How is CGI used and applied in modern day?

By Adam Woodruff

Introduction

CGI or computer-generated imagery has progressed exponentially over the years and is now at the point where anyone with a computer and a few skills can make photo realistic scenes. With new open-source software like Blender the consumer can even implement assets into a real time engine for free. This accessibility has brought a lot of momentum in recent times helping to move the technology forward.

CGI is a very broad term referring to the use of computers to create media, ranging from scientific models to simple art, there is lots to be done with this technology. Some of the biggest applications of CGI are in video games where city designers virtually create huge environments for players to explore down to the smallest detail, and the latest technology enables Realtime photo realism. Movies have also taken aspects from the gaming industry using similar technologies to help actors to feel inside the shooting scene rather than using a green screen.

I have decided to research this topic, not only because of my interest in video games and 3D rendering, but also because the use of technology in media has become part of everyone's lives and its significance and influence is more than ever. But very few people have knowledge of the methods used in CGI.

In my research I intend to develop not only my knowledge but also my skills in 3D modelling and rendering, applying different techniques while educating myself on the technical aspects of the methods and the technologies used.

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Aims and Objectives

In summary the aim of my research is to document the use and application of 3D in the world today. While looking at how it has progressed, the impacts it has had and expressing the basics and commonly used techniques. More specifically, I am going to investigate the topics:

- Hardware and software requirements.
- Use of Blender and how it has affected the consumer.
- Breakdown of techniques used in modern entertainment.
- Film sets
- Technologies used in media
- Outstanding use cases of CGI
- Architecture visualisation
- How technology has adapted to the times.

With all my research I intend to display how techniques and technologies have improved over time. While displaying some methods used in a range of ways, I also plan to give a better understanding on how various pieces of media are made.

I intend to create and follow set objects for my research to keep my work concise and on track. These will consist of various milestones that I will achieve in my research or in my documentation. My objectives consist of the following:

- **Learn how to write a solid report.**
  - In doing this I will develop fundamental skills to help with further projects in my A levels and other endeavours.
  - This will also help me to be succinct with my writing and research while putting emphasis on important topics.
  - I will also make every effort to ensure good use of correct writing technique keeping my work punctuated and have a good flow for ease of reading.
- **Develop my analytical skills.**
  - In my research I will have to review lots of software documentation and work done by other people and in doing this I must be efficient with my data interpretation
  - This skill has a lot of cross over with other academic subjects. As quick information ingestion and interpretation can be an invaluable skill.
- **Determining the validity of research.**
  - A common caveat to all the accessible information on the web is misinformation, be it from bad research or misleading documents. Whilst I carry out my research, I must be cautious to verify the validity

of the source and see if there is any other media to back up potently dubious claims.
    - I will also use primary research done by myself to collect vital information on core topics. This will be reliable information that I can write about from experience allowing me to provide more detail.
    - I will also write about specific sources at the bottom in the section test *Assessing the Validity of sources I have used*
- **Determining the importance of research.**
    - While misinformation is an issue the misuse of information can be just as detrimental, be it out of context or just out of the frame of reference of the project. In cementing reliable information, I must make sure I have a thorough understanding of what the source is talking about.
    - This skill will also help if I intend to go into a research-based degree or even in my A level computer science project.
- **Developing my writing skills**
    - A core component of writing a good essay is having good structure and keeping the information in clear parts to improve the readers attentiveness. This is a skill that must be developed.
    - The document must also be well written with clear information and references showing where the information is from and headings describing the content of each section.
- **Improving my usage of technical language.**
    - To write a detailed report, I must use technical language to show a thorough understanding of the topic.
    - This can be picked up through research but for the reader to understand the more technical language I will document all words of importance in the glossary.
- **Improving my knowledge in CGI**
    - A core part of writing an in-depth report is showing an understanding of the subject at hand. For me to do this I must have a strong understanding of a broad range of topics.
    - I must demonstrate an understanding of how techniques work as well as showing a selection of use cases and how professionals might use that technique in high production media.
- **Demonstrate how to apply skills learnt.**
    - To demonstrate a deep understanding of CGI and 3D, I must do some primary research and display some techniques used in various ways.
    - To do this I will create different renders of various scenes to show a wide range of techniques and include them in this document. This will show that not only do I understand the topic but also that I have an interest in it and how it is used in the wider world.
- **To learn more on how CGI is used in industry.**
    - To learn how 3D is used I must also learn where it is used. In this objective I intend to document and write about differing studios around the world creating a huge selection of media.
    - I will also document what software is used in different studios and more importantly how it is used.

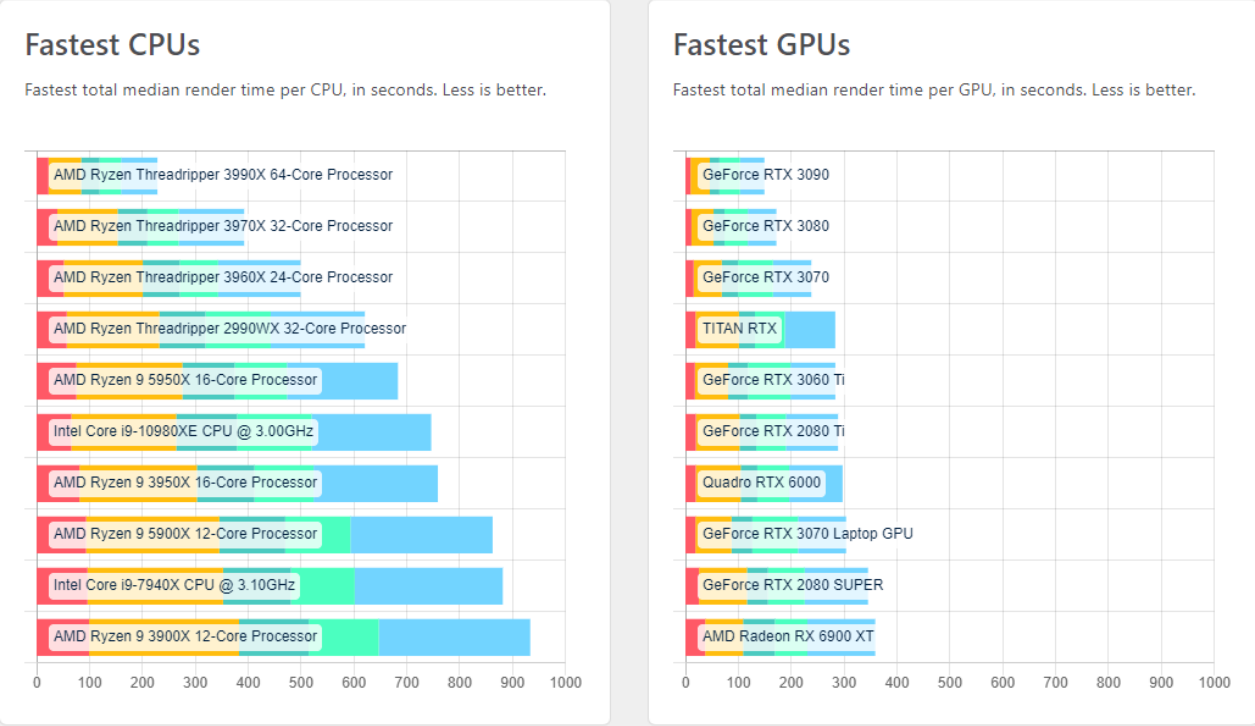
- **Enhance my knowledge on the application of 3D software.**
  - Like the application of skills, I must also demonstrate that I understand what each piece of software is used for but in a wider sense.
  - To do this I must show that I know the intentions of different applications and their importance for specific techniques, in addition to the type studios use that software.
- **Learn how the 3D pipeline takes place in a studio.**
  - The 3D pipeline is a core concept in CGI and VFX, so it is of importance that I show an understanding of how it is used and the purpose of it.
  - As well as documenting how it is used, I will also display how it varies depending on the software, type of studio and country.
- **To expand my interest in design**
  - To write a document to the expected standard of an EPQ on a single topic of which I have specific interest. In my research I intend to build on this interest creating different pieces of media do develop my skills and enjoy a hobby.
- **To have talking points at university interviews.**
  - CGI is just one of multiple areas for serious consideration in terms of my chosen career path. Therefore, ensuring that I have a broad range of technical knowledge and interests is important.
  - Also, having a project containing an excellent level of detail and quality can be used to demonstrate my knowledge, learning abilities and interest in the topic.
- **Expand upon my time management skills.**
  - Gain a greater understanding and more effective use of the time and commitment required to collate and document detailed information on a specific topic.
  - Whilst creating this document I need to balance my time with all my A-Level studies and other commitments which will help me learn to prioritise my time more effectively on things which are both worthwhile and rewarding.
- **To show a further interest in CGI and VFX**
  - I must also show an interest of CGI and VFX outside of my research. I feel enjoying a subject is very important to learning it and doing work outside of what is being researched can help.
  - Whilst I research this topic, I would also like to explore different possibilities with CGI. For example, linking in with my computer science studies I would be inclined to understand how render engines work and the code powering them.

Hardware

The processing power of a computer varies drastically from application to application, even down to what the user will be doing in that programme. For example, the basic rule in 3D modelling is the size and complexity of a scene is relative to the amount of RAM or VRAM (depending on what is being used to render) required to load and render the model. In a similar way to using multiple programmes simultaneously, the volume and speed of assets which are being loaded into a scene is relative to the capability and performance of the hardware upon which the task is being performed. This is especially prominent in the view port render that most modern 3D modelling applications use, because it actively renders the light paths and how it will interact with textures directly from RAM.

The complexities of 3D models and renders are directly related to not only the computers RAM and/or VRAM but also the computational power of the CPU and, especially in 3D applications the GPU. However, unlike RAM which can often be easily increased, it is not as straightforward to upgrade the performance of the CPU & GPU. These components are strategically released commercially to the public annually by a very limited number of manufacturers. AMD or Intel for CPU's and AMD or Nvidia for GPU's.

In general, for GPU's Nvidia is considered better especially with the lighting aspects. This is because of the use and implementation for ray tracing cores in their graphics processing unit. However, the ray-tracing cores are not the only thing to consider in a graphics card there is also the clock speed of the processing unit, this determines the number of calculations per second the processor can perform. For example, a modern graphics card has a base clock of 1,440MHz, this means it can do 1,440 million binary calculations per second. But keep in mind there are other deeper factors affecting the performance. In addition, a graphics card also has a specialised type of RAM called VRAM or video random access memory, this has a similar purpose to normal RAM but is entirely dedicated to the GPU. The required amount of VRAM varies from application to application as does RAM but in general a minimum amount of RAM is considered to be 16Gb, but in graphics cards a good baseline is 8Gb for a reasonably priced consumer card.



***Benchmark results taken from Blender open data**

The above image displays the time taken to render 5 different complex scenes from Blender open data[1]. This shows that not only is GPU rendering much faster to their similar costing CPU counterpart, but also that even last generations GPU's can be faster than some of the latest and greatest CPUs only recently released.
In addition to the internal computer components, you also require input and output devices for most functions, typically a keyboard, mouse, and monitor. However, another input device that may be considered is a drawing pad. This is because when using texture paint features in certain software it can be easier to do it with a classical style pen. This is due to the pressure and flexibility you have with a pen is leagues better than a typical mouse. Although the use case for this device is limited it gives the artist considerably more flexibility in many scenarios.

A new technology for laptops, external graphics cards are also gaining popularity for high graphics-based workloads. External graphics cards are as they sound, they are a graphics card that you can plug in to your laptop usually via Thunderbolt 3 to give the power of a full size, high end graphics card. This new technology adds flexibility despite hindering the laptops main selling point the portability.

Industry hardware

Like common components this again varies from company to company as well as use case. But Disney's use of technology is noteworthy. Disney use a render

[1] https://opendata.blender.org/

farm, which is a huge cluster of computing "nodes" controlled by management software. This technology dedicates one frame per node and depending on the number of nodes, rendering multiple frames at the same time thereby increasing the speed of render times. The specific hardware Disney uses changes and contradicts itself from source to source, but it is generally considered to be an extremely powerful supercomputer. A quote from peter Collingridge, a Pixar scientist – he claims:

"Pixar has a huge "render farm," which is basically a supercomputer composed of 2000 machines, and 24,000 cores. This makes it one of the 25 largest supercomputers in the world. That said, with all that computing power, it still took two years to render Monster's University."

This statistic helps put into perspective the scale and computing power needed to create a Pixar film.

In a studio tour of Barnstorm VFX done by Andrew Price or the Blender Guru[2] shows the various tasks that undergo in a VFX studio, at the same time as giving a small insight to some of the hardware used. The interviewee claimed to be using mostly gaming computer components in the VFX machines, with some computers having multiple high end titan Z graphics cards[3].

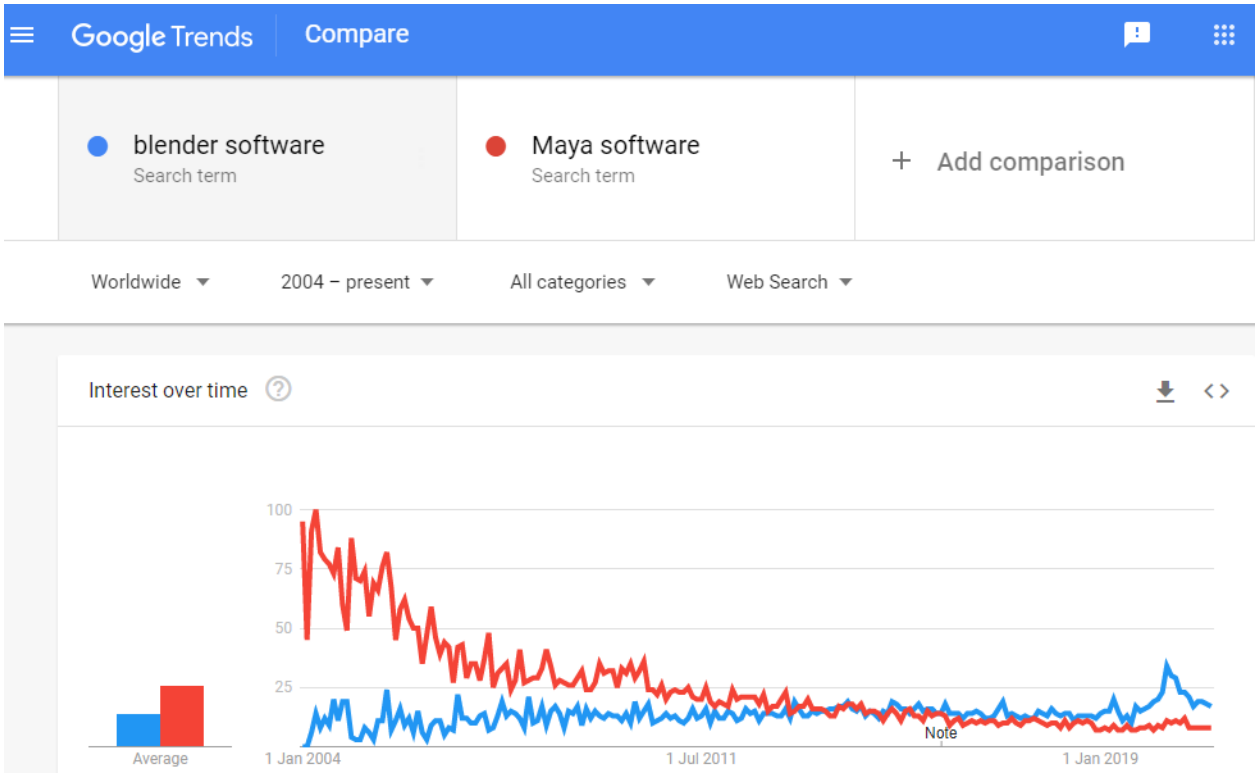
Software

There is a vast range of software for an even wider array of functions and applications. However, for 3D modelling, animation, and texturing applications for commercial and personal use the industry standard product is considered to be Maya[4]. Due to its flexibility and reliability it is used in a wide variety of ways, varying from game development to film and television. It is also extremely popular as it is licensed to organisations and can be tailored to meet that organisations specific needs and different workflows, like character modelling. Having a dynamic piece of software that can do it all, is invaluable for productivity and speeding up the VFX pipeline. While being the standard, it is commonly used as there is a good API which enables users to write and use custom tools and addons while having much better sculpting and painting features in comparison to other software's while also just being reliable.

Despite Maya being the industry standard for animation and modelling etc, as of recently Blender[5] has been becoming increasingly accessible for consumers and because of this, it has had a huge increase in popularity. This is shown in the ever-popular Blender Guru doughnut tutorial with over 6.5 million views[6] in

[2] https://www.youtube.com/watch?v=ZpfUJDxEfz4
[3] https://www.nvidia.co.uk/gtx-700-graphics-cards/gtx-titan-z
[4] https://www.autodesk.co.uk/products/maya/overview?term=1-YEAR
[5] https://www.blender.org/
[6] As of 1/03/2021

addition to google showing a huge surge in popularity. It's clear that Blender has grown considerably in popularity, and more people than ever are trying to learn it due to its accessibility. Like Maya, Blender is an extremely powerful piece of software while being completely free. Personally, I have lots of experience in Blender so when I refer to 3D software, I am biased as most of my 3D experience has been learning the ins and outs of this software.



***data from google trends displaying maya vs Blender**

Like most things, there is rarely a single product that does it all. Despite the undoubted quality of the Maya and Blender other dedicated pieces of software are often used for specific applications. A very popular piece of software commonly used in 3D is photoshop. In the world of 3D, Photoshop is used quite often in UV unwrapping,[7]where users modify images of textures to be imported into 3D software. Photoshop is also used post-render in static scenes to add characteristics that are hard to replicate in 3D software like the slight imperfections of cameras for example depth of field, saturation, and contrast.

[7] Refer to **UV Mapping/Unwrapping**

Techniques

In 3D like most things there are hundreds of ways to do the same thing be it in different software, doing it in a different order or even using different techniques and everybody does things the way that work for them. But there are considered best practices for best efficiency and work-arounds for seemingly impossible tasks.

Modelling

Modelling is arguably the most important part of 3D as without it there would be no 3D. It is also the first thing you will learn as a beginner because without any knowledge you are setting yourself up to fail. Even with the rise of downloadable assets some knowledge and skill in modelling is still required.

At its core modelling in 3D is simply the manipulation of vertices to create shapes.

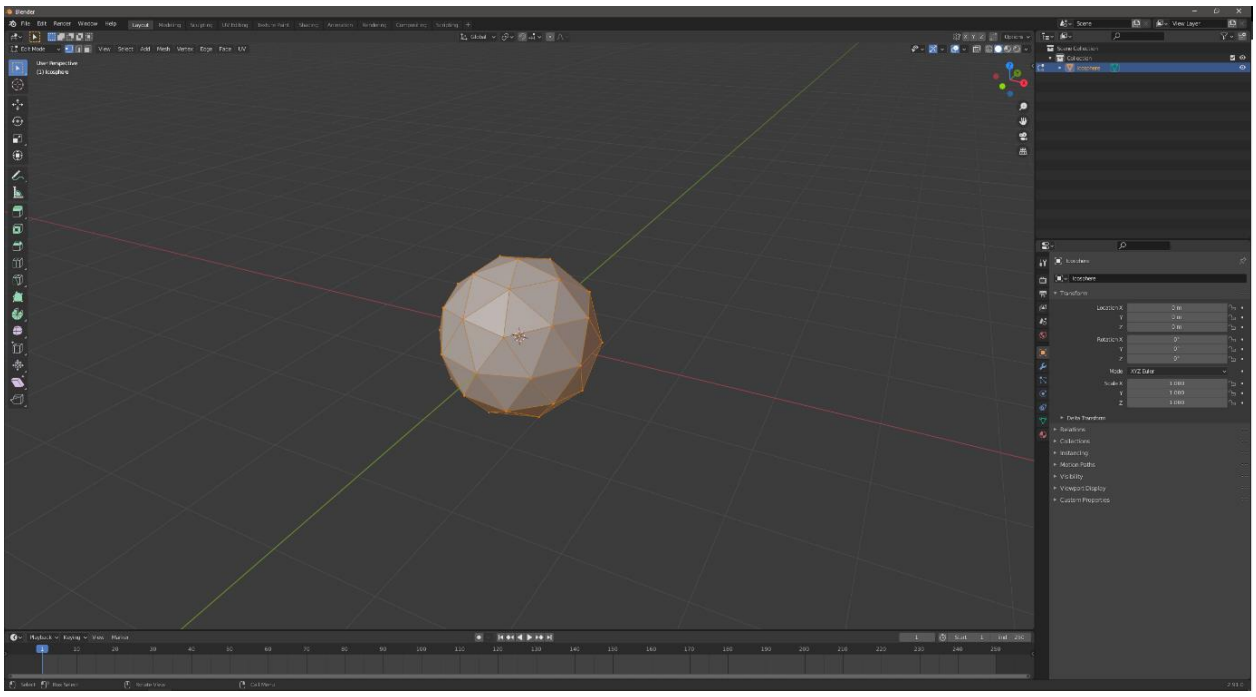


*image of icosphere in Blender

In 3D, modelling is done by adding a mesh that most resembles the object you are trying to model into a scene. Then you are free to "manipulate the vertices". A very important thing to consider while 3D modelling is the vertex count. This number can drastically affect your experience as the more vertices there are, the more your computer must calculate so the general rule is that you model with a low number of vertices. Then, before the render you add detail, as this is easy to

do using modifiers[8] and sub dividing the mesh[9]. Subdivision is a core concept of 3D modelling as it adds more vertices to the mesh allowing you to create mode complex models. It can be used to make rough surfaces smooth and enable users to add more detail to parts.

Some other modelling tools in Blender include the Extrude[10] tool that takes a face and "extrudes" it from the mesh. This tool, in my experience, is used frequently in modelling objects ranging in complexity. There is also the Inset[11] tool that takes a selected face and adds another face inside it while giving the mesh more detail. This can be combined with the Extrude tool to create very complex and intricate designs. As well as the Extrude and Inset tool there is a Bevel[12] tool which does exactly as it sounds and bevels edges. Lastly of the main handful, is the loop cut[13] tool. This tool creates a cut around the circumference of the mesh adding a vertex to intersecting edge. There are many more tools and variants of the tools mentioned that do slightly different things, but they are used less often and have very specific use cases.

[8] https://docs.blender.org/manual/en/latest/modeling/modifiers/index.html
[9] https://docs.blender.org/manual/en/2.80/modeling/meshes/editing/subdividing/subdivide.html
[10] https://docs.blender.org/manual/en/2.80/modeling/meshes/editing/duplicating/extrude.html
[11] https://docs.blender.org/manual/en/2.80/modeling/meshes/editing/duplicating/inset.html
[12] https://docs.blender.org/manual/en/latest/modeling/meshes/editing/edge/bevel.html
[13] https://docs.blender.org/manual/en/latest/modeling/meshes/tools/loop.html

Model Composition

The detail needed on a model varies massively, because the further away the camera is from the model, the less detail it will pick up. Therefore, artists can add more detail only to the elements of a scene that require it thereby saving time by not adding unnecessary detail. The scene below is a render which I created following the Blender guru tutorial. This scene uses a particular skillset only used in objects that have imperfections and a more natural round shape, like the doughnut.

"Imperfection is the digital perfection" **Andrew Price**

***image of final render after following the Blender guru doughnut**

To model the doughnut, I first started with a torus as it is the shape that most resembles the object. I then set the major and minor segments of the torus to a reasonable amount still resembling the shape of a doughnut. After that I added some variation in the model by randomly selecting vertices and moving them to create a more handmade look. After getting the shape of the doughnut I added a subdivision surface modifier, making the doughnut smoother giving it a higher vertex count, this enabled me to add more detail to the model. Once the subdivision surface modifier was added I copied the top 10 vertices and made them their own object. This acted as the icing on top of the doughnut. On the icing I then extruded some of the edges to create another face on the outside of the doughnut, this gave a dripping effect making the model look more realistic. Following that I then used the sculpting tab in Blender, this allowed me to manipulate multiple vertices at once, changing the shape of the mesh. This too can be useful for natural shapes as rather than stretching faces it adds more

vertices to parts that need it reducing the stretching in the mesh. In this tab I used the inflate tool to add more weight to the icing as well as both the inflate and draw brushes on the dough to create a typical baked doughnut with a slight ring around the outside. I then textured the model to complete the doughnut.

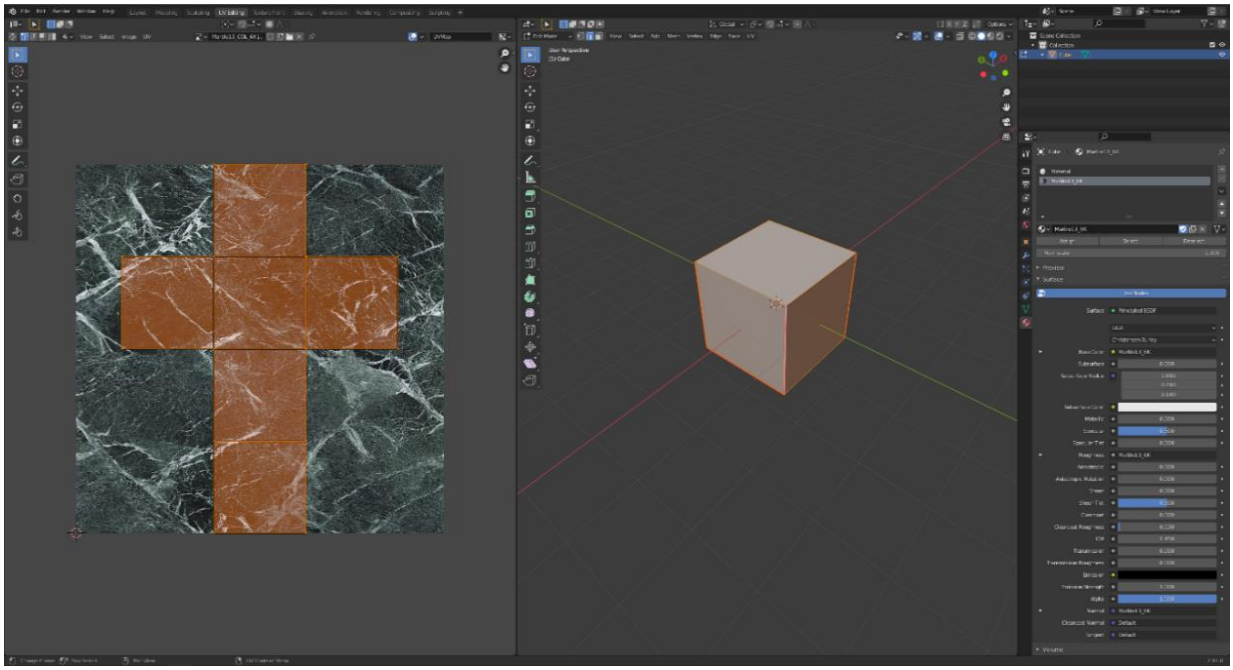
Texturing

Texturing is a key aspect of 3D and good use of this technique can easily improve the realism of a model two-fold if done correctly. Despite seeming simple first glance there are many different parts, techniques and differing methods that can go in to texturing a simple model.

UV Mapping/Unwrapping

To put it simply, UV unwrapping[14] is just the flat representation of a model. In 3D the most simple shape to unwrap is a cube. This is done in most modern software by marking seams along edges in such a way that all the faces could be unwrapped and made flat. This converts the XYZ coordinates of all vertices to 2D UV coordinates where a flat texture can be mapped across it by the user.

[14] https://docs.blender.org/manual/en/2.79/editors/uv_image/uv/editing/unwrapping/index.html



UV wrapping is most used in modelling if there is a photo realistic texture that needs putting on an object. This texture could be a scan, downloaded from a website[15] or even created in specialised software like Pixplant[16]. UV unwrapping can also be used for mapping an image onto an object, for example the image of the earth shown below which is a simple UV map of a satellite photo onto an icosphere.

***image of a simple UV unwrap of an image of the earth on to a UV sphere made by me**

This technique is very affective for adding texture to objects but can be very time consuming for more delicate and detailed models.

[15] https://www.poliigon.com/
[16] https://www.pixplant.com/

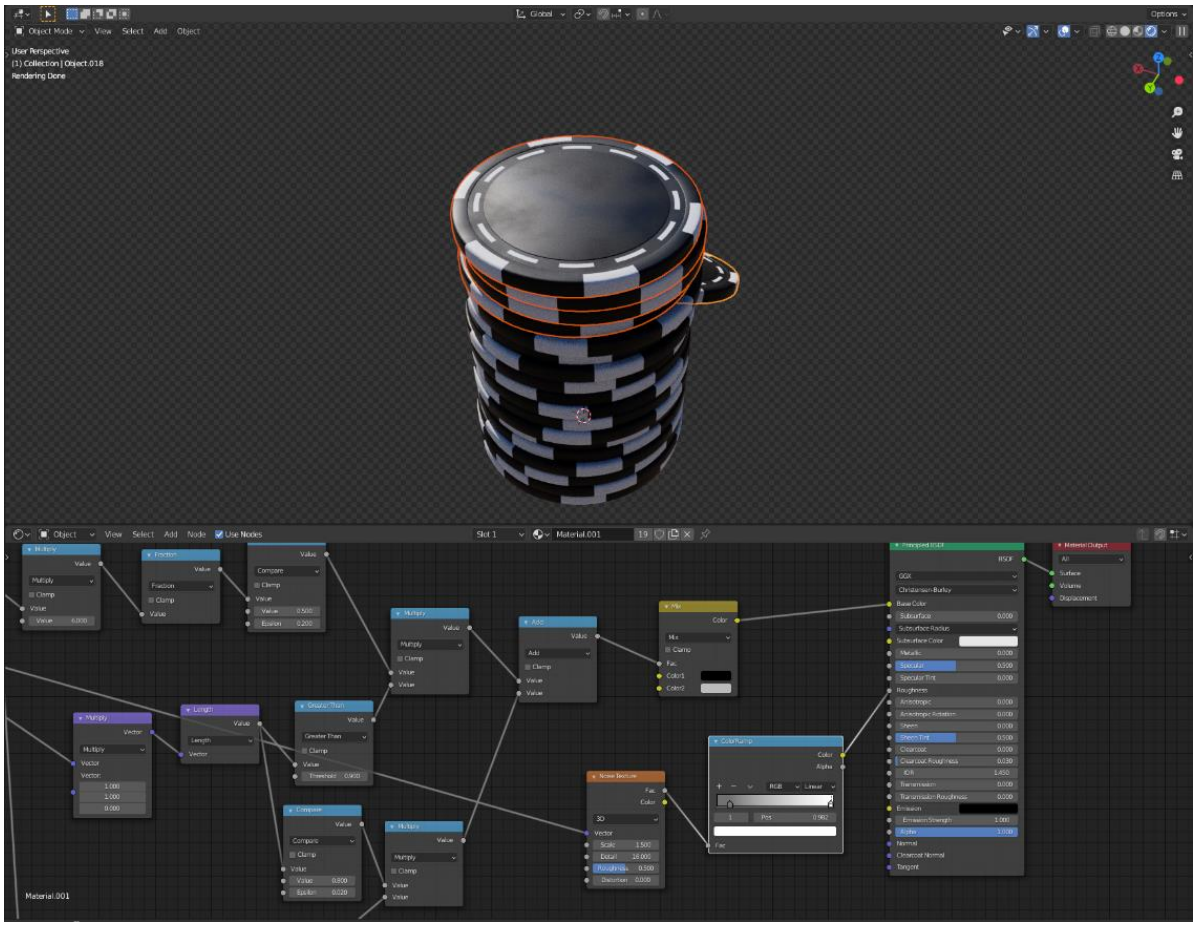
Texture Nodes

Texture nodes[17] allow you to generate procedural textures directly onto a model. This allows seemingly infinite possibilities enabling users create specialised textures for models. Texture node tools are commonly built into the functionality of the software. Despite still using UV mapping to ensure the texture is not stretched or distorted nodes have a quite different use case.

Texture nodes cannot just be narrowed down to just one application as there are so many different combinations and possibilities. But some benefits of texture nodes include the ability to generate variation in textures which can be helpful if there is repetition of the models, furthermore the finer dexterity to change colours and the roughness, while having built in noise generation textures to help add in realism can be extremely valuable.

The following image was made using entirely node-based texture generation. I used the built-in gradient texture for the stripes and the fraction math node to split the colour and add the striped appearance. I then repeated this again for the second spiral. I then used a noise texture to add the appearance of ware and tare plugged in to a colour ramp to emphasize the less rough areas. finally adding a mix RGB node to determine the colours of the rings.

***image of modelled poker chips using texture nodes made by me**



[17] https://docs.blender.org/manual/en/latest/editors/texture_node/types/textures/index.html

Lighting

Above all other techniques lighting has the biggest impact on a scene. It determines what is seen and what is not as well as putting emphasis on specific parts of the scene drawing the eye to the desired areas. Once again, there are various methods which are commonly used for this purpose. In Blender there are two main render engines each having a different impact on lighting and looks of a scene. These render engines have differing characteristics but importantly Cycles[18] is a path traced render engine meaning it has realistic lighting. While the render engine plays a key factor in the lighting of the scene, the main determining factor of the lighting are the lights themselves. In Blender there are a few types -

- Sun light.
- Spotlight.
- Point light.
- Area light.

These lights[19] have varying differences but in most cases can be swapped out with no dramatic change to the scene. All lights in Blender allow you to adjust the wattage making the light brighter and more intense as well as darker. This enables the user the scale the brightness to the scene enabling the scene to have more lifelike lighting. You can also change the hue of the light to anything on the RGB spectrum. This lets the user quickly change the mood of a scene by making minor adjustments to the brightness and shade of the colour.

Render Engines

Render engines[20] allow users to bring their creations to the real word letting them export in extreme quality. There are two main types of render engines, CPU and GPU based, both making use of their respective memory[21] (VRAM and RAM). Despite CPU rendering being vastly more popular[22] they both have their pros and cons. Typically if your computer has one, GPU rending is faster[23] but may have slightly lower graphic fidelity. Modern render engines enable the user to decide whether to use the GPU or the CPU and sometimes in specific use cases both. But in general, the pros of the GPU far outweigh the cons making it a better option to use a graphics card if available.

[18] Refer it **Cycles**
[19] https://docs.blender.org/manual/en/latest/render/lights/light_object.html
[20] https://www.blender.org/features/rendering/
[21] Refer to **Hardware**
[22] https://opendata.blender.org/
[23] Refer to **Hardware**

Eevee

The Eevee render engine is what is called a real time render engine. These are commonly found in video game engines and are renowned for being fast. [24]The Eevee render engine works by rasterizing[25] the mesh of a model onto a pixel on the camera to then generate an image. While doing this it considers the texture, alpha, depth, and lighting. It then averages these variables to an RGB value which it gives to its face. This process is then repeated for each face of a mesh until the full image has been created. This enables the user to have Realtime updates letting the user see the rasterized image in the view port in real time as this process is very fast.

But there are a few downsides to this engine, for example is does not support true reflections, hair particles and other simulations. While being a downside, there are workarounds which can make use of less computational power than the path tracing counterpart.

This type of engine is most used in the gaming industry, as even modern gaming hardware cannot output a path traced video feed at the frames per second required for an enjoyable experience. Plus, the speed at which even old hardware can rasterize video games is perfectly adequate.

Cycles

Cycles is an immensely powerful path tracing engine that does everything Eevee can't at the cost of time. The cycles render engine is used for realistic renders where attention to detail is paramount and no corners can be cut. It uses a path tracing algorithm that sends light pulses out from the camera that hit an object. Here it factors in the texture, alpha, depth and colour ect. The particles then bounce off the object, if the particles hit a light they are recorded as data. This tells the computer there should be shadows where the light from the camera didn't hit the light source. This enables much finer detail in some cases. This is because there can be thousands of samples, each a particle with their own values resulting in better more dynamic shadows and higher quality on intricate parts of a model. Unlike the Eevee render engine Cycles does support hair particles and true reflections again adding to the immersion of the scene. But this engine does have a compromise as it commonly gives noise issues with low amounts of samples meaning the user must use more slowing down the render time but yielding a better result.

[24] Oversimplification

[25] rasterization in render engines

Arnold

The Arnold render engine like cycles is extremely powerful and outputs detailed path traced lighting and can handle various particles. It is also renowned for its large feature set and ability to handle with ease huge scene sizes.

Even though it is a very popular engine for big-budgeted studios Arnold has some cons for example, it is very expensive. For an annual single user subscription it would cost £350, which is significant compared to its free competitors. Arnold is also considered a bit slower than other competing GPU render engines, which can make a large difference when rendering large animations with lots of frames per second.

Technology's

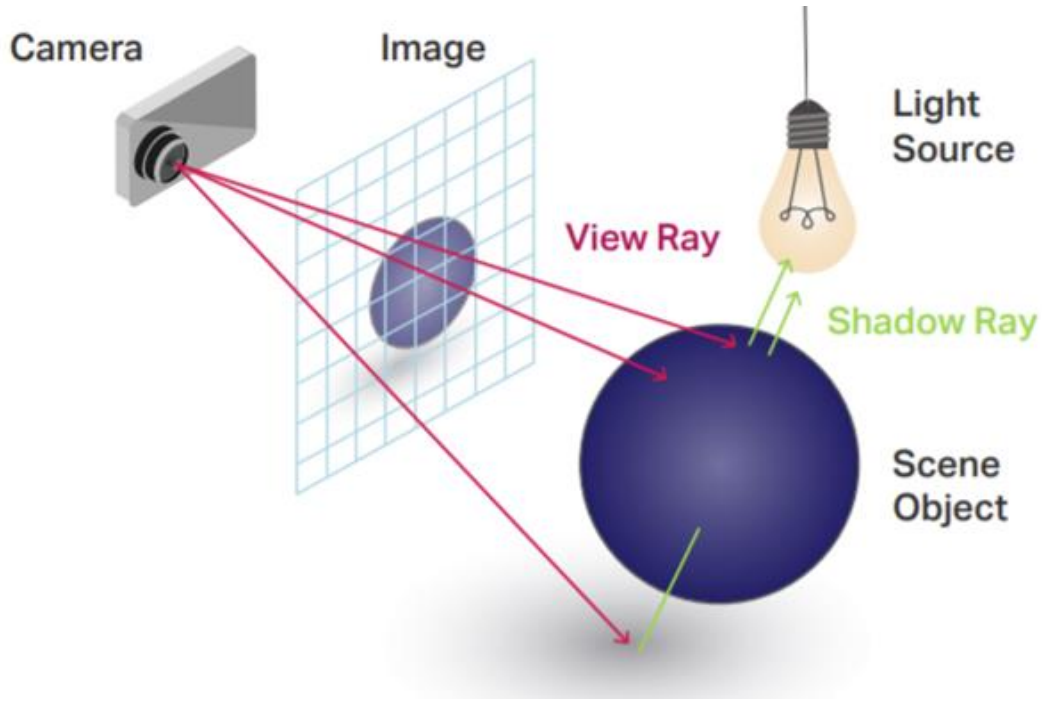
Ray Tracing

Ray tracing is a method of rendering a scene. At its core it works by calculating the colour of a pixel in an image by sending "rays" from the camera to interact with the scene.

Ray tracing works firstly by collecting light, mesh, and camera data. Using this data, the camera then emits a view ray and the tracing engine then finds the point of intersection between the ray and the mesh using a parametric function. By substituting the points of the mesh into the equation of the ray you can find the exact point of intersection between the two in a coordinate system. After this point is found the ray tracer can then calculate the colour of that pixel determined by the specular reflection and the diffusion as well as the colour of the mesh.

This process is repeated for the shadow ray where the engine calculates a path from the mesh to the light source to determine if there is light on the object and light intensity and hue of it.

Ray tracing is a very popular technique as enables unprecedented realism in comparison to simpler raster graphics. Also, with hardware advances this technique is being implemented in video games despite the computation cost. This adds a new level of detail into games that could not be achieved by prebaked shadows.



Despite how powerful ray tracing can be there are some downsides that make it unpractical in the real word and this is mainly due to its computational cost. Raytracing has come a long way, but individually calculating each ray of light takes a long time and only with the latest graphics cards can it be used affectively, real time in both video games and the view port of 3D software. Another downside particularly in video games, is that graphics cards with dedicated raytracing cores must be used for the best experience. This is because cards without the specific cores are very slow and ineffective at the specific calculations.

Chroma Keying

Chroma keying is the use of a green or blue screen to composite video together. It is used in post-production to remove a specific hue form a video allowing you to put another piece of media in the background. This background media is called a plate, and this could be a static image or another video.

Very old or even bad use of this technique can be spotted buy the green or blue tint usually around the actor's face. This is because of the light from the background is reflecting of their body. But due to improvements in technology keying out parts of a video is much simpler and effective than ever before.

When keying out an image, any colour can be used but, green and blue are most used as they most contrast human skin. This is because keying is most used in movies where actors are the primary focus of the shot. But green screens are not always ideal. This is because the lighting, angle and ideally the camera location must match the plate perfectly or the viewer will be able to see slight

imperfections.[26] But this technology is very valuable in that it allows studios to create virtual scenes rather than creating a set for actors to be on. This allows more flexibility in shooting as the set design can be altered in post-production.

Tracking

There are several different ways of tracking in modern digital media each used in different ways but all for a similar affect. Digital motion tracking, boiled down is where you track the movement of a pixel. This can be done by a wide range of software as its application in media is very wide. For example, the motion tracking feature in Blender can be used to place a 3D modelled object into a video. This can be done by getting a video of the scene and placing tracking points on objects that stand out. After you have done this the software can calculate the movement of the camera in relation to the image. This allows you to place an object in the scene while the virtual camera moves like the one in the real video. This gives the effect of making the object look like it is in the scene. It also enables you to match the light easily as the relevant virtual light will be in the exact same position as the real life. This enables easier light matching.

Motion tracking has a similar application in video editing but rather than placing 3D objects in the scene it can be used to add text and even stabilise the video. This works because the software understands how the camera moves making it easy to mitigate swaying movement.

Motion Capture

Motion capture is an expensive technology used mainly in big budget movies and modern games. The process consists of a series of sensors and computers capturing the movement of people or objects. The technique works by attaching usually between 20 and 40 ping pong ball like sensors to the person or object. These sensors track the 3D movement and send the data to a computer. Here it can be used in software to translate the movement of the actor or object into animated rigs for characters. This is commonly used in modern video games where they use real actors to get motion data from and model looks after. This is especially prevalent in video games where the developers try to convey the maximum amount of emotion from actors. In doing this they use motion tracking on a high-fidelity model to display the full range of emotion of a face on an animated character.

Performance capture like motion capture, takes the actors movement but this time rather, it takes all movement, sound and facial expressions. This technology allows the use of the whole actor’s performance, and in post-production the use of reflective or infrared markers enables computers interpret this information and use the movement and facial expressions on a 3D model. The main benefit of this is the ability to retain the actor's performance and facial

[26] https://www.youtube.com/watch?v=E5HRvQNg4pQ

features as much as possible. Not only making the movement and the body language of the models more realistic but also the facial expressions of the actor can be translated on to a model keeping their main characteristics.

In the movie Dawn of the Planet of the Apes, Andy Serkis (A famous motion capture actor) describes there being an actor avatar relationship as he "knew that his facial design was going to accentuate some of my own facial structure"

Dynamic Diffuse Global Illumination

Dynamic global illumination or DDGI is a relatively new technology most used in the gaming industry. Its primary task is to calculate how the light diffuses in a scene. It does this using data from ray tracing to make the scene more dynamic allowing the light source to me moved anywhere in the scene still letting the user have an enjoyable raytraced experience. This technique avoids baking in shadows, but this comes at the cost of computational power. But the result of the dynamic shadows is very encompassing and look very affective. The use of this technology has been showcased in the unreal engine 5 showing a dramatic difference before and after

Unreal Engine

The unreal engine is a video game engine initially developed for first person shooters. Despite the first iteration of this engine having a very specific use case its latest version the Unreal Engine 5 boasts very desirable traits for next generation consoles. Some of the main benefits include real time dynamic Diffuse global illumination (DDGI)[27], scenes with upwards of 16 billion triangles additionally the ability to directly import film-quality assets into the real time engine. The latest Unreal Engine 5 has only had one demonstration as it has not been commercially released yet, but the full launch is expected in late 2021 for next generation consoles. As of March 2021, the open-source Unreal Engine 4 is still used in a vast variety of ways. Despite being released in 2014 its new implementation as live sets[28] has very valuable in some of the latest movies. Not only this but in video games like the ever-popular Fortnite, Gears 5 and Player Unknown Battle Grounds this engine still manages to prove its strength with modern features like path tracing and real time simulations etc.

Application of CGI

As shown all technologies are evolving and improving, this is the same for how the required skills are applied. Knowing these skills is one thing but knowing the correct time to use and apply them is another. In this section I will decompose

[27] Refer to **Dynamic Diffuse Global Illumination**

[28] the Mandalorian (2019)

the aspects of a 3D scene and mention a handful of the techniques used in varying pieces of media.

CGI in the movies

Westworld (1973)

Computer generated imagery has been used in movies for decades in a vast array of place's, some obvious and some where you would never expect. But the movie Westworld (1973) is considered the first movie to ever use CGI. It used, what is now considered very simple raster graphics. The director Michael Crichton wanted to show the robots point of view in the movie. To do this, machines would scan the film then rasterize it to convert it into digital video. Here they adjusted the contrast and brightness even going as far as to make the characters wear makeup and cloths the contrasted the background, just so the computers could make out a good image. This pixelated affect was then added to the movie to great avail changing how movies would be made forever.

The Mandalorian (2019)

Despite seeming like your average TV series, the Mandalorian made use a lot of unconventional techniques as seems to be commonplace in the Star Wars trilogy's. The core of this series is the application of the unreal engine[29] to easily create and change parts of the scene in real time. These virtual sets allow the actors to be in the scene, displaying how the world around them will look and change as the scene moves along. It works by rendering a scene in real time and displaying it on LED displays encompassing the actor. This is then linked to the movement of the camera so the actor can seamlessly explore their environment with no boundaries. The use of led displays in the background goes deeper than first glance. Not only does it show the actor the surroundings, but it also acts as the light source marching perfectly to the scene, this is as the scene is the lighting. It also means changes can be made quickly in software rather than making and changing props which makes it much quicker and cost effective to make moves and series.

Blade Runner 2049 (2017)

Unlike its 1982 counterpart blade Runner 2049 while not creating a ground-breaking technique it did show expert use of how CGI done right. This movie used the Arnold render engine[30] a very popular engine in movies. The reason

[29]Refer to **Unreal Engine**

[30] Refer to **Render Engines**

this is notable is because of the vast wide-angle shots of the dark city scape making this a very affective choice. In general, the film is comprised of lots of CGI characters scanned in person then put in the film with a lower opacity to give a holographic affect. There are also lots of futuristic high-rise buildings each unique and hand modelled to give the city its aesthetic.

Picture from a reddit user showing the use of green screen in the blade runner 2049.

This picture shows the ingenious use of green screen placing the city in the background of a real life shot. And the used of mixing CGI and real-life props that are often used.

Architecture visualization

Architecture visualization or commonly abbreviated down to arch viz is a common place technique used in modern architecture and design. It makes use of modern software's and techniques to create photorealistic representations of

imaginary scenes or real-world spaces. It is most frequently used in contracted work where a client needs to be able to see the finished product and visualize it before its completion. The increase in popularity in this futuristic technique has meant lots of companies are using it. The furniture giant IKEA offers most of their products for free download[31]. This is affective as their products will be used different scenes promoting them to customers that would be interested in buying their products.

***image of bathroom rendered by me in Blender**

The above image is a scene which I rendered following a reference. I used a selection of the techniques mentioned in this document like simulations, modelling, UV unwrapping and lighting to create a somewhat realistic bathroom. Despite modelling all the assets in this scene, it is standard practice to download assets from libraries and websites. This is because it not only saves time but also displays real products that can be purchased in the real world. The time saved from downloading assets can make modelling a design first more cost effective than not. This is because it helps avoid costly mistakes in construction in the real world.

The creation of assets for 3D scenes has a huge market. The mega scans asset library has a vast range of downloadable assets from carrots to buildings. These assets are used every day in scenes by people all over the world to help visualise spaces.

[31] https://www.polantis.com/ikea

Scene composition

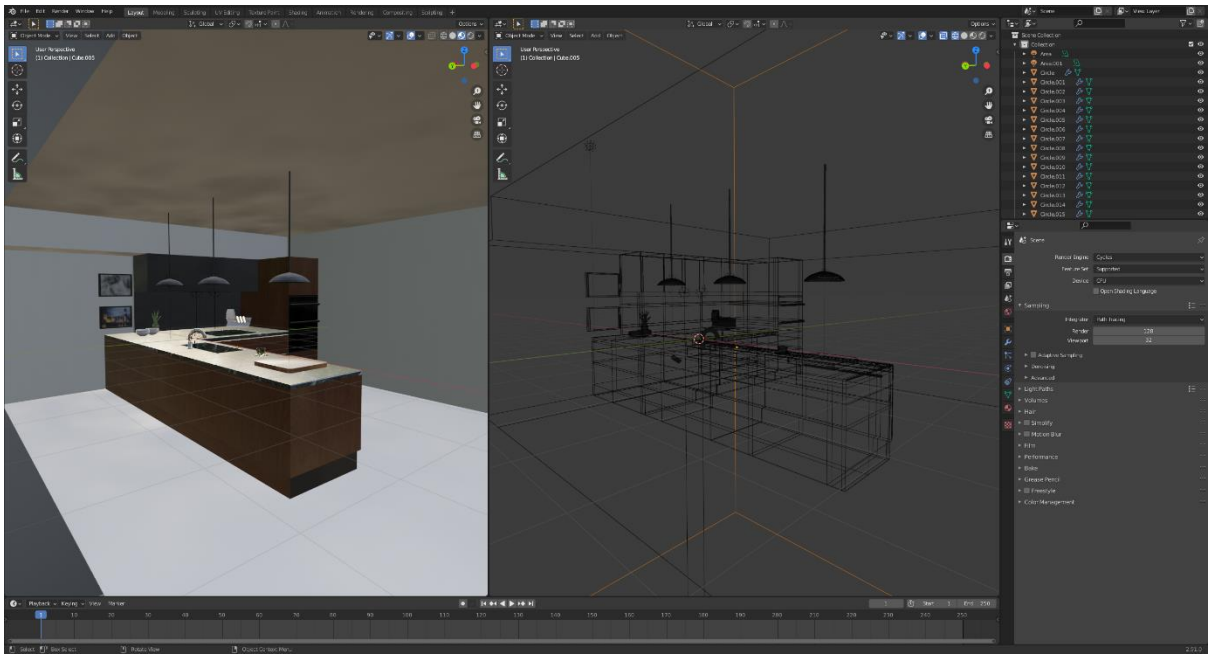
Here I will break down what goes into creating a 3D Arch Viz scene showing some of the methods and how 2D images can be translated into 3D.

***the scene above is a render made by me from a kitchen reference in Blender**

To make the scene above, I first started with reference image and using a software called fspy[32] I aligned the virtual camera in Blender with the camera in the image. This meant I could create the scene exactly to scale to the image. After aligning the cameras, I then manipulated a cube to resemble the basic shape of the countertop. After it vaguely looked similar, I added more detail using the loop cut and extrude tool to create the overhanging lip at the top and the cupboards. I then modelled some of the objects that would go in the scene like the chopping board, plates and tap. After modelling these I placed them in the scene where I thought they looked best. Post modelling some of the smaller assets I then started to UV unwrap the scene. As the counter was one big object that needed multiple different textures, unwrapped in parts. I started with the top of the counter making the seams on sides that would not be seen by the viewer and adding a marble texture which I downloaded from a texture library. After adjusting the scale of the marble texture, I then moved on to the cupboards. This was much more difficult, as there were lots of intricate parts like where the cupboard door meets the frame but, despite being more complex, once finished it look very fitting for the scene. Once the countertop was modelled, I then started adding texture to some of the other assets in the scene. The plates and bowls were simple as I just used the node editor to lower the roughness increase the sheen and metallic values, this looked as close to

[32] https://fspy.io/

ceramic as I needed. I then Unwrapped the chopping board making sure that the grain of the wood texture was in line with the sides of the model.



After finishing all the UV unwrapping, I started experimenting with different lighting. I eventually decided to make the light's really dim, this would not only help hide some of the imperfections but would also draw the viewers' attention to the more eye-catching parts of the scene. After adjusting the lights to the right intensity, I added a cube surrounding the scene and gave it a volume absorption property. This meant the scene had a slight fog so the light would not penetrate so far giving a unique affect to the scene. To finish the scene and bring it all together I added some paintings to add to the detail needed to make the scene look realistic. To add the paintings, I imported an image as a plane and created a rudimentary frame by extruding the sides of a flattened cube. These paintings really brought the scene together and to finish it I downloaded a potted plant from CG trader and placed it in my scene. To render the scene, I used the cycles engine at 5000 samples. I used a high sample rate as cycles struggles the volume absorption I used in the scene. So, to counter act this I used very high samples and to make the render as fast as possible I used my GPU.

How has CGI Progressed?

Computer graphics, CGI and VFX are an ever-growing industry. Progressing with technology starting from simple techniques like rotoscoping and developing and evolving into real time ray tracing engines that can be used as backgrounds for actors but this progression has been pushed by its popularity in media. The hugely successful Toy Story released in the 1995 was the first fully computer-generated movie and it was ground-breaking at the time. This success pushed the industry forward along with the release of maya Autodesk and its use in big budget movies like Lord of the Rings. Another huge mark of the progression of CGI was the movie Avatar (2009) the highest grossing movie of all time. This

movie used performance capture to get the characters movement and facial expressions for expressive and engaging characters and used various applications of 3D modelling texturing and lighting all to create a believable world. All in all the total disc space used from all the data from motion capture, modelling etc is rumoured to amount to over 1 petabyte.

Developing from Avatar, ever popular superhero movies are regularly being released, these movies particularly modern ones have exceptional use of chromakeying, creating immense battles with just a few props and the whole scene being digitally created in post-production.

The future of CGI

Although impossible to predict, seemingly the future of CGI is very bright. Following previous trends, it is only inevitable that ultra-realistic fully animated films are commonplace. As it seems the natural progression following modern movies, that are mostly green screen.

Developing on from Blender I expect more open-source software will be released to make 3D modelling more accessible. Not only will modelling software be more accessible, but I expect it will also be easier to make complex scenes and with the development in technology, simulations be it in real time video games or in renders will be much faster. But, in the time all this has been achieved thousands of triple A games and big budget moves will have been released all using different technologies and one day making even the most complex techniques used today obsolete due to inefficiencies and bad practice. This being the case one can only guess what the future of CGI will look like but I think it is safe to assume there will be big improvements in technology.

NFTs

NFTs or non-fungible tokens are a new way to show ownership of an art piece, using a crypto currency block chain usually Ethereum this technology allows consumers to buy and sell online art. While you could just download the media from the internet if it is widely available an NFT shows the ownership of all the rights to the work. Like in real life anyone can buy a replica of a painting but only one person can have the real thing. This new way to buy and sell art has become very popular, and as of 2021 this popularity is only expected to grow. Mike Winkelmann a digital artist compiled a collage of 5000 of his daily art pieces to be sold as an NFT until eventually the NFT sold for over $69 million. In the future I expect this will only gain more traction. Despite their convenience at first glance, NFTs have a caveat in that they are very bad for the environment. This is because of all the computers that must process the transaction. This being so, I predict NFTs will not become industry changing until this process is made more efficient.

Assessing the Validity of sources I have used

For my document to be a reliable means of information the primary and secondary research I have carried out must be by reliable sources and ideally backed up by other sources. Some sources do contradict but I have taken precaution to make sure that each source is factual and backed up.

- **The rookies**
  - The rookies is a reputable news source read by millions and trusted by professionals as shown in their testimonials page. On their website they have blogposts including competitions, tutorials and art portfolios all written by named professionals that have the qualifications and portfolios to back up their knowledge.
- **Phil De Semlyen A History of CGI in the Movies**
  - Phil De Semlyen is a reputable editor from a selection of big-name news outlets. He is also a member of the London critic's circle, a group of professional critics of movies books drama and dance. This leads me to believe his article on A History of CGI in the Movies is factual despite not showing specific sources of information.
- **Wikipedia**
  - Despite being renowned for its unreliability at times Wikipedia has a vast wealth of information collected and is a good means of finding other reliable sources. Whilst I didn't take information directly from Wikipedia's website, I did use the website to back up claims from other sources and my own knowledge.
- **Youtube**
  - Youtube was a very valuable source when it came to gathering information that was easily digestible. I also used it for technology demonstrations from companies like Unreal and VFX companies displaying their work. Despite being impossible to pin perfectly if a video is reliable, I can say with confidence that videos from brands displaying a technology like this video about the unreal engine are reliable.
- **Unreal Engine website**
  - I think it is reasonable to say that information regarding the unreal engine from the unreal website is reliable and can be trusted. Most information involving its application was gathered from here as everything is in once place in a simple manner
- **The Science Behind Pixar**
  - This is an educational website developed by the museum of science and Pixar studios explaining some of the science behind the making of animated movies. It goes in depth into some of the more

technical aspects of CGI like rigging and simulation. In gathering information from this website, I can say that this website is undoubtedly reliable containing some very interesting and valuable information.

- **Nvidia website**
  - The Nvidia website contained lots of information regarding the hardware and software powering CGI I consider it a primary source as they develop both hardware and software. I also believe it to be reliable as it is cited by mass news outlets all over the world and create products for millions.
- **The Blender Foundation**
  - The Blender foundation website is home to all the documentation for Blender, the Blender download, and differing tutorials. This is a reliable source of information as the developers of the software know how to use it like no other and are experts.
- **Escape Studios webinars**
  - Escape studios did a handful of webinars to promote their university courses. While attending these they showcased some of the techniques you would learn while on one of their courses. This event was very informative and contained reliable information from professionals.
- **Computer graphics Techniques**
  - This website contained a selection of papers regarding the use and application of different complex techniques in extreme depth explaining the science behind it. This website is open access and peer reviewed leading me to believe that the information contained in this website is truthful. This source proved not only interesting but also very helpful in my research.
- **Quora how many people are using 3D software**
  - It was impossible to track down the origin of some of the information provided by this source and whether it is entirely reliable. However, this article has many unanimous opinions that back up each other which leads me to believe it is reliable despite me not being certain.
- **CPU vs GPU rendering - render pool**
  - This website is a provider of a cloud rendering service and in the article displays the pros and cons of GPU vs CPU rendering. As they are providing a service this leads me to believe that the source is reliable as they do not want to miss represent their services.
- **Khan Academy**
  - This source proved very useful in researching the maths behind some of the render engines and how techniques are used. In particular the Pixar rendering series displayed how render engines are used at Pixar. This series was made by named researchers at Pixar. These professionals display the primary research and facts clearly making it an undoubtedly reliable source.
- **Rasterization and Raytracing - Scratchapixel**

- This website contained a detailed rundown of how rasterization and raytracing is used while showing maths and code to back it up this extremely detailed source is seemingly reliable, but it does not show the sources nor who it was written by. Although this is the cast I still used the website to back up some of the other claims from other websites.

Glossary

A

AMD: (Advanced Micro Devices) a major manufacture of computer processors.

API: (application programming interface) an interface for code to interact between software.

C

CPU: (central processing unit) the primary component of a computer. It runs the operating system and all applications.

Clock Speed: the rate at which a processor carries out its processing cycles. measured in hertz

Core: a core refers to a part of the processor that carries out one particular task at a time.

CGI: (Computer Generated Imagery) meaning the use of computers to create digital media.

Circumference: The distance around the edge of a circle

D

Depth: the distance an object is perceived to be.

F

FPS: Frames per second

G

GPU: (Graphics Processing Unit) A computer component dedicated to doing more simple calculations like graphics processing more efficiently

I

Intel: A major manufacture of computer processors

Icosphere: a sphere made up of triangles with 20 sides it could also be called an icosahedron

M

Modifiers: a non-destructive way to manipulate a mesh using pre-determined operations

Memory: referring to main memory or RAM a form of storage in this context measured in GB or gigabytes

N

Nvidia: A major manufacture of computer processors

P

Pipeline: referring to the steps that need to undergo to create a asset or scene

Prebaked: in the context of 3D this refers to software caching the shadow data so, the computer does not have to keep calculating it

Petabyte: 100 terabytes

R

Renderer: the process in which a virtual 3D asset is turned into an exportable 2D image or video

RAM: (Random Access Memory) A form of computer memory that is used to store running applications while the computer is on.

Ray Tracing Cores: A specific type of core found in graphics cards dedicated to ray tracing applications.

Render Farm: A series of processors or nodes dedicated to calculating light, shadows, reflections ect. Used only in big budget studios due to cost.

RGB: (RGB) meaning the 3 different hues that can be mixed to create all the colours that need to be displayed on a computer screen.

S

Scene: A collection of meshes lighting and a camera arranged for render

Supercomputer: an extremely powerful computer composed of lots of processors working together.

T

Textures: in 3D this refers to the use of different materials to give the effect of texture

V

VRAM: (Video Random Access Memory) A specific type of ram fount in graphics cards

VFX: (Visual Affects) refers to the use of affects in media.

Reflection

In hindsight I feel that my project generally went very well. I gathered a great deal of information on CGI and documented it in a readable manor. I attempted to structure facts and information so that one would have the learn the technical aspects and then learn how it is applied which helped keep the document much more readable. While doing this I also used lots of images to express my point and make it more understandable to someone with no knowledge on the topic.

I generally feel that my research was relevant to the current day when talking about technology used in industry both in the past and present. While also making sure the research was digestible and made sense in context.

While writing I found it very difficult to explain some of the more complex techniques in a simpler way. This is because most techniques can be done a wide variety of ways in different software making it very hard to be specific.

I also had difficulty explaining as much as I wanted to as my question is very broad there is so much that comes under CGI it would be impossible to explain everything. This being the case I have tried to explain the most critical points that enable the reader to understand some of the more useful techniques used in day-to-day media.

Ensuring my document is readable was a big concern of mine as I find writing skills particularly challenging. Despite this, in my opinion my project document is perfectly readable. To keep it as readable as possible I made sure to use quotes and images to break up big chunks of text. I also made use of lots of subheadings allowing the reader to know exactly what they are reading about before it starts the use of subheading again broke up the longer blocks of text.

I carried out primary research in my project in that I learnt some of the techniques and methods used in industry and applied that knowledge to create renders of my own. I then explained some of the techniques used in the renders with images showing the result. In creating renders of my own I learnt some workarounds and limitations of the software (Blender specifically), but most importantly I learnt how difficult it can be to get picture perfect images. It also gave me a sense of scale of how big, budgeted movies are made and that 3D rendering, and modelling can be very time consuming.

All In all, I feel I have covered my question to a degree that people with varying knowledge in the topic could pick up my project and learn lots of new information. I also feel I have achieved most, if not all, of my aims and objects to a satisfactory standard and in some places gone beyond. While changes could still be made to my project, I am happy with my knowledge on the topic, how I have documented my work and my application of this knowledge renders. Overall, I enjoyed researching my topic and learning independently.