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**“Except where explicitly stated, all work in this report, is my own original work and has not been submitted elsewhere in fulfilment of the requirement of this or any other award”.**

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# Introduction

## The Standard Geometric Primitive - Polygons

Polygons are accepted as the current standard geometric primitive for both the 3D Modelling and Video Games industries; they can be defined as any closed 2D shape made of entirely straight lines. Current GPU manufacturers and tech giants have heavily invested into polygons, originating back to the late 1990s when the term was popularized by the GeForce 256 GPU. (TheBat!, 2023) This can be ascribed to their simplicity and efficiency with the many rasterization techniques at that time. However, their most prominent drawback is within its ‘*imitation*’ of real-world objects, as many techniques are only aesthetically, and not physically simulating the mesh. This is more specifically seen in games within the 3D dissection of polygonal models at runtime, where the model holds no data for the new face required to be created.

## An Alternative - Voxels

A suggested alternative, Voxels; also known as volumetric pixels; are a geometric primitive holding data for the entire model, including what cannot be seen. This primitive is used to represent values in three-dimensional space on a grid. Voxels function similarly to physical particles, therefore creating a more sophisticated implementation used to imitate the real world. Often, Voxels are referred to as 3D pixels and have a wide use in Procedural Generation, Particle Simulation, and Destructible Physics. Voxels are uniquely stored within a grid, allowing efficient usage of Object-Oriented Programming (OOP) and the Entity Component System (ECS), allowing each voxel to hold a unique property. This is shown within the 3D voxel game ‘*MakeFarm*’ by David Szymon Grobert, as each block held a definition for if its object was breakable, and if so, what item should be dropped. (GROBERT, 2023)

Polygons have held their position as the standard geometric primitive in many of the 3D visualization industries for over 20 years. This has resulted in many of the competing primitives to fall behind, as new technologies advance polygons forward. Many rendering practices for these primitives require the conversion of their structures into polygons, a major of which being the Marching Cubes algorithm. (Lorenson & Cline, 1987) Most previous rendering techniques for mainstream geometric primitives are insufficient for modern day usage, as researchers are now aiming to create greater realism. Due to the observation that is Moore’s law, which dictates that the number of transistors within computer chips double every two years, graphics are no longer restricted by our hardware, but by our software approach. A common implementation includes Ray Tracing, a method of emulating the light reflections and refractions of the real world. Ray Tracing is entirely possible within Voxels, although a similar process named Ray Marching is generally used, however, both of which do not require the need to convert to a polygonal mesh. These techniques potentially creating a new use case for Voxels, with the possibility of gaining a wider acceptance as an alternative to polygons. The improved graphics that come with Ray techniques leads way into the necessity for Particle Simulation and Destructible Objects, creating a greater sense of realism, and both of which voxels are suited towards.

## Voxel Development

Atomontage, a leader in voxel development with a 13-year running micro-voxel engine, are consistently pushing the boundaries of voxel development forward. Atomontage are known for their usage of projection based voxelization, soft-body dynamics and their voxel editor’s recent open beta launch in 2021. (Atomontage, 2023) Daniel Tabar, and Branislav Siles, the founders of Atomontage, shared that the future of voxels lies within cloud services, as with their current implementation, the voxels are relatively inexpensive on both the view, and the server. The future of Atomontage aims to revolutionize both the cloud gaming industry, and the interactive sandbox games genre, and Daniel Tabar has stated that their engine could be compared to “*Roblox + Minecraft + a higher resolution*”. (JTVentures, 2023)

Atomontage is not only invested within the games industry, but also has ties to medicine from one of its most supportive angel investors, Tommy Palm (Siles, 2019). Voxel-based 3D visualization is an incredibly large sector within medicine, with competing software such as ‘*3D Slicer*’, ‘*Voxel-Man ENT*’ and ‘*SolidWorks 3D-Doctor*’. These provides a multitude of tools ranging from CT Lung Analysis to Virtual Training Simulators, all of which involve intensive usage of volumetric data. The usage of voxels within medicine comes from the necessity of creating not only a realistic model, but also for accurate mapping of different tissue types (Slicer Community, 2023) (Voxel-Man, 2023) (Dassault Systemes, 2023) As voxel techniques are researched, these software could potentially receive updates allowing more realistic, and accurate models for its users. A study within the effect of Field-Of-View and Visual Realism on virtual training tasks found that visual realism may impact the virtual training performance negatively, it impacts the real-life assessment positively. (Ragan, et al., 2015) This suggests that if voxels gain more realistic rendering techniques, that it could positively impact training procedures for users of Medical Simulations.

The games industry is at the forefront of voxel realism development, a recent voxel success story includes Tuxedo Labs ‘*Teardown*’. Featuring a fully destructible environment, particle simulations of fire and smoke, and an incredible in-house lighting system, it has garnered almost 76,000 positive reviews on steam, gaining the award for ‘*Excellence in Design*’ at the Independent Games Festival in 2021. (Tuxedo Labs, 2023) (Informa Tech, 2023) According to the Tuxedo Labs modding wiki, the artists used ‘*MagicaVoxel*’, a lightweight voxel art editor, to create all assets for the game. (Tuxedo Labs, 2023) This art editor is still supported, is fully open source and has hundreds of modelling tutorials. It is an incredibly powerful tool within the modelling of 3D voxel environments; however, they require hundreds of hours in development to take form. A more efficient method, used for both rapid prototyping and final model products is LiDAR (Light Detection and Ranging). LiDAR uses pulses of light to rapidly generate point clouds, which are simply a collection of points in three-dimensional space. As suggested by Xu, Tong & Stilla, point clouds can be efficiently converted into a voxel representation, and then suggests their usage within structural analysis and 3D simulation of fluids, volume estimation and pathfinding. They state that voxels are one of the best primitives used to transfer point cloud data into a higher data format, due to their speed and efficiency, although suggests they may lack accuracy in conversion. (Tong, Stilla, & Xu, 2021)

## 1.4 Research Question

The aim of this paper is the investigation of the possible voxel future, as a replacement for polygons as the standard geometric primitive for 3D visualization. The strengths and weaknesses of voxels should be highlighted, suggesting further research avenues. The research question is,

*“Could voxels replace polygons, as the standard geometric primitive for 3D visualization?”*

# Contextual Review

## Performance Enhancing Techniques

Research within Design & Technology (Telea & Jalba, 2011), Engineering (McNeely, Puterbaugh, & Troy, 2005) and Biomedical Studies (Mason, et al., 2000) suggests a common limitation of large memory consumption whilst using the standard implementation of regular voxel grids. The regular grid structure creates a memory footprint of O(n^3) where n represents the width, length and height, however recent studies have explored the manipulation of a regular grid using warp fields to create dynamic irregular grids, which significantly reduced memory cost within their use case. (Lombardi, et al., 2019) Many have attempted to solve this issue, specifically, a major Australian software company named ‘*Euclideon*’. A video posted in 2010 by the CEO, Bruce Dell, showcases an ‘*Unlimited Detail Technology*’, which garnered mass attention towards an engine which could dynamically render any number of objects in any scene no matter how large. (Quipster99, 2010) Although the technology has yet to be revealed, their implementation is similar to that of Sparse Voxel Octrees (SVOs). SVOs are a compression technique combining that of Sparse Voxels, and Octree Voxels. The compression technique sparse voxel removes the data of all unoccupied values. (Figure 1) The compression technique octree voxel divides 3D space into a hierarchy of octants, that are recursively divided until a goal is achieve, e.g. the final level of detail is reached. (Figure 2)

A diagram of a circle and a cross

Description automatically generated

Sparse Voxel Compression (Figure 1)

A diagram of a circle and a cross

Description automatically generated

Octree Voxel Compression (Figure 2)

Studies have suggested that both the compression methods Sparse Voxels, and Octree Voxels, can be incredibly efficient in terms of physical memory, a mentionable study by Gebhardt, Scott et al. finding both file sizes to reach as low as 0.0008x that of their traditional regular grid counterparts. It can then be presumed that this technique could be further improved by the combination of each technique, to create the Sparse Voxel Octree structure. However, these compression techniques are not perfect, due to the nature of their compression, models that are more densely populated, with zero empty space or duplication would not receive the same benefits as others without.

Improving performance with voxels is not necessarily restricted to file size, as with these new voxel techniques, there can be both compression and possibly even decompression costs associated within the CPU and the GPU. Morton’s order, also known as a Z-order curve, is used to convert multidimensional data into a linear sequence. It is used to linearly traverse any dimension of data, in our case three-dimensional voxel space. Pan, Yucong when investigating the traversal of Sparse Voxel Octrees using Morton’s Order, states this technique, or one of similar efficiency, is required if the voxel grid will be dynamically updated at run-time, especially if global illumination is necessary. (Pan, 2021)

Unique rendering practices are required, a major one named Ray Marching, which uses rays to traverses through the voxel grid using distance estimations. Dreams, a voxel-based game creation system with in-built 3D modelling software uses a form of Ray Marching known as Sphere Tracing, used to smoothen surfaces. (Alex Evans, 2015) These improvements are proved effective, as shown through the entire creation tool being run within the limited PS4’s specifications.

## Current Tools

Technology within games constantly expands the possibilities of 3D visualization, Unreal Engine being a main contributing factor. Although Unreal Engine was initially created for the First Person Shooter ‘*Unreal*’ (1998), the engine quickly gained popularity and was eventually released for public use in

Link game engines to 3d visualization (media, product design, matrix, madalorian), explain options within unreal engine

Paper on voxel options within unity

NVIDIA GVDB

Briefly discuss John Lin, other voxel engines, then lead into Hybrid Rendering.

## Hybrid Rendering

Investigate hybrid rendering within 3D visualization, show voxplat which uses both polygonal and voxel rendering dynamically. Teardown which has the occasional polygonal mesh (smooth amp) May touch on aesthetics

## Voxels and Polygons

Comparison and conclusion to contextual review

Previous research on the comparison between voxels and polygons.

* Put relevant materials of this study into context.

# Methods & Design

## Method Plan

* What are you going to do?
* How are you going to do it?
* How does it help *solve* the research question?
* Describe the methods including its design features.
* Can include references, sources and constraints.

## Hypothesis

## Development Environment

## Data Gathering

## Data Analysis

## Relevance/Usefulness of analysis towards question

## Ethical Considerations

What ethical issues should be considered

Evidence of approved application

# Project Timeline

Gantt Chart

# Project Plan

* What are the main tasks involved within this project?
* What are the intended deliverables at the end of this project?
* Create a work plan, e.g. Using a Gantt Chart

# Appendices

# **References**

Alex Evans. (2015, August 12). Learning from failure. *Advances in Real-Time Rendering in Games. MediaMolecule, SIGGRAPH*, Volume 2.

Atomontage. (2023, May 1). *Home: Atomontage*. Retrieved from Atomontage Web Site: https://www.atomontage.com

Dassault Systemes. (2023, December 3). *3D-DOCTOR: Able Software Corporate*. Retrieved from SolidWorks: https://www.solidworks.com/partner-product/3d-doctor

Fedorov, A., Beichel, R., Kalpathy-Cramer, J., Filnet, J., Fillion-Robin, J.-C., Pujol, S., . . . Kikinis, R. (2012). 3D Slicer as an Image Computing Platform for the Quantitative. *Magnetic Resonance Imaging*, 1323-1341.

Gebhardt, S., Payzer, E., Salemann, L., Fettinger, A., Rotenburg, E., & Seher, C. (2009). *Polygons, Point-Clouds, and Voxels, a Comparison of High-Fidelity Terrain Representations.* Environmental Science.

GROBERT, D. S. (2023). *Implementation of 3D game MakeFarm with infinite terrain model and basic physics in OpenGL API.* Gliwice: Silesian University of Technology.

Informa Tech. (2023, December 3). *Independent Games Festival Finalists & Winners 2021*. Retrieved from Independent Games Festival: https://igf.com

JTVentures. (2023, December 3). *Atomontage: We've solved the problems with 3D that even Google and Meta are struggling with*. Retrieved from JTVentures: https://www.jtventures.cz/

Lombardi, S., Simon, T., Saragih, J., Schwartz, G., Lehrmann, A., & Sheikh, Y. (2019). Neural Volumes: Learning Dynamic Renderable Volumes from Images. *ACM SIGGRAPH* (pp. 1-14). New York, NY, USA: Association for Computing Machinery.

Lorenson, W. E., & Cline, H. E. (1987). Marching cubes: A high resolution 3D surface construction algorithm. *Computer Graphics* (pp. 163-169). New York, N.Y.: ACM.

Mason, P. A., Hurt, W. D., Walters, T. J., D'Andrea, J. A., Gajsek, P., Ryan, K. L., . . . Ziriax, J. M. (2000). Effects of frequency, permittivity, and voxel size on predicted specific absorption rate values in biological tissue during electromagnetic-field exposure. *IEEE Transactions on Microwave Theory and Techniques*, 2050-2058.

McNeely, W. A., Puterbaugh, K. D., & Troy, J. J. (2005). Six degree-of-freedom haptic rendering using voxel sampling. *ACM SIGGRAPH* (pp. 42-49). Los Angelos, California: Association for Computing Machinery.

Quipster99. (2010, February 26). *Unlimited Detail Technology.* Retrieved from Youtube: https://www.youtube.com/

Ragan, E. D., Bowman, D. A., Kopper, R., Stinson, C., Scerbo, S., & McMahan, R. P. (2015). Effects of Field of View and Visual Complexity on Virtual Reality Training Effectiveness for a Visual Scanning Task. *Visualization and Computer Graphics*, 794-807.

Randles , B., Welcher, J., Szabo, T., Jones, B., Elliot, D., & MacAdams, C. (2010). *The Accuracy of Photogrammetry vs. Hands-on Measurement Techniques used in Accident Reconstruction.* Detroit, Michigan, United States: SAE International.

Siles, B. (2019, June 24). Atomontage Inc.’s Branislav Siles on the Limits of Polygons, the Voxel Future, Streaming, AI and more. (D. Aubrey, Interviewer)

Slicer Community. (2023, December 3). *Slicer: Home Page*. Retrieved from Slicer: https://www.slicer.org/

Telea, A., & Jalba, A. (2011). Voxel-Based Assessment of Printability of 3D Shapes. *Mathematical Morphology and its Applications to Image and Signal Processing* (pp. 393-404). Verbania-Intra, Italy: Springer-Verlag.

TheBat! (2023, May 1). *GeForce 256, GPU Database: Tech Power Up*. Retrieved from Tech Power Up Web site: https://www.techpowerup.com

Tong, X., Stilla, U., & Xu, Y. (2021). Voxel-based representation of 3D point clouds: Methods, applications, and its potential use in the construction industry. *Automtion In Construction*.

Tuxedo Labs. (2023, May 1). *Teardown Modding. Tuxedo Labs*. Retrieved from Teardown game website: https://www.teardowngame.com

Tuxedo Labs. (2023, May 1). *Teardown, Steam*. Retrieved from Steam/Valve Corporation. Websitie: https://store.steampowered.com

Voxel-Man. (2023, December 3). *Voxel-Man: Home Page*. Retrieved from Voxel-Man: https://www.voxel-man.com/

Wilder, M. W. (2015). *An Investigation in Implementing a C++ Voxel Game Engine with Destructible Terrain.* Akron, Ohio: University of Akron.

## 1. Introduction Notes (part of 60%)

* Opening statement should be clear, the issue I am looking to solve should be well argued and should naturally lead into the research question.

1. Introduce current ‘standard’ geometric primitive.
2. Give insight as to why polygons are the standard geometric primitive.
3. Introduce alterative of voxels and give definitions.
4. Give insight as to why voxels are not the current standard geometric primitive.
5. Suggest that voxels have been overlooked when looking at its specific use case/the future of voxels could have more voxels use cases.

## 2. Contextual Review Notes (part of 60%)

* Extensive use of literature from scholarly articles. Follows smoothly from statement to statement and shows critical engagement with literature.

## 3. Methods & Design Notes (20%)

* Clear description of design methods that are to be employed. Methods are well justified over any alternative methods, which is backed up by supporting materials. Description of procedures and tools is clear.

## 4. Project Plan (20%)

* High level of understanding of the tasks involved within the project objectives. Document is fully chaptered with sufficient detail. Work plan describing all considerations. Ethics is fully presented, approved, or not required based on evidence.

## Notes

### RSPI Project

### Topic

Reaffirm already existing research that Morton’s code/Z-Order curve can help Sparse Voxel Octree tree traversal.

Show the point of contention within voxels and showcase best use cases for each. Main point – Mention although Polygons may be better than voxels in terms of many rasterization techniques, however looking into the future of computer graphics, ray marching can hold its own against ray tracing.

## Questions

[Traversing Sparse Voxel Octrees](https://nccastaff.bournemouth.ac.uk/jmacey/MastersProject/MSc18/05/traversingsparsevoxeloctrees.pdf)

It is fine to introduce a topic direction in the introduction, and pivot within the contextual review as long as it is relevant and makes sense. For instance, going towards see if voxels have a potential future, then changing to well this future will require an aesthetical component.

What field(s) am I interested in contributing to, and how could I explain to this/these fields information they may not have read before.

## Unused References

Project uses a voxel-based approach to haptic feedback. Has limitations within its voxel size due to memory consumption and states it accepts a common engineer rule of 0.5-inch clearance wherever possible.

(McNeely, Puterbaugh, & Troy, 2005)

Project uses a neural voxel volume to dynamically render 3D objects from 2D images. Discusses limtiations of voxels cubic relationship of resolution and memory and solves this limitation using warp fields to create dynamic irregular grids.

(Lombardi, et al., 2019)

Project discusses printability of models sent to a 3D printer using a voxel-based representation. Defines the projects main limitation as the voxelization resolution capable by their GPUs, as certain characteristics have not been calculated within the model. Discusses the solution of this problem as more GPU memory.

(Telea & Jalba, 2011)

Project discussing various factors within biological tissue during electromagnetic-field exposure. Explains that generally in this field, they need incredibly small voxel sizes, of which when calculated came out to much more RAM usage than their computers could handle. This was one of the main limitations of this project.

(Mason, et al., 2000)

Investigating destructible terrain using voxels in C++. Currently limited by terrain size as entire terrain is rendered, suggests the usage of an Octree.

(Wilder, 2015)