with mipmap. The 7 different level of qualities presented are 4096 x 4096 (A), 2048 x 2048 (B), 1024 x 1024 (C), 512 x 512 (D), 256 x 256 (E), 128 x 128 (F) and 64 x 64 (G). The highest resolution of 4096 x 4096 is the current highest supported resolution for all 3D graphic cards in 3D applications. Therefore, it is logical to use it as the highest resolution in the test. In addition, it is considered the highest texture resolution used in the world today in texture mapping for 3D models. The textures chosen are commonly used in buildings – wood grain, stone slabs and rocks. The wood grain texture is applied on a flat surface, the stone texture is on curved walls and the rock texture is on organic form of a rock. The textures are mapped to a correct real world scale on the surfaces and the models are projected on the screen to its real world size.

Figure 4. Wood grain on horizontal surface— Texture resolution test. Decreasing quality from left to right. Each table was shown one at a time on the screen.

Figure 5. Stone texture on curved walls — Texture resolution test. Decreasing quality from left to right. Each wall was shown one at a time on the screen.
Figure 6. Rough texture on rocks — Texture resolution test. Decreasing quality from left to right. Each rock was shown one at a time on the screen.

3. Survey Results

3.1 TRIANGLE COMPLEXITY TEST

For the Chair survey, Chair D was chosen by the most persons (15 persons) as the object from which point onwards the visual quality is unacceptable. It has 35% of the original chair’s triangles of 69,854 i.e. it has been compressed by 65%. Chair B, which is 55% of the total amount and Chair C, which is 45% of the total amount, were selected by 6 and 7 persons each respectively.

Figure 7. Responses for Chair quality (Triangles Complexity Test)

For the Sink survey, Sink E was chosen by the most persons (14 persons) as the object from which point onwards the visual quality is unacceptable. It has 25% of the original 69,482 triangles i.e. it has been compressed by 75%. 6 persons chose Sink B (55%), 8 persons chose Sink C (45%) and 11 persons chose Sink D (35%).

Figure 8. Responses for Sink Quality (Triangles Complexity Test)
3.2 TEXTURE RESOLUTION TEST

For the wood grain texture on flat surface survey, 8 persons chose C (1024 x 1024 pixel texture) and the most persons (23 persons) chose D (512 x 512 pixel texture) as the object from which point onwards the visual quality is unacceptable. That means that the next higher resolution of 1024x1024 is acceptable by most persons for flat surface.

![Figure 9](image_url)

*Figure 9. Responses for visual quality of wood grain texture on flat surface (Texture Resolution Test)*

For the stone texture on curved surface survey, 8 persons chose Curve Wall C (1024 x 1024 pixel texture), 14 persons chose Curve Wall D (512 x 512 pixel texture) and the most persons (28 persons) chose Curved Wall E (256 x 256 pixel texture) as the object from which point onwards the visual quality is unacceptable. That means that the next higher resolution of 512 x 512 pixel texture is acceptable by most persons for curved surface.

![Figure 10](image_url)

*Figure 10. Responses for visual quality of stone texture quality on curved walls (Texture Resolution Test)*

For rough texture on organic form rock, there are more divided views. 5 persons chose Rock B (2058 x 2058 pixel texture), 6 persons chose Rock C (1024 x 1024 pixel texture), 6 people chose Rock D (512 x 512 pixel texture) and 9 persons chose Rock E (256 x 256 pixel texture). But the most persons (20 persons) chose Rock F (128 x 128 pixel texture) as the object from which point onwards the visual quality is unacceptable. That means that the next higher resolution of 256 x 256 pixel texture is acceptable by most persons for organic shapes.
4. Conclusion

For a curve form, the more triangles it is modeled in, the smoother the curves. However, if a user is limited by his computer power, in a scene that has many complex curve forms such as an office with many chairs, it is prudent to reduce the complexity of the geometries in order not to slow down real-time walkthrough of the model. The survey results clearly indicate that the participants can visually accept 65% compression for 3-dimensional curve forms and 75% compression for 2-dimensional curve forms. This will serve as a guide for how much to compress the triangles. Though the survey was done on a chair (a 3-directional curve form) and a sink (2-directional curve form), the results are generally relevant for other objects with curves such as cars, trees and humans.

For textures, the survey results showed that to be visually acceptable, a minimum of 1024 x 1024 pixel resolution textures is required for flat surfaces, a minimum of 512 x 512 pixel resolution for curved surfaces and a minimum of 256 x 256 pixel resolution for small organic shapes. These corroborate with industry practice of using 256 and 512 pixel textures. However, the 1024 pixel required for flat surface indicates that user expectations are higher. Gaming is becoming more prevalent and gamers are used to higher quality graphics.

Though the surveys were done with users seeing static objects, the results are also relevant for walking past objects because a user sees less detail on the move. As the survey was conducted on a very large screen with the objects projected at life size, the results are definitely applicable to standard display screens such as LCDs and laptop screens. For the same image, fewer details can be discerned on small screens versus a 2m high screen. We can expect that the visual quality standards demanded by viewers on smaller screens would be less stringent. This can be verified with future survey. Moreover, the models were first checked for quality on a standard 15-inch screen before being projected on a large screen.

These results will guide designers and architects during modeling and texture mapping stage to plan well, thus, saving resources such as shortening the time taken to prepare a model for real-time walkthrough. As the number of triangles impact the lagging of a walkthrough the most, the survey results provide a guide on how much a reduction of triangles would still be acceptable visually to the viewers. It is not necessary to use a very high resolution texture for curved surfaces when a lower resolution texture will suffice. While higher resolution texture will not affect the frame rate significantly, it does affect the texture memory and vertex memory resource. The survey results provide a general guide for texture mapping flat, curved and small rough surfaces.

Not everyone can afford the best hardware. In such cases, optimizing the model and texture to a limit that is visually acceptable will free computer resources to use other advance features such as shaders to improve realism. The goal is to create stereoscopic VR architectural...
visualisation that will satisfy the visual quality expectations of the general audience and at the same time, run efficiently on affordable hardware setup thus saving resources.

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References


