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The Graphic Complexity Index

MEASURING THE COMPLEXITY OF 3D ASSETS FOR USE IN GIS

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Measuring the complexity of 3D assets for use in GIS

Executive Summary

This white paper introduces the concept of a Graphic Complexity Index based upon asset geometry and textures to describe 3D feature content that may be used in location-based systems. Storing, processing, and visualizing 3D location-based content is rapidly becoming a required capability for any modern GIS. The density and complexity of geometry in 3D models can overload traditional content processing mechanisms in GIS applications. Currently, there exists no common approach for measuring or describing the complexity of a 3D model or determining how it will perform in a GIS. The Graphic Complexity Index is introduced as a tool for users, data providers, and GIS software vendors to gauge software capability to consume, display, and analyze 3D model assets.

Why doesn't my model perform well in my GIS?

For a user who needs 3D GIS content, the most frustrating thing is to discover that newly acquired 3D assets don't perform well inside GIS applications after conducting an expensive and time-consuming procurement process. The 3D data user often doesn't understand why their new assets are not performing as expected. The user only knows that they followed conventional procurement methods for specifying the 3D model assets and received what they asked for as was specified by contract.

For example, a common type of 3D content that is needed by many modern cities is the 3D building model. Criteria for specifying 3D building models may include the 3D model file format, the types of architectural detail in the model, and a range of descriptive metadata. Unfortunately, these criteria often have little to do with the performance of 3D models when they are used as GIS features. Industry-standard 3D model formats and graphically-oriented exchange formats support a wide range of variability and features. These formats were designed to encapsulate properties that can be used to simulate realistic and artistic properties of imaginary and real-world assets. Flexibility within these formats is required because multiple techniques may be used to create visual simulations or to be processed in analysis.

In the case of buildings, similar levels of architectural detail can be captured at significantly different levels of geometric complexity. Often the user who paid for content specified a 3D modeling standard and requirements focused only on the characteristics of the real-world building. However, models constructed to such a standard without specifying the characteristics of geometric model content may result in unpredictable model complexity. Specifications based on purely real-world descriptive characteristics will almost certainly result in unpredictable results across subsequent data creation or collection projects.

In addition to buildings, plants can be another problematic real-world feature type to capture in 3D GIS. Plant models can have widely divergent properties and complexity, some of which may not be useful or required for different types of interactive 3D GIS experiences.

Terminology confusion

Lack of consistent terminology across 3D content model and delivery formats is a major contributing factor to procurement frustrations. For example, there are widely different uses of the term Level of Detail (LOD) in the industry. This leads to confusion about the term “LOD” which then contributes to user frustration. LOD is used in several different contexts:

- ✚ **CityGML Level of Detail** – The Open Geospatial Consortium (OGC®) CityGML standard declares that Levels of Detail (LOD) “reflect independent data collection processes with differing application requirements” and goes on to state that “all LOD appearance information such as high resolution textures can be mapped onto the structures.”

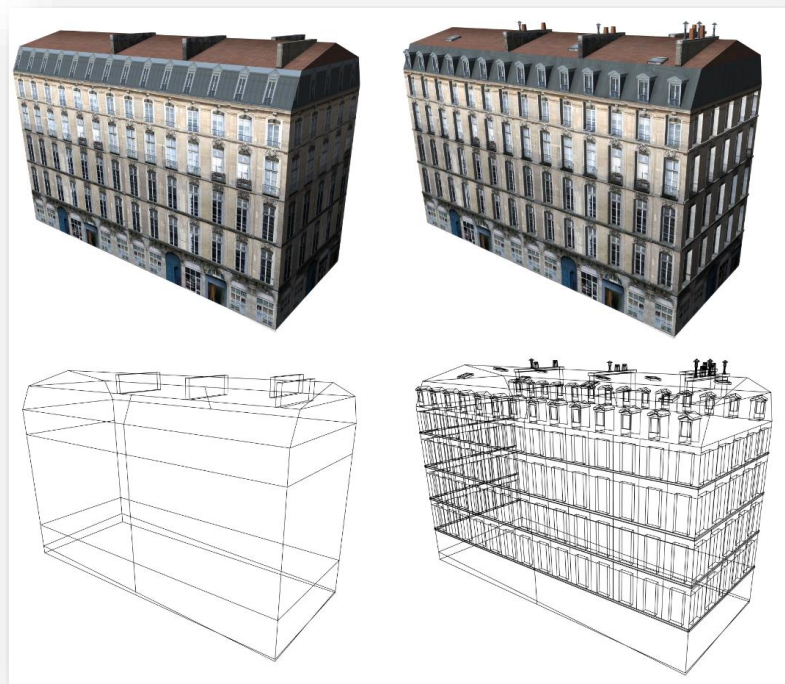


Figure 1. Building models that appear architecturally similar may have drastically different geometric complexity. The building on the left has 47 polygons and the building on the right is made up of 2053 polygons. According to some user specifications, both models could fulfill the qualifications for the same CityGML LOD representation of the building.

- ✚ **Film and Game Level of Detail** – In the film and game market, the same 3D asset may be represented in different scenes or at different times in a scene by progressively generalized versions of the asset depending on camera coordinates and performance requirements. These generalized versions, referred to as LOD, are typically generated by a combination of automated and manual processes and may even be only partial assets. For example, a building may not have a rear wall when the rear is never seen.

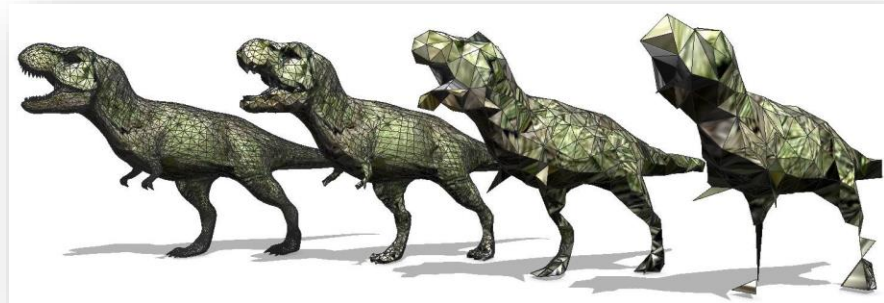


Figure 2. This dinosaur model, from TurboSquid.com, is shown in 4 different LODs, generated using Esri CityEngine mesh reduction tools. LODs like this are often used as a multi-LOD symbol for a game or film project. From left to right, the dinosaur model has 20,000, 4,000, 1,000, and 400 triangles, respectively. Refer to Appendix II for more information about LOD and mesh reduction.

- ✚ **Building Information Modeling Level of Detail or Level of Development** – The Building Information Modeling (BIM) world introduced the Level of Development concept which is also sometimes called Level of Detail. This concept of LOD helps owners and architects arrive at predictable model output that meets planning, visualization, and design needs while preventing overpayment for extra detail or underdevelopment of detail required for a particular step in the design process. BIM LOD are optional, manually created, likely to diverge significantly from the final design, and have no set rules for content or level of precision. Many BIM project contracts may not require the creation of LOD in the design process.
- ✚ **Raster and Terrain Levels of Detail** – The 2D raster industry and the 2D/3D Modeling and Simulation (M&S) industry have strong formal definitions for LOD based on gridded partitioning of content into rapidly traversable hierarchical trees of multi-scale content. The OGC CDB specification describes this type of hierarchy and LOD usage.

The concept of CityGML LOD typically appears in an organization's 3D model data specifications and in procurement requirements. BIM LOD may be specified as part standard data requirements in the design and construction process. Technologies for streaming large 3D GIS datasets, such as Indexed 3D Scene (I3S) layers, take advantage of a LOD concept that is closer to the film and game industry concept.

There are some notable differences between the film and game industry type of LOD and other LOD approaches:

- ✚ Software rendering systems are typically programmed to swap out LOD to balance interactive rendering performance with visual quality. LOD swapping is used for film rendering, game play, native 3D graphics computing, and 3D WebGL GIS experiences.
- ✚ Rarely will a user expect a 'lower' (less resolution) LOD when a 'higher' LOD is determined by the game experience to best fit the current experience or analysis. Similar to game engine behavior, when moving the view toward an asset in a GIS application, the software typically loads in progressively higher LOD as the user approaches closer to the asset if the assets is represented by a multi-LOD dataset.
- ✚ Algorithmically generated LOD used for performance may not have the same physical characteristics as the highest LOD version of an asset. In some visualizations, individual assets may not be represented at all, even if the asset is conceptually within the view of the camera. For example, an algorithm may fuse several different structures together or not display the asset at all if it is within view but its relative screen size is diminishingly small.
- ✚ The film and game LOD concept was designed to be used when the distribution of content within a scene may be significantly heterogeneous and irregularly grouped. Some parts of scenes may have a high amount of graphics content and other parts of the scenes may have relatively little content or much simpler content regardless of LOD.

New terminology to describe Complexity

Given the recurring issues experienced by users when specifying performance-related criteria when procuring and using 3D GIS content, Esri proposes to introduce new terminology to help describe GIS asset complexity and patterns of usage in 3D models. Specifically, we recommend introducing the terms Levels of Simplification (LOS) and Graphic Complexity Index (GCI).

-  **Graphic Complexity Index (GCI)** – The “Graphic Complexity Index” helps to describe the complexity of a 3D model. The index indicates the complexity of a model as defined by its geometry, texture size and quantity, as well as other properties used in the display and behavior of the model.
-  **Levels of Simplification (LOS)** – When datasets are created with multiple versions of varying complexity that are intended for performance-based display, the term “Levels of Simplification” may provide a distinction from LOD, which is often associated with analytical and semantic content of a model. For example, if the four dinosaur models in Figure 2 were used as alternate symbols for an asset with multiple LOS, a graphics engine might use the right-most model with the fewest triangles and simplest textures to represent the dinosaur when the camera view was far from the feature.

GCI and LOS are compatible with CityGML LOD when specifying dataset properties.

The definition of GCI encompasses multiple properties of a 3D model and can be characterized through a system as described in Table 1. The GCI designation is used to characterize both *individual assets* and the *typical asset* in a 3D dataset composed of many assets. Outliers in a dataset may significantly influence performance and behavior of a dataset with many models. Based upon continuing research and the adoption of new graphics display and processing technologies, this definition may be expanded upon or refined in the future.

The Graphic Complexity Index

Table 1. Individual assets in a 3D GIS dataset may be described by a Graphic Complexity Index rank with optional characteristics that help users evaluate how their assets will perform in a 3D GIS and what workflow will be required to import the assets into the GIS. Version 1.0 of the GCI is shown.

Graphic Complexity Index	Number of triangles ^a	Attribute-driven symbology	RGBA textures ^b	Texture mapping ^c	Multi-textured ^d	Texture size ^e	3D Materials ^f	Procedural facades ^g	Rigging & Animation
A	<20	Optional	Optional	Repeated/ Explicitly mapped	Optional	128	Optional	None	None
B	<100	Optional	Optional	Repeated/ Explicitly mapped	Optional	256	Optional	None	None
C	<500	Optional	Optional	Repeated/ Explicitly mapped	Optional	512	Optional	None	None
D	<2500	Optional	Optional	Repeated/ Explicitly mapped	Optional	1K	Optional	Optional	Optional
E	<20000	Optional	Optional	Repeated/ Explicitly mapped	Optional	4K	Optional	Optional	Optional
F	<100000	Optional	Optional	Repeated/ Explicitly mapped	Optional	8K	Optional	Optional	Optional
G	<1,000,000	Optional	Optional	Repeated/ Explicitly mapped	Optional	Any	Optional	Optional	Optional
H	>1,000,000	Optional	Optional	Repeated/ Explicitly mapped	Optional	Any	Optional	Optional	Optional

^a Triangles are the most basic structural arrangement of 3D planar geometry which are processed and reported on by most graphics applications. An application that refers to faces may not necessarily be referring to triangles.

^b RGBA textures accommodate simple imagery information that captures Red-Green-Blue-Alpha values in separate channels where Alpha represents opacity.

^c Textures may be repeated, sometimes referred to as tiled, or they may be uniquely mapped to the surface of an object. Geotypical textures on buildings, for example, are often repeated while geospecific textures are explicitly mapped on the model surfaces.

^d Multitextured models may include additional imagery information that captures additional information about how to represent a model surface. Additional textures may include bump maps, decals, normal maps, specular maps, and more depending on the process and tools used to create the model.

^e In cases where the assets use shared textures, the performance impact of texture size may be eliminated or greatly reduced. Note that texture sizes refer to pixels in either the x or y dimensions, not size in bytes. 4K textures, for example, will have approximately 4000 pixels in at least one dimension.

^f 3D materials can be modeled using algorithmic or programmatic information attached to a model, often referred to as shaders. Shaders are often used to add aesthetic information such as light sources, smoke and fog, or periodically repeating texture changes, such as for simulated water surfaces.

^g Procedural facades, not to be confused with procedural textures, define the geometry and textures of assets through rules that can be applied dynamically by client software.

How to apply GCI

As seen from Table 1, the range of complexity of 3D models can be diverse. This table does not capture all the possible variety of characteristics that may be found in 3D models. A basic assessment of model complexity may take into consideration the number of triangles in the mesh components of a model and the type of textures. Beyond simple textures and geometry, models may include many other behaviors and properties that can be generated during the asset creation pipeline.

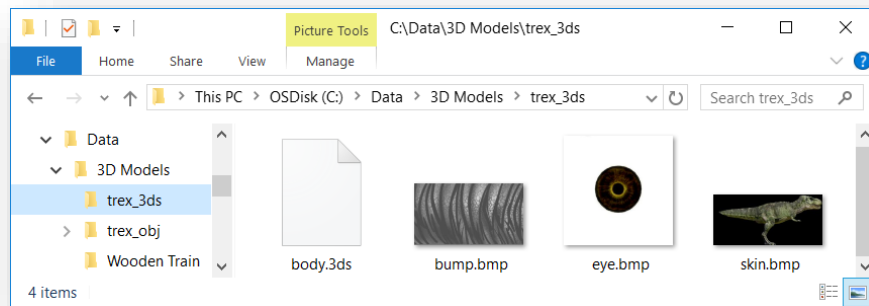


Figure 3. The 3DS format of this T-Rex model from TurboSquid can be seen to have explicitly mapped imagery textures for the eye, skin, and a repeated texture that is used for the tongue (bump.bmp).

When reporting GCI, we recommend referring to the GCI letter rank that describes triangle count and simple texture size along with other properties for the individual assets in a dataset. Experience has shown that users encounter more issues using datasets with higher GCI letter rank and with more optional properties.

Some examples of using GCI might include:

-  **GCI D:** A tree dataset which has only 15 triangles per tree and simple 1K RGBA textures
-  **GCI D:** A tree dataset which has only 15 triangles per tree and simple 1K RGBA textures
-  **GCI E:** A tree dataset with trees that has less than 5000 triangles per tree and simple 4K RGBA textures
-  **GCI F:** A tree dataset with 90K triangles per tree and simple repeated textures
-  **Untextured GCI E:** A buildings dataset with building models that have less than 5000 triangles and no imagery textures
-  **GCI F:** A bridge model with 90K triangles and RGBA textures
-  **GCI H model with materials:** A BIM model with 2M triangles and explicit materials

GIS datasets may contain geometry derived from different sources. As such, users must be consistent about reporting the provenance and complexity of their data. For example, a dataset composed of a single layer that includes 1000 GCI A building models procedurally modeled from building footprints and 5 GCI F models derived from BIM data will have different expectations for performance than if the 5 GCI F models were in a separate data layer by themselves.

Why triangles?

We often hear from users who have acquired data that is assessed for complexity based upon the number of surfaces or number of faces in each model. Given that triangles are the fundamental geometric unit that is used by many graphics systems to perform display and calculation operations, at this time, we feel it is better to focus on number of triangles as a key component of a metric for complexity. Faces and surfaces describe more complex structures that may have arbitrarily large numbers of triangles and thus cannot reliably be used to assess model complexity.

A user example

An example that a user recently brought to us described the following dataset which has:

- ✚ 30,000 buildings in a single multipatch dataset
- ✚ Covering approximately 30 km² of land area
- ✚ Approximately 1000 faces per building

The user believed that the buildings were not that complex because each building had an average of only 1000 faces. This dataset might at first appear to be GCI D.

However, upon further study, we discovered that each face could potentially contain from 100 to over 1000 triangles. This increased the potential number of triangles per building up to around one million. The whole dataset totals over 30 billion triangles, which is a large and complex set of 3D building models that would probably fall into category GCI H.

To achieve good performance with this dataset in a web-distributed GIS, the user will have to simplify assets or use hardware and software that is highly optimized for displaying this number of 3D models at this rank of complexity.

Additional factors that influence performance and visual quality

The complexity of the 3D properties of the individual assets in a data layer may account for most of the variation in performance, usage, and visual quality that may be experienced with a dataset. Additional factors may impact the workflow for converting 3D model content into a GIS. The factors described below may have a direct impact on the types and quality of visualizations in which the data may be used.

Georeferencing

In many cases, model content will have no intrinsic or accompanying georeferencing information. For example, when GIS users attempt to import models from an online repository such as Trimble's 3D Warehouse or TurboSquid, the models may not be geolocated or in a unit scale that fits a users' map scale. In these cases, the GIS user will be required to apply a transformation to make sure that models end up in the correct location, elevation, rotation, and dimensional scale. Some applications provide an interactive 3D georeferencing workflow, but this can be tedious work if a user has many individual models with no georeferencing and will not guarantee a high level of accuracy in each model's location.

Projected, unprojected, or world coordinate system

Dynamic reprojection of data in 3D clients is atypical due to the performance costs of recalculating asset dimensions on the fly. Most GIS systems will require that 3D content is stored in the target coordinate system in which the user wants to view and analyze the content.

For example, models coming from engineering and architecture applications will often be modeled in a local projected coordinate system such as UTM or State Plane. In most cases, end users will want to view and analyze data in its source coordinate system. However, the user may desire to switch to a different Cartesian coordinate system, a whole Earth coordinate system, or the data may have been created in an arbitrary system that is not tied to a specific geolocation. Viewing or using the data in a different coordinate reference system will require transformation.

For users who will be receiving large amounts of 3D data from services providers or from their community, we recommend that these users declare explicit requirements for their coordinate reference systems, measurement units, and geolocation of assets in order to simplify their data pipeline.

In some jurisdictions, governments and their service providers may be restricted by statute to viewing and analyzing data in their local coordinate system. These users will benefit most from clearly specifying the coordinate reference system requirements for data creation and submission.

Users seeking to work with data in augmented reality (AR) and virtual reality (VR) experiences may need to override or ignore the source data coordinate system for best results.

Vertical coordinate systems

Different 3D datasets, such as data measured on the ground and data created from satellite Earth observation, may rely on different models to define elevation and the relative direction of 'up.' Esri recently introduced a software implementation for a standardized Vertical Coordinate System (VCS) across ArcGIS applications. The VCS can be specified in 3D datasets with well-known text descriptors so that geographically coincident datasets will display correctly in a known orientation and elevation.

When commissioning data or specifying standards for data creation and collection, users should attempt to stipulate that providers create datasets with well-known VCS information so that client software can accurately position and use the data. Legacy data, including most 2D GIS data, will not define VCS information and GIS client software will make assumptions about the vertical coordinate system to correctly georeference the dataset.

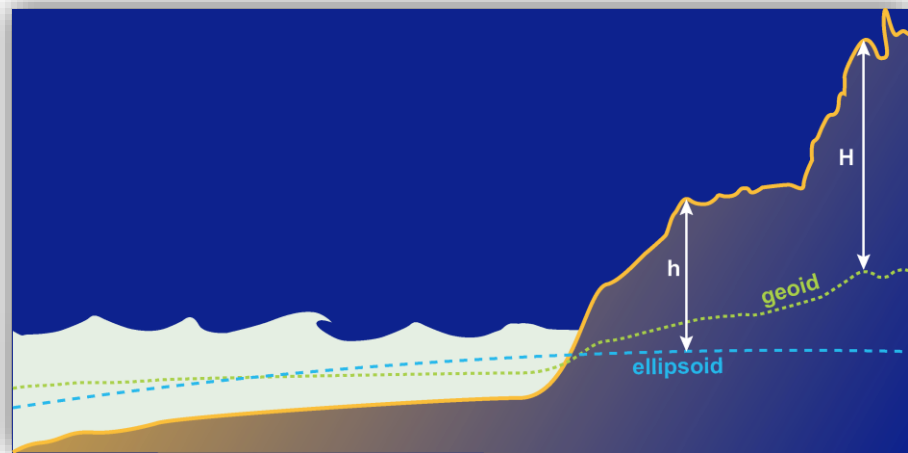


Figure 4. Vertical Coordinate Systems (VCS) enable GIS applications to correctly locate data measured against different Earth elevation reference models.

Tiled with many other features

Some datasets, especially those created in film and game software packages, may be structured in large tiles of 3D models that have no relationship with GIS attribute information. To be used in GIS, these datasets must be put through a preprocessing workflow, often called a pipeline, that subdivides the tile into individual features and then loads the features into a geospatial data store with feature attribution and identity information.

In nearly every case, the workflow to process raw 3D tiled datasets is highly custom and may involve several format conversions as well as the use of tools such as Safe Software's FME. During processing, extra steps may be required to simplify models, merge textures, and reproject and translate models into the correct geographic location.

Some data vendors have developed pipelines for creating 3D GIS datasets from tiled data. In these cases, the dataset may include properties such as built-in LOS and associated feature datasets with attribution.

Individual models containing many distinct features

With recent improvements in the capabilities and capacity of 3D GIS applications, users are attempting to load many non-traditional types of 3D content into their GIS, such as BIM information. While many classic GIS use cases focus on viewing and analyzing numerous assets over large geographic extents, BIM information can pack many assets into small spatial extents. GIS applications often aren't designed to navigate and interact easily with assets at the large map scales at which small, clustered assets are individually visible.

Typical issues that users may encounter when attempting to bring 3D BIM information into GIS include:

- ✚ **Large mesh triangle counts** – In some cases, the graphics to describe a single BIM structure may encompass millions of triangles. Individual BIM files may reach several GBs in size, representing a single building, bridge, or other real-world asset.
- ✚ **Partial structures** – Many BIM files encapsulate partial structures such as single floors, interior components of a building, or selected components of a structure under construction, such as a new addition to an airport.
- ✚ **Embedded or encoded attribute information** – Depending on the goals of the owner/operator who has initiated a BIM project, the BIM may include user-defined attribution in a project-based or industry standard that may be difficult to access in the BIM for purposes of use in GIS. In many cases these attributes will be incompletely populated in the BIM adding to the uncertainty of extracting information.
- ✚ **Instanced or parametric assets** – BIM applications typically work with categories of standardized assets that may be repeated many times in a model. Some instances of these assets may have parametric behavior based on unique attributes that define dimensions or materials. This parametric behavior is often not captured after an asset is converted for use in a GIS.
- ✚ **Missing or undefined georeferencing information** – In many cases, BIM information will be designed with arbitrary “zero-zero” or site-based coordinate systems. Data in this category require processing through a workflow in which the user can add well-known georeference information to accurately locate the model. For large sets of models this process can be time intensive and error prone.
- ✚ **Units** – Some BIM files will be dimensioned in units as small as millimeters. GIS applications may have difficulty converting from small units to systems with larger units.

Generated with precalculated asset simplifications (LOS)

Some datasets, especially those coming from experienced commercial 3D data vendors, will be generated with precalculated Levels of Simplification. In these cases, the vendor will often have created the LOS so that their datasets perform optimally for visualization and analysis in GIS clients.

Datasets designed for multiplatform experiences may have distinct LOS that conform to expected platform requirements. Client applications can select the appropriate LOS to display depending on performance capabilities or user experience requirements. For example, a mobile app loading a web-distributed GIS layer with multiple LOS may choose to retrieve and display a lower complexity LOS than a desktop GIS tool that is displaying the same layer from the same camera position. When characterizing these layers, users may need to explicitly describe assets in each LOS, including describing the typical GCI for assets in that LOS.

Generated with explicit and functionally distinct CityGML-type LOD

Datasets may contain explicitly defined LOD, such as in OGC CityGML modelled data. Explicit LODs may be used as functionally distinct representations of the same assets for purposes of analysis and visualization. In these datasets, 3D models for different LOD of the same asset may have unexpected variation in complexity that does not correspond to the LOD classification. Users should understand the GCI for each LOD when making decisions about data performance. Users should also not assume that LOD and LOS are equivalent for performance purposes. For example, some datasets may not have a corresponding LOS for an asset at a specific LOD.

Generated with multiple texture formats

Some vendors or systems may include multiple texture formats that are optimized for high performance on specific platforms or operating systems. In this case, the dataset specification should describe the formats provided and clients should be able to select the format that is optimized for each respective platform.

Impact of texture sharing on complexity

Texture size complexity greatly depends on whether assets share textures or not. If all assets in a dataset have unique textures, the effect of these textures will be to increase the overall complexity-related behavior of the dataset. For example, if a GPU with 2GB of RAM could render 5M triangles at 60 frames per second (FPS), it could render 250k assets of GCI rank A in terms of triangle count, but only hold ~2000 1K textures. On the other hand, if all assets in a dataset share one or a few textures, such as if a point dataset references a small set of markers, then 4K image textures may still perform well even for assets of rank A.

Dataset total spatial extent

New standards for sharing 3D spatial content, such as the OGC I3S Community Standard, enable GIS clients to retrieve content with consistent performance regardless of spatial extent. Users who are working with large 3D GIS datasets that cover large heterogeneous spatial extents are encouraged to work with distribution formats that enable scalable retrieval, visualization, and analysis of their data.

End client software application architecture

The desired GIS end client application architecture or pattern may also impact the user experience with different GCI rank datasets. Mobile applications with bandwidth restrictions and web applications that are operating in high lag or latency networks may experience poor interactive performance if datasets require large amounts of geometry or textures to be downloaded. For the best performance, many of these applications require datasets that have been put through a rigorously constrained content management pipeline.

Hardware specifications and platform

3D graphics visualization and analysis are computationally intensive and application and data design requires consideration of the target platform and experience. For example, mobile browser-based WebGL 3D is currently bottlenecked by caching limitations that are far more limited than what is achievable with a native mobile app. Desktop and server-based 3D applications can take advantage of high end software and hardware, such as GPUs designed to process operations on triangles.

Examples of common datasets

Thousands of 3D datasets have been published to ArcGIS Online and can be viewed in desktop, web, and native mobile apps. Some examples of types of layers that we can see are as follows.

Figure 5. CityGML LOD1 buildings from Netherlands that are classified as an untextured GCI A dataset. Models are stored as I3S which intrinsically contains multiple Levels of Simplification that are not equivalent to CityGML LOD. Within the I3S, organized into nodes, the complexity rank is effectively GCI E.



Figure 6. In this open data layer, over one million CityGML LOD2 buildings from New York City can be described as untextured GCI B data at the individual building level. Often with increasing geometric complexity, users will need to work with higher complexity data.

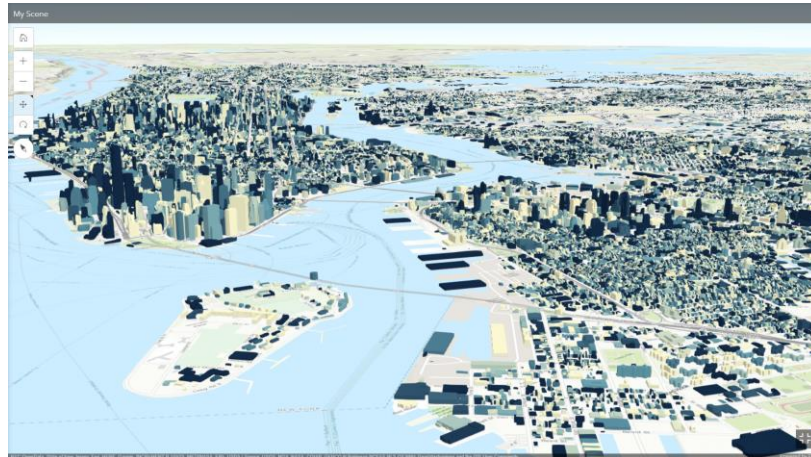


Figure 7. CityGML LOD2 buildings from the City of Montreal open data can be categorized as textured GCI C. Buildings with geospecific textures, like these, will consume more bandwidth when downloaded over the web than will an untextured dataset.

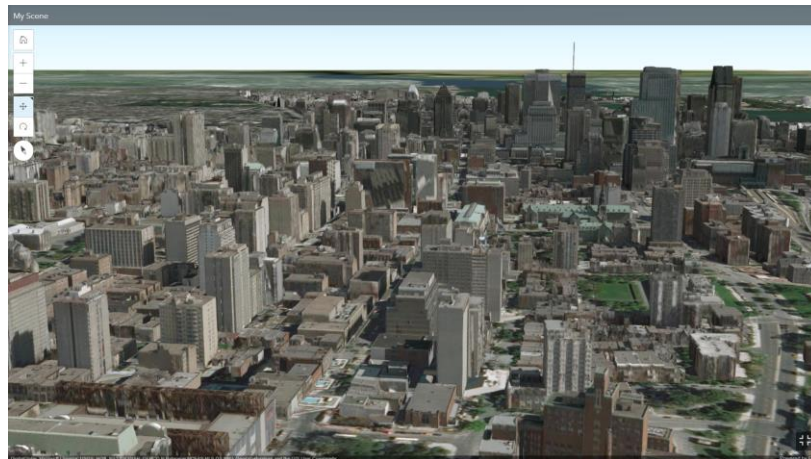


Figure 8. 3D datasets, such as this massive 120GB file-based dataset from Vricon, can perform well as local or web-distributed content if structured for performance. Vricon's data creation pipeline creates large continuous meshes from satellite imagery and then subdivides them into consistent GCI mesh 'features' with multiple LOS that are used by clients for rapid display.

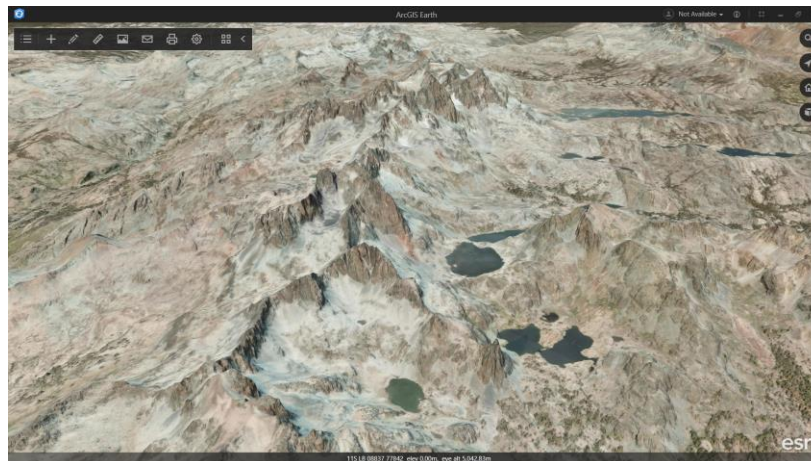
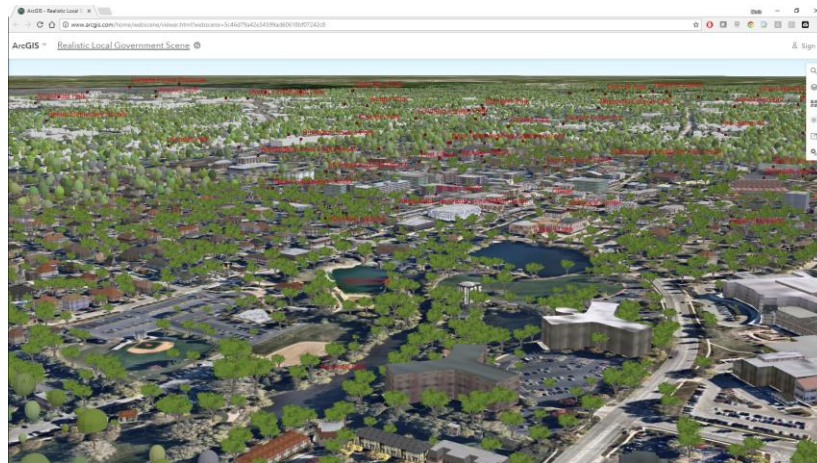


Figure 9. Software applications such as Bentley Systems' ContextCapture enable users to produce textured meshes with predictable GCI data and calculated LOS. Aerometrex used ContextCapture to create this textured mesh data for Melbourne, Australia.



Figure 10. 3D models representing city furniture and trees, such as the realistic and schematic trees shown in this image, can have widely varying GCI.



Summary

For many users and organizations 3D content has become an essential component of enterprise GIS and applications. We expect the use of 3D GIS content to accelerate over time as reality capture technologies and IoT systems proliferate in support of increasingly accurate real-world visualization, simulation, and analysis.

Users expect to easily consume and use the 3D content they are creating, converting, and purchasing in a variety of GIS experiences. Different platforms will diverge greatly in performance for visualization and analysis of data of the same complexity. This divergence is due to the diversity of strategies for creating and supporting graphically intensive applications in different browsers, on mobile devices, and in newly emerging experiences such as wearable computing devices.

To reliably characterize 3D asset performance in GIS applications, users require mechanisms and terminology to help them describe how data with particular structure and characteristics should be created or generated for optimal use.

We recommend that users begin to describe individual 3D feature content with a Graphic Complexity Index rank based upon asset geometry and textures. Additional descriptors based on industry-standard 3D concepts and terminology may be required to specify extended 3D model properties.

Beyond the individual features in a 3D GIS data layer, many other factors may determine the performance and visual quality of a dataset. When working with 3D content, GIS users will need to consider the pipeline of content coming into the GIS, the types of end user experiences that the user wishes to create with the data, and the visual quality and performance requirements of their intended audience.

Appendix I. Evaluating models

Numerous free, open source, and proprietary 3D modeling tools may be used to inspect and evaluate basic model characteristics such as the number of triangles, texture characteristics, and more advanced properties, such as shaders and materials.

These applications will typically work with standard film and game industry 3D model formats but may not yet work well with 3D GIS data formats.

Figure 11. The Open 3D Model Viewer is a freeware application that supports a variety of 3D model formats and can be used to inspect models. It can be found at www.open3dmod.com.

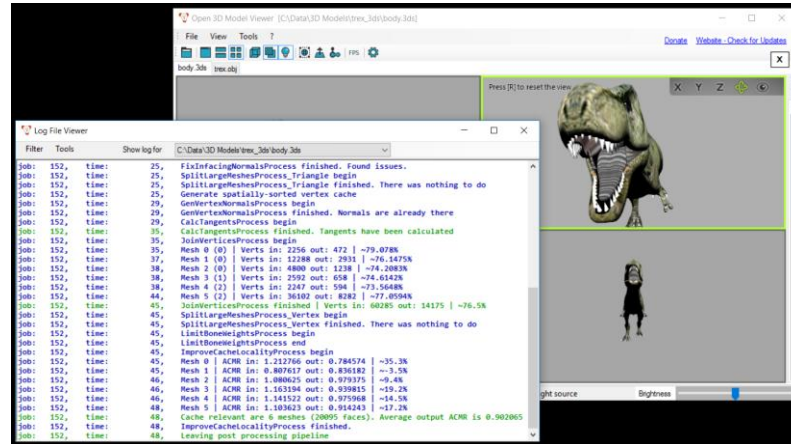
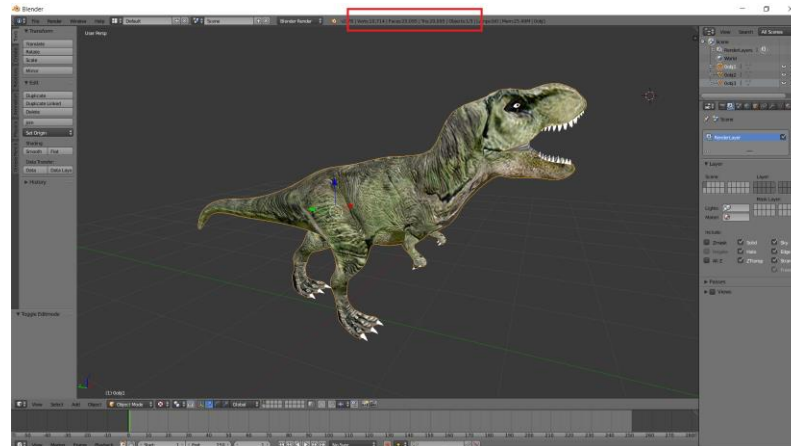


Figure 12. [Blender](https://www.blender.org/) is a sophisticated open source 3D modeling application that can be used to create and inspect individual 3D model assets.



Other applications and tools that may be used to inspect 3D model content include:

- ✚ Autodesk applications including [FBX Review](https://www.autodesk.com/products/fbx/review) (free), [3DS Max](https://www.autodesk.com/products/3ds-max), and [Maya](https://www.autodesk.com/products/maya)
- ✚ [FME](https://www.safe.com/fme) by Safe Software Inc
- ✚ [MAXON Cinema 4D](https://www.maxon.net/en/Cinema4D)
- ✚ [Clara.io](https://www.clara.io)
- ✚ [Model Info extension](https://www.trimble.com/SKU.aspx?pid=12345) for Trimble SketchUp
- ✚ [Open Asset Import Library](https://openassetio.org/)
- ✚ [Open Scene Graph Library](https://openassetio.org/)

The dinosaur model used in examples may be found here: <http://bit.ly/3DTRex>

Appendix II. For more information on LOD

Understanding concepts such as LOD and how to generate multiple LODs for assets is important for projects that require reducing the complexity of 3D model assets for better performance. We recommend further reading from both the GIS and the entertainment industries to explore different techniques and patterns for model creation and specification.

For more information on different concepts for LOD, we recommend the following reading material:

- ✚ Level of Development Specification at BIM Forum: <http://bimforum.org/lof/>
- ✚ CityGML documentation: <https://www.citygml.org>
- ✚ CDB documentation: <http://www.opengeospatial.org/standards/cdb>
- ✚ Numerous books and references in the entertainment software world including:
 - [Level of Detail for 3D Graphics by David Luebke](#), 2012
 - Amazon Lumberyard LOD documentation: <http://docs.aws.amazon.com/lumberyard/latest/userguide/char-export-maya-lumberyard-tools-lod.html>
 - Wikipedia LOD reference: https://en.wikipedia.org/wiki/Level_of_detail

The entertainment industry concept of generating – automatically or manually – LODs from higher resolution assets is often referred to as mesh reduction or polygon reduction. Numerous 3D graphics software packages, including Esri CityEngine, have capabilities for mesh reduction, though exact features vary greatly by industry and technology.

About the Author

Chris Andrews is the Product Manager for 3D across the Esri ArcGIS platform and leads a team of product managers focused on BIM, urban planning, city modeling, and globe 3D visualization. During his 20-year career, Chris has focused on exposing the value of GIS throughout organizations by combining cutting edge technology with ease of use to put capability in users' hands without requiring specialized technology expertise. Chris has worked with customers in the crime mapping, defense, real property, utilities, and AEC industries. Chris holds a Bachelor of Science in Geology-Biology and a Master of Science in Ecology and Evolutionary Biology from the University of Rochester where he concentrated on spatial clustering analysis and spatial population simulation modeling.

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Contact Esri

380 New York Street
Redlands, California 92373-8100 USA

1 800 447 9778
T 909 793 2853
F 909 793 5953
info@esri.com
esri.com

Offices worldwide
esri.com/locations

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