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OGC Public Engineering Report

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Chapter 1. Subject

The following is, as all texts in double parentheses, a helper text. Please remove this and all other helper texts once done.

The Subject clause shall define without ambiguity the topic of this document and the aspect(s) covered. It shall be succinct so that it can be used as a text for bibliographic purposes.

This section shall be between 2-3 sentences and not longer than 140 words total.

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The following is, as all texts in double square brackets, a helper text. Please remove this and all other helper texts once done.

The Executive Summary clause shall contain the key findings and results in a concise form. A more detailed description of the findings should be in the body of the report.

The Executive Summary shall contain a business value statement that should describe the value of this Engineering Report to improve interoperability, advance location-based technologies or realize innovations.

This section shall include precise descriptions of the requirements that have been addressed by the work documented in this Engineering Report; together with the research motivation that answers the fundamental question: What motivated us to address this topic in this report?

This section provides an overview of recommendations on how to further proceed with the achievements documented in this ER.

This section shall be between 1-3 pages.

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Chapter 3. References

NOTE	***Draft*** This section is not complete. The bulleted lists will be turned into prose with references to the detailed descriptions. Additional items may be added based on additional reviews of the participant material.

The following normative documents are referenced in this document.

NOTE: Only normative standards are referenced here, e.g. OGC, ISO or other SDO standards. Other references may be listed in the bibliography.

Example:

- OGC 06-121r9, OGC® Web Services Common Standard [https://portal.opengeospatial.org/files/?artifact_id=38867&version=2]
- General
  - CDB
- Ecere
  - GeoPackage
  - 3D Tiles
  - OGC API - Tiles
  - 3D Tile Matrix Set and Tileset Metadata
  - glTF
  - COLLADA

Chapter 4. Terms and definitions

NOTE	***Draft*** This section is not complete. The bulleted lists will be turned into prose with references to the detailed descriptions. Additional items may be added based on additional reviews of the participant material.

For the purposes of this report, the definitions specified in Clause 4 of the OWS Common Implementation Standard OGC 06-121r9 [https://portal.opengeospatial.org/files/?artifact_id=38867&version=2] shall apply. In addition, the following terms and definitions apply.

NOTE	***Structure*** Many of these are acronyms and not really *terms*. Should the acronums be included here or not?

- *3dsMax*

  tbd

- *3D Tiles*

  tbd

- *3D Tiles Next*

  tbd Links to https://github.com/CesiumGS/3d-tiles/blob/3d-tiles-next/3D_TILES_NEXT.md

- *ArcGIS*

  tbd

- *CDB*

  tbd

- *CDB X*

  tbd

- *OpenFlight*

  tbd COLLADA

- *B3DM*

  tbd

- *CityGML*

  tbd

- *COTS*

  tbd

- *CNAM*

  tbd

- *DIIL*

  Disconnected, Interrupted, Intermittent, Low-Bandwidth

- *DIS*

  Distributed Interactive Simulation

- *DOF(s)*

  Degrees of Freedom. Full freedom in space has six degrees of freedom - left/right, front/back, up/down, roll, pitch, and yaw.

- *E3D*

  tbd

- *EOS*

  tbd

- *Feature Manipulation Engine*

  tbd

- *FlightSafety*

  This is a participant, not a term

- *FLIR*

  tbd

- *GeoPackage*

  tbd

- *GeoSpecific*

  A 3D model of an object that has a specific place on Earth. Examples include Eifel Tower, US Capitol, Mt. Rushmore, and many other objects that are unique and may be used to immediately identify a location and potentially time.

- *GeoTypical*

  A 3D model of an object whose existance does not identify a location and where the model may be used repeatedly. Examples include trees, most warehouses, and many residential buildings. *tbd*

- *glb*

  See *glTF*.

- *glTF*

  The 3D model standard from the Khronos Group. It stands for "graphics language Transmission Format". The V2.0 standard is documented [https://github.com/KhronosGroup/glTF/tree/master/specification/2.0]. The standard is in the process of becoming an ISO Standard. A glTF model may be represented in multiple files with the primary file having the extension **.gltf**; or typically a single file with the extension **.glb**.

- *GNOSIS*

  tbd

- *GTModel*

  tbd

- *HLA*

  tbd

- *I3DM*

  tbd

- *IoT*

  Internet of Things

- *LOD*

  Level Of Detail. A highly detailed model may be created to display at reduced detail when the scene camera is far away. The model typically defines the number of levels, the detail shown at each level, and the applicable viewing range.

- *MModels*

  tbd

- *MOVINT*

  tbd

- *NGA GRiD*

  tbd

- *NVG*

  tbd

- *One World SDK*

  tbd

- *OpenFlight*

  A data modeling language… *tbd*

- *OSG Software*

  tbd

- *PBR*

  Physically Based Rendering. This is a means for calculating the appearance of a model based on a number of physical parameters including metal-roughness, normals, and transmission. glTF uses this model for rendering.

- *SensorThings API*

  tbd

- *skp*

  tbd

- *SWIR*

  Short-Wave InfraRed. The spectrum of electromagnetic energy with wavelength longer than visible red, but shorter than thermal energy.

- *TIFF*

  Tagged Image File Format. This format is used for storing raster graphics images. It is a container format that can store multiple diffrent image formats. Images stored as TIFF files frequently are uncompressed or lossless-ly compressed. See also Wikipedia - TIFF [https://en.wikipedia.org/wiki/TIFF].

- *TinyGLTF*

  tbd

- *Trimble Sketchup*

  tbd

● *x3d*

tbd

NOTE

Question

RP: How crazy do I go with Terms, like XML, PNG and the likes of *obvious* internet jargon isn't needed right?

● *term name*

text of the definition

● *term name*|*synonym*

text of the definition

4.1. Abbreviated terms

NOTE: The abbreviated terms clause gives a list of the abbreviated terms and the symbols necessary for understanding this document. All symbols should be listed in alphabetical order. Some more frequently used abbreviated terms are provided below as examples.

- COTS Commercial Off The Shelf
- DCE Distributed Computing Environment
- IDL Interface Definition Language

Chapter 5. Overview

Section 6 describes the **Material and Purpose** of the Sprint. All of the material that was provided to the participants is either included here or referenced.

Section 7 presents the overall **Findings** from the Sprint. The discussion includes material learned from all participants and the Sprint leadership team in carrying out the Sprint.

Section 8 presents the major **Conclusions** from the Sprint. This represents the collective knowledge and experience of the participants and editor.

Sections 9-14 contain the **Participant Detailed Reports**.

Section 15 contains the consolidated **Future Recommendations**. Much of this content was gathered from participant detailed reports.

Appendix A contains a copy of the *OGC Standards/Specifications and Scenarios* table from https://portal.ogc.org/files/?artifact_id=96942#StandardSpecScenarioCrossReference.

Appendix B contains a copy of the *Feature comparison table (or equivalent)* with additional notes and comments.

Appendix C contains a list of the datasets that were used by the various participants. Included with the list is additional data describing the reference location, creator, license, and other useful items.

Appendix D contains a list of the display applications that were used by the participants for their results. The table highlights the use of game engines, mobile devices, and 3rd party display applications.

Appendix E contains the document Revision History.

Appendix F contains the document Bibliography.

Chapter 6. Material and Purpose

6.1. Call for Pariticipation

The OGC ISG Year 2 Sprint: Call for Participation (CFP) [https://portal.ogc.org/files/?artifact_id=96942] was released on 1 April 2021 by the Open Geospatial Consortium for the purpose of obtaining proposals from organizations interested in studying data and model handling within the CDB environment. The CfP provided all of the material necessary for organizations to make a proposal for participantion either by direct inclusion in the doucment or publicly available links.

The CfP specificed the schedule from kickoff meeting (2 June 2021) through the two spring weeks (weeks of 7 June and 21 June), and the participant final report inputs (31 July). The Sprint was designed from the beginning to be virtual dur to pandemic safety restrictions and precautions. The descion was made prior to the release of the CfP.

The schedule for the Sprint work was defined in the CFp and is listed below. Of important note is the two non-contigious weeks of Sprint Work (Mini-Sprint #1 and Mini-Sprint #2) separated by the OGC Member meeting. The Findings section addresses participant comments on the scheduling. It was decided in June to seek CDB SWG review and comments prior to *pending* publication because of the close and important work this Sprint was performing relative to current work within CDB SWG. That addition did not change any contractual arrangements.

Milestone	Date	Event
M01	March 31, 2021	Release of Call for Participation (CFP)
M02	**April 30, 2021**	**CFP Proposal Submission Deadline (11:59pm EDT)**
M03	May 31	All Participation Agreements signed (OGC will start sending preliminary offers in early May).
M04	**June 2**	Half-day **Kickoff Workshop** to be organized as a virtual meeting.
M05	Week of June 7	Mini-Sprint #1 (two scheduled teleconferences plus ad hoc calls as needed).
M07	Week of June 14	Quarterly OGC Member Meeting: submit formal review request to selected OGC WG to review the ER later in the timeline (probably at the Sep. Member Meeting).
M06	Week of June 21.	Mini-Sprint #2.
M08	June 29 & July 6	**Dry-Run (29 June) and Stakeholder Demo Event (6 July)**.
M09	July 31	All participant Engineering Report (ER) contributions submitted.
M10	August 19 & August 30	Near-Final ER draft posted to CDB SWG (19 August) and Pending (30 August) for ISG DWG review.

Milestone	Date	Event
M11	September 20	Quarterly OGC Member Meeting: ER Publication Vote; Presentation(s) of Final Results.

Table 1. The master schedule provided to all potential bidders in the CfP. Actual dates substituted for 'TBD'. Comments from the participants are addressed in the **Findings** *section.*

6.2. Discussion of Scenarios

6.2.1. Overview

The CfP described four possible scenarios. Scenario 1 was split into a A and B part. Particiapnts could chooise to work on any combination (to a maximum of three) of these or propose their own within the guidelines established by these scenarios and the rest of the CfP.

6.2.2. Scenario 1

This scenario related to the conversion of data formats from one to another. They differed in whether the new format was user-requested on-demand or a batch pre-demand process. In both cases the participants were requested to use OGC Standards and specifications or provide a good reason why that did not work. Note that in both scenarios, glTF is considered an OGC format.

Scenario 1A addressed the needs of on-demand conversion from one OGC data format to another. The results needed to be quantified in terms of response times from initial request to content delivery. The use of existing OGC Standards, API, and Specifications (OSAS) for this scenario was important to the process. It allowed for variations if a good reason could be provided and a recommendation was made for an alternate.

Scenario 1B addressed the needs of pre-demand batch conversion from formats found in a CDB dataset to other OGC formats. This sub-scenario was designed to quantify the server resources needed for a batch conversion. The conversion process was not required to use existing OSAS, but did need to propose a prototype of a new standard. This sub-scenario was also designed to provide guidance on recommended sizing limits of future versions of CDB.

6.2.3. Scenario 2

Scenario 2 was designed to address the issues involved from navigating from outside to inside. Traditionally these models serve different purposes and are not necessarily compatible. CDB defines buildings and their relationship to other objects in the scene. Other OGC Standards (e.g., Indoor Mapping Data Format and IndoorGML) define the interior structures. Moving from outside to inside without loosing context of the other side has not been a smooth process.

6.2.4. Scenario 3

The integration of animated transportation networks is critical in understanding how a region operates. This scenario requires the participant to show transportation networks with animated vehicles. There was no limitation placed on the the network type except that it be land- or air-based. This scenario also tested incompleteness in existing OGC specifications for tracking moving objects.

6.2.5. Scenario 4

CDB is considering using glTF as its modeling format. It is necessary to understand the advantages and disadvantages of glTF compared to the existing CDB model format - OpenFlight. Preliminary work included in the CfP (and included in **Appendix A**) showed that glTF and OpenFlight were similar in features. Participants working on this scenario were to analyze the formats in the context of CDB and specify additional capabilities needed by glTF to functionaly replace OpenFlight.

6.3. Material provided to Participants

6.3.1. General OGC Information

Potential bidders were provided with a variety of information including Data Sets, Specification / Scenario cross reference table (Appendix A), and OpenFlight / glTF capability cross reference (Appendix B).

6.3.2. Data Sets

The primary data set for the Sprint is known as San Diego CDB (licensed under the SanGIS Legal Notice - SanGIS GIS Data End User Use Agreement and Disclaimer for Data Released to the Public). This data set was collected using a number of sensors and methods and encompassed nearly all of the downtown San Diego and vicinity, including the port, sports stadium, recreational facilities, commercial, and housing areas.

Figure 1. An overview of the coverage of the San Diego CDB V4.1. It is a single geocell with the southwest corner at N33 V118. The image was provided by CAE during Sprint Year 1.

Figure 2. A rendering of a portion of this dataset. Up is approximately north-east with the San Diego Convention Center at bottom center-right. The rendered view was provided by CAE during Sprint Year 1.

Participants were free to use other data sets to provide the sufficient and necessary data for development and testing. Several participants did choose to use other data sets. The full list of data sets used along with other reference and meta-data information is provided in **Appendix C**. The table below summarizes data set usages and the participants.

Data set	Cesium	Ecere	FlightSafety	InfoDao	SimBblocks	Steinbeis
Austin	-	-	-	-	X	-
Berlin	-	X	-	-	-	-
Honolulu	-	-	X	-	-	-
Miami	-	-	-	X	-	-
New York CDB	-	X	-	-	-	-
Paris	-	-	-	-	X	-
San Diego CDB^	-	X	-	X	X	-
Stuttgart	-	X	-	-	-	X
Yeman	X	-	-	-	-	-

*Table 2. Data sets used by the participants. Details on each data set are provided in Appendix **C**.*

Chapter 7. Findings …

Draft

NOTE

This section is not complete. The bulleted lists will be turned into prose with references to the detailed descriptions. Additional items may be added based on additional reviews of the participant material.

7.1. Introduction

These findings all come from comments (written or verbal) from the participants. These represent either items that were deemed important by the participants. The information here comes from achieved results, not unachieved stretch goals.

7.2. Aspects of Investigation

Each participant was free to choose which one (or more) scenarios to pursue. Four scenarios were discussed in the Call for Proposals [https://portal.ogc.org/files/?artifact_id=96942]. Participants could also define their own scenario. Compensentation was based on the number of chosen scenarios and the depth to which each chosen scenario was pursued. OGC reviewed each participant's proposal and suggested revisions to better align with the goals of the Sprint, the interest of the Sponsor, and the coverage by the other participants. Table 3 provides a summary description of the selected scenarios. Table 4 shows the coverage of scenarios by the participants.

Scenario	Summary Description
1A	Develop efficient on-demand conversion from on OGC 3D format to another.
1B	Develop efficient batch conversion from on OGC 3D format to another.
2	Integrate indoor and outdoor displays with metadata.
3	Integrate animated transportation networks with 3D tiled display.
4	Perform actual-use gap analysis on OpenFlight and glTF core + modules.
4C	Develop specific glTF extensions to support needed capabilities in CDB.

Table 3. A summary of the scenarios used during Sprint Year 2. Scenarios 1-4 were defined in the Call for Participation. Cesium proposed in-kind work as a modification of Scenario 4.

	Scenario					
Participant	**1A**	**1B**	**2**	**3**	**4**	**4C**

	Scenario					
Cesium						✓
Ecere	✓	✓	✓			
FlightSafety					✓	
InfoDao	✓	✓				
SimBlocks		✓		✓		
Steinbeis			✓	✓		

Table 4. A summary of the scenarios used during Sprint Year 2. Scenarios 1-4 were defined in the Call for Participation. Cesium proposed in-kind work as a modification of Scenario 4.

7.2.1. Cooperative Efforts

Unlike the ISG Sprint Year 1 [http://docs.ogc.org/per/20-087.html] or the GeoVolumes Pilot [https://docs.ogc.org/per/20-030.html], this Sprint did not require or make major use of a Technology Integration Experiment (TIE). There was still substantial cooperation between some of the participants that need to be recognized. The following list is presented without order.

- **Cesium** and **FlightSafety** cooperated on the understanding and development of glTF extensions and OpenFLight feature analysis.
- **Ecere** and **Steinbeis** worked together on the indoor/outdoor display capabilities required by Scenario 2.
- **Cesium's** geospatial client, CesiumJS, was used by **Ecere**, **FlightSafety**, **Steinbeis**, and **Cesium**.

7.3. Results

7.3.1. General Results

- Don't split a 2-week sprint by the member's meeting
- Best to entirely avoid member's meeting week
- glTF needs additional work to fully support geospatial work and CDB in particular

7.3.2. Discovered Inconsistecies

Various inconsistencies with various aspect or external items were discovered. These include OGC Standards, OGC data, modeling standards, and software. Some of the inconsistencies are documented, and others reflect documentation that needs improving.

- Ecere

    - Minor mistake in prototyped CDB X dataset
    - Error in CesiumJS interpertation of empty tiles (a clarification may be needed in 3D Tiles specification)
- FlightSafety
    - OpenFlight coordinate reference system is different than glTF or 3dsMax
        - OpenFlight is a left-handed system with Z-up (Volume 6: OGC CDB Rules for Encoding Data using OpenFlight)
        - glTF is a right-handed system with Y-up [https://github.com/KhronosGroup/glTF/blob/master/specification/2.0/README.md#coordinate-system-and-units]
        - 3DS Max is a right-handed system with Y-up [https://knowledge.autodesk.com/support/3ds-max/learn-explore/caas/CloudHelp/cloudhelp/2020/ENU/3DSMax-Basics/files/GUID-0F3E2822-9296-42E5-A572-B600884B07E3-htm.html#GUID-0F3E2822-9296-42E5-A572-B600884B07E3]
- SimBlocks.io
    - Some open source software is not as reliable or performant as needed

7.3.3. Game Engine Interface

The following participants incorporated game engine (Unreal or Unity) into the client display of geospatial data while working on their chosen scenarios.

- **InfoDao** displayed results in Unity while investigating moving models
- **SimBlocks.io** used Unreal and Unity game engines as the client display when batch converting CDB and other geospatial data.
- **Steinbeis** achieved an indoor / outdoor scenario that incorporated real-time interface to SensorThings API and drone-view that allowed a merged over-the-shoulder and altitude view of the 3D environment. They integrated display capabilities from Unreal Engine (e.g., trees) into their scene.

It was not part of their Sprint work, but it needs to be noted that Cesium has a plugin for Unreal that on-demand imports 3D geospatial data [https://cesium.com/blog/2021/03/30/cesium-for-unreal-now-available/].

7.3.4. Conversion (Scenario 1)

- Timing diagram from InfoDao
- Ecere's work on tiles and LOD
- Simblocks work importing to Unity & Unreal

7.4. Indoor / Outdoor (Scenario 2)

- Steinbeis' work in the video
- Ecere’s work without a game engine

7.4.1. Moving models (Scenario 3)

- Limited results
- See Steinbeis & SimBlocks

7.4.2. glTF as Modenling Standard (Scenario 4)

- FlightSafety’s shuttle model; Materials Variants tree example
- Cesium’s metadata texture
- InfoDao’s real-time building replacement

7.4.3. Other Accomplishments

- Steinbeis create AR app that integrates SensorThings using OGC API’s on back-end servers == Conclusions …

Introduction The ISG Year 2 Sprint started to layout the path from today’s environment with data stored in CBD V1.0 datasets and models stored in OpenFlight to the future. The path indicated by the participants efforts is data-similar and feature-richer then today’s capabilities. This path is most clearly indicated by enhanced capabilities using glTF models, batch-driven and interactive data conversions, and game engine driven displays.

Models stored as glTF glTF models have the potential to offer a visually richer display using current and widely-adopted transmission file format. glTF uses physically based rendering (PBR) for its material model. PBR can more accurate depect real-world materials in all wavelengths than the specular model used by OpenFlight. glTF has a large number of extensions that support much of what is needed in a CDB environment. It was shown by Cesium and OpenFlight that development of features not currently supported by glTF is not difficult. OpenFlight has recommended that CDB start to allow glTF models to be used in a near-future version of CDB.

Data conversions Time-consuming, non-trivial task. Necessary to support the wide range of missions that CDB supports. InfoDao proposed batch conversion for long-term and allow real-time/interactive updates as needed.

Game engine driven displays SimBlocks.io, Steinbeis, and InfoDao (others?) showed how game engines (e.g., Unity or Unreal Engine) can be used to drive the client displays. These engines can be used in desktop, virtual (e.g., headsets), or augmented environments making them one of the most useful client side display drivers.

Conclude The path is laid out through data conversion, use of modern model transmission formats, and standard commercial display engines. Travel along the path needs to be well-planned so that the entire community can fully participate and evaluate the progress. Progress towards this goal needs to be at a pace sufficiently fast to get there without leaving anyone or any critical features behind. There is much development to do and specifications to write

Chapter 8. Component Implementation: Cesium

8.1. Overview

In this Sprint, the Cesium team focused on exploring how extensions to glTF enable runtime-efficient storage and attribution of data stored in OpenFlight [https://www.presagis.com/en/glossary/detail/openflight/], the 3D model format used in CDB [https://www.ogc.org/standards/cdb] datasets. Similarly, the team also investigated extensions to 3D Tiles [https://github.com/CesiumGS/3d-tiles] that facilitated the conversion from CDB to 3D Tiles.

In the previous OGC ISG Sprint, the Cesium team focused on investigating the optimal method of serving 3D content from a CDB dataset into a web viewer. The result of that effort was an open source CDB to 3D Tiles conversion pipeline [https://github.com/CesiumGS/cdb-to-3dtiles]. The results of this Sprint were derived from work done to extend the pipeline to support new extensions to glTF [https://github.com/KhronosGroup/glTF] and 3D Tiles.

8.2. Conversion from *CDB* to *3D Tiles* 1.0

The work in the previous Sprint covered the steps to convert a CDB dataset with 3D models to a 3D Tiles 1.0 tileset. Here's a brief top-down summary:

- Each available dataset is converted to a tileset, with references to each instance of the dataset across geocells.
- The root tileset references all the dataset tilesets.
- The CDB dataset's level of detail hierarchy is used for creating the spatial index in the tileset.json
- The Elevation and Imagery datasets are stitched together to create a terrain tileset.
- Tilesets created from all datasets except GeoTypical models use the Batched 3D Model (.b3dm) format for their content.
- The GeoTypical models use the Instanced 3D Model format (.i3dm) format for their content.
- The metadata for each cultural feature is encoded in the Batch Table.
- The geometry is converted to glTF.

8.3. Conversion from *CDB* to *3D Tiles Next*

8.3.1. Introduction

This section discusses the conversion of data stored in CDB to a new Cesium-developed format 3D Tiles Next [https://github.com/CesiumGS/3d-tiles/blob/3d-tiles-next/3D_TILES_NEXT.md]

8.3.2. Conversion to glTF

As mentioned above, in 3D Tiles 1.0, the B3DM and I3DM formats use glTF to store the geometry and an additional binary payload, called the Batch Table, to store metadata associated with each feature. Features are identified using Batch IDs, which are stored as vertex attributes in the glTF.

There are cases where per-vertex attribution is not sufficient, and per-texel attribution is required. Such is the case with the Raster Material datasets (RMTexture, RMDescriptor), where a raster band in a TIFF file is used to index into an XML file. Such a capability is not currently supported by 3D Tiles 1.0; therefore, an extension to glTF 2.0 was utilized.

8.3.3. Feature Metadata

The Cesium-developed feature metadata extension (EXT_feature_metadata [https://github.com/CesiumGS/glTF/blob/feature-metadata/extensions/2.0/Vendor/EXT_feature_metadata/1.0.0]) to glTF 2.0 enables per-vertex and per-texel attribution of metadata, metadata storage in binary or in textures, and specification of metadata schemas with support for enumerations. Through this extension, metadata can be embedded within the glTF payload, without need for an external payload such as the Batch Table.

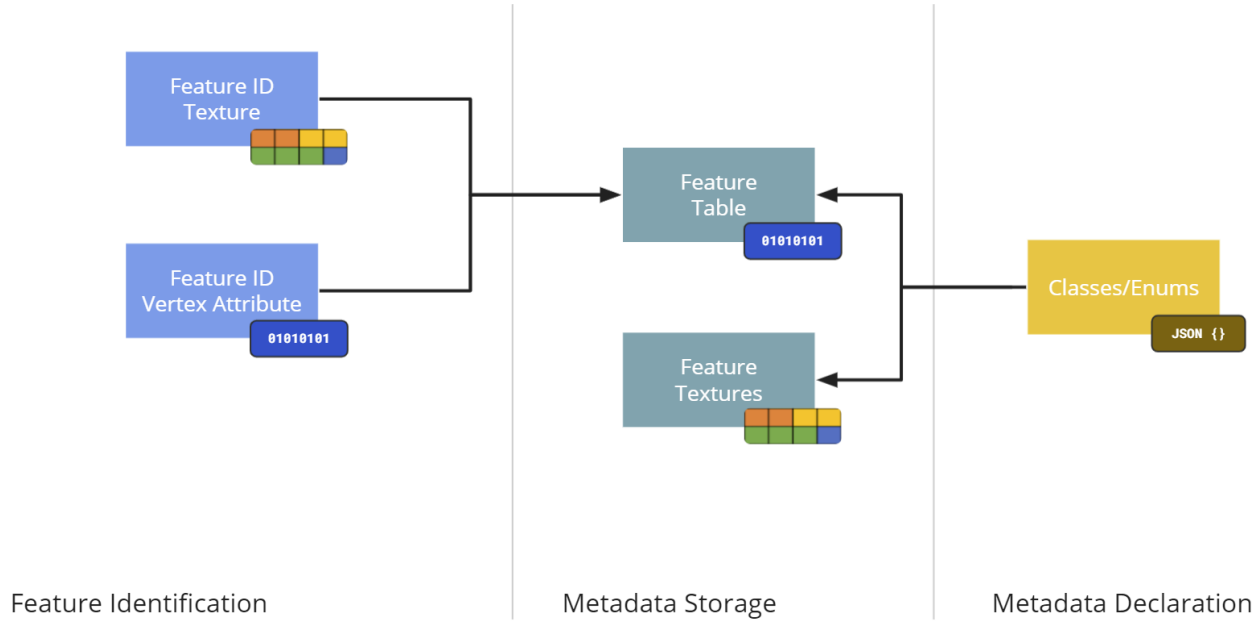


Figure 3. A block diagram showing the high-level data structures implemented in the feature metadata extension.

Per-Texel Metadata - Source Data

The team utilized this extension to store the data in the Raster Material datasets when converting from CDB to 3D Tiles.

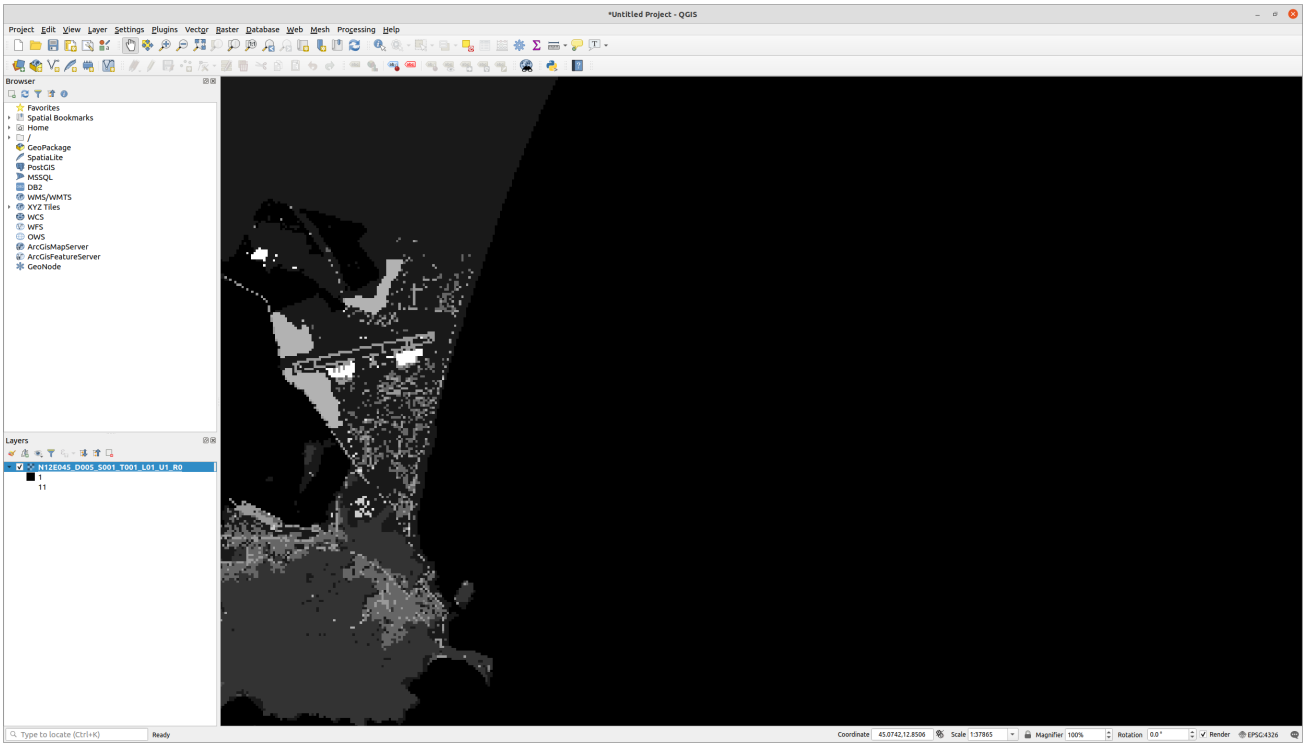


Figure 4. Feature information in the RMTexture from Aden, Yemen CDB (provided by Presagis) stored as TIFF.

The Raster Material datasets are the RMTexture and RMDescriptor datasets, where the RMTexture contains a TIFF file with a raster band, with each texel in the band containing an index value. The value in each texel is an index into a corresponding XML file, in the RMDescriptor dataset, which contains the material information for the area covered by the texel. Each Composite Material may have a Primary Substrate and one or more Secondary Substrates. The weights of all Base Materials in a Substrate must add up to 100.

Composite Material Table

```
<Composite_Material_Table>
    <Composite_Material index="1">
        <Name>OCEAN</Name>
        <Primary_Substrate>
            <Material>
                <Name>BM_WATER-OCEAN</Name>
                <Weight>100</Weight>
            </Material>
        </Primary_Substrate>
    </Composite_Material>
    <Composite_Material index="2">
        <Name>CITY</Name>
        <Primary_Substrate>
            <Material>
                <Name>BM_CONCRETE</Name>
                <Weight>40</Weight>
            </Material>
            <Material>
                <Name>BM_FOLIAGE-DECIDUOUS</Name>
                <Weight>20</Weight>
            </Material>
            <Material>
                <Name>BM_ASPHALT</Name>
                <Weight>20</Weight>
            </Material>
            <Material>
                <Name>BM_WOOD-DECIDUOUS</Name>
                <Weight>10</Weight>
            </Material>
            <Material>
                <Name>BM_SHINGLE</Name>
                <Weight>10</Weight>
            </Material>
        </Primary_Substrate>
    </Composite_Material>
</Composite_Material_Table>
```

The Materials referenced in the Substrate(s) of a Composite Material are stored in the Base Material Table.

Base Material Table

```
<Base_Material_Table>
    <Base_Material>
        <Name>BM_DRYWALL</Name>
        <Description>Drywall panel (aka plasterboard)</Description>
    </Base_Material>
    <Base_Material>
        <Name>BM_MACADAM</Name>
        <Description>Macadam (roadway constructed by compacting into a solid
mass of broken stone using cement or asphalt as binder)</Description>
    </Base_Material>
    <Base_Material>
        <Name>BM_METAL-IRON</Name>
        <Description>Raw iron</Description>
    </Base_Material>
</Base_Material_Table>
```

Per-Texel Metadata - Extension

To bring these values into the EXT_feature_metadata extension, a `class` with `properties` needs to be defined to represent this metadata. In the example below, the `compositeMaterials` class represents a `Composite_Material` element from the Composite Material Table shown above.

EXT_feature_metadata Composite Materials Class

```
{
  "classes": {
    "compositeMaterials": {
      "properties": {
        "name": {
          "type": "STRING"
        },
        "material": {
          "type": "ARRAY",
          "componentType": "ENUM",
          "enumType": "baseMaterials"
        },
        "weight": {
          "type": "ARRAY",
          "componentType": "UINT8"
        }
      }
    }
  }
}
```

To efficiently represent the base materials, they were encoded as an enum (using a `UINT8`) instead of strings. In metadata storage, enums are referenced by their `value`, which can be assigned any value of the selected `valueType`.

EXT_feature_metadata Base Materials Enumeration

```
{
  "enums": {
    "baseMaterials": {
      "valueType": "UINT8",
      "values": [
        {
          "name": "BM_DRYWALL",
          "description": "Drywall panel (aka plasterboard)",
          "value": 0
        },
        {
          "name": "BM_MACADAM",
          "description": "Macadam (roadway constructed by compacting into a
solid mass of broken stone using cement or asphalt as binder)",
          "value": 1
        },
        {
          "name": "BM_METAL-IRON",
          "description": "Raw iron",
          "value": 2
        }
      ]
    }
  }
}
```

The TIFF was converted to a PNG, with the values from the raster band stored in the red color channel of the PNG, and the same texture coordinates as those of the imagery were utilized in the extension at the mesh primitive level, since they cover the same area and use the same projection:

EXT_feature_metadata Primitive Extension

```
{
  "primitives": [
    {
      "attributes": {
        "POSITION": 0,
        "TEXCOORD_0": 1
      },
      "indices": 2,
      "material": 0,
      "extensions": {
        "EXT_feature_metadata": {
          "featureIdTextures": [
            {
              "featureTable": "compositeMaterialsTable",
              "featureIds": {
                "texture": {
                  "texCoord": 0,
                  "index": 0
                },
                "channels": "r"
              }
            }
          ]
        }
      }
    }
  ]
}
```

Finally, the actual values for each composite material was stored in the composite materials feature table, encoded in binary according to the Cesium 3D Metadata Specification [https://github.com/CesiumGS/3d-tiles/tree/3d-tiles-next/specification/Metadata/1.0.0], stored in glTF buffers and references using glTF bufferViews.

Figure 5. CesiumJS visualization of the per-texel metadata from Aden, Yemen CDB. The metadata was overlaid on the satellite imagery of the terrain.

Figure 6. CesiumJS visualization of the per-texel metadata from Aden, Yemen CDB at a low-level of detail. Unlike Figure 5 there were no overlays involved.

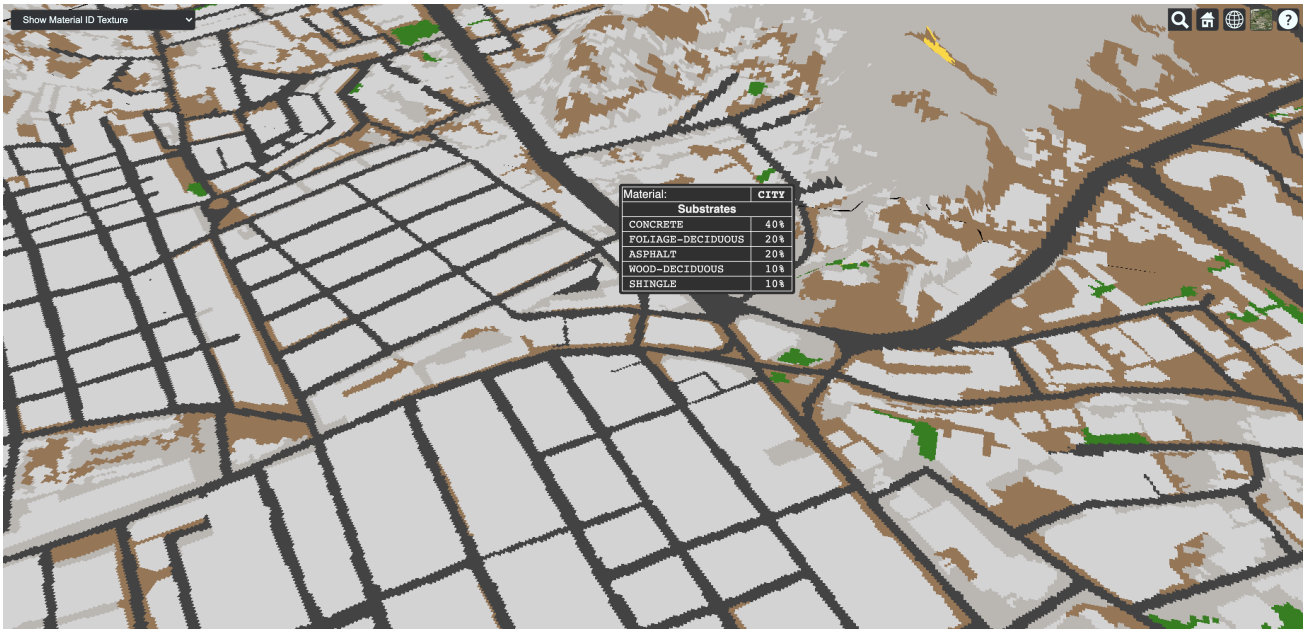


Figure 7. CesiumJS visualization of the per-texel metadata from Aden, Yemen CDB at a high-level of detail taken near the center of Figure 6.

Per-Vertex Metadata

3D Tiles 1.0 supports metadata attribution through vertex attributes in glTF. EXT_feature_metadata takes a similar approach by adding a `_FEATURE_ID` vertex attribute that is used as an index into the Feature Table specified at the mesh primitive. The EXT_feature_metadata extension allows each metadata property to specify an identifier, a name, a data type and a description. As shown in the screenshot below, making these properties available to the user through a user interface helps add more context to the information being presented. It also aids in analysis and helping a user apply the right styling for the tileset.

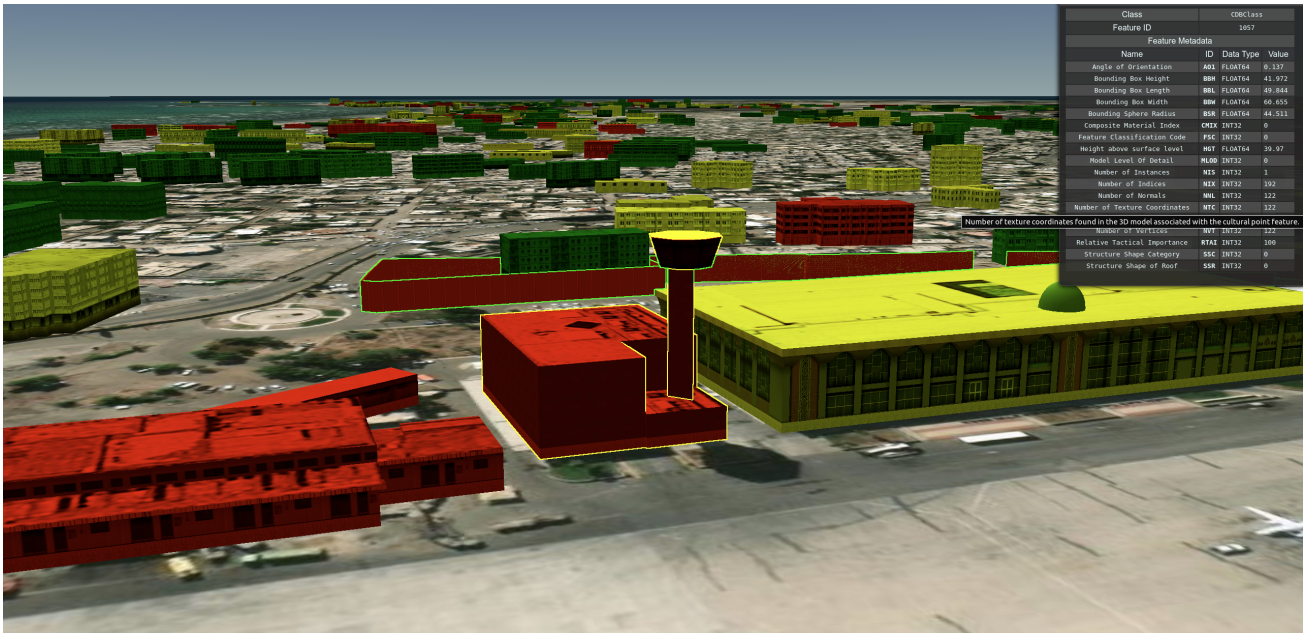


Figure 8. The per-vertex metadata (as opposed to the per-texel metadata shown in figures Figure 5 through Figure 7) from CDB of Aden, Yemen CDB and visualized in CesiumJS. The vertices were classified and color coded according to their metadata.

8.3.4. GPU Instancing of Meshes

In 3D Tiles 1.0, the Instanced 3D Model (.i3dm) format is used to represent instanced meshes. This is the format of choice when converting 3D models from the GeoTypical model dataset. The I3DM format pairs an external payload, called the Feature Table, to the glTF to provide the transforms for each instance of the model. A Batch Table may also be added to include metadata per instance.

In 3D Tiles Next, the EXT_mesh_gpu_instancing [https://github.com/KhronosGroup/glTF/tree/master/extensions/2.0/Vendor/EXT_mesh_gpu_instancing] extension is used to represent instanced meshes. The metadata per instance is stored in the EXT_feature_metadata object, which is applied as an extension to the EXT_mesh_gpu_instancing object.

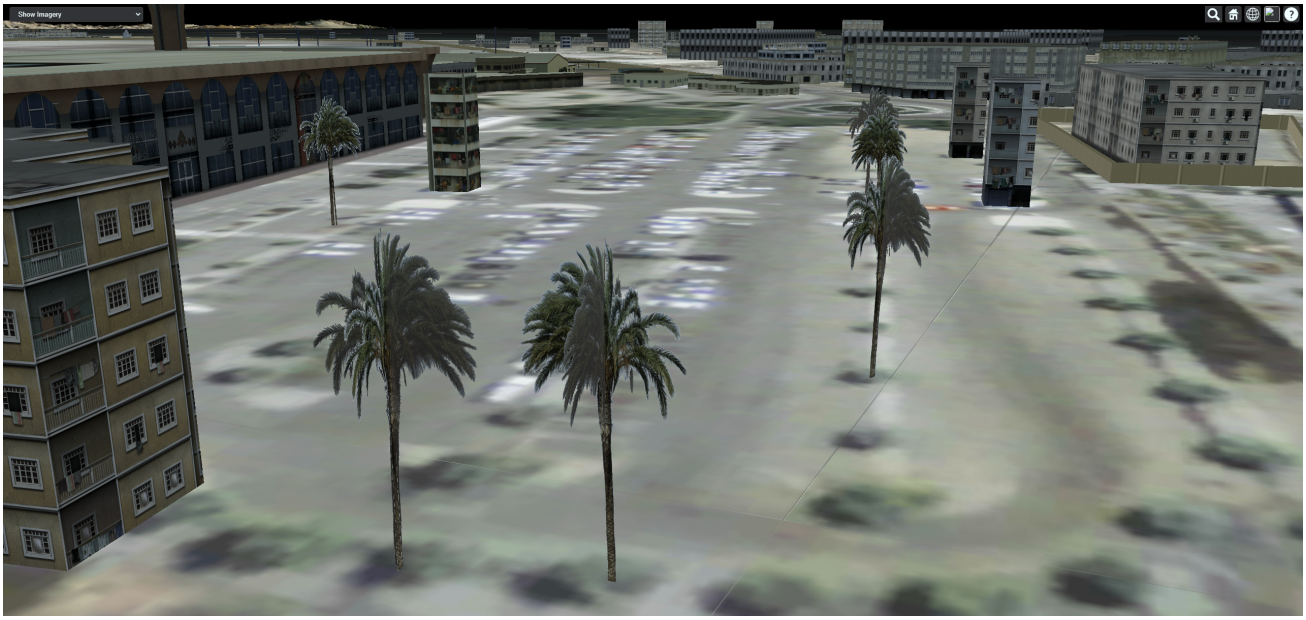


Figure 9. Using the CesiumJS renderer meshes from GeoTypical tree models are stored once and rendered from CDB of Aden, Yemen.

8.3.5. Conversion to 3D Tiles Next

Using glTF as 3D Tiles

The 3DTILES_content_gltf [https://github.com/CesiumGS/3d-tiles/tree/3d-tiles-next/extensions/3DTILES_content_gltf/0.0.0] extension to 3D Tiles enables using glTF files directly as content for tiles. This allows greater compatibility with existing tools that create or process glTF models. Runtime engines that currently support glTF can more easily support 3D Tiles.

Implicit Uniform Tiling

In 3D Tiles 1.0, the tileset.json is used to create a spatial index to obtain a hierarchical level of detail, which helps with runtime performance. This flexibility in the spatial data structure is useful as tilesets may require different spatial hierarchies, based on the type of content and its density. However sometimes a uniform tiling scheme is desired. This is the case for the CDB geocells that subdivide evenly into 4 smaller tiles i.e. in a quadtree structure. The 3DTILES_implicit_tiling

[https://github.com/CesiumGS/3d-tiles/tree/3d-tiles-next/extensions/3DTILES_implicit_tiling] extension enables a compact and efficient representation of such hierarchies, where information about each tile's availability is stored in a bitstream. Additionally, this extension enables random access of a tile in the tileset.

```
{
  "asset": {
    "version": "1.0"
  },
  "extensionsRequired": [
    "3DTILES_implicit_tiling"
  ],
  "extensionsUsed": [
    "3DTILES_implicit_tiling"
  ],
  "root": {
    "children": [
      {
        "children": [
          {
            "content": {
              "uri": "N12E044_D001_S001_T001_L{level}_U{y}_R{x}.glb"
            },
            "extensions": {
              "3DTILES_implicit_tiling": {
                "maximumLevel": 1,
                "subdivisionScheme": "QUADTREE",
                "subtreeLevels": 7,
                "subtrees": {
                  "uri": "subtrees/{level}_{x}_{y}.subtree"
                    }
              }
            }
          }
        ],
        "content": {
          "uri": "N12E044_D001_S001_T001_LC1_U0_R0.glb"
        }
      }
    ],
    "content": {
      "uri": "N12E044_D001_S001_T001_LC2_U0_R0.glb"
    }
  }
}
```

Since each negative level of a CDB geocell has only one descendent and covers the same area as its parent, explicit tiling is used. For the positive levels, the 3DTILES_implicit_tiling extension can be applied. Tiles can be randomly accessed using their level and x-y coordinates in the content

URI template. The folder structure looks as follows:

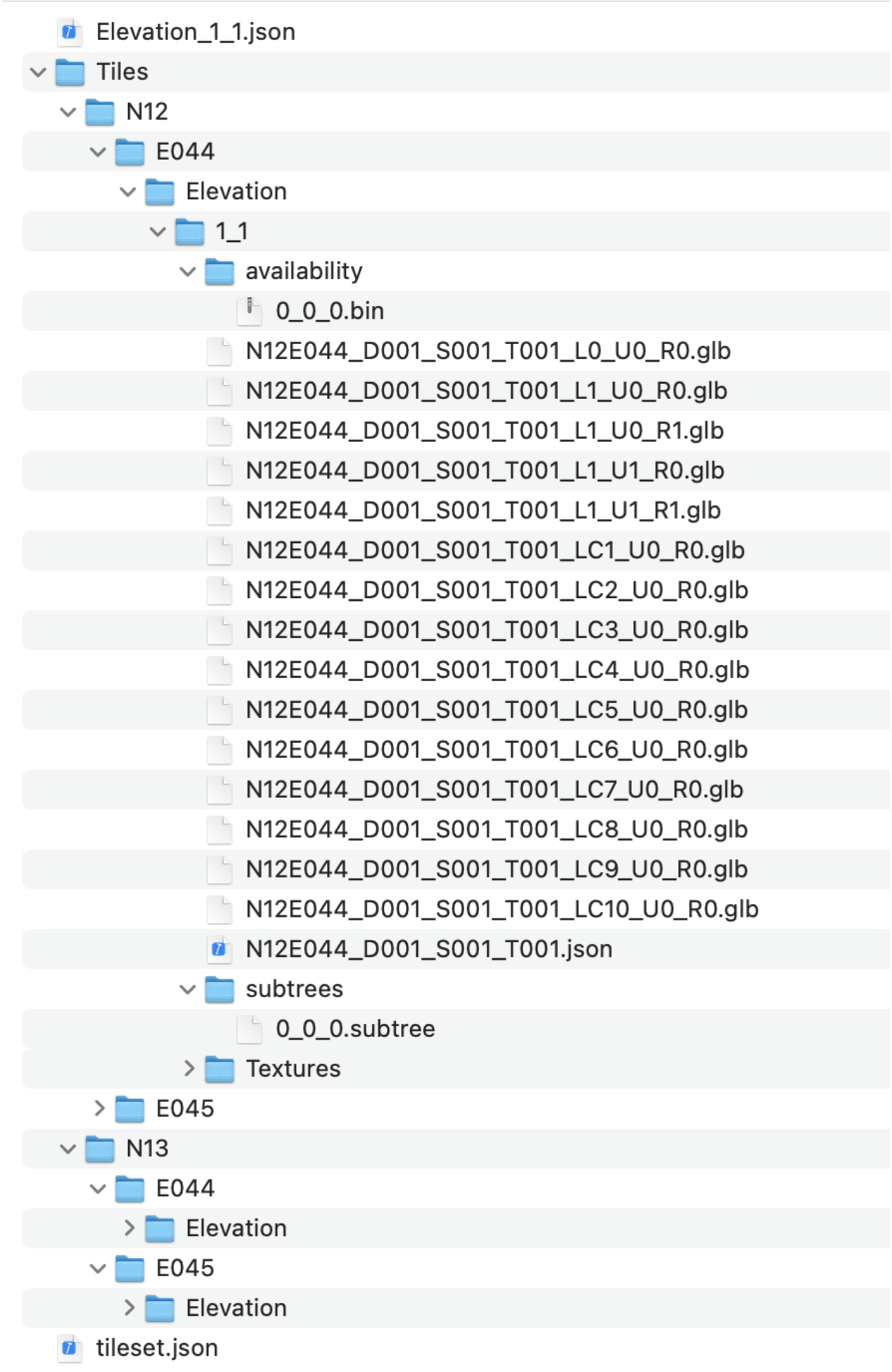


Figure 10. An image showing the folder Structure with the 3DTILES_implicit_tiling extension.

8.3.6. Conclusion

The Cesium team’s efforts resulted in a validation of glTF and 3D Tiles extensions that add new capabilities to 3D Tiles such as implicit tiling and per-texel metadata. These capabilities enable better representation of CDB datasets as 3D Tiles as they retain more semantic metadata and allow for random access for tiles. This yields a much richer simulation environment at runtime and facilitates the dissemination of CDB datasets with optimal runtime performance.

Chapter 9. Component Implementation: Ecere

9.1. Overview

For the second year OGC Interoperable Simulation and Gaming Sprint, Ecere focused efforts on improving visualization and streaming of 3D geospatial content. Those efforts spanned multiple tasks, improving capabilities in its GNOSIS geospatial software [https://ecere.ca/gnosis] for:

- visualizing and distributing the GeoPackage [https://www.geopackage.org/] data store prototype of the next version of the OGC CDB [https://www.ogc.org/standards/cdb] standard,
- generating and visualizing 3D Tiles [http://www.opengis.net/doc/CS/3DTiles/1.0] tilesets,
- distributing and accessing 3D data using 3D extensions of the *OGC API - Tiles* [http://docs.ogc.org/DRAFTS/20-057.html] and *2D Tile Matrix Set and Tileset Metadata* [https://docs.opengeospatial.org/DRAFTS/17-083r3.html] standards and
- importing and exporting 3D models between glTF [https://www.khronos.org/gltf/], COLLADA [https://www.khronos.org/collada/] and Ecere's E3D open 3D model format [https://github.com/ecere/E3D-spec].

9.2. CDB X Prototyped GeoPackage Store

In the 2020 3D Tech Sprint to lay the foundations for the next version of the OGC CDB standard, provisionally named CDB X, Ecere was part of the team prototyping a data store for it based on the OGC GeoPackage standard and extensions.

In this year's ISG Sprint, Ecere aimed to visualize the San Diego dataset produced according to this prototyped CDB X data store as well as provide distributions sourced directly from it.

Good progress was made towards achieving this goal.

As a result of the visualization attempts, some minor mistakes were identified in the prototyped CDB X dataset, including a mismatched reference to a GeoPackage table where the `tiles_` prefix should not have been included, as well as wrong scaling and offset values in tables for the Gridded Coverage extension used for representing elevation data. Once corrected, Ecere plans to update those GeoPackage CDB X data store prototypes which are hosted on the OGC portal within a directory of the CDB SWG [https://portal.ogc.org/index.php?m=projects&a=view&project_id=466&tab=2&artifact_id=95315].

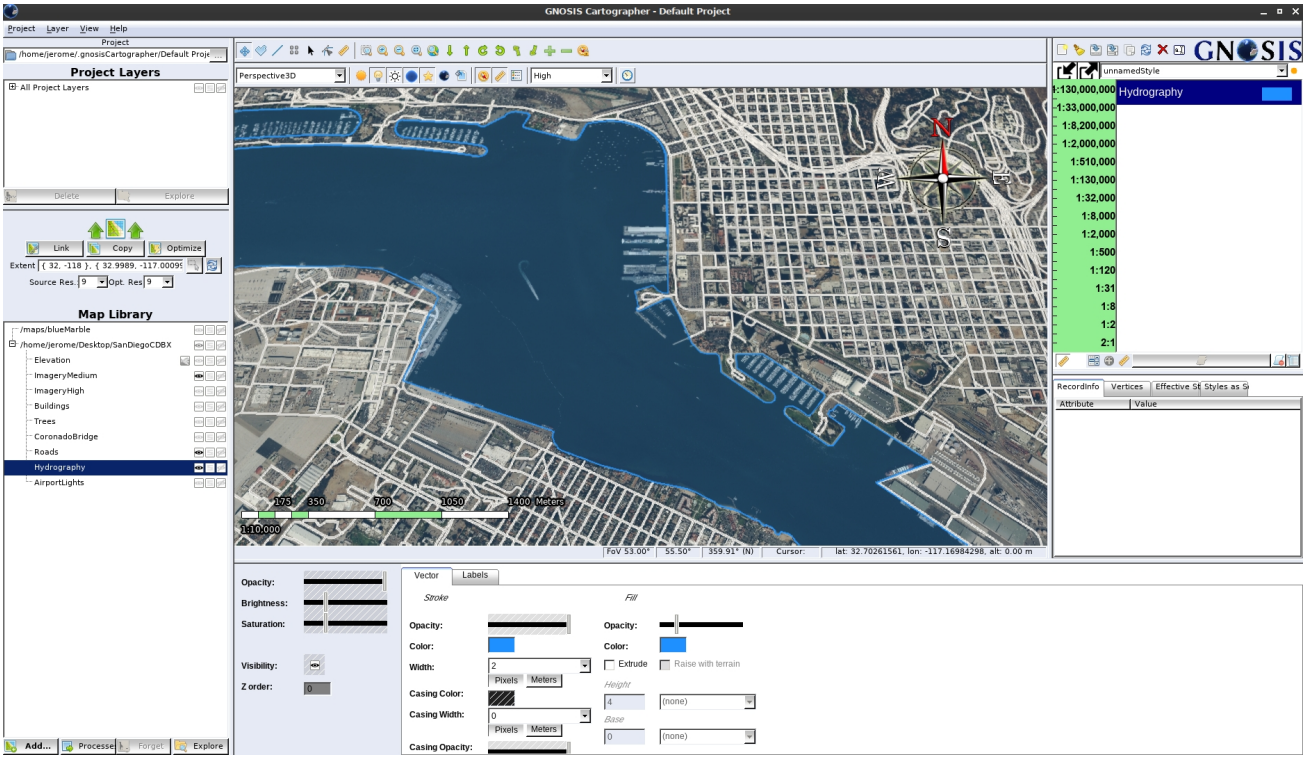


Figure 11. Imagery, roads and hydrography from San Diego CDB X prototype configured with 5-LODs per GeoPackage visualized using new GNOSIS CDB X data store in GNOSIS Cartographer.

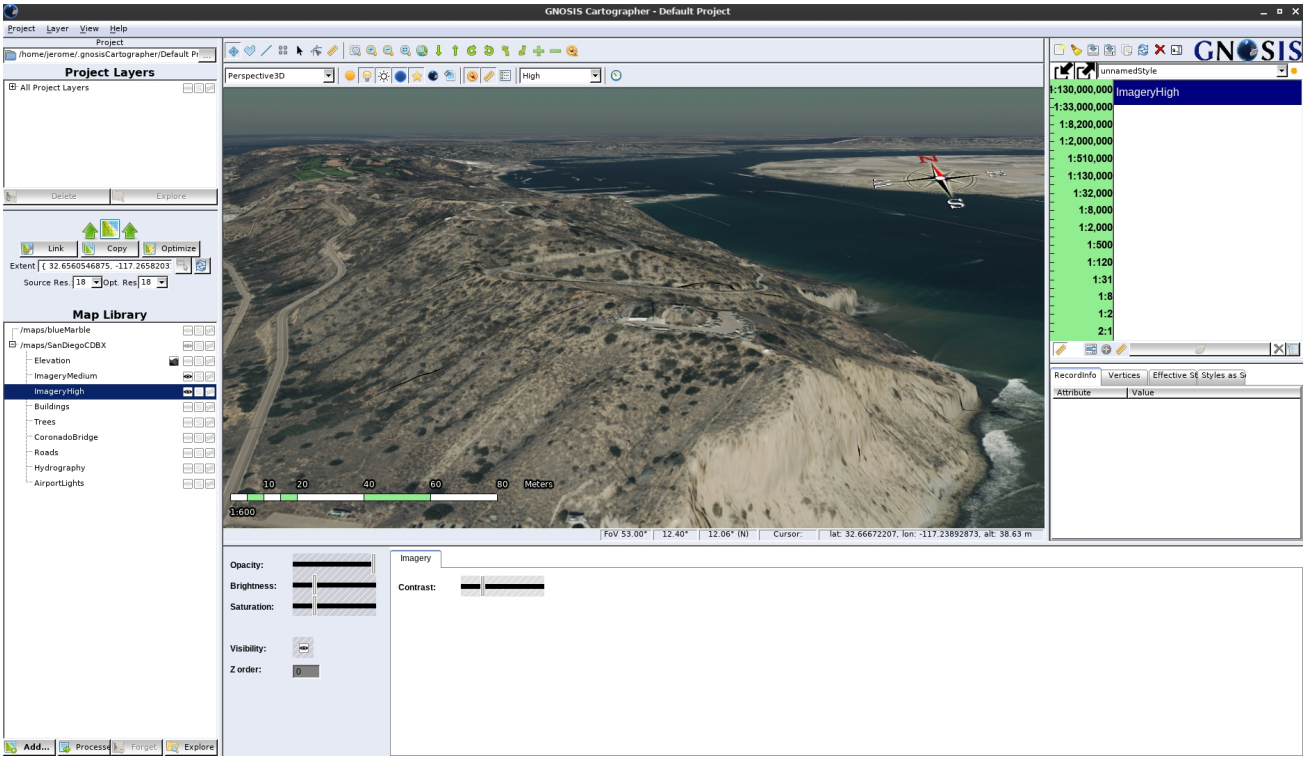


Figure 12. Imagery and 3D Terrain from San Diego CDB X prototype configured with 5-LODs per GeoPackage visualized using new GNOSIS CDB X data store in GNOSIS Cartographer.

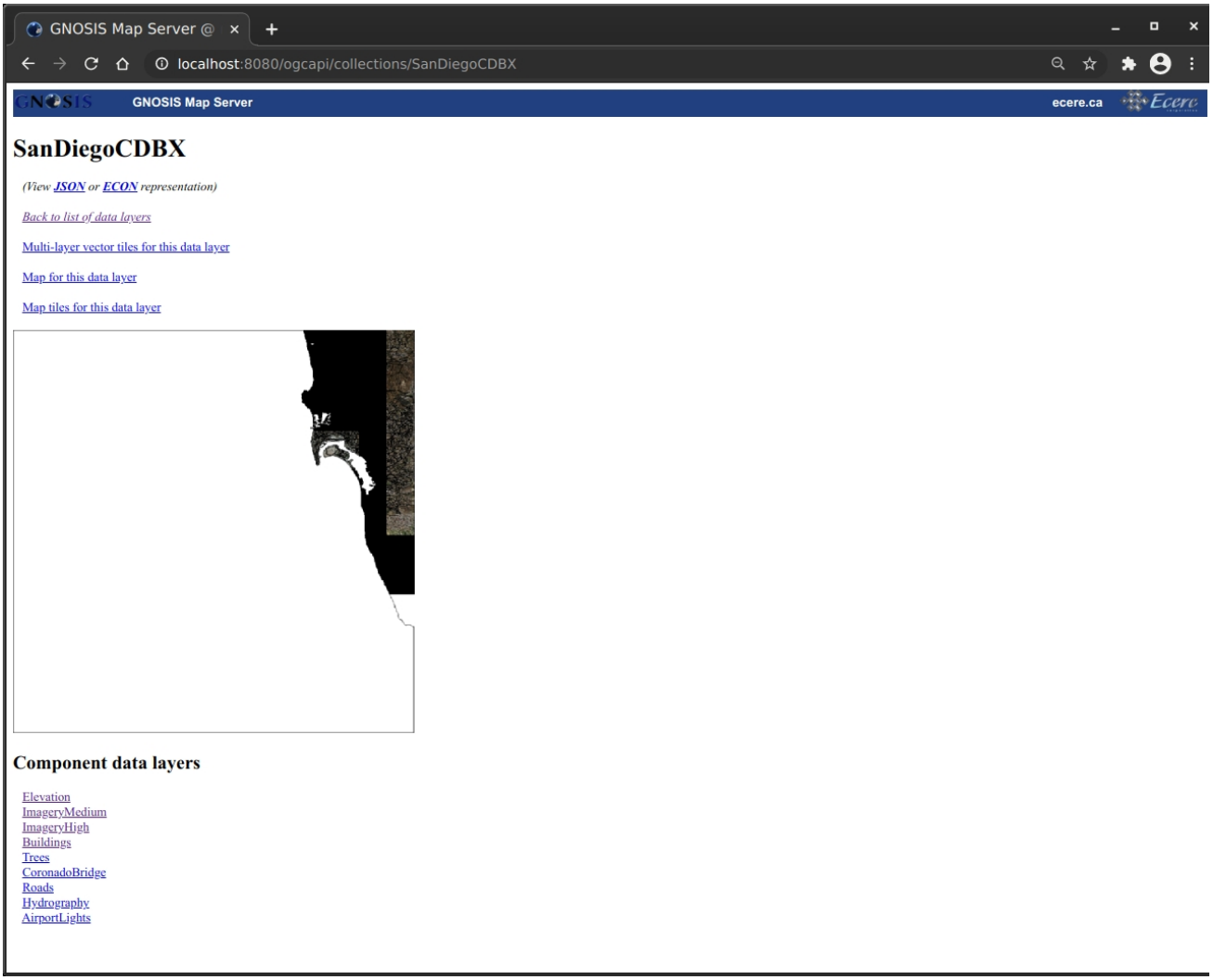


Figure 13. San Diego CDB X prototype configured with 5-LODs per GeoPackage served directly in GNOSIS Map Server using new CDB X data store.

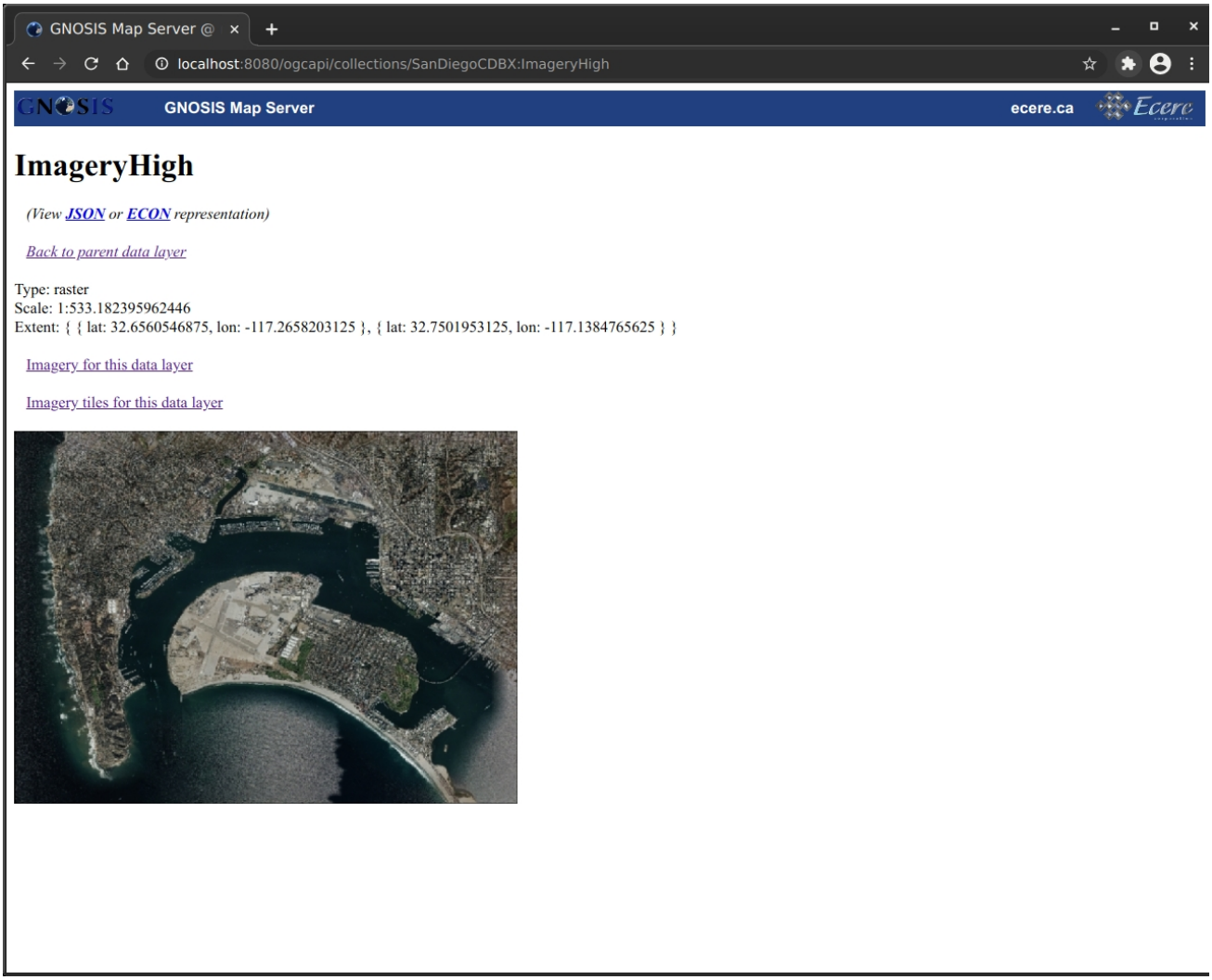


Figure 14. High resolution imagery from San Diego CDB X prototype configured with 5-LODs per GeoPackage served directly in GNOSIS Map Server using new CDB X data store.

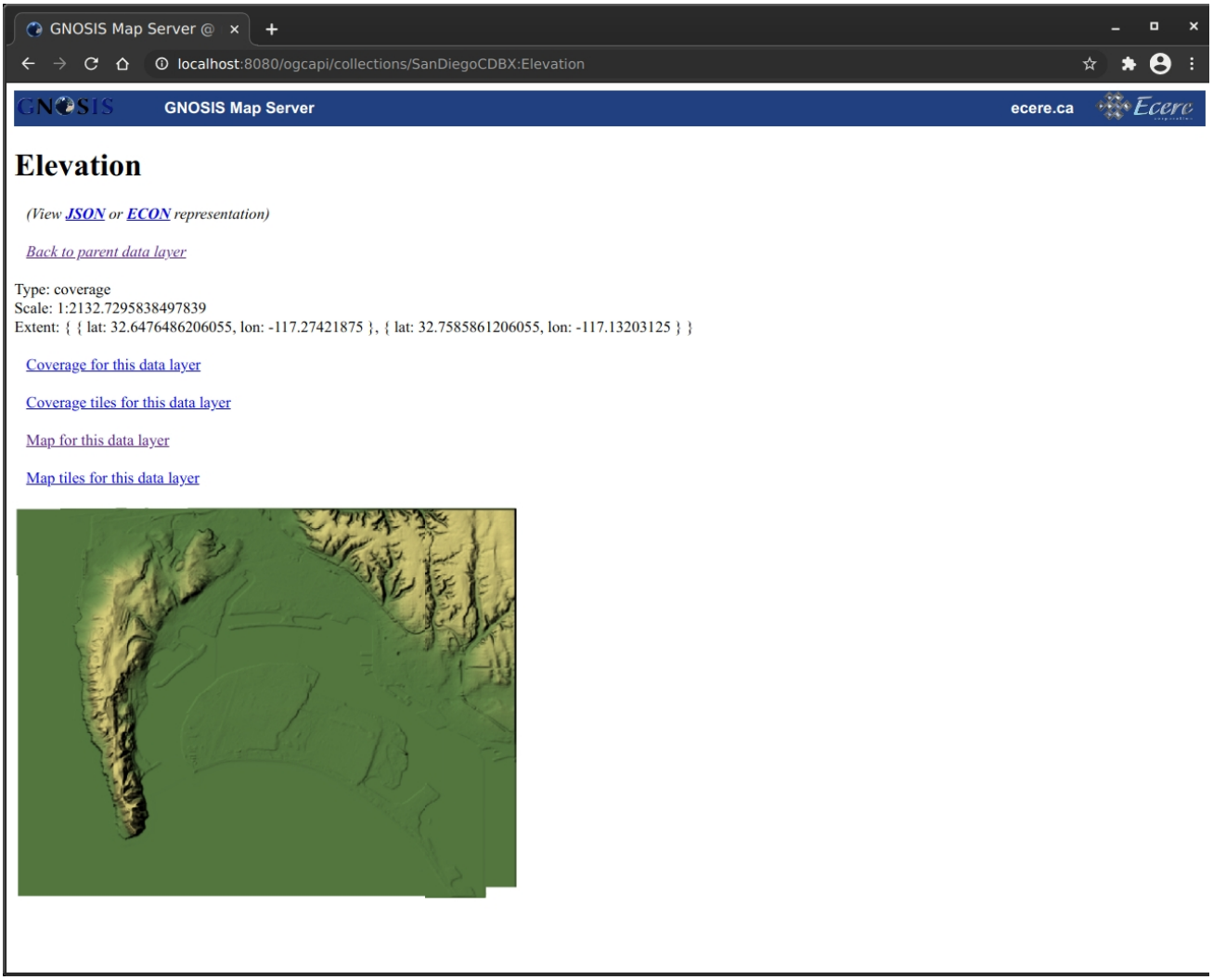


Figure 15. Elevation data from San Diego CDB X prototype configured with 5-LODs per GeoPackage served directly in GNOSIS Map Server using new CDB X data store.

9.2.1. Configuration of data layers and zoom levels grouping

A key aspect of the proposed CDB X GeoPackage store is a configurable and deterministic system to partition very large datasets. This allows a global data at high resolution to be particioned into multiple GeoPackages, allowing the system to balance the number of files with the size of each file. In one configuration, a single GeoPackage may contain the entire CDB content for a small area, making it easy to pre-load on mobile devices, e.g. for a specific mission. In another configuration, an individual GeoPackage may contain only a particular data layer, such as e.g. terrain elevation, satellite imagery or 3D models.

A decision can also be made whether data should be split into multiple GeoPackages based on geographic location or not. When such a split is desired, each GeoPackage can still regroup multiple data tiles within the same extent. One purpose of tiles is to ensure a deterministic amount of data being loaded at any given time for any camera location. For this reason, tiles have an associated "zoom level" (a "tile matrix" in the 2D Tile Matrix Set standard), and tiles of lower zoom levels would contain data at lower resolution but cover a larger geographic extent. The grouping of multiple tiles inside a single GeoPackage is therefore decided by configuring how many zoom levels of tiles will be contained within a single GeoPackage tile pyramid. The GeoPackages file and directory names will be identified by the lowest resolution tile contained

within, and will contain all tiles within the extent of that tile for the next (more detailed) zoom levels up to that configured maximum number of grouped zoom level. The grouping of zoom level starts from the maximum level so as to minimize the file count, so that if the total number of zoom levels is not divisible by the zoom level grouping, the GeoPackages starting grouping tiles at level 0 will contain fewer zoom levels. Details can be found in the Tiling section [https://github.com/sofwerx/cdb2-eng-report/blob/master/11-tiling-coverages.adoc] of the CDB X Tech Sprint Discussion Paper (OGC document number 20-092).

During the Sprint, Ecere implemented the capability to present a CDB X GeoPackage data store as a single data source with nested data layers, each representing components such as terrain elevation, satellite imagery or 3D models, supporting any of the possible configurations of how data layers and tiles are grouped. The configuration is read from the proposed `cdb.json` file describing how the data is packaged. These data sources can then be visualized in GNOSIS Cartographer, or distributed from GNOSIS Map Server as either 3D Tiles tilesets (with support for the GeoVolumes API) or through OGC API - Tiles, including 3D extensions for retrieving 3D models. Ecere developed a new dedicated data store driver for CDB X to be able to access data as needed from different GeoPackages based on different configurations and manage the use of multiple databases at once. The GNOSIS GeoPackage driver was also refactored to facilitate code re-use with this new CDB X data store.

9.2.2. GeoPackage 3D Models extension

A second important aspect of the proposed CDB X GeoPackage store is an extension for storing 3D models inside GeoPackages. Those 3D models may be stored in a shared 3D models table and instanced at multiple geographic locations, which is particularly useful for geotypical models such as trees making up a forest. They may also be batched 3D models, best suited for geospecific models, where all 3D models within a tile are stored inside a single tile blob of a GeoPackage tiles table record. In either case, the format of the model may be OpenFlight or glTF, or an alternate format such as E3D [https://github.com/ecere/E3D-spec] in the case of some of the Ecere experiments. In the instancing approach, either regular vector point features (encoded as Well Known Binary) or GeoPackage vector tiles would contain the geographic coordinates allowing geo-referencing of the 3D model, and optionally additional attributes orienting and/or scaling the model, as in the OGC CDB 1.x standard. In the batched 3D models approach, the origin of the 3D model is the center of the tile at the ellipsoid height. The 3D model is oriented relative to the tangent of the Earth surface at the geo-referencing position so that:

- the positive X axis of the 3D model points Eastwards,
- the positive Y axis of the 3D model points upwards away from the center of the Earth, and
- the positive Z axis of the 3D model points Northwards for model formats using a left-handed coordinate system (such as E3D), but Southwards for model formats using a right-handed coordinate system (such as OpenFlight and glTF).

In the case of instanced models, any specified rotation is relative to this orientation.

A positive rotation specified outside of the model itself is counter-clockwise when looking in the positive direction of the axis around which the rotation is performed. For roll, this follows the left-

handed coordinate system rules as they align with the cardinal direction signs, i.e. a positive roll rotating around the South-North axis banks counter-clockwise to the left.

During the Sprint, Ecere migrated the draft specifications for this 3D models extension [https://github.com/ecere/geopackage/tree/master/spec/3d-models] (developed during the CDB X tech sprint) to a fork of the official GeoPackage repository. Work is ongoing to improve these specifications to take the form of formal requirements and use OGC templates for specifications. Ecere also began implementing support for directly accessing those 3D models in the GNOSIS GeoPackage and CDB X drivers, so that they can be visualized in GNOSIS Cartographer and published from GNOSIS Map Server.

9.3. 3D Tiles distribution

9.3.1. Generating tilesets

Ecere improved the generation of 3D Tiles tilesets in its GNOSIS Map Server. A sample of the newly generated 3D Tiles tileset is available for the San Diego buildings here [https://maps.ecere.com/ogcapi/collections/SanDiegoCDB:Buildings/3DTiles/tileset.json]. One major improvement was generating 3D Tiles for data at lower resolution levels and associating a correct geometric error to each level. This enabled visualization clients such as the CesiumJS library to perform better while loading data for a larger geographic area. Models further away can be presented at lower resolution, while those closer to the camera can be displayed at full resolution. Lower resolution tiles may also contain fewer models than higher resolution ones. The 3D Tiles tilesets generated by the GNOSIS Map Server leverage the *OGC API - Tiles* end-points and the GNOSIS Global Grid tile matrix set. Therefore the geometry inside each batched 3D models (`.b3dm`) 3D Tile is oriented relative to the tangent of the Earth surface at the center of the tile so that:

- the positive X axis of the 3D model points Eastwards,
- the positive Y axis of the 3D model points upwards away from the center of the Earth, and
- the positive Z axis of the 3D model points Southwards, since glTF models use a right-handed coordinate system

The JSON tileset description then provides transformation matrices re-orienting the models in the Earth Centered Earth Fixed (ECEF) 3D Cartesian system expected by *3D Tiles*. Ecere suggests that such a setup could be one kind of implicit tiling schemes supported by *3D Tiles Next*, based on the *2D Tile Matrix Set and Tileset Metadata* standard, where a client would not require a JSON tileset description at all, and tiles could be directly accessed in a deterministic manner, as in CDB.

It was particularly difficult to correctly populate these transformations, especially as each level is relative to the parent tile's transform. Each level may or may not provide a content payload and additional rules determine the mapping of glTF model axes to 3D Tiles.

A major challenge encountered had to do with the presence of one of parent tiles in a hierarchy not having an associated content payload. In this case, setting the refinement method to `REPLACE`

prevented refinement of the tileset for CesiumJS, with the result that more detailed levels would never be requested. CesiumJS appears to not consider that all children were refined since one of them had no content specified at a particular level and its geometric error was not suitable for refinement yet, and as a result none of its siblings tile (already suitable for refinement based on their geometric error) would be refined either. Various attempts at tweaking the refinement mode at different levels of the hierarchy and figuring out the proper interpretation of the specifications were made but to no avail. A previously reported CesiumJS issue [https://github.com/CesiumGS/cesium/issues/9356] was discovered that seems to describe this exact problem. It is not clear if this is a bug in the code or the 3D Tiles specifications not properly explaining this behavior. To work around this issue, Ecere added a `.b3dm` file with empty content for those parent tiles with no associated content and this solved the issue:

```
"content" : { "uri" : "/ogcapi/empty.b3dm" },
```

Since the client behaves as expected with this awkward work-around, Ecere's opinion is that the behavior of the CesiumJS implementation should be fixed to reflect the likely interpretation of the 3D Tiles specifications.

While the generated tilesets, like the source CDB data, re-used shared textures with the same external URLs for different models, it was noted that the CesiumJS implementation does not yet seem optimized to take this into account. This may result in a very significant unnecessary overhead in texture memory usage which was also highlighted by other participants as a major challenge in distributing and accessing content 3D Tiles generated from CDB.

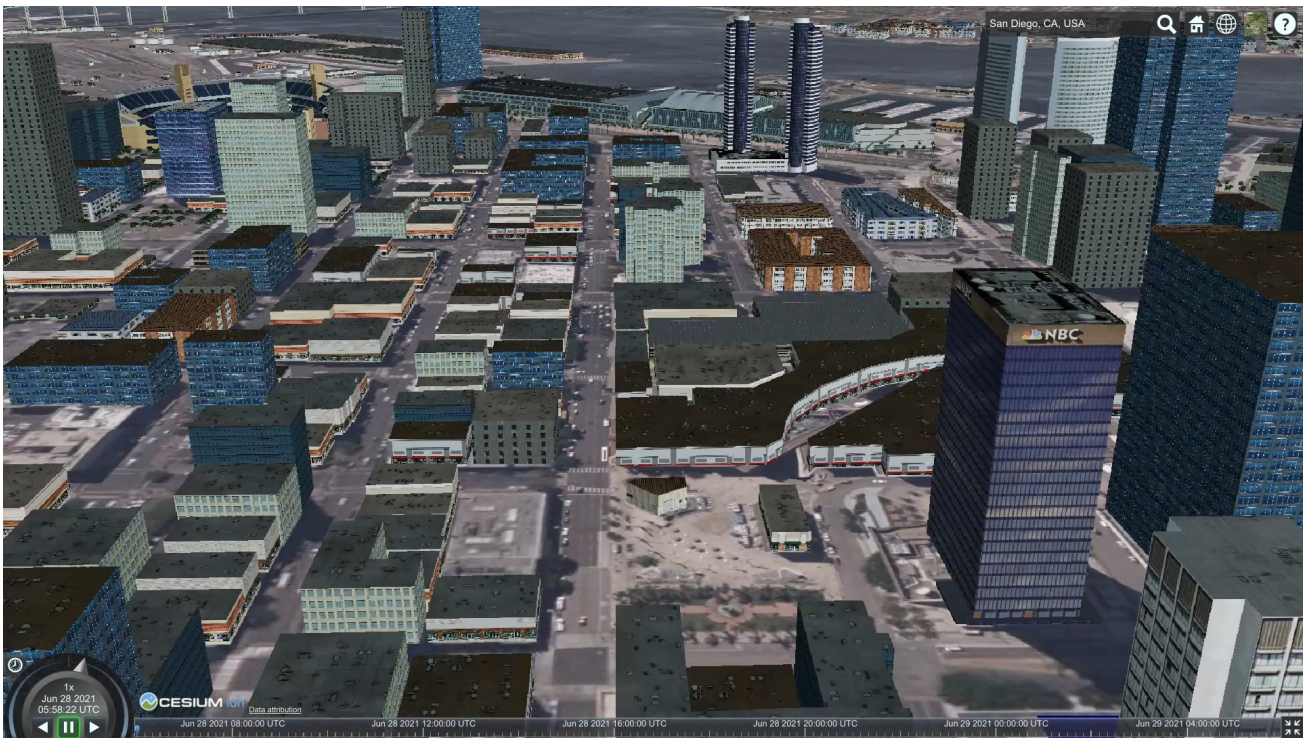


Figure 16. Using CesiumJS to visualize the generated San Diego 3D Tiles tilesets.

Figure 17. Using CesiumJS to visualize a second view of the generated San Diego 3D Tiles tilesets.

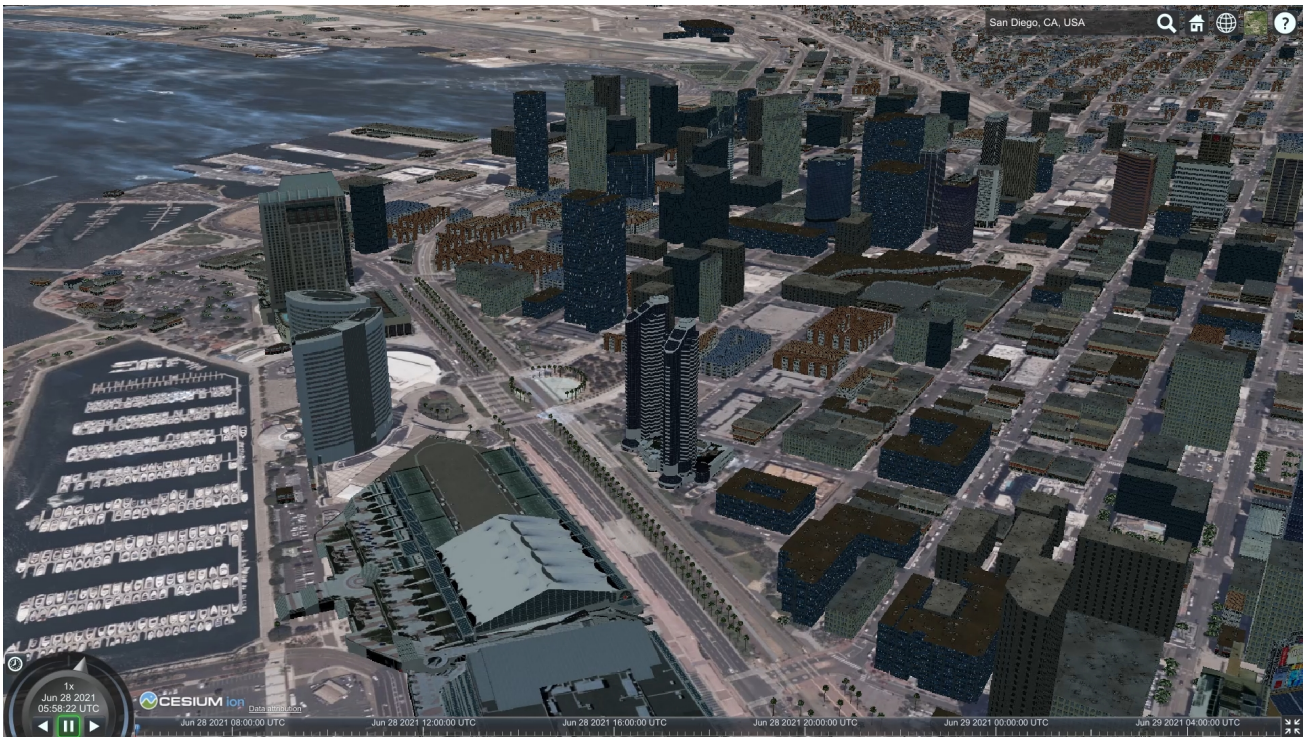


Figure 18. Using CesiumJS to visualize a third view of the generated San Diego 3D Tiles tilesets.

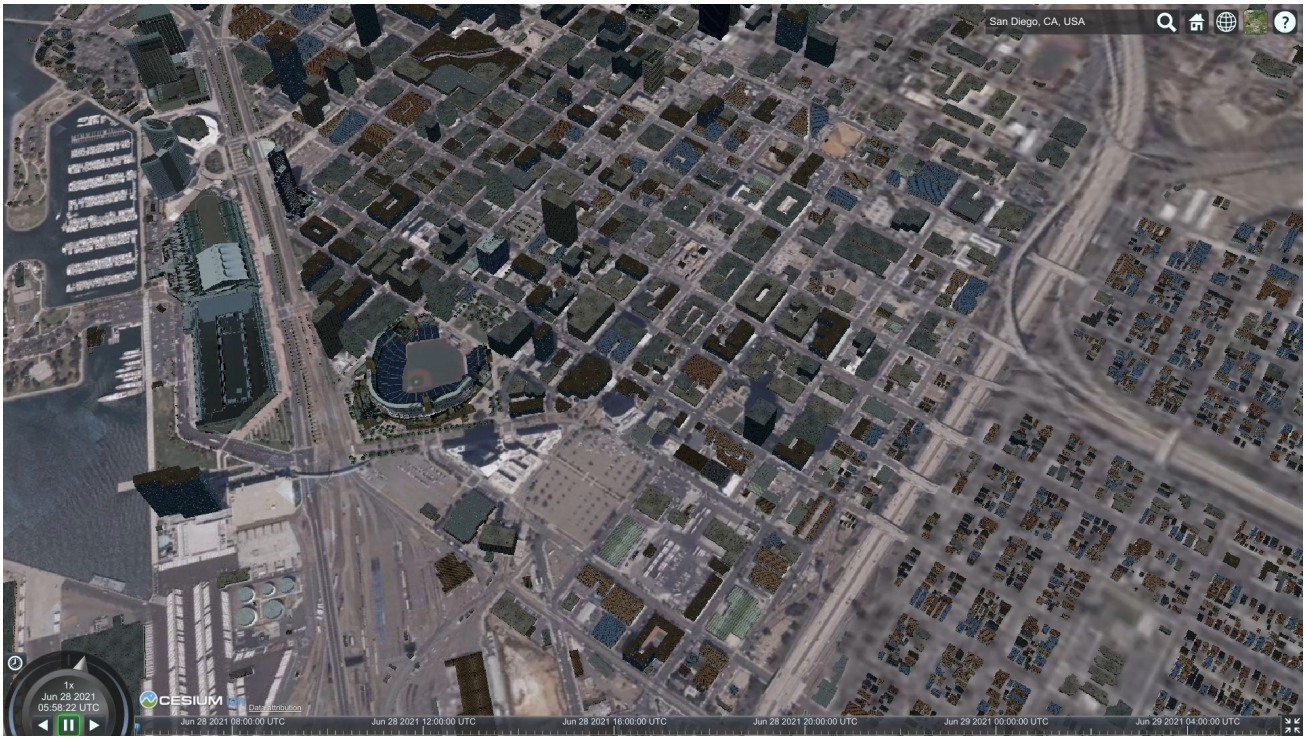


Figure 19. Using CesiumJS to visualize a top-down view with many models of the generated San Diego 3D Tiles tilesets.

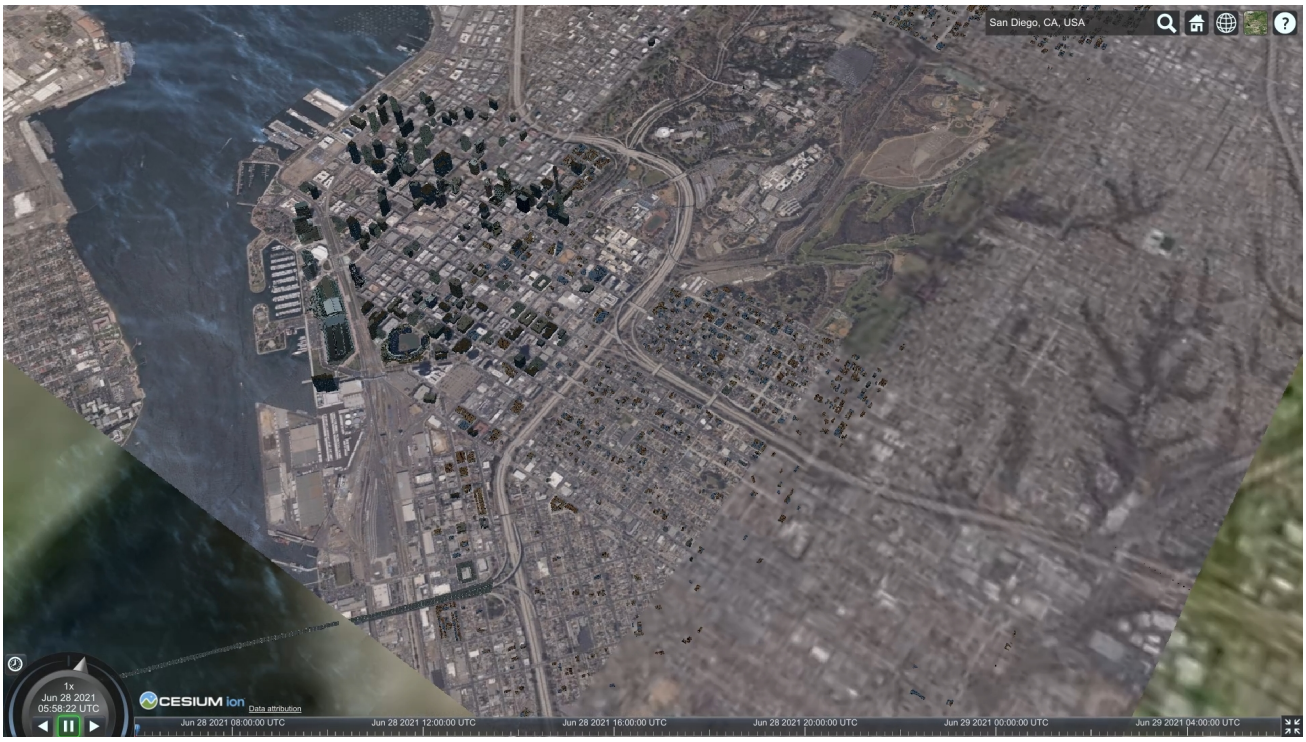


Figure 20. Using CesiumJS to visualize a top-down view with fewer models (relative to Figure 19) of the generated San Diego 3D Tiles tilesets.

Figure 21. Using CesiumJS to visualize a top-down view with minimal models (relative to Figure 19 and Figure 20) of the generated San Diego 3D Tiles tilesets.

9.3.2. Client visualizing *3D Tiles*

Ecere improved its *3D Tiles* client to better handle tilesets generated using different approaches, such as where transforms are specified. This was necessary to properly visualize the new tilesets generated by the GNOSIS Map Server which now contains transforms at different levels of the hierarchy. The variability in how transforms are specified, such as differences between tilesets generated prior to 3D Tiles version 1.0, the RTC extension, and the optional presence of transforms at different levels of the hierarchy or at the root of the tileset, the fact that transforms are relative to parent transforms as well as an implied change of orientation between glTF and 3D Tiles makes properly handling transformations quite difficult.

Multiple datasets were used for validating these improvements, including the new San Diego tilesets generated by the GNOSIS Map Server, the New York OpenStreetMap 3D buildings from the 3D Containers & Tiles pilot and the OGC Testbed 13 Berlin dataset from Virtual City Systems. More testing with additional datasets is planned to ensure the logic is now correct.

Ecere also attempted to visualize the data provided by the Steinbeis *GeoVolumes* server; however, the GNOSIS client was not able to handle the coordinates which seemed to be specified in a projection with no clear indication of how the geo-referencing should be done.

9.4. *OGC API - Tiles* distribution

In previous initiatives, including the OGC Testbed 14 CityGML and Augmented Reality [https://docs.ogc.org/per/18-025.html], 3D Containers and Tiles pilot [https://docs.ogc.org/per/20-029.html], and last year's ISG Sprint [http://docs.ogc.org/per/20-087.html], Ecere prototyped and demonstrated a simple approach to deliver 3D content by leveraging and extending the *OGC API -*

Tiles specifications. In this year's sprint, Ecere further improved support for this approach in both its GNOSIS Map Server and its GNOSIS Cartographer visualization client. Additionally, Ecere developed a new informative annex [https://docs.opengeospatial.org/DRAFTS/17-083r3.html#annex-extending-additional-dimensinos] for the *2D Tile Matrix Set & TileSet Metadata* standard extending its capabilities to support content of higher dimensions, such as 3D content. This annex will form a basis for standardizing temporal and 3D extensions for *OGC API - Tiles*. Furthermore, as a result of an increased appreciation of the simplicity and interoperability of this approach, the charter for the *GeoVolumes* standard working group was expanded to cover the development of such extensions to *OGC API - Tiles* as a mechanism to deterministically access 3D data for a specific area of interest, in a manner agnostic to the format of the data.

Extensions specific to 3D models would also be developed for both:

- points vector tiles referencing and instancing shared models (available from a new `⋯/models/{modelId}` resources path within the OGC API *collection*), which can also contain additional properties to orient and scale individual models, best suited for geotypical models,
- batched 3D models where a tile's payload batches all 3D models contained within the tile's extent, best suited for geospecific models, which are oriented relative to the tangent of the Earth surface at the center of the tile so that:
  - the positive X axis of the 3D model points Eastwards,
  - the positive Y axis of the 3D model points upwards away from the center of the Earth, and
  - the positive Z axis of the 3D model points Northwards for model formats using a left-handed coordinate system (such as E3D), but Southwards for model formats using a right-handed coordinate system (such as OpenFlight and glTF).

A positive rotation specified outside of the model itself is counter-clockwise looking in the positive direction of the axis around which the rotation is performed. For roll, this follows the left-handed coordinate system rules as they align with the cardinal direction signs, i.e. a positive roll rotating around the South to North axis banks counter-clockwise to the left.

Both approaches could also re-use textures also available from a new `⋯/textures/{textureId}` resources path within the OGC API *collection*.

For shared 3D models, supported formats may include glTF, OpenFlight, or alternatives such as the open E3D model format [https://github.com/ecere/E3D-spec] developed by Ecere. For geospecific tiles payloads, supported formats may additionally include *3D Tiles* formats such as `.b3dm`, and may also be directly linked as the `content` for defining *3D Tiles* tilests.

The imagery and elevation components from CDB 1.x or CDB X data stores can be delivered without the need for an extension, as map tilesets and coverage tilesets respectively.

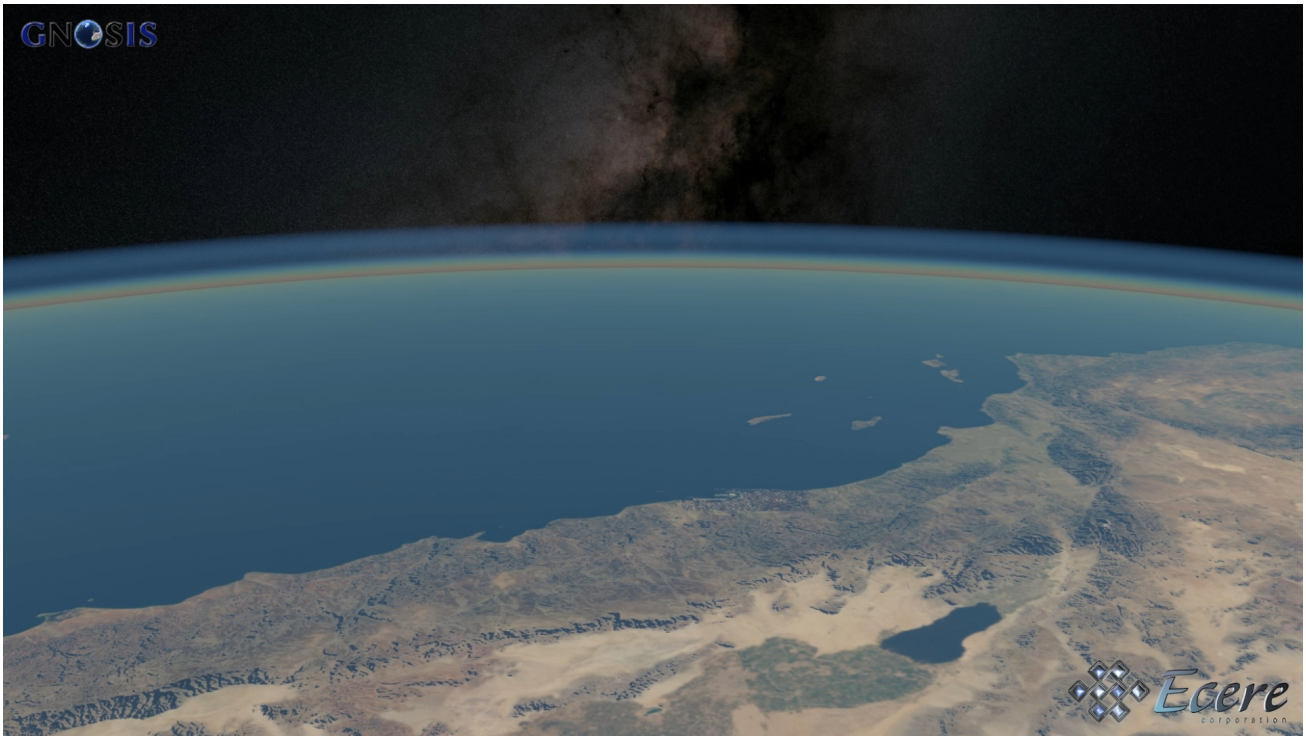


Figure 22. A composite visualization of the San Diego CDB dataset in GNOSIS Cartographer client. High altitude view showing Gaia Sky in color from ESA, Visible Earth Blue Marble from NASA, and elevation data from Jonathan de Ferranti's ViewFinderPanorama (including data from SRTM, NASA / USGS).

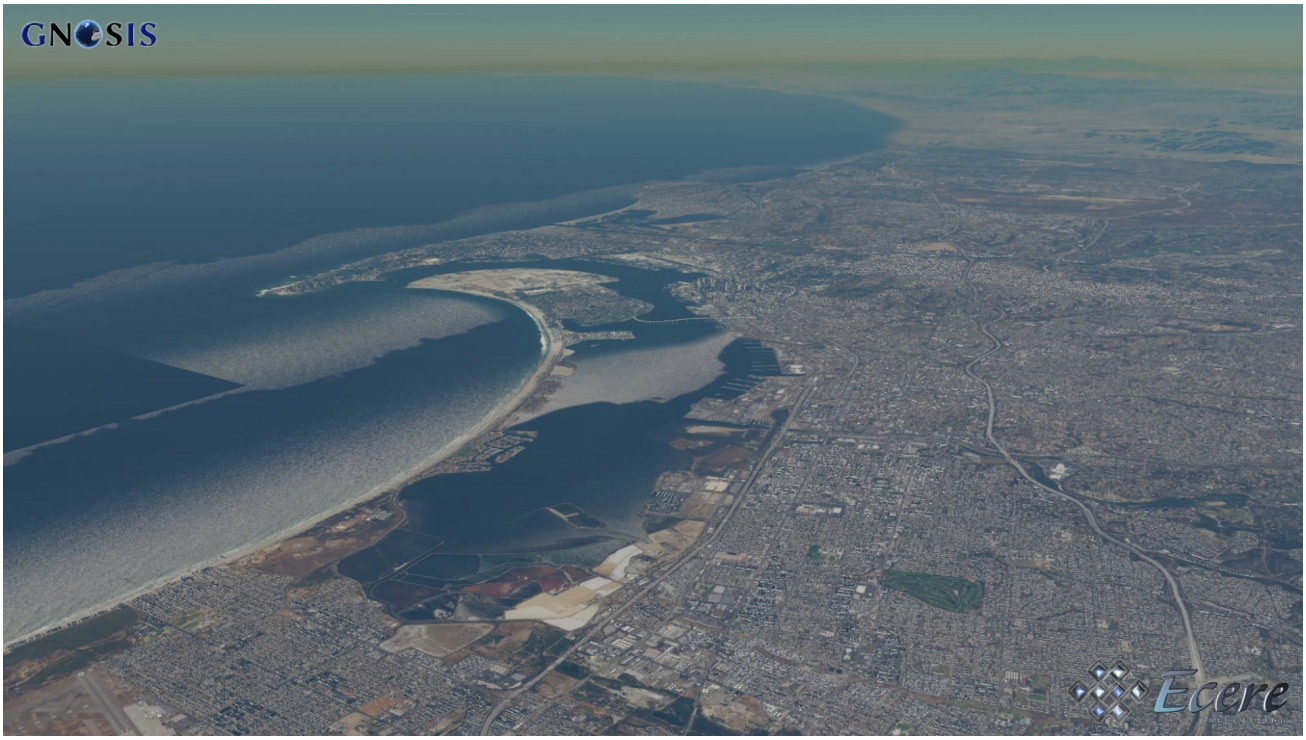


Figure 23. A composite visualization of the San Diego CDB dataset in GNOSIS Cartographer client at lower elevation relative to Figure 22.

Figure 24. A composite visualization of the San Diego CDB dataset in GNOSIS Cartographer client showing all of San Diego Bay.

Figure 25. A composite visualization of the San Diego CDB dataset in GNOSIS Cartographer client showing Coronado Cays.

Figure 26. A composite visualization of the San Diego CDB dataset in GNOSIS Cartographer client with downtown San Diego in the background.

Figure 27. A composite visualization of the San Diego CDB dataset in GNOSIS Cartographer client showing Coronado Bridge.

Figure 28. A composite visualization of the San Diego CDB dataset in GNOSIS Cartographer client showing Petco Park.

Figure 29. A composite visualization of the San Diego CDB dataset in GNOSIS Cartographer client showing Children's Park.

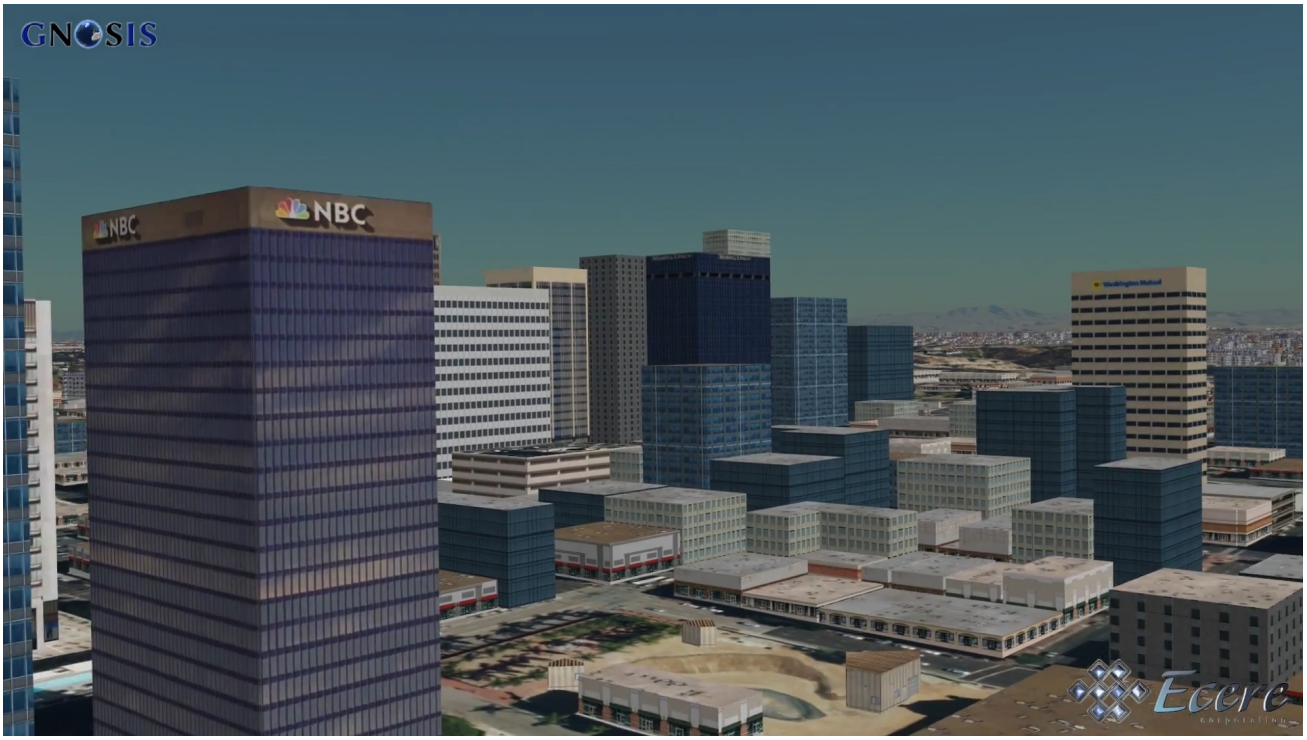


Figure 30. A composite visualization of the San Diego CDB dataset in GNOSIS Cartographer client showing buildings in downtown San Diego.

Figure 31. A composite visualization of the San Diego CDB dataset in GNOSIS Cartographer client showing a view from downtown to the eastern suburbs.

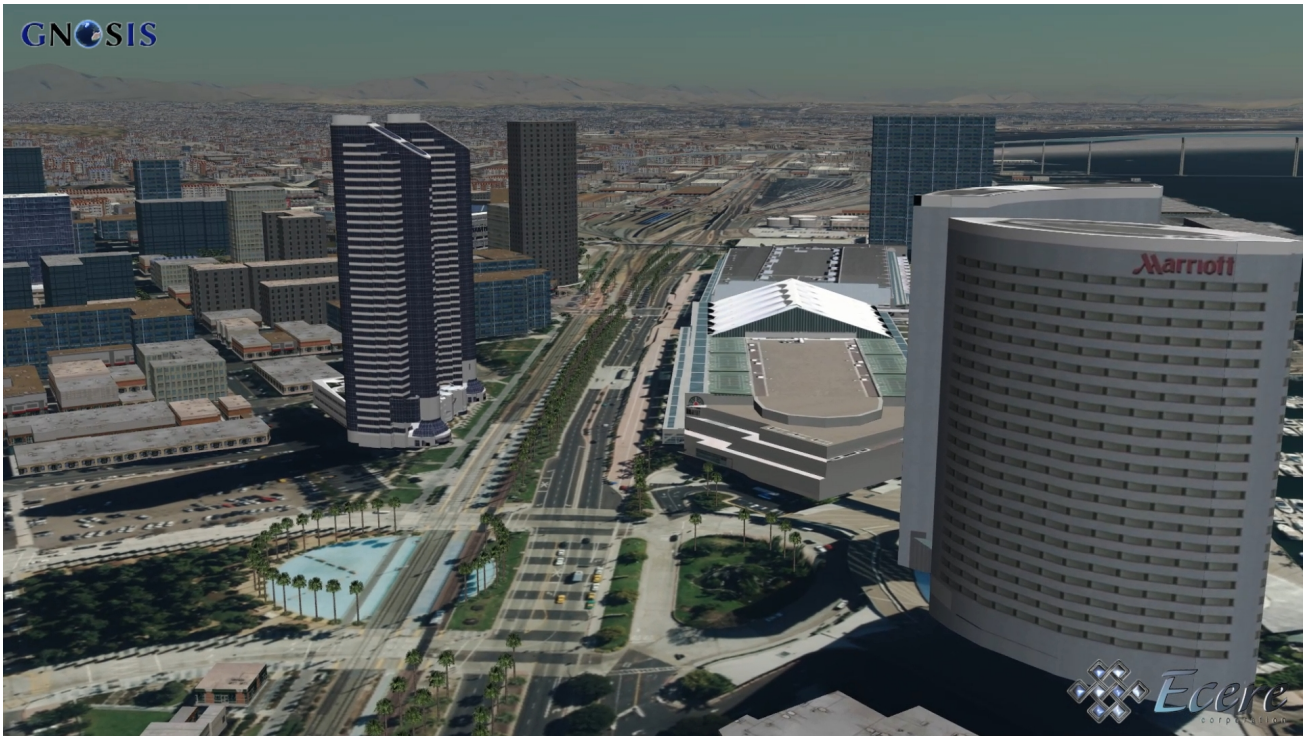


Figure 32. A composite visualization of the San Diego CDB dataset in GNOSIS Cartographer client showing a view to the south of Children's Park.

Figure 33. A composite visualization of the San Diego CDB dataset in GNOSIS Cartographer client showing San Diego Bay and Coronado.

Figure 34. A composite visualization of the San Diego CDB dataset in GNOSIS Cartographer client showing housing on Coronado.

Figure 35. A composite visualization of the San Diego CDB dataset in GNOSIS Cartographer client showing North Island Naval Air Station.

Figure 36. A composite visualization of the San Diego CDB dataset in GNOSIS Cartographer client showing Point Loma.

Figure 37. A composite visualization of the San Diego CDB dataset in GNOSIS Cartographer client showing Sam Diego International Airport.

9.5. Interoperable 3D model formats

In collaboration with Steinbeis, Ecere initiated work towards demonstrating the visualization of integrated indoor and outdoor geospatial data. Leveraging the advantages of tiling, Ecere's GNOSIS geospatial visualization Software Development Kit can support visualization of data from a global scale to local scale at high resolution, such as for indoor Augmented Reality scenarios.

Experiments focused on visualization of a 3D model of a Hochschule für Technik (HfT) Stuttgart building, including interior details, integrated within data from its surrounding geographic area, such as buildings sourced from OpenStreetMap data.

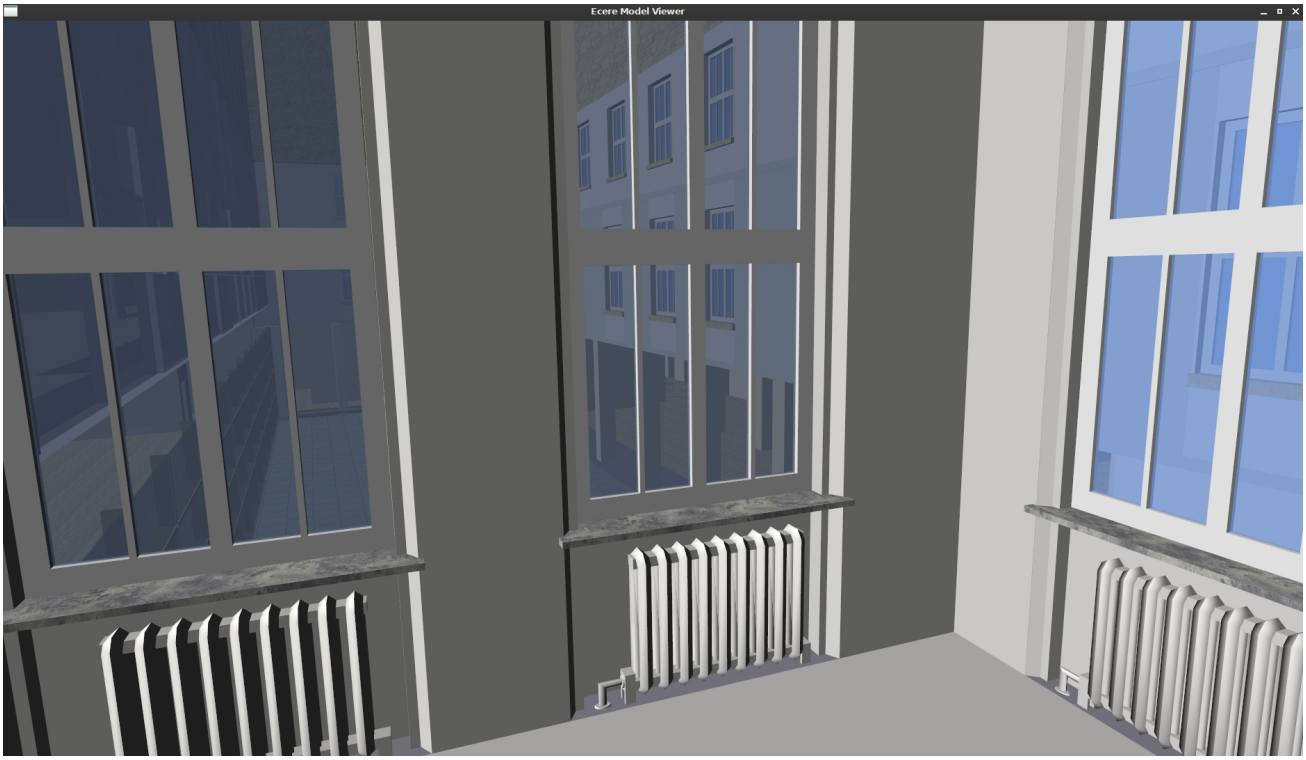


Figure 38. 3D Model of Hochschule für Technik (HfT) Stuttgart provided by Steinbeis in COLLADA as visualized in Ecere's 3D Model viewer.

Figure 39. A global view of the Earth in Ecere's GNOSIS Cartographer in which HfT 3D Model was integrated with other geospatial data. This view includes Gaia Sky in color from ESA, Visible Earth Blue Marble from NASA and elevation data from Jonathan de Ferranti's ViewFinderPanorama (including data from SRTM, NASA / USGS).

Figure 40. This is an intermediate zoom into Europe with a view of the Alps.

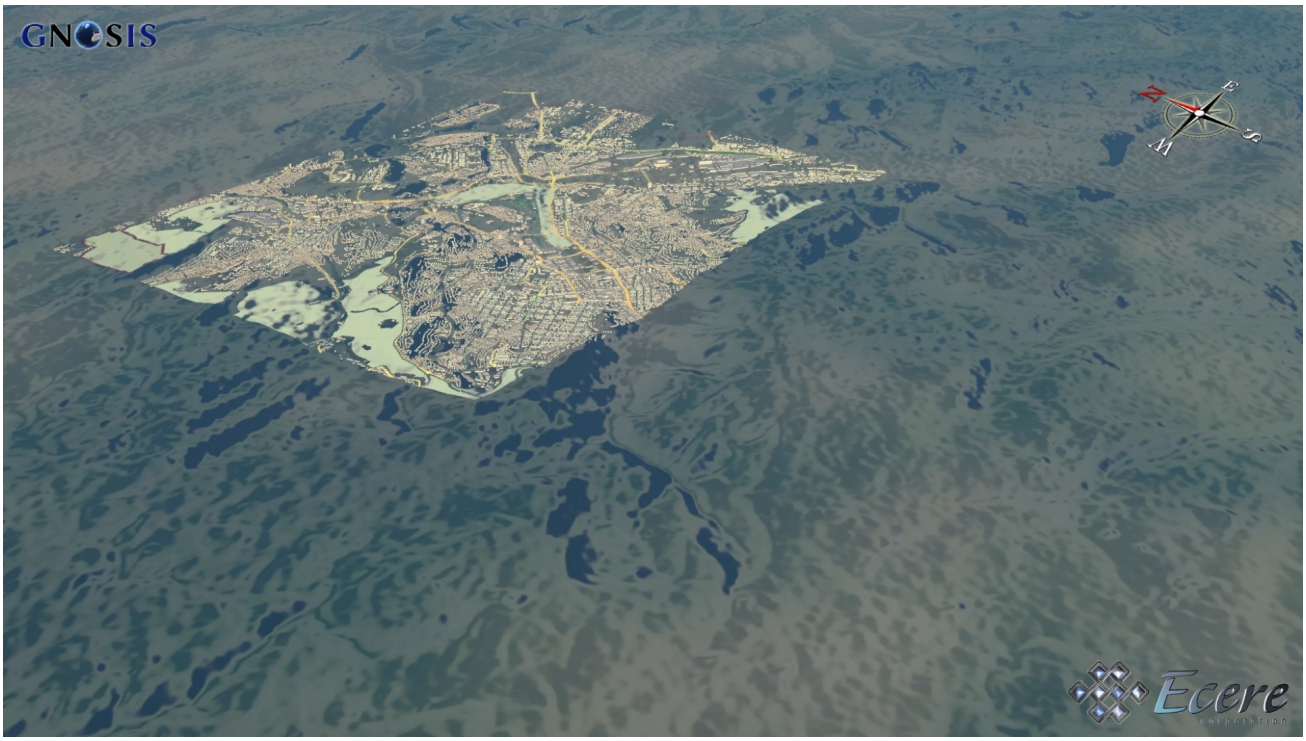


Figure 41. An aerial view of Germany's Baden-Wuerttemberg region (data Copyright © OpenStreetMap contributors) showing the placement of higher resolution HfT Stuttgart.

Figure 42. A view of 3D buildings in Stuttgart from altitude.

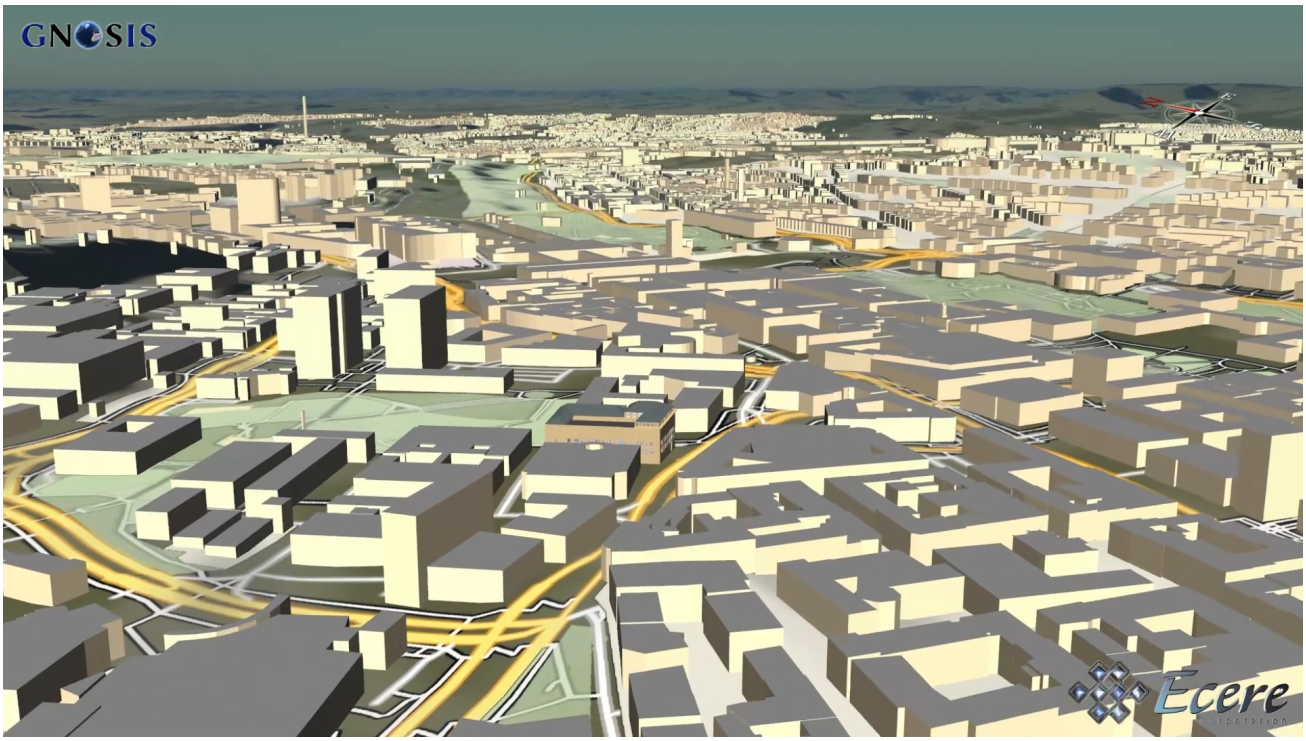


Figure 43. A closer view of 3D buildings. The HfT building models were provided by Steinbeis.

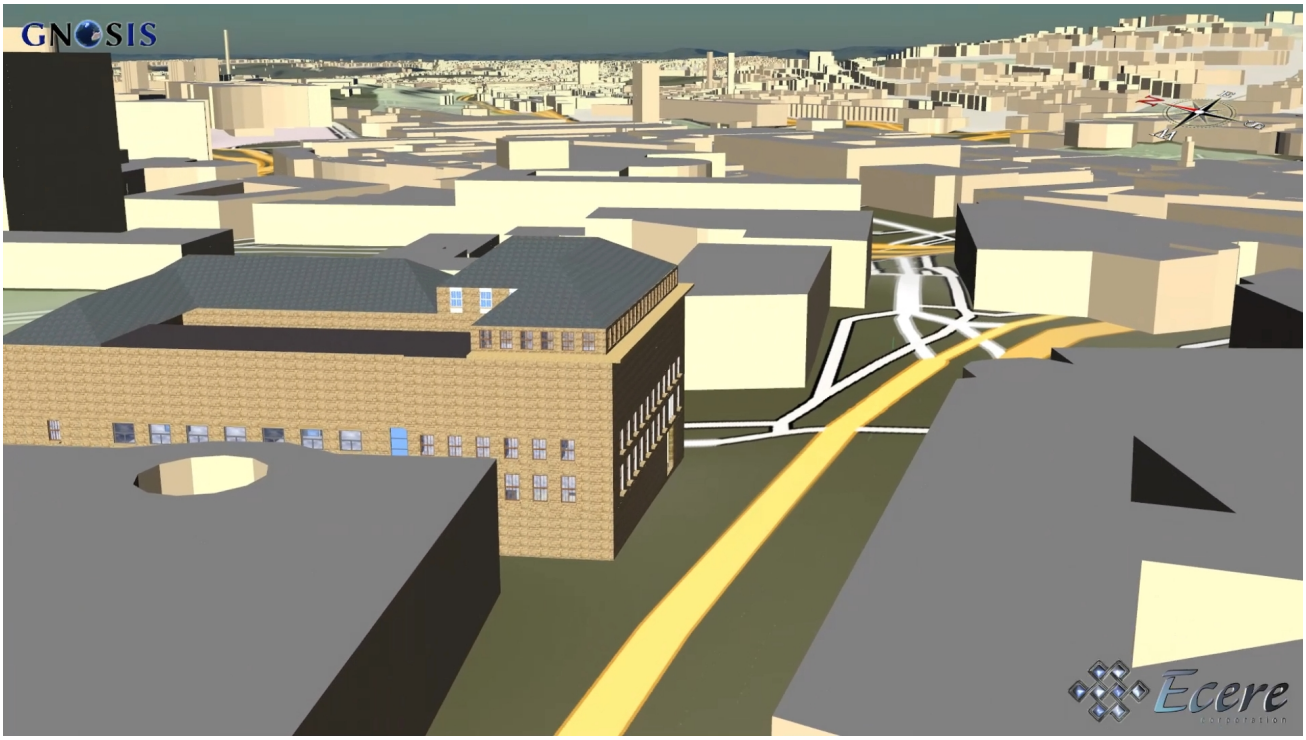


Figure 44. A rooftop view close to HfT buildings.

Figure 45. One of many View HfT buildings provided by Steinbeis.

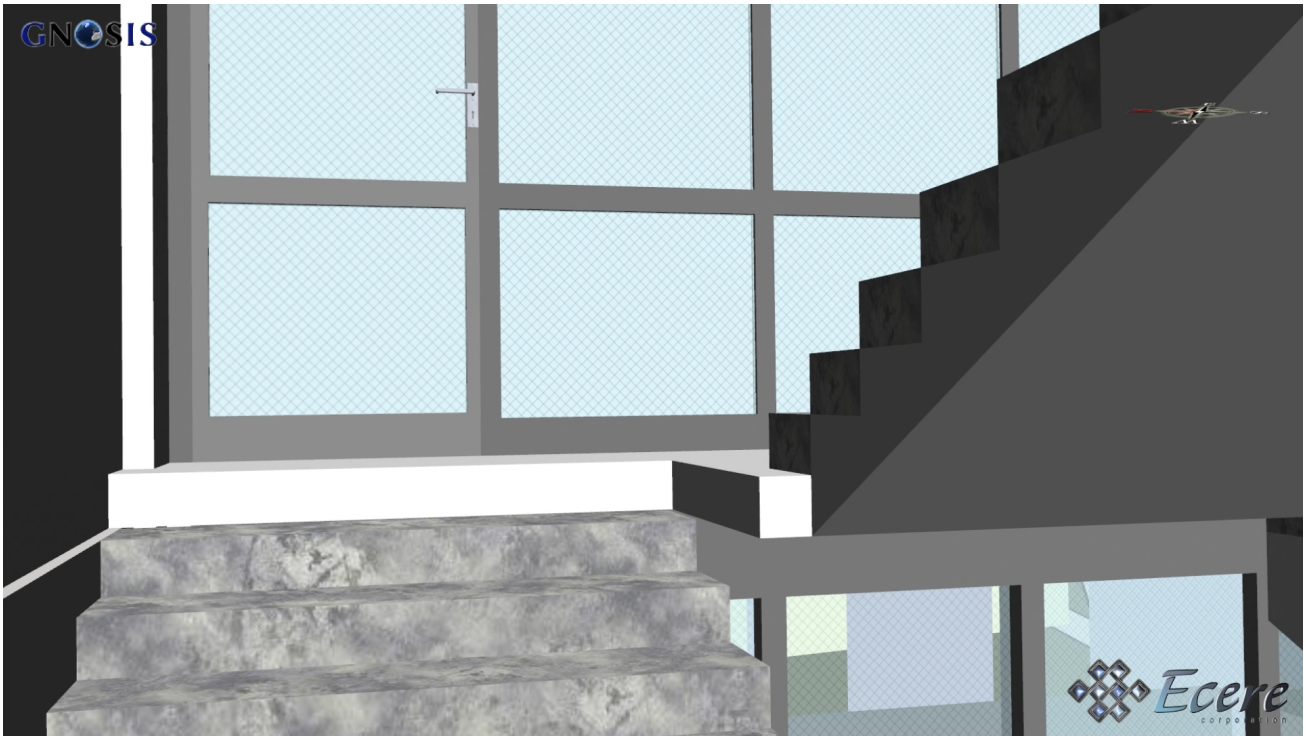


Figure 46. The first view of a staircase inside an HfT building.

Figure 47. The second view of a different staircase inside an HfT building.

Since, as described previously, the GNOSIS client could not readily display *3D Tiles* tilesets retrieved from the Steinbeis GeoVolumes server, the participants sought an alternative way to achieve interoperability. Firstly, Steinbeis provided a glTF model exported from the Sketchup software in which the model was originally produced. Unfortunately, this glTF export proved to have incorrect normals that would result in incorrect lighting of surfaces. Attempts to display that glTF model however led to Ecere making some improvements to its importing module for glTF

which leverages the Open Asset import library [https://www.assimp.org/] (*libassimp*), as well as to libassimp itself. In a following attempt to achieve interoperability, Steinbeis provided a COLLADA export from Sketchup, which is known to usually give good results. In this attempt, normals turned out fine, but for an unknown reason (which could also be an export issue or a simple mistake during the export process, such as leaving some objects hidden at exporting time) some floor surfaces ended up missing from the exported COLLADA model. The takeaway from these experiments is that improving widely used open-source libraries to import and export glTF 3D models might lead to better interoperability.

Ecere's contributions to the libassimp [https://github.com/assimp/assimp] glTF 2 driver made as part of this sprint included:

- Fixes to build for C compiler (PR 3966 [https://github.com/assimp/assimp/pull/3966])
- Improved support for opacity (PR 3967 [https://github.com/assimp/assimp/pull/3967])

As part of these interoperability experiments during the sprint, Ecere produced both binary glTF and E3D [https://github.com/ecere/E3D-spec] versions of the HfT models provided by Steinbeis.

In addition, Ecere realized the need to improve aspects of materials and textures management in its open-source cross-platform Ecere SDK [https://ecere.org] and the importing and exporting driver [https://github.com/ecere/ecere-sdk/tree/latest/ecere/src/gfx/3D/models/e3d] for the E3D model format [https://github.com/ecere/E3D-spec], which remains ongoing development work happening on the materialsReview [https://github.com/ecere/ecere-sdk/tree/materialsReview] branch at the time of this report. Other improvements to the Ecere driver for libassimp included correctly handling hierarchical transforms and translucency. Proper support for translucent 3D models integrated in Ecere's GNOSIS visualization SDK remains ongoing development work at the time of this report.

Given the limited time allocated to the sprint (two weeks interspersed by an OGC Members Meeting), improving and demonstrating support for Virtual and Augmented Reality is also the subject of ongoing and future development work.

Chapter 10. Component Implementation: FlightSafety

10.1. Introduction

10.1.1. Company Introduction

FlightSafety International is a professional aviation training company that supplies flight simulators, visual systems, and displays for commercial, government, and military organizations. FlightSafety has deep experience with both CDB and OpenFlight formats, with the ability to both create and consume data in these formats. FlightSafety has used OpenFlight for decades for models and terrain. Also, in support of USSOCOM, FlightSafety implemented CDB as early as 2006. FlightSafety continues to support the evolution of CDB through Interoperability Experiments and Tech Sprints.

10.1.2. Scenario Plan

FlightSafety chose to participate in the ISG Year 2 Sprint by investigating Scenario 4, identifying and defining missing CDB functionality in glTF. Previous work had focused on comparisons between features of OpenFlight and glTF. But CDB only uses a subset of OpenFlight nodes. In particular, it does not make use of the more esoteric nodes that lack straightforward conversions to glTF. In addition, CDB details how to use the existing OpenFlight nodes and attributes to implement typical simulation features and concepts, which are not 1-to-1 conversions to glTF.

Also, there are additional layers in a CDB to support use cases that do not involve visible spectrum lighting, such as Infrared and Radar wavelengths. FlightSafety is interested in the practicality of supporting these use cases.

FlightSafety proposed three areas of investigation:

1. How to preserve CDB attribution and conceptual features in a glTF model, especially in CDB Moving Models. This covers CDB concepts like named zones, damage states, attach points, configurations, motion blur textures, and other semantic attribution.
2. How to encode and store multi-spectral textures of wavelengths that are primarily reflective such as Near Infrared and Short Wave Infrared wavelengths (SWIR). These are used for Night Vision Goggle (NVG) simulation and/or stimulation, and SWIR sensors.
3. How to encode and store material data. This involves storing the underlying material property information. This data is used for Radar and sensor systems such as Thermal IR (FLIR or EOS).

There are basically three uses of OpenFlight within a CDB. All uses of OpenFlight need to be looked at when proposing using glTF models in a CDB.

1. CDB Static Models - GeoSpecific and GeoTypical 3D models that are anchored in a specified location within the CDB
2. CDB Moving Models - 3D Models that are not anchored onto the terrain or in a specified location in the CDB
3. CDB Tiled 2D dataset - Geometry that is layered or projected onto the terrain skin, to provide higher detail than terrain and imagery alone

10.1.3. Limits of Investigation

FlightSafety did not investigate the conversion of all the CDB to glTF. FlightSafety found that there is additional flexibility with using the original CDB datasets to create runtime formats (like glTF or other more runtime focused formats), without indicating how those datasets are to be used. The ability to mix and match different datasets and different levels of detail from a CDB creates the flexibility to support simulation systems with different capabilities and/or use cases.

Also, due to the limited time frame of this effort, not all of the proposed glTF extensions were tested and verified to fully replace specific CDB 3D model functionality.

10.2. CDB Model Attribution

10.2.1. Background

The Interoperable Simulation and Gaming Year 2 Sprint Call for Proposals produced a table of similarities and differences between OpenFlight and glTF (reproduced in **Appendix B**). The focus here was on arbitrary OpenFlight features. CDB does not use pure OpenFlight, but rather a profile of the OpenFlight specification, as seen in Volume 6 [https://docs.ogc.org/bp/16-009r5.html] of the CDB standard. There are features and nodes in OpenFlight that CDB does not use, and there are portions of OpenFlight that are narrowly defined to make different features more interoperable. For some model use cases, preserving the functionality of a CDB 3D model is more than just preserving the structure in glTF.

10.2.2. Proposed glTF Solution

The first step in this investigation was to identify the features and concepts that are unique to how CDB uses OpenFlight. Next, each feature or concept is described as to how it is used, and a glTF extension is proposed to implement the feature or concept.

CDB Feature Category	CDB Feature	CDB Model Type	Description	Proposed glTF Extension
Zones	**Zone** [https://github.com/opengeospatial/cdb-volume-6/blob/master/clause_6_5_ModelZones.adoc]	All CDB Models	Metadata on Group nodes, used to provide a hierarchical naming scheme for other features in this table, such as switches, DOFs, etc.	KHR_xmp_json_ld [https://github.com/KhronosGroup/glTF/tree/master/extensions/2.0/Khronos/KHR_xmp_json_ld]
Points *[https://github.com/opengeospatial/cdb-volume-6/blob/master/clause_6_6_ModelPoints.adoc]* *Category*	Identifies a location on a model that is of interest to at least one CDB consumer. Similar to zones, but typically is not visually modeled.			

CDB Feature Category	CDB Feature	CDB Model Type	Description	Proposed glTF Extension
	Model DIS Origin Point [https://github.com/opengeospatial/cdb-volume-6/blob/master/clause_6_6_ModelPoints.adoc#model-dis-origin]	Moving Models	Model origin used with DIS/HLA, which can be different than the modeled origin	KHR_xmp_json_ld [https://github.com/KhronosGroup/glTF/tree/master/extensions/2.0/Khronos/KHR_xmp_json_ld]
	Model Viewpoint [https://github.com/opengeospatial/cdb-volume-6/blob/master/clause_6_6_ModelPoints.adoc#model-viewpoint]	All models	Viewpoint from a model (aircraft pilot's seat, ship's navigation post, etc.)	Cameras [https://github.com/KhronosGroup/glTF/tree/master/specification/2.0#cameras]

CDB Feature Category	CDB Feature	CDB Model Type	Description	Proposed glTF Extension
	Attach Point [https://github.com/opengeospatial/cdb-volume-6/blob/master/clause_6_6_ModelPoints.adoc#model-attach-point]	Primarily Moving Models, Power Line Pylons	Position on a model that other models can be attached to (e.g. fighter aircraft with points to attach munitions or fuel tanks). Includes power line attach points for a power pylon.	AGI_articulations [https://github.com/KhronosGroup/glTF/tree/master/extensions/2.0/Vendor/AGI_articulations]
	Anchor Point [https://github.com/opengeospatial/cdb-volume-6/blob/master/clause_6_6_ModelPoints.adoc#model-anchor-point]	Moving Models	Counterpoint of the **Attach Point**, point where this model can be attached to another model	AGI_articulations [https://github.com/KhronosGroup/glTF/tree/master/extensions/2.0/Vendor/AGI_articulations]

CDB Feature Category	CDB Feature	CDB Model Type	Description	Proposed glTF Extension
	Center of Mass [https://github.com/opengeospatial/cdb-volume-6/blob/master/clause_6_6_ModelPoints.adoc#model-center-of-mass]	Moving Models	Center of mass of a model	KHR_xmp_json_ld [https://github.com/KhronosGroup/glTF/tree/master/extensions/2.0/Khronos/KHR_xmp_json_ld]
Model Conforming *[https://github.com/opengeospatial/cdb-volume-6/blob/master/clause_6_7_ModelConforming.adoc]*	**Model Conforming**	Static Models, 2D Tiled Models	A set of modes used to place or project model geometry onto the terrain	KHR_xmp_json_ld [https://github.com/KhronosGroup/glTF/tree/master/extensions/2.0/Khronos/KHR_xmp_json_ld]

CDB Feature Category	CDB Feature	CDB Model Type	Description	Proposed glTF Extension
Level of Detail *[https://github.com/opengeospatial/cdb-volume-6/blob/master/clause_6_8_ModelLevelsOfDetail.adoc]*	**Level of Detail**	Static and Moving Models	Provides device level control of rendering/processing load and memory footprint	MSFT_lod [https://github.com/KhronosGroup/glTF/tree/master/extensions/2.0/Vendor/MSFT_lod] - *See LOD Note Below*
Switch *[https://github.com/opengeospatial/cdb-volume-6/blob/master/clause_6_9_ModelSwitchNodes.adoc] Category*	Implemented in an OpenFlight **Switch** node. Used to control the state of Model Components (zones and points), based on one or a set of masks that enable or disable child nodes.			
	Articulations [https://github.com/opengeospatial/cdb-volume-6/blob/master/clause_6_9_ModelSwitchNodes.adoc#articulations]	Moving Models	Used when articulated parts are implemented for only a few set positions (e.g. aircraft flaps)	No direct conversion, but glTF animations can accomplish the same effect.

CDB Feature Category	CDB Feature	CDB Model Type	Description	Proposed glTF Extension
	Damaged States [https://github.com/opengeospatial/cdb-volume-6/blob/master/clause_6_9_ModelSwitchNodes.adoc#damage-states]	Static and Moving Models	Select one of multiple modeled representations of a model with different amounts of damage (0-100% damaged)	See Switch Note Below
	Motion Blur Textures [https://github.com/opengeospatial/cdb-volume-6/blob/master/clause_6_9_ModelSwitchNodes.adoc#temporal-anti-aliasing]	Moving Models	Provides temporal anti-aliasing on rotating parts (such as rotors or propellers) to reduce strobing effects. These are special textures that are semi-transparent.	KHR_materials_variants [https://github.com/KhronosGroup/glTF/tree/master/extensions/2.0/Khronos/KHR_materials_variants] along with glTF Animation

CDB Feature Category	CDB Feature	CDB Model Type	Description	Proposed glTF Extension
Articulations *[https://github.com/opengeospatial/cdb-volume-6/blob/master/clause_6_10_ModelArticulations.adoc]*		Implemented in an OpenFlight **DOF** node. Gives a system control over all 9 degrees of freedom: translation, rotation, scaling on all 3 axes. One allowed per zone for unique naming and control of the DOF.		
	Articulated Part [https://github.com/opengeospatial/cdb-volume-6/blob/master/clause_6_10_ModelArticulations.adoc#definition]	Moving Models	Allows a simulation (DIS or other) to control an articulation on a model	AGI_articulations [https://github.com/KhronosGroup/glTF/tree/master/extensions/2.0/Vendor/AGI_articulations]
	Rotating Part [https://github.com/opengeospatial/cdb-volume-6/blob/master/clause_6_10_ModelArticulations.adoc#rotating-parts]	Static or Moving Models	An articulation that can be animated/rotated automatically in the environment.	glTF Animations

CDB Feature Category	CDB Feature	CDB Model Type	Description	Proposed glTF Extension
Attribution *[https://github.com/opengeospatial/cdb-volume-6/blob/master/clause_6_12_ModelAttributes.adoc]*	**Attribution**	All Model Types	General mechanism using structured XML comments to add attribution to portions of a 3D model	KHR_xmp_json_ld [https://github.com/KhronosGroup/glTF/tree/master/extensions/2.0/Khronos/KHR_xmp_json_ld]

CDB Feature Category	CDB Feature	CDB Model Type	Description	Proposed glTF Extension
Model Configuration *[https://github.com/opengeospatial/cdb-volume-6/blob/master/clause_6_14_ModelDescriptorMetaDataDatasets.adoc#model-configurations]*		Moving Models	Allows the selection and use of one of a set of possible equipment and/or ordinance loads for a Moving Model.	Keep in CDB XML Metadata file. *See Configuration Note Below*

Table 5. CDB Features Implemented in OpenFlight vs glTF core plus extension capabilities.

There are a large variety of texture types in a CDB. Below, in Table 6, is a complete listing of texture types and their uses, along with proposed glTF replacements.

CDB Texture Class	CDB Texture Type	Description	Proposed glTF Extension
Model Textures - Base *[https://github.com/opengeospatial/cdb-volume-6/blob/master/clause_6_13_ModelTextures.adoc#base-texture-layer]*		Textured appearance of a model	
	Year Round Texture [https://github.com/opengeospatial/cdb-volume-6/blob/master/clause_6_13_ModelTextures.adoc#base-texture-layer]	Base appearance of a model	glTF Materials
	Time of Year Texture [https://github.com/opengeospatial/cdb-volume-6/blob/master/clause_6_13_ModelTextures.adoc#model-skin-textures]	Time of Year appearance either Quarterly or Monthly.	KHR_materials_variants [https://github.com/KhronosGroup/glTF/tree/master/extensions/2.0/Khronos/KHR_materials_variants]

CDB Texture Class	CDB Texture Type	Description	Proposed glTF Extension
	Paint Scheme Texture [https://github.com/opengeospatial/cdb-volume-6/blob/master/clause_6_13_ModelTextures.adoc#model-skin-textures]	Textured Paint Schemes (Paint color, Camouflage, Airline Livery)	KHR_materials_variants [https://github.com/KhronosGroup/glTF/tree/master/extensions/2.0/Khronos/KHR_materials_variants]
	Multi-Spectral Texture Layer [https://docs.opengeospatial.org/is/17-080r2/17-080r2.html]	CDB Extension of Base Textures, covering non-visual reflective textures in the Near Infrared and Short Wave Infrared bands.	KHR_materials_variants [https://github.com/KhronosGroup/glTF/tree/master/extensions/2.0/Khronos/KHR_materials_variants]
Model Textures - Subordinate *[https://github.com/opengeospatial/cdb-volume-6/blob/master/clause_6_13_ModelTextures.adoc#subordinate-texture-layer]*		Provides additional detail to the Base texture	

CDB Texture Class	CDB Texture Type	Description	Proposed glTF Extension
	Light Map [https://github.com/opengeospatial/cdb-volume-6/blob/master/clause_6_13_ModelTextures.adoc#model-light-maps]	Emissive texture map representing color and intensity of light being emitted or reflected	glTF Emissive Map [https://github.com/KhronosGroup/glTF/tree/master/specification/2.0#additional-maps]
	Night Map [https://github.com/opengeospatial/cdb-volume-6/blob/master/clause_6_13_ModelTextures.adoc#model-night-maps]	Used in conjunction with Light Maps to simulate light sources inside a model	glTF Emissive Map [https://github.com/KhronosGroup/glTF/tree/master/specification/2.0#additional-maps]
	Tangent-Space Normal Map [https://github.com/opengeospatial/cdb-volume-6/blob/master/clause_6_13_ModelTextures.adoc#model-tangent-space-normal-maps]	Tangent-Space Normal map	glTF Normal Map [https://github.com/KhronosGroup/glTF/tree/master/specification/2.0#additional-maps]

CDB Texture Class	CDB Texture Type	Description	Proposed glTF Extension
	Detail Texture Maps [https://github.com/opengeospatial/cdb-volume-6/blob/master/clause_6_13_ModelTextures.adoc#model-detail-texture-maps]	Method of adding high-frequency (spatial) details to a low-frequency image.	No direct glTF equivalent
	Contaminant and Skid Mark Textures [https://github.com/opengeospatial/cdb-volume-6/blob/master/clause_6_13_ModelTextures.adoc#model-contaminant-and-skid-mark-textures]	Historical method of controlling the appearance of airport runways and surfaces.	No direct glTF equivalent
	Cubic Reflection Map [https://github.com/opengeospatial/cdb-volume-6/blob/master/clause_6_13_ModelTextures.adoc#model-cubic-reflection-maps]	Reflection map	EXT_lights_image_based [https://github.com/KhronosGroup/glTF/tree/master/extensions/2.0/Vendor/EXT_lights_image_based]

CDB Texture Class	CDB Texture Type	Description	Proposed glTF Extension
	Gloss Map [https://github.com/opengeospatial/cdb-volume-6/blob/master/clause_6_13_ModelTextures.adoc#model-gloss-maps]	Describes whether a surface is matte or gloss.	glTF metallicRoughnessTexture [https://github.com/KhronosGroup/glTF/tree/master/specification/2.0#metallic-roughness-material]
Material Textures *[https://github.com/opengeospatial/cdb-volume-6/blob/master/clause_6_13_ModelTextures.adoc#model-material-textures]*	Texture map of the underlying surface material, independent of the visual appearance.		**EXT_feature_metadata** [https://github.com/CesiumGS/glTF/tree/3d-tiles-next/extensions/2.0/Vendor/EXT_feature_metadata/1.0.0] - Feature ID Texture

Table 6. Standard texture types used in CDB vs equivalent or comparable types from glTF.

Due to time constraints, not all of the proposed extensions could be tested or evaluated. There remains work to ensure that all of the CDB features and concepts can be converted into glTF features and extensions. Also, since the goal of CDB is interoperability, it would be unwise to

choose a specific implementation without multiple organizations evaluating the suitability of the extension to their use cases.

Notes

- *Levels of Detail*: The MSFT_lod extension does not define what constitutes a "screen" for the purposes of screen coverage calculation. CDB would need to define what a "screen" is for purposes of conversion to significant size. One possible definition would be that a screen is considered Full HD (1920x1080pixels aka 1080p), so that a scaling between this screen definition and screens that are higher (e.g. WQXGA or 4K) or lower resolution (e.g. VGA or 720p) can be used.
- *Model Configurations*: Currently, the model configuration data is stored globally in the Metadata directory as an XML file. One option is to keep the location and format. Another option is to encode this information into the model itself, using the KHR_xmp_json_ld [https://github.com/KhronosGroup/glTF/tree/master/extensions/2.0/Khronos/KHR_xmp_json_ld] extension.
- *Switches*: There are no direct glTF features or extensions that work in the general case for switches. If an entire model was to switch geometry, a new scene in glTF would work. But most use cases have only portions of the mesh changing, like a damaged wing. So this solution is not considered complete enough for CDB conversion.

10.2.3. Recommendations

1. Create a new glTF extension to support mesh switching that can be used for Damaged States and simple geometry switching. This probably involves extending glTF nodes, to allow switching between a default set of child nodes and alternative sets (masks) of child nodes. Since nodes are referenced by index, this would be a lightweight extension.
2. Additional testing of the proposed extensions is needed, to see if they cover the capabilities of CDB using OpenFlight. In addition, interoperable experiments are recommended to ensure that these extensions are effective for all users.
3. There are a number of CDBs that are available for OGC members to use for testing purposes. However, there are no CDB Moving Models that can work as test cases for all features. Creating some standardized models available would make this work easier.

10.3. Multi-Spectral Model Textures

10.3.1. Background

Most near infrared and short-wave infrared energy in an environment is produced by the sun, as part of its solar black body radiation. The exceptions are typically very hot materials (e.g. aircraft engines, exhaust) or man-made emitters of these wavelengths (e.g. TV remotes, military NVG lights).

CDB accommodates these wavelengths using the Multi-Spectral Imagery Extension to CDB. This

extension provides additional textures that can be used in cases where near infrared or short wave infrared portions of the electromagnetic spectrum are needed. In this case, the extension is using the same technique that CDB uses for seasonal and quarterly texture and imagery, as well as paint and camouflage schemes for moving models.

10.3.2. Proposed glTF Solution

The conversion of this data to glTF was relatively straightforward. There is a glTF extension developed for commercial applications, KHR_materials_variants [https://github.com/KhronosGroup/glTF/tree/master/extensions/2.0/Khronos/KHR_materials_variants], that works well for this use case. It allows for switching textures on a model based on a name, where the set of textures use the exact same texture mapping. This approach should also handle the quarterly and seasonal texture representations, as well as paint and camouflage texture skins. Table 7 shows some of the different texture types that can be added to a 3D model.

Variant Type	Labels
Year Round Texture	`CDB_Base`
Monthly Texture	`CDB_January` `CDB_February` `CDB_March` `CDB_April` `CDB_May` `CDB_June` `CDB_July` `CDB_August` `CDB_September` `CDB_October` `CDB_November` `CDB_December`
Quarterly Texture	`CDB_Q1` `CDB_Q2` `CDB_Q3` `CDB_Q4`
Multi-Spectral	`CDB_NIR` `CDB_SWIR`
Uniform Paint Scheme	`CDB_Paint_Gray` `CDB_Paint_White` `CDB_Paint_Green` `CDB_Paint_Black`

Variant Type	Labels

Camouflage Paint Scheme	`CDB_Camo_Desert`
	`CDB_Camo_Winter`
	`CDB_Camo_Forest`
	`CDB_Camo_Generic`
	`CDB_Camo_Urban`

Airline Paint Scheme	`CDB_Airline_AAH`
	`CDB_Airline_AAL`
	`CDB_Airline_AAR`

Table 7. Table of example texture types frequently found in CDB data sets.

There is a concern that encoding multiple texture layers into a single binary glTF model could lead to non-optimal solutions. Consider, for example, a model that uses a large number of different material variants. For most use cases, there would be no need to load all of these texture layers, thus it might be best to reduce the file size and I/O load of the CDB client. Another example would be several models sharing a texture. Encoding these into a binary glTF file would use more storage than necessary. Most of these concerns can be addressed by using glTF texture URIs, rather than encoding the texture directly into the glTF.

10.3.3. Experimentation

FlightSafety created some sample glTF models using the KHR_materials_variants extension. The images below are being rendered by the Don McCurdy glTF viewer, showing 3D models that are using the materials variants extension. Figure 48 is a 3D model showing a typical visual texture. Figure 49 is a 3D model showing the Near Infrared texture that would be used for Night Vision Goggle training.

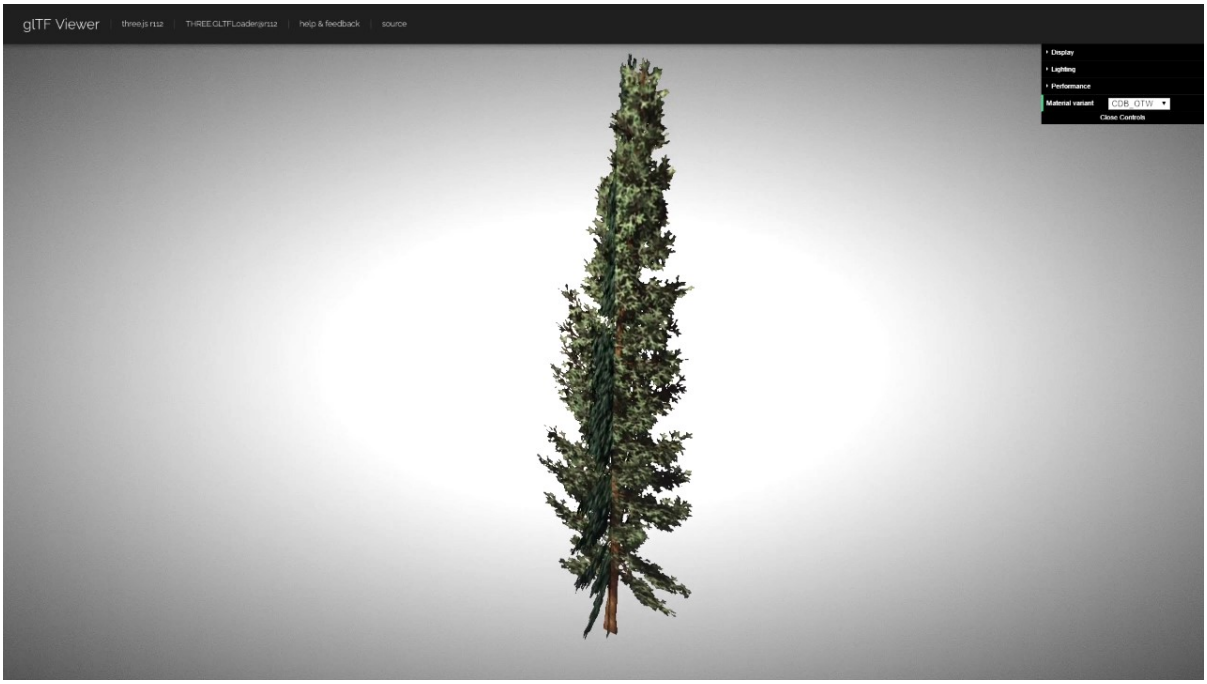


Figure 48. A basic glTF tree model textured with visual spectrum appearance.

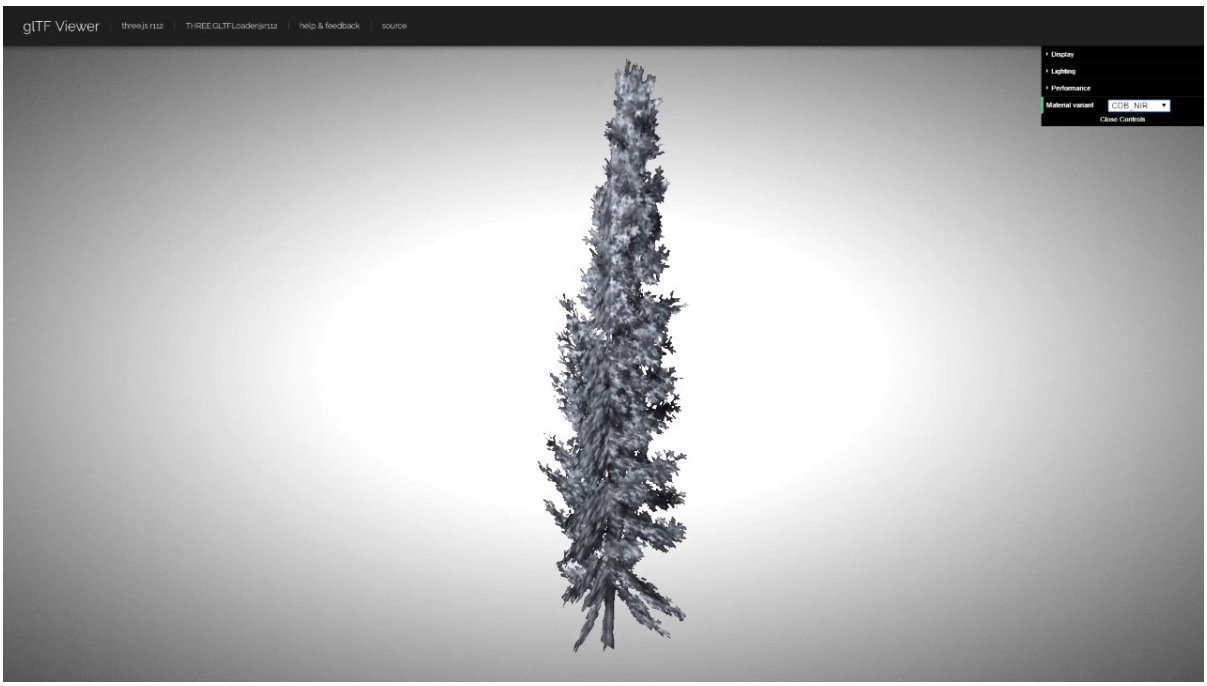


Figure 49. The same glTF tree model textured with a near infrared texture.

This same extension can be used for other texture types. In Figure 50, this is the same tree with a winter seasonal texture applied.

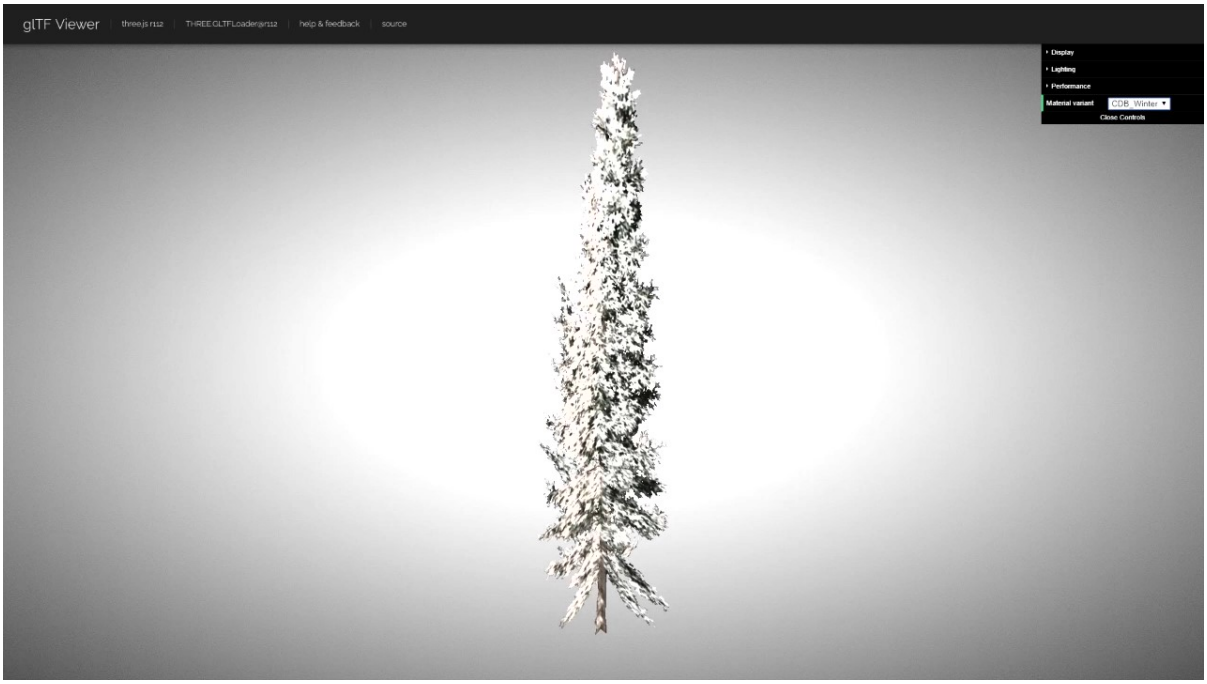


Figure 50. The same glTF tree model textured with a winter texture.

10.3.4. Recommendations

These items are recommendations for representing optional texture layers for glTF models to support current CDB capabilities:

1. CDB glTF models should support the KHR_materials_variants extension, if there is more than the default base texture for a model. This can include quarterly or seasonal representations, uniform paint schemes, camouflage paint schemes, airline paint schemes, or Near Infrared reflectance, or Short-Wave Infrared reflectance textures.
2. The material names for the different variants should conform to a naming convention in CDB. For example, the material variant for Near Infrared texture should always be CDB_NIR. More examples are in Table 7.
3. Textures, other than the base texture, should not be encoded into the glTF model. Any non-base texture, or a texture that is reused in other models, should be referenced via a URI into the CDB, so that the client or renderer can access only the set of textures necessary.

10.4. Model Material Textures

10.4.1. Background

There are certain use cases that cannot be covered solely by visual appearance or reflectance of specific bands of electromagnetic solar radiation. Some of these use cases include thermal Infrared where a sensor is detecting the temperature of an object, and Radar where an emitter is producing pulses of energy that reflect off objects partly based on the physical material of that object.

CDB allows for the storage of material data for both the terrain (Raster Materials) and for 3D

models (Model Material Texture). In both cases, the material storage is similar. CDB supports a material texture that contains a single channel/band of index values (note: Raster Materials supports multiple layers of data), and an XML file that contains a Composite Material Table that maps the index into either a simple material (such as glass), a mixture of materials (such as 40% brick and 60% wood), or a complex arrangement of materials (such as a steel drum, with water inside, and painted on the outside).

A CDB consumer can then use the material data, along with other non-static simulation information, to create a sensor representation. For example, material information plus atmospheric data (temperature and humidity), plus knowing the amount of solar irradiance (or lack thereof in the case of shadows) on the surface, can allow a device to simulate a thermal irradiance texture for the simulation. Similarly, a Radar simulation can use the material information along with a surface's orientation to simulate the reflection of Radar energy.

10.4.2. Proposed glTF Solution

FlightSafety used a proposed glTF extension called EXT_feature_metadata [https://github.com/CesiumGS/glTF/tree/3d-tiles-next/extensions/2.0/Vendor/EXT_feature_metadata/1.0.0] to encode material data in a glTF model. The Feature ID Textures [https://github.com/CesiumGS/glTF/tree/3d-tiles-next/extensions/2.0/Vendor/EXT_feature_metadata/1.0.0#feature-id-textures] feature allows for placing a metadata texture on a surface, along with a metadata table. The value in the texture is an index into a table.

FlightSafety was able to encode everything from a CDB Composite Material Table into this metadata table, with only one slight difference. A CDB allows for a primary substrate (main material), an optional surface substrate (like paint), and optional secondary substrates that act like multiple material layers behind the primary material. In practice, FlightSafety did not required more than one secondary material, so there was a limit to the material table to only a single secondary substrate.

The new JSON composite material table consists of entries that have:

- A Name
- An Index
- An array of the primary substrate materials (referenced by enumeration)
- An array of the primary substrate weights (by percentage)

Optionally, the following can also be included:

- An array of the surface substrate materials (referenced by enumeration)
- An array of the surface substrate weights (by percentage)
- The primary substrate thickness (in meters)
- An array of the secondary substrate materials (referenced by enumeration)

- An array of the secondary substrate weights (by percentage)
- The secondary substrate thickness (in meters)

Example Material Table Schema

```
"extensions": {
  "EXT_feature_metadata": {
    "schema": {
      "classes": {
        "compositeMaterials": {
          "properties": {
            "name": {
              "type": "STRING"
            },
            "index": {
              "componentType": "UINT8"
            },
            "primarySubstrate": {
              "type": "ARRAY",
              "componentType": "ENUM",
              "enumType": "baseMaterials"
            },
            "primarySubstrateWeights": {
              "type": "ARRAY",
              "componentType": "UINT8"
            }
          }
        },
        "cdbCompositeMaterialIndex": {
          "properties": {
            "index1": {
              "type": "UINT8",
              "normalized": false
            }
          }
        }
      }
    },
    "enums": {
      "baseMaterials": {
        "valueType": "UINT8",
        "values": [
          {
            "name": "BM_WOOD",
            "description": "Wood for building doors",
            "value": 0
```

```
            },
            {
              "name": "BM_BRICK",
              "description": "Brick for building exterior walls",
              "value": 1
            },
            {
              "name": "BM_GLASS",
              "description": "Glass for building windows",
              "value": 2
            }
          ]
        }
      }
    }
  }
```

The actual table would then be encoded into a glTF bufferView object. For illustrative purposes, the following JSON would represent how the metadata table would look like to represent a CDB Composite Material Table.

Example Composite Material Table

```
        "featureTables": {
            "compositeMaterialsTable": {
            "count": 3,
            "class": "compositeMaterials",
            "properties": {
             /*
              * These values are for illustrative purposes only. When actual
ly implementing this
              * extension, the values must be stored in binary form and point
to a glTF bufferView.
              */
              "name": [
                "DOOR",
                "EXTERIOR_WALL",
                "WINDOW"
              ],
              "index": [
                0,
                1,
                2
              ],
             "primarySubstrate": [
                [0],
                [1],
                [0, 2]
              ],
              "primarySubstrateWeights": [
                [100],
                [100],
                [10, 90]
              ]
            }
          }
        }
```

Experimentation

FlightSafety created a sample building model, using the EXT_feature_metadata extension to store the material data as a table within the model. This model is being rendered in CesiumJS in Figure 51. This was created with help from Cesium.

Figure 51. A simple model of a building rendered with a metadata texture.

10.4.3. Recommendations

These items are recommendations for representing CDB material textures for glTF models to support current CDB capabilities:

1. CDB glTF models should encode materials using the EXT_feature_metadata extension if there is material data for the model.
2. A standardized table format should be used. The above table schema can be that standard, if the additional optional fields are implemented.
3. Maintain the current list of CDB materials for easier transformations between CDB OpenFlight and glTF.

10.5. FlightSafety glTF Implementation

FlightSafety implemented a simple glTF model loader for FlightSafety's VITAL 1150 Image Generator, to help test the feasibility of using glTF models in a CDB. Below are images of the Space Shuttle Discovery model sitting at the end of runway 4R at the Honolulu International Airport, in a CDB of Hawaii.

Figure 52. A glTF model in FlightSafety's VITAL 1150 showing a NASA space shuttle at the end of Honolulu International Airport runway.

Figure 53. The same setup as Figure 52, but with evening environmental conditions.

10.5.1. Observations

Converting a glTF model to work in the FlightSafety VITAL 1150 Image Generator was relatively straightforward. The node and mesh structure, materials and textures, all work well. Some

observations:

- glTF models use a different coordinate reference system than OpenFlight or 3dsMax. They also use a slightly different texture mapping. Both of these are straightforward to adjust for.
- The Physically Based Rendering (PBR) approach of glTF materials (metalness) is different than OpenFlight's extended material palette (specular), but there are workflows that can convert from one to the other.
- Most models tested had their textures packed into a texture atlas. This was probably because they were conversions from other model formats, and packing the textures was done for rendering performance. Using a texture atlas will make the data repository use case of CDB more difficult, as making any modifications to the model's texture or geometry can become nearly impossible.
    - See Figure 54 for the visual effect of a texture atlas on the model imported into VITAL 1150.
    - See the 2020 3D Geospatial Tech Sprint OGC CDB 2.0 [https://github.com/sofwerx/cdb2-eng-report] Engineering Report from SOFWERX on the different use cases needed by USSOCOM for the next major revision of CDB.

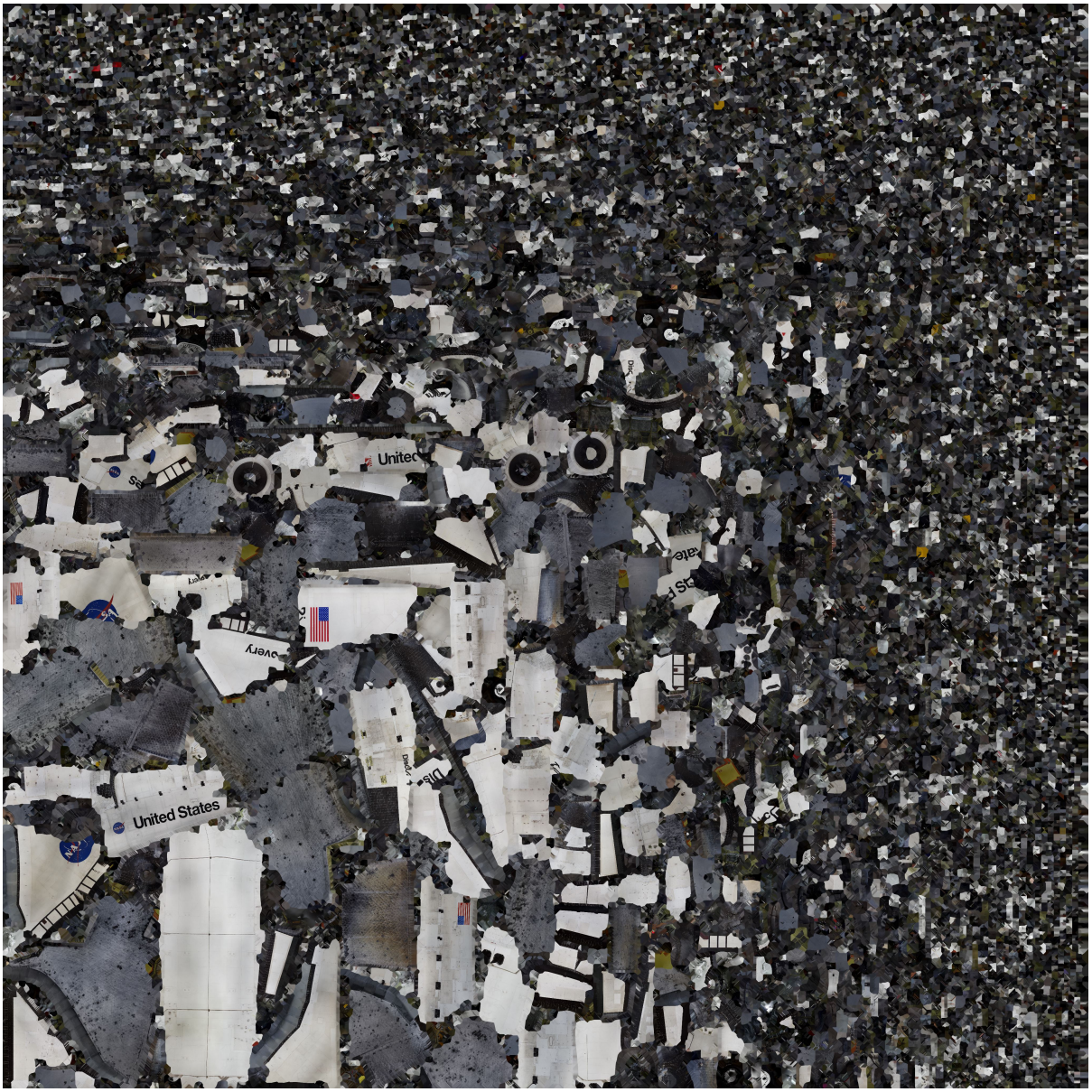


Figure 54. The image texture to be applied to the shuttle model from Figure 52 and Figure 53.

10.6. Conclusions

- glTF encoded 3D models can be a good option for future versions of CDB. The models are well organized and easily extendable.
- glTF models can be used with a variety of sensor systems. Further performance profiling would be needed for Radar and Thermal IR, as simulating these sensors relies more on computations based partly on the simulation environment and atmosphere, rather than pure rendering.
- Because one of the CDB use cases is to act as a data repository that allows editing of the CDB content, creating any model (glTF or otherwise) in a CDB with a texture atlas that makes editing the geometry or texture difficult is not advisable. In this case, either a conversion to glTF without the texture atlas, or storing the original model's format and texture is a better choice.
- FlightSafety would not recommend using glTF models as a replacement for CDB Moving

Models (models that are not anchored in a specific location), without additional interoperability experimentation. One goal of CDB is interoperability, and that cannot be determined by a single organization.

10.7. Future Work

- More extensive testing of the proposed extensions in Table 5. There was not enough time to test all of the proposed feature replacements, and more than one organization should participate and attempt to use a set of shared models.
- More testing on the approach for encoding material data. Additional work should be done to convert the material table and material ID texture into an Infrared irradiance and a simulated sensor representation.
- Work to determine if CDB specific extensions for glTF need to be developed, particularly for handling switch beads that modify the mesh geometry that is rendered. One other extension that might be needed is a Level of Detail extension that is more generic than the MSFT_lod extension.

Chapter 11. Component Implementation: InfoDao

11.1. Sprint Summary and Highlights

This Sprint highlighted 4+ scenarios that participants worked toward. InfoDao focused on Scenarios 1 and 3, with suggestions for more robust conversion between CDB and GeoPackage and applications in Scenario 4 (notably, "non-visible" electro-magnetic radiation). This report will show breakdowns of times between conversions and analyze the costs-benefits of the CDB pre-conversion and runtime conversion. InfoDao also explored concepts in the MovingModels (MModels) framework that should be expanded upon in future efforts.

11.2. Scenarios

11.2.1. Scenario 1

For the first scenario, InfoDao converted from The San Diego CDB GeoPackage provided by Ecere. Here are the sample times of conversion, along with a pie chart to graphically show proportions of time. Note that each level corresponds to its CDB Level of Detail (LoD) (e.g. Level 3 would be in the L03 Directory)

Layer	Objects (Tiles/3D Geometry)	Time
Level 3	1	3.4563
Level 4	1	0.0155
Level 5	1	0.0153
Level 9	4	0.1877
Level 10	6	0.4843
Level 11	12	2.9183
Level 12	30	7.1093
Level 13	108	33.552
Level 14	432	30.665
Level 15	1680	88.756
Level 16	6486	104.93
Level 17	25482	415.64
Level 18	101380	1558.6
Buildings	1164	154.72

Table 8. The time required to convert each layer of

the San Diego CDB dataset.

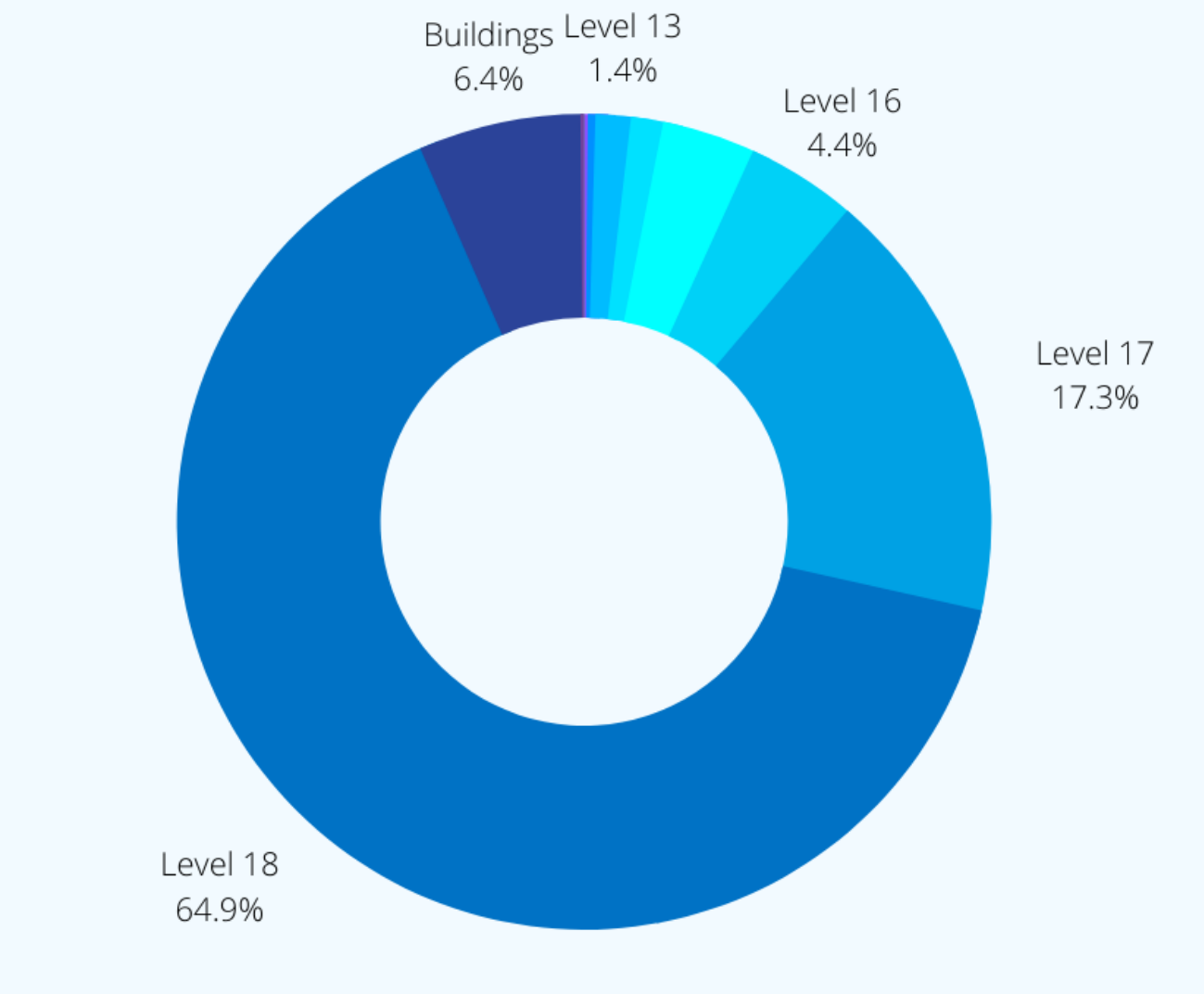


Figure 55. This image graphically shows the time required for conversion of the layers of the San Diego CDB dataset.

This breakdown brings two perspectives for implementing CDB in Geospatial workflows:

1. Offline conversion requires transfer of the entire CDB. A representative timing is ~30min for a 13.5 Gigabyte zip repository. Once transferrer, files can be accessed in constant time.
2. Run-time conversion requires CDB streaming capabilities. An example timing 1-5 seconds per viewport. Run-time caching depends on desired file-formats and requires validation checks.

For "Disconnected, Interrupted, Intermittent, Low-Bandwidth" (DIIL) applications; the tradeoffs are between computation power and bandwidth. Clients may not have the computation on Size, Weight, and Power (SWaP) restricted devices, and the network may not have bandwidth due to terrain and noise. One example of a hybrid approach is using a baseline CDB that is pre-converted and creating a stream-able edition to the CDB that can use Run-time conversion for connected devices. InfoDao explored this by creating a CDB of Miami and editing a new feature. For comparison; the Base CDB is 2.4 GB, and the edition of the wreckage is only 3MB.

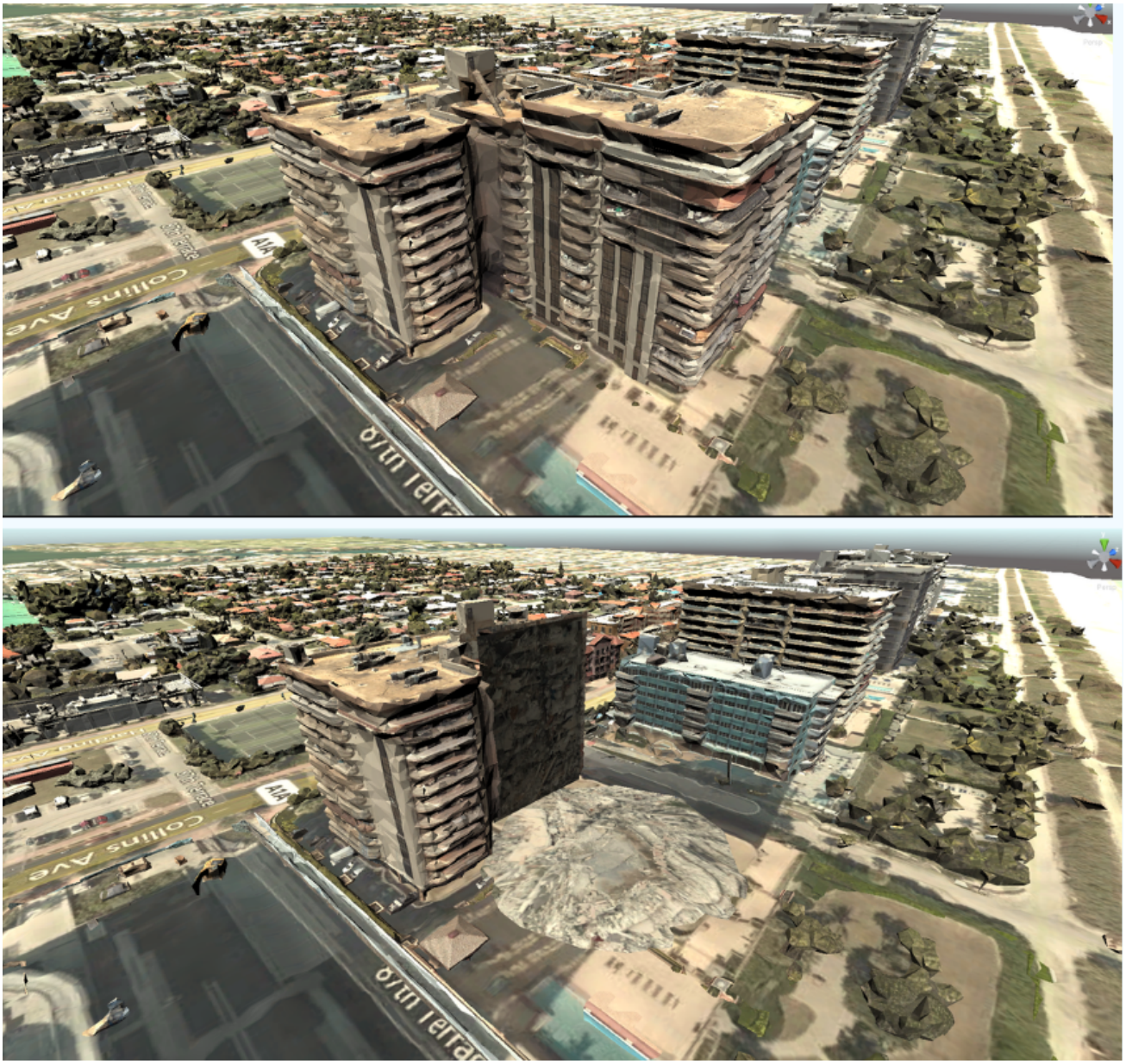


Figure 56. A "Before" and "After" image of the Surfside condo collapse using the Miami CDB as a base with a run-time update.

11.2.2. Scenario 3

For Scenario 3, InfoDao looked at using MovingModels (MModels) for representations of real-world MOVINT data. Two CDBs were made to examine how MModel data can be viewed in the Unity Engine.

However, scenario 3 needs more testing in order to ensure good fit for MOVINT and real-world applications. One source of examination is in the conversion between glTF and OpenFlight (specifically with their respective animation specs). Another point to mention is the compatibility of rigged models with other engines and clients.

11.3. Suggestions

1. Update the Best Practices for CDB in GeoPackages to use Related-Tables. Also add data to

GeoPackages to ensure better translation between file system CDB and GeoPackages (e.g. named layers that conform to the CDB spec).

2. Next efforts should include more use of MModels and examining how to store time sensitive location data.

Need Definition

NOTE

Please expand on 'Related-Tables' in #1 as not all readers of this report (especially those only reading the **Findings** section) will be familiar with that term.

Chapter 12. Component Implementation: SimBlocks.io

12.1. Subject

This Sprint Report reviews the participation of SimBlocks.io in the OGC Interoperable Simulation and Gaming Sprint Year 2, which was held from June 2 through July 6, 2021.

12.2. Summary

The purpose of the OGC Interoperable Simulation and Gaming Sprint Year 2 was to advance the use of relevant OGC and Khronos standards in the modeling and simulation community. In support of these goals, SimBlocks.io focused on support the CDB and GeoPackage standards in commonly used real-time 3D game engines, including Unity and Unreal. The SimBlocks team submitted a proposal in April 2021 in response to an open call for participation in the sprint and was accepted in May. SimBlocks is an Associate Small Company Member of the Open Geospatial Consortium.

12.3. Previous Work

The SimBlocks.io team specializes in connecting commercial gaming technologies with real-time 3D geospatial visualization applications by supporting industry standards for geospatial terrain, 3D models, and communication interoperability. SimBlocks previously participated in the OGC ISG Sprint 1, where SimBlocks integrated 3D Tiles and glTF model content from several vendors providing OGC GeoVolumes-compliant servers.

SimBlocks has created a whole-earth visualization plugin for the COTS Unity game engine capable of rendering the entire globe at any location at multiple levels of detail for imagery and elevation data. The One World SDK for Unity can consume geospatial data from cloud providers using web services technologies to process imagery, elevation data, and vector data. SimBlocks has tested ingesting data over web services including as Microsoft Bing Maps, OpenStreetMap, and a CDB web service provider. The One World SDK for Unity also supports high-detailed content insets using a variety of modeling formats, including OpenFlight, CDB, and have prototyped support for GeoPackage. Due to the rapidly increasing interest in visualizing geospatial data using real-time 3D game engines, SimBlocks recently made the One World SDK for Unity [https://github.com/SimBlocks/OneWorldSDKforUnity] open-source to increase its accessibility across a large user-base.

In addition to supporting Unity, SimBlocks has developed two tools to view CDB content in Unreal. The CDB Datasmith Exporter enables users to quickly export a desired CDB area into the Datasmith format, which can then be loaded and edited in the Unreal Editor, which is ideal for use cases where the area of interest is small and the user desires to manipulate or add to the terrain. The second tool SimBlocks has developed is the CDB Runtime Publisher SDK for Unreal, which enables developers to dynamically stream CDB content at runtime through a software

plugin on top of the Unreal Engine. This SDK is ideal for viewing large CDBs and in use cases where the underlying CDB is frequently updated.

Although both of these tools are proprietary software developed by SimBlocks, they both leverage open-source software for reading and visualizing CDB, including osgEarth, OpenSceneGraph (OSG), and improvements made by other vendors. Evaluation of any enhancements to these existing open-source libraries can be made public consistent with their licenses.

12.4. Architecture

The software architecture supports showing CDB content in the Unity and Unreal game engines. To support Unity, the CDB terrain is converted into GeoPackage and then streamed at runtime through a GoePackage Streaming plugin implemented by SimBlocks. These high-fidelity content insets are placed on top of the One World SDK global terrain. To support Unreal, the CDB terrain is exported to an Unreal-specific Datasmith format, which can be loaded directly into the Unreal Editor.

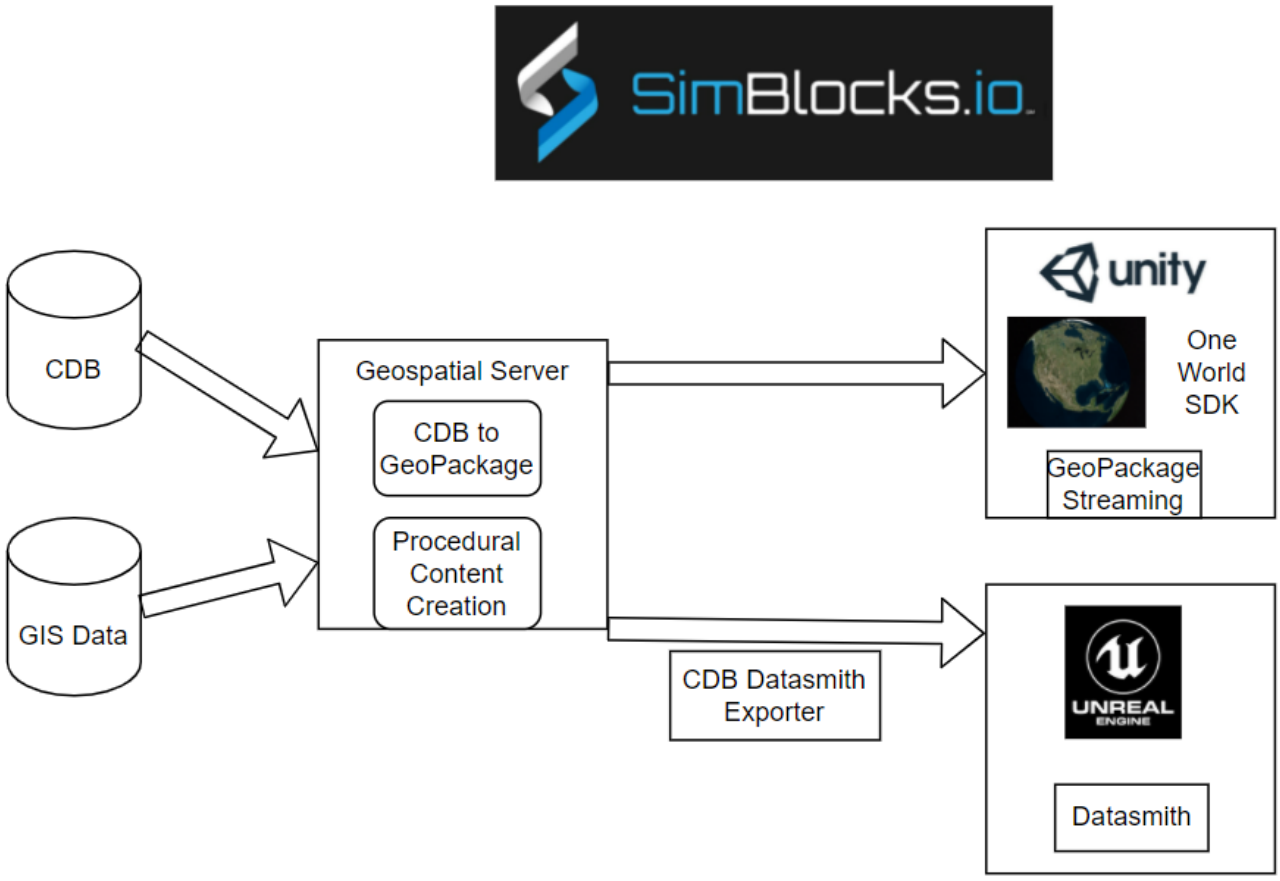


Figure 57. The software architecture of the SimBlocks.io CDB data exporter for Unity and Unreal.

12.5. Proposed Activities

12.5.1. Batch Data Conversion (Scenario 1B)

Prototype large scale batch conversion of CDB to GeoPackage and the conversion of OpenFlight models within CDB to glTF binary encodings within GeoPackage. The terrains and models will then be visualized within the Unity and Unreal game engines. Results from this effort may inform the next version of CDB.

Prototype CDB conversion to GeoPackage containers as recommended by the 3D Geospatial Series Tech Sprint II –OGC CDB 2.0 held last year. In order to meet the timing goals and funding limitations of the Tech Sprint SimBlocks will incorporate this capability using an internally developed libraries for content conversion and creation.

Define an xml structure that describes the GeoPackage structure to be created to allow varying packaging of the GeoPackage output from the CDB. Items such as tiling structure and layer content of the output GeoPackage files that are output as well as model formats stored. OpenFlight models will be read and stored as glTF buffers in GeoPackage. While the San Diego CDB will at least be supported in this effort, if other open CDB data stores are contributed for this Sprint they may be considered as well.

Integrate with Unreal Engine through a SimBlocks developed CDB Runtime Publisher SDK as a part of its capabilities to support CDB in Unreal Engine.

Integrate with Unity. SimBlocks will integrate the loading of GeoPackage on top of the One World SDK for Unity to enable visualizing geospecific 3D content on top of a world-wide base terrain.

12.5.2. Scenario 3

Leverage a procedural city generation capability that SimBlocks has developed to quick create 3D content from source data including imagery, elevation, and building footprints.

Proposes to add transportation elements procedurally to this database using additional openly available and sharable data sources which will then be added to the GeoPackage.

The current SimBlocks generation tool has focused on geotypical and geospecific 3D buildings. SimBlocks will enhance the tool to support transportation features to support traffic simulation on roads and rails. As well as, use several 3D entity models representing cars, trucks, trains, and aircraft in a real-time traffic simulation and explain how articulations and animations are supported in the models. SimBlocks preference will be to use existing OpenFlight models. Additionally, there will be integration of historical flight information to show an aircraft flying over the city.

12.6. Accomplishments

SimBlocks accomplished much of but not all of the planned goals.

1. Conversion of CDB content into GeoPackage keeping OpenFlight Models.

2. Conversion of CDB content into GeoPackage using glTF binary as model format.
3. 3d content creation directly into GeoPackage using glTF binary as the model format.
4. Capture performance metric of format choices using OSG software.
5. GeoPackage playback using the Unity Game Engine.
6. GeoPackage content conversion into Unreal Engine.
7. The SimBlocks team now has a much better understanding of glTF.
8. Utilize Unity's "Advanced" Mesh API for better runtime performance.
9. Major software upgrade to improve support for CDB and GeoPackage in Unity.

12.6.1. Austin in Unity

Figure 58. These images show three cities (Austin, Paris, and San Diego) rendered in three different rendering engines (Unity, Unreal Engine, and OpenSceneGraph). This first image is Austin showing in Unity.

12.6.2. Paris in Unity

Figure 59. The second image is Paris in Unity.

12.6.3. Austin in Unreal

Figure 60. The next two images were rendered with the Unreal Engine. This one is Austin.

12.6.4. San Diego in Unreal

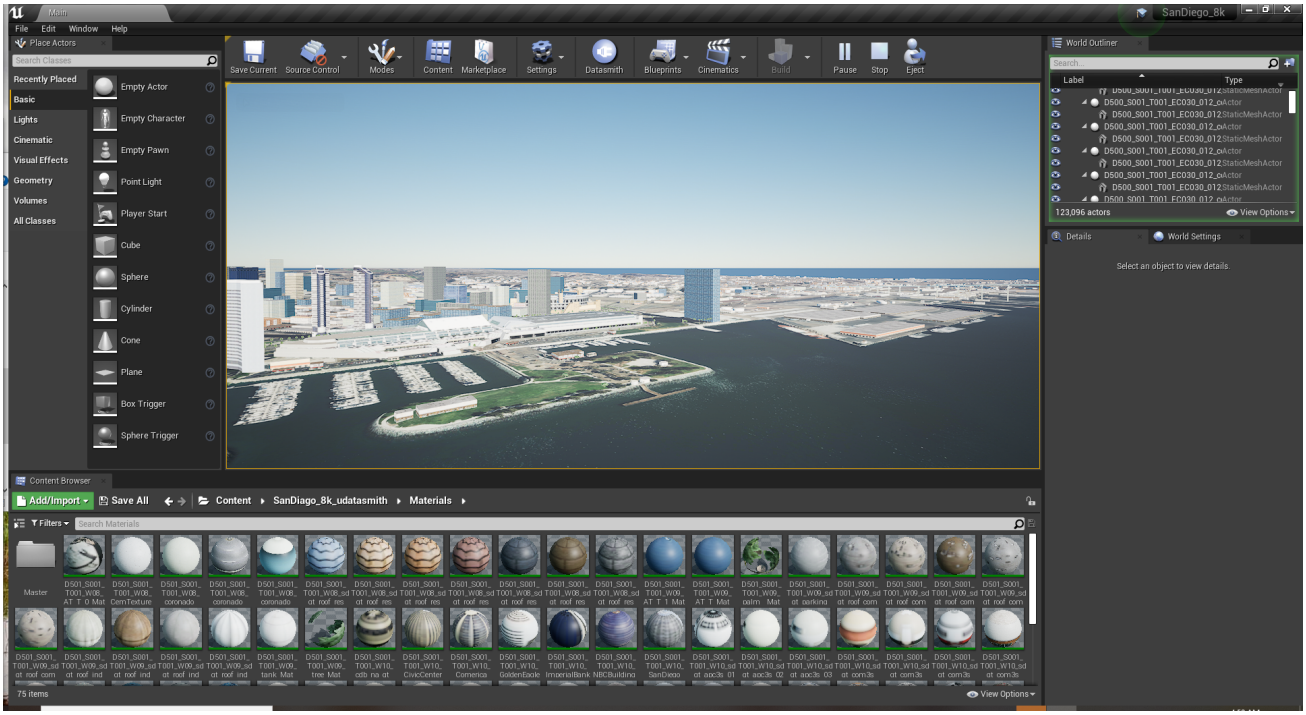


Figure 61. The penultimate image of this set is San Diego rendered in Unreal Engine.

12.6.5. San Diego GeoPackage in OpenSceneGraph

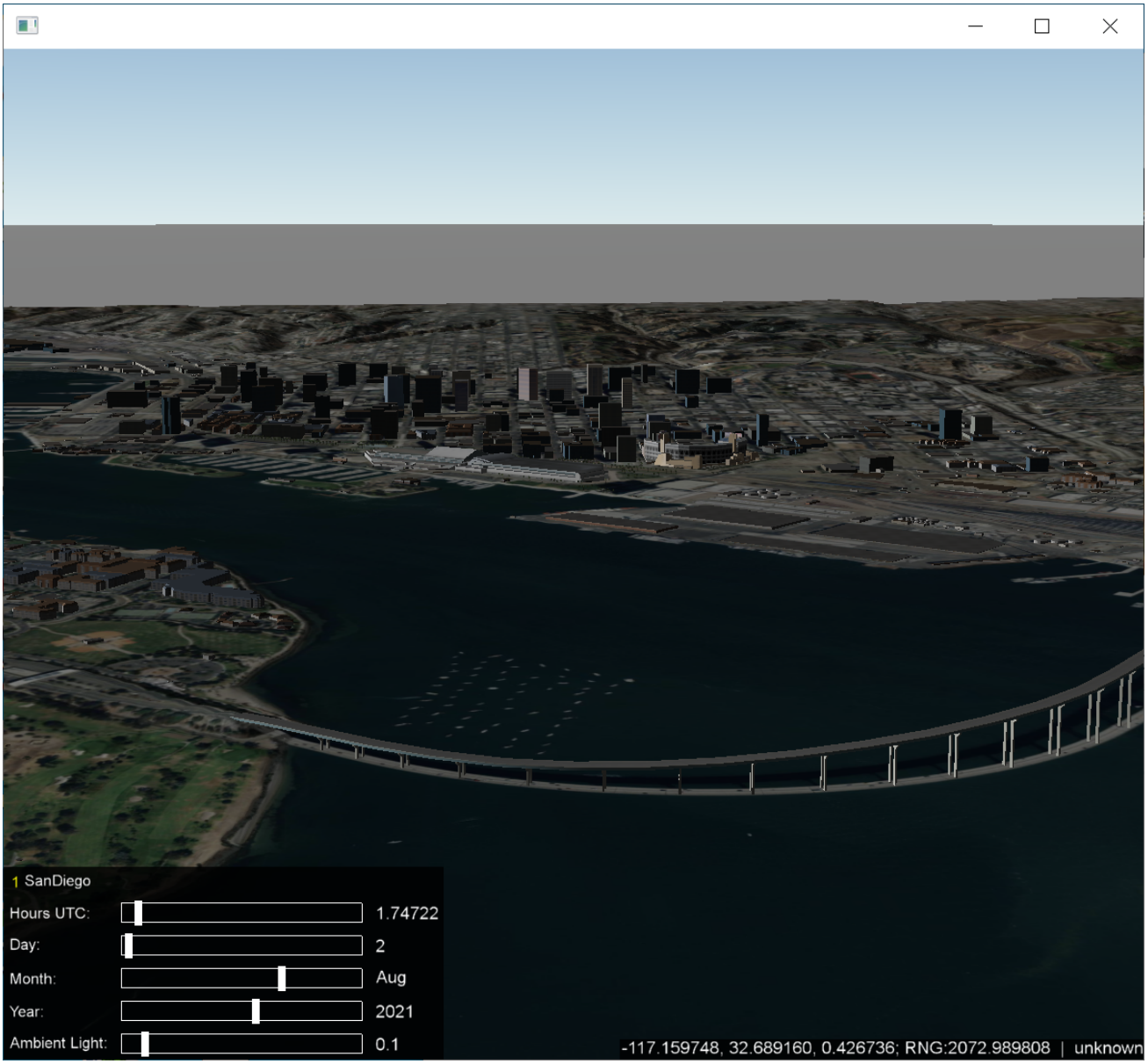


Figure 62. OpenceneGraphi was also used to render downtown San Diego and Coronado Bridge.

12.7. Methodology

12.7.1. Converting CDB into GeoPackage with OpenFlight Models

GeoPackage Structure Overview

The GeoPackage output created from CDB under this topic can represent either GeoPackage tiles created relative to a CDB Level of Detail's (LOD) tiling structure or generated around some arbitrary bounds that cover an Area of Interest (AOI). In this structure if it is tiled based on a CDB's level of detail the CDB LOD chosen selects the tiling structure for the GeoPackage Tiles coverage. All levels of detail contained within a CDB are written to the GeoPackage tile that covers the content area of the GeoPackage. For example, using the San Diego CDB (see **Appendix C**) US R6 represents the LOD level 3 data which covers the San Diego Harbor and Coronado Bridge.

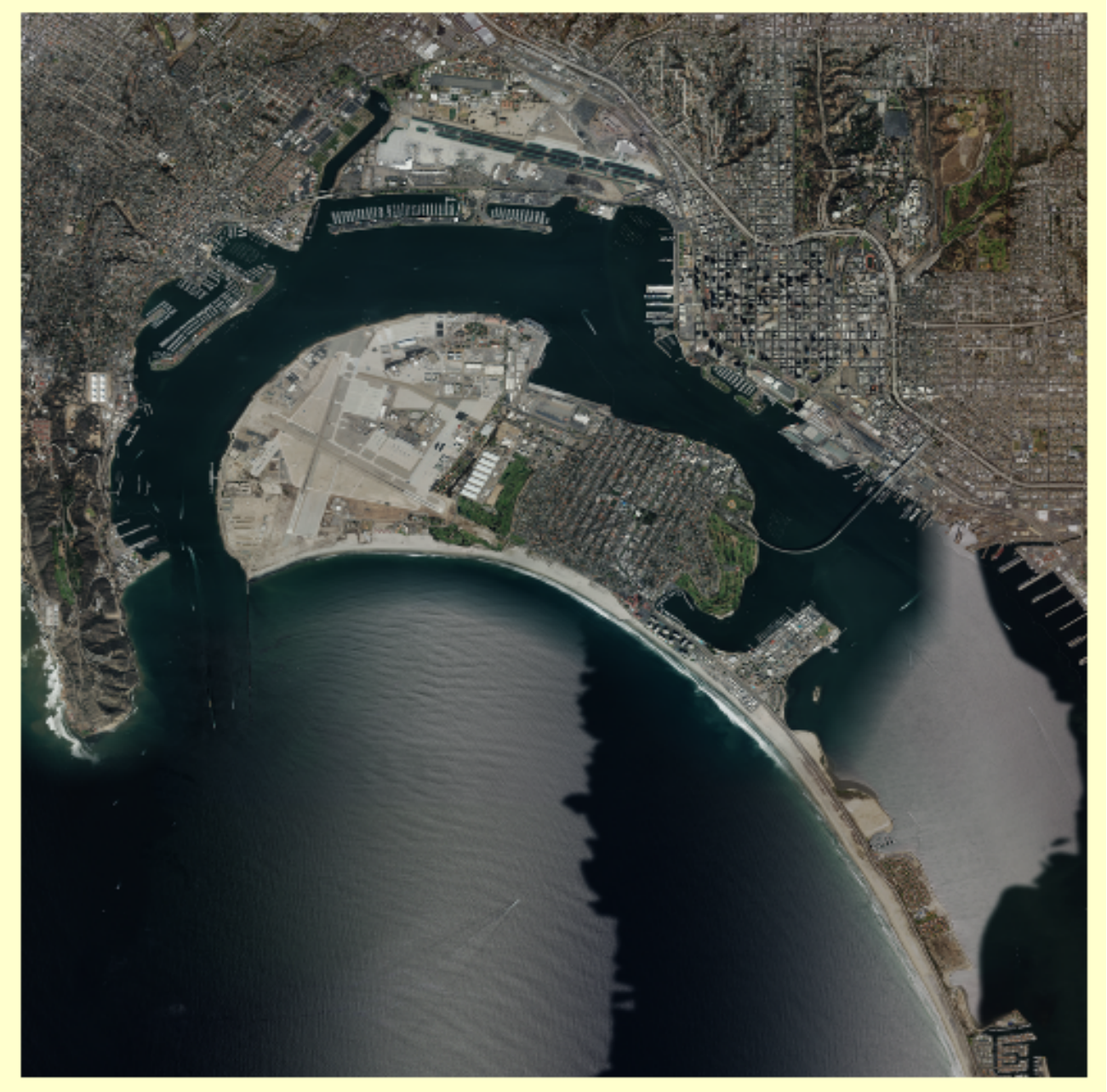


Figure 63. San Diego CDB LOD 3 Image Tile U5 R6 is shown. The tiles extents are from Latitude 32.625 to 32.75 and Longitude -117.125 to -117.25.

CDB Imagery Layer

When examining the San Diego CDB the highest resolution imagery found in the coverage for this tile is LOD 9. The sample spacing for LOD 9 of CDB at latitude 32 deg. is ~0.2173 m per pixel (1.9073e-6 Deg.). This gives us a raster size of 65536 x 65536 (64 LOD 9 tiles) which is written to the GeoPackage into the layer Imagery_S001_T001 at the CDB LOD 9 resolution.

CDB Elevation Layer

When examining the elevation content in the CDB for the highest resolution it is seen that the highest resolution coverage is CDB LOD 7. The sample spacing for LOD 7 of this CDB at 32.0 degrees North is 0.8493 m per pixel (7.6294e-6 degrees). This gives us a raster image size of 16384 x 16384 (16 LOD 7 tiles) which is written to the GeoPackage into the layer Elevation_S001_T001 at the CDB LOD 7 resolution.

CDB GeoSpecific Model Layers

The GeoSpecific model layers considered in this sprint were the 100_GSFeature and 300_GSModelGeometry layers. For the 101_GSFeature layer the contents of each LOD contained by the area represented by the GeoPackage tile were written as a layer into the GeoPackage. The CDB model layers as referenced in the San Diego GeoPackage use an instance dataset and a class dataset (i.e., files) containing S001_T001 in this layer refer to the instance parameters while files containing S001_T002 contain the class reference information for the entries in the instance layer. The class layer information is referenced using value contained the string attribute CNAM. In this experiment instance and class information were merged, creating an instance layer with both the instance and class attributes. In the image below the vector layers for both the GeoSpecific and GeoTypical model layers. Model instances that reside in LOD layers less than 0 have been included in the LOD 0 layers. Layers 100_GSFeature_…L00 through 100_GSFeatue …L04 and 300_GSModelGeometry…_L00 through 300_GSModelGeometry…L04 contain the models and model references for the GeoPackage tile. The 300_GSModelGeometry layers contain the tiled model geometry for the CDB Tiles represented as zip archives and are written into the GeoPackage with a mime type of application-zip. The access to the 300_GSModelGeometry layer uses the CDB U and R numbers of the corresponding CDB tile data in the SQL query to read the model tile zip fie. This also places the requirement on the software accessing the reference information to query the layer using the geospatial extents of the CDB tile being referenced.

NOTE

Bad Sentence

Half-way through the above paragraph the "sentence": "In the image below the vector layers for both the GeoSpecific and GeoTypical model layers." is not a complete sentence and needs to be removed or corrected.

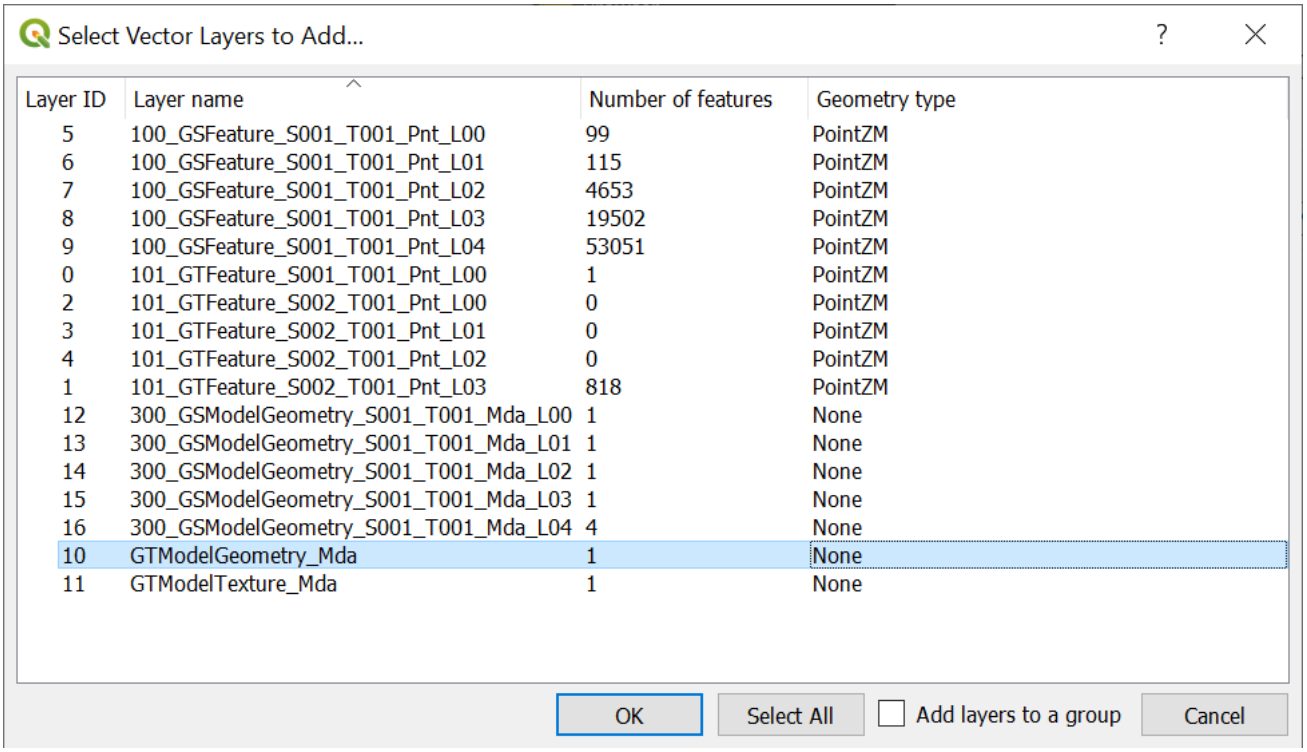


Figure 64. GeoSpecific and GeoTypical Model layers shown in the tiled GeoPackage

CDB GeoTypical Model Layers

The GeoTypical model references (101_GTFeature) are handled similarly to the GeoSpecific model references are represented in layers 101_GTFeature…L00 through 101_GTFeature…L03 in the figure above. The model geometry for the GeoTypical models resides in the GTModelGeometry_Mda layer in a zip archive file structure that follows the CDB GTModels structure starting at the 500_GTModelGeomtry level. The textures for the OpenFlight models used are stored in the GTModelTexture_Mda layer. This includes both the textures for both GeoTypical and GeoSpecific models for this database since the 301_GSModelTexture layer was not used for the San Diego CDB.

Creation Process

Software routines were added to the SimBlocks Content Creation application allowing for selection of CDB and output areas for incorporation into GeoPackage tiles. This Application uses library functionally from the open source osgEarth / OpenSceneGraph that have CDB support added that is referenced below.

File Counts

The San Diego CDB contained 25,461 files and 757 folders space on disk listed as 37.3GB. A targeted area GeoPackage file represents one file. A tiled GeoPackage set requires one file for each tile of each LOD down to the GeoPackage tile LOD for the xml reference files and one GeoPackage file at the target LOD. For a CDB using LOD3 for the GeoPackage tiling this would be 149 files and 85 folders.

Performance

Open source versions of osgEarth and OpenSceneGraph software were used to directly visualize CDB and record metrics on data load times.

12.8. Converting CDB into GeoPackage with Models Converted to Binary glTF

12.8.1. GeoPackage Structure Overview

Imagery and Elevation

The imagery and elevation in these files is exactly as described above in Converting CDB into GeoPackage with OpenFlight Models.

CDB GeoSpecific Model Layers

The Geospecific layer names used when converting the CDB OpenFlight Models to glTF Binary representations are the same as in the OpenFlight version, however the process of writing the models into the 300_GSModelGeometry layers varies in that for each individual model a unique

integer key is generated, the model is written into the layer using the model/gltf-binary mime type, and the key is recorded in the models reference (instance layer) as and attributed value. All models were written into their respective 300_GSModelGeometry layers with textures embedded as JPEG images for opaque textures and as PNG for transparent textures.

CDB GeoTypical Model Layers

The GeoTypical layers created in this process were the 101_GTFeature… layers and the GTModelGeometry_Mda layer. As with the GeoSpecific Mode Layers each individual GeoTypical model is written into the GTModelGeometry_Mda with a unique integer key and the key value is recorded in the 101_GTFeatures as an attributed value.

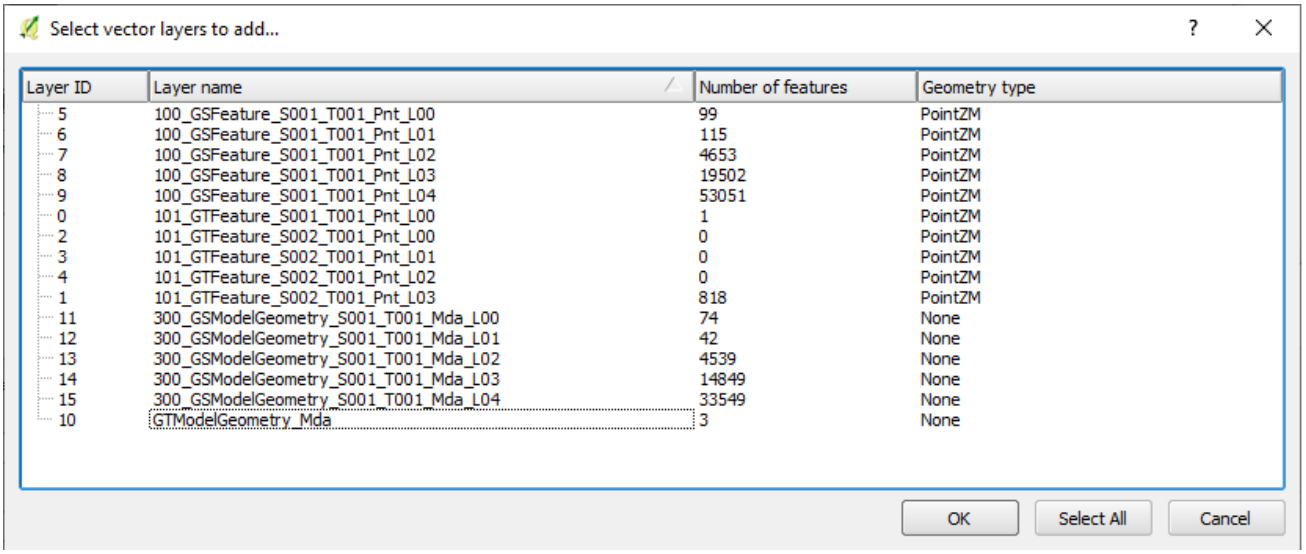


Figure 65. GeoSpecific and GeoTypical Model Layers from Tiled GeoPackage using glTF Binary (.glb) model files.

Creation Process

Software routines were added to the SimBlocks Content Creation application allowing for selection of CDB and output areas for incorporation into GeoPackage tiles while converting the 3d model content from OpenFlight to glTF models. The model conversion process was performed using libraries from the open source osgEarth / OpenSceneGraph libraries referenced above in this document. These were output as binary glTF files.

Lessons Leaned

The output capability for the glTF models is provided by an OpenSceneGraph (OSG) plugin provided in the osgEarth project. This project intern relies on the TinyGLTF project to perform the basic glTF (binary or JSON) reads and writes. While reading glTF, the data seemed to work fine, SimBlocks discovered and corrected several issues related to writing the glTF binary data. These fixes are present in the repositories referenced in the previous section.

File Counts

The file count issues vs CDB are the same as reference in the section Converting CDB into GeoPackage with OpenFlight Models.

File size

For the example GeoPackage Tile LOD3 U5 R6 required 2,390,364 KB of disk space with OpenFlight models while it took 34,583,256 KB of disk space with the glTF Binary files with embedded textures. This increased file size for the GeoPackage is a result of duplicating the texture content stored in the GTModels/GTModelTexture layer into many GLTF models as the San Diego CDB was created using only GeoTypical textures from this layer for both the GeoTypical and GeoSpecific models.

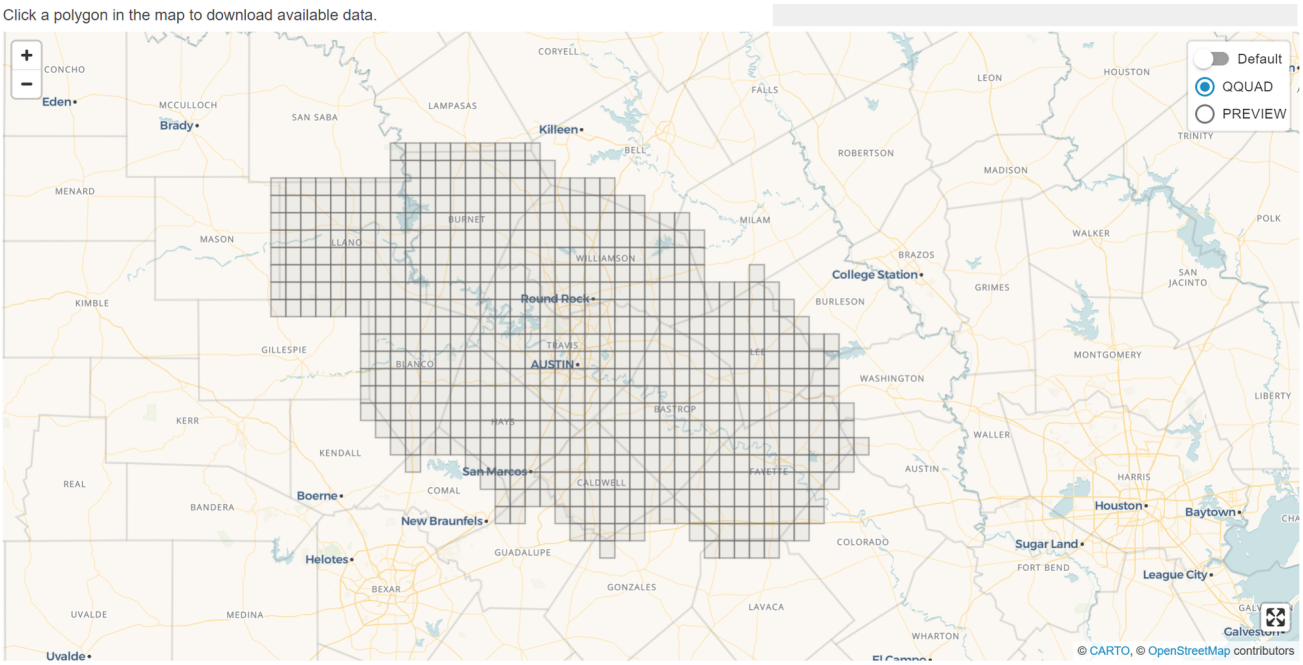
NOTE | *All of the links in the section below need to be extracted into **Appendix C**. References should be made to that appendix.*

12.8.2. GeoPackage Content Creation (Austin, TX) for Unreal Engine and Unity

An area around Austin TX was created to demonstrate the ability to create unified content in GeoPackage dataset that can be applied in both the Unity and Unreal game engines. Austin TX was selected for its rather rich GIS environment that is publicly available.

Imagery

The imagery information that was originally downloaded from City of Austin's GIS sight is from the CapArea Imagery 2019 dataset can now be found on the Texas Natural Resources Information System [https://data.tnris.org/collection/f84442b8-ac2a-4708-b5c0-9d15515f4483].



Description

This orthoimagery dataset was acquired by Fugro USA Land, Inc. in January 2019 during leaf-off conditions in Bastrop, Blanco, Brazos, Burnet, Caldwell, Fayette, Hays, Lee, Llano, Travis and Williamson counties and portions of Burleson and Grimes counties. Aerial orthoimagery flown during leaf-off conditions allows the data user to 1) identify man-made features through the deciduous tree canopy and 2) distinguish between evergreen and deciduous vegetation. The Austin, Bastrop, Bee Cave, Bryan, College Station, Burnet, Lockhart, Round Rock, and West Lake Hills city limits as well as the entirety of Brazos and Travis counties are available at 6-inch pixel resolution. The remaining areas have a coarser 12-inch pixel resolution. Both pixel resolutions allow the user to identify detailed features on the ground such as road turning lanes, fences, and park benches. The entire dataset is available as a 4-band (RGBIR) product which allows the user to display the imagery in natural color (RGB) or color infrared (IRRG). Flight date is in each filename as YYYYMMDD, and each image tile covers one-64th of a USGS Digital Orthophoto Quad (DOQ), resulting in a DO4Q or approximately 1 square mile with minimum 300-foot buffers.

Figure 66. City of Austin, Texas map showing 6-inch GSD imagery coverage.

While SimBlocks originally downloaded Jpeg 2k tiles from the Cities GIS page, TRNS now also provides the data as a Web Map Service (WMS) [https://imagery.tnris.org/server/services/StratMap/StratMap19_NCCIR_CapArea/ImageServer/WMSServer].

Elevation

Elevation for the area was pulled from USGS via the Download server [https://apps.nationalmap.gov/downloader/#/].

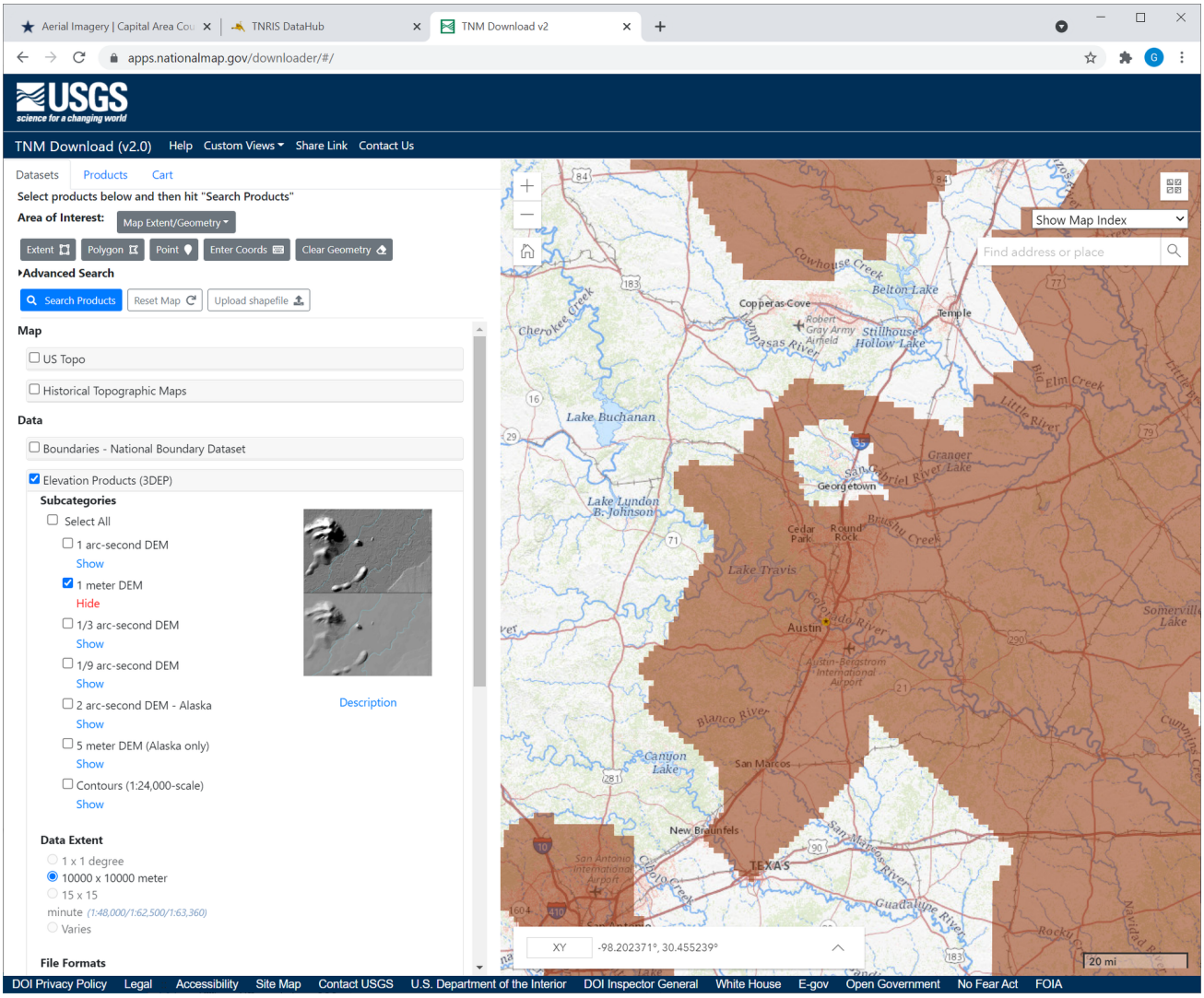


Figure 67. The 1-meter elevation coverage in the Austin region is shown here.

The data used for Austin was pulled from the USGS Web Coverage Service (WCS) found at https://elevation.nationalmap.gov/arcgis/services/3DEPElevation/ImageServer/WCSServer (Note: The Timeout setting for this site had to be increased to 60 seconds to prevent timeout errors during initialization and download)

NOTE

Link Error

This link returns a 404. Either refer to the Download server (above image) or fix the link. It is also necessary to descibe which timeout. Is it a browser setting or something else? In my case, the response was so fast that I don't think any timeout change would matter. It would be better to make a "Note" this way rather than in-line in the text.

Building Footprint information

The main portal for Austin's GIS data [https://austintexas.gov/department/gis-data] contain links to all of the geographic data available. The Building footprint information can be found in the city's Box account [https://austintexas.app.box.com/s/8ah8itbha7u6lis9eipypnz5ljvwta4t]. The building footprint file is *building_footprints_2019.gdb.zip*. This file contains accurate building footprints that match the

2019 imagery layer with height information for each building.

Tree Location Information

The City of Austin maintains a tree inventory of trees within its geographical limits. The data is delivered as a CSV file [https://data.austintexas.gov/Locations-and-Maps/Tree-Inventory/wrik-xasw] and contains location, species, and truck diameter information.

The National Geospatial Intelligence Agency provides open US Cities data from its Geospatial Repository and Data Management System (GRiD). The system may be found here: https://grid.nga.mil/grid . One of the datasets available from the US Cities is a tree locations dataset. This dataset also contains the point location of the tress as well as tree height information for each tree in the dataset. This data was downloaded for the Austin area as a GeoPackage dataset.

GeoPackage Creation Process

The SimBlocks Content Creation tool was used to process the Imagery (6in GSD) and Elevation (1m GSD) information into a selected area.

For Unreal Engine Imagery and Elevation

The size of the area was set according the Unreal Landscape requirements [https://docs.unrealengine.com/4.26/en-US/BuildingWorlds/Landscape/TechnicalGuide/]. For the Austin area 4033x4033 and 8129x8129 were utilized.

NOTE

Unreal Engine Requirement

These sizes are for the Elevation Grid and in this dataset Imagery raster sizes are paired to this dataset based on Unreal's UDIM requirements [https://docs.unrealengine.com/4.26/en-US/RenderingAndGraphics/VirtualTexturing/Streaming/].

SimBlocks used a maximum individual texture size of 8192x8192 and in the 4033x4033 landscape this resulted in 4x4 UDIM texture set. (i.e., sixteen 8192x8192 image tiles covering the 4033x4033 elevation coverage). For the 8129x8129 case it also resulted in a 4x4 UDIM texture set.

For Unity Imagery and Elevation

The Unity system does not place the same constraints on us regarding elevation post size. For convenience however, with this effort the same elevation sizes were used. The image layer for unity was written as a single raster layer at the 6in GSD. This resulted in an image raster of 26499x26499 for the 4033x4033 elevation grid. For the 8129x8129 elevation grid an image raster of 53413x53413 was utilized.

3D Building Geometry (both Unreal and Unity)

For the area being created the Content Creation Software creates a 3D model in memory using the polygonal information provided from the Building Footprint information. The models were written to the GSModels Layer creating an integer unique key for the reference and the Location information was written to the GSModelReferences Layer as a point feature with the unique key added to the attribute table.

3D Tree Features

Within the SimBlocks Content Creation tool a process was created to merge the content from the City of Austin tree inventory with the NGA GRiD tree information. The NGA GRiD information contains a broader area then the cities data. For each match found in the datasets the NGA data was updated with the cities species data and trunk diameter info. If no match was found the species field was set to “default”. This file was then used to create a mapping from each individual species found in the data to a tree species in the SimBlocks tree library. Once the mapping was set the GeoPackage creation process used the resulting data to place a model reference in the GTModelReference Layer of the output GeoPackage and storing one instance of each tree model mapped in the GTModels table.

12.9. Performance Metrics

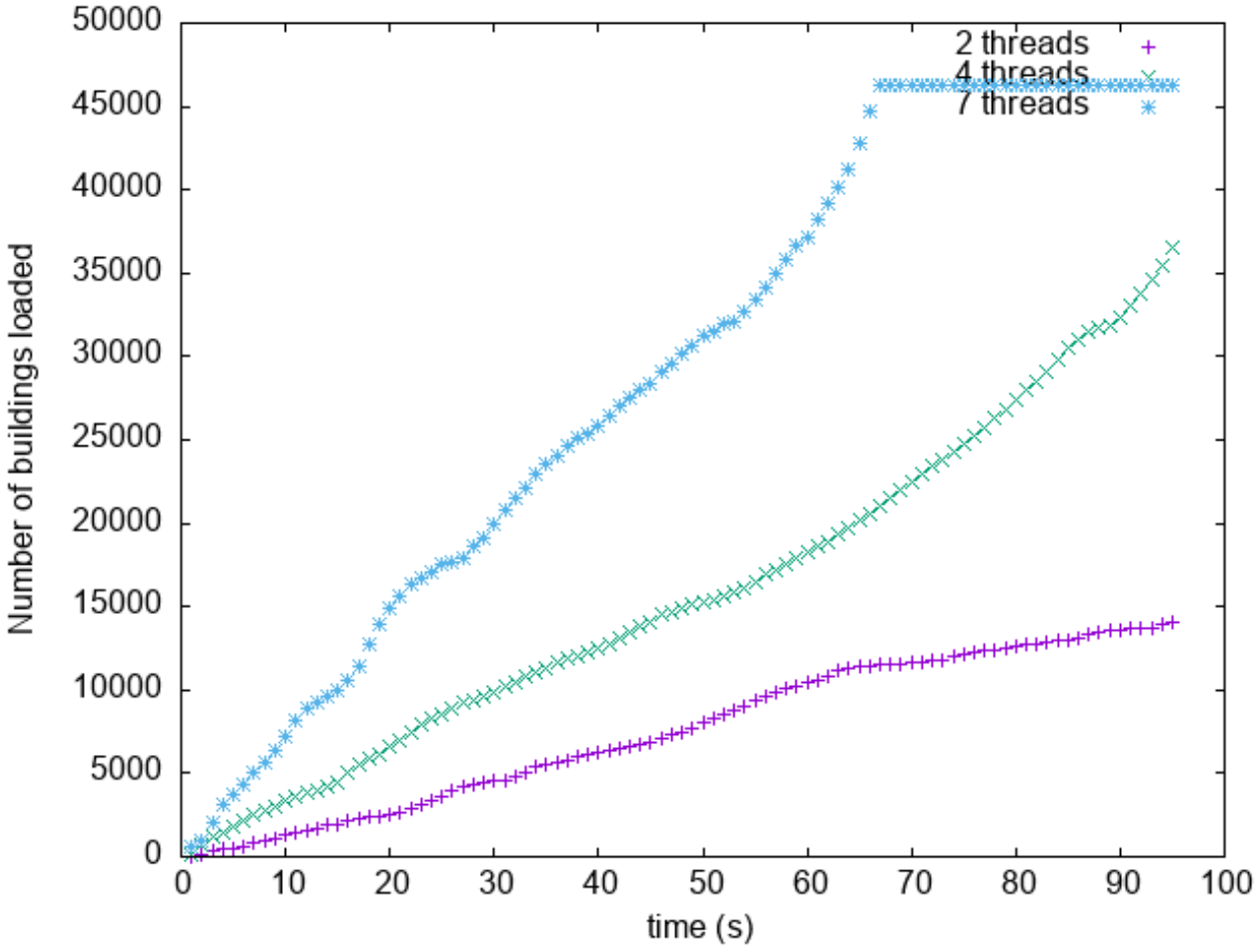


Figure 68. The number of buildings loaded vs. the total load time shown for varying numbers of threads.

The above graph shows the number of buildings loaded vs the time in seconds when using 2, 4 and 7 threads. Not shown is how much time it would have taken for a single thread in debug mode. Debug mode was tremendously slower than release. A single area took 7 minutes to load and since it was loading on the main thread, the screen was frozen. There is a noticeable difference between 7 threads and 2 threads, imagine what 12 threads would be like.

The program is quite simple. When the One World SDK visits an area, it sends the geodetic extents to the plugin and puts it on a stack and notifies a sleeping thread that it has a task to do. The woken thread queries GeoPackage; and if it finds models there, it then generates a “Work” structure. The thread then puts it on a queue and wakens N-1 threads to start converting these models. The thread that is processing the last building in the chunk, then takes all the buildings and batches them together and then converts them to graphics buffers and puts it on a queue. The main thread will call an Update function that checks this queue and then converts this to a Unity mesh. The thread will then take the next “Work” structure and process that as described above. The program takes around 7 gigabytes once all buildings are loaded.

SimBlocks investigated time performance by measuring the time taken to do the various steps described above. It was found that the C++ plugin consumes around 50% of the processing time with 95% of that time used by TinyGLTF loading strings. Surprisingly, more time is spent in deleting the glTF models than actually batching them together at runtime. Only a tiny fraction (less than 1%) is spent querying the models from the GeoPackage. Clearly, the bottleneck is TinyGLTF. 19% of the time spent in TinyGLTF is in parsing image data. This can be reduced to nearly zero by sharing the images between models. Apart from the glTF loading from string, the other reason TinyGLTF may be slow is that the models are read from a magnetic disk.

12.10. Created / Converted Content in Unreal Engine 4.26.1

The export process to Unreal Engine utilizes the SimBlocks content creation tool’s Datasmith transformation capability to convert the GeoPackage contents into forms that the Unreal Engine editor can consume. Keeping in mind that the GeoPackage raster and elevation are as described in the For Unreal Engine Imagery and Elevation section above. In this process the elevation and imagery tiles are extracted from the GeoPackage and rotated 90 degrees. The elevation in the GeoPackage is stored as 32-bit floating point datum. In its scaling to the 16 bit PNG required by Unreal. In this mapping 0 is mapped to 32768 and min to max elevation values are scaled from 32768 to 65536. Each Image raster is rotated 90 deg. as it is converted to 8 bit PNG raster images. An Unreal Datasmith output is then created describing the geometry of all 3d content in the GeoPackage file. The directory structure below shows the export of the Austin 8129x8129 output. The output Datasmith xml files are in the Datasmith subdirectory.

NOTE	*Bad Sentence* Half-way through the above paragraph the "sentence": "In its scaling to the 16 bit PNG required by Unreal." is not a complete sentence. It also does not make sense relative to the material before it. The text either needs to be removed or corrected.

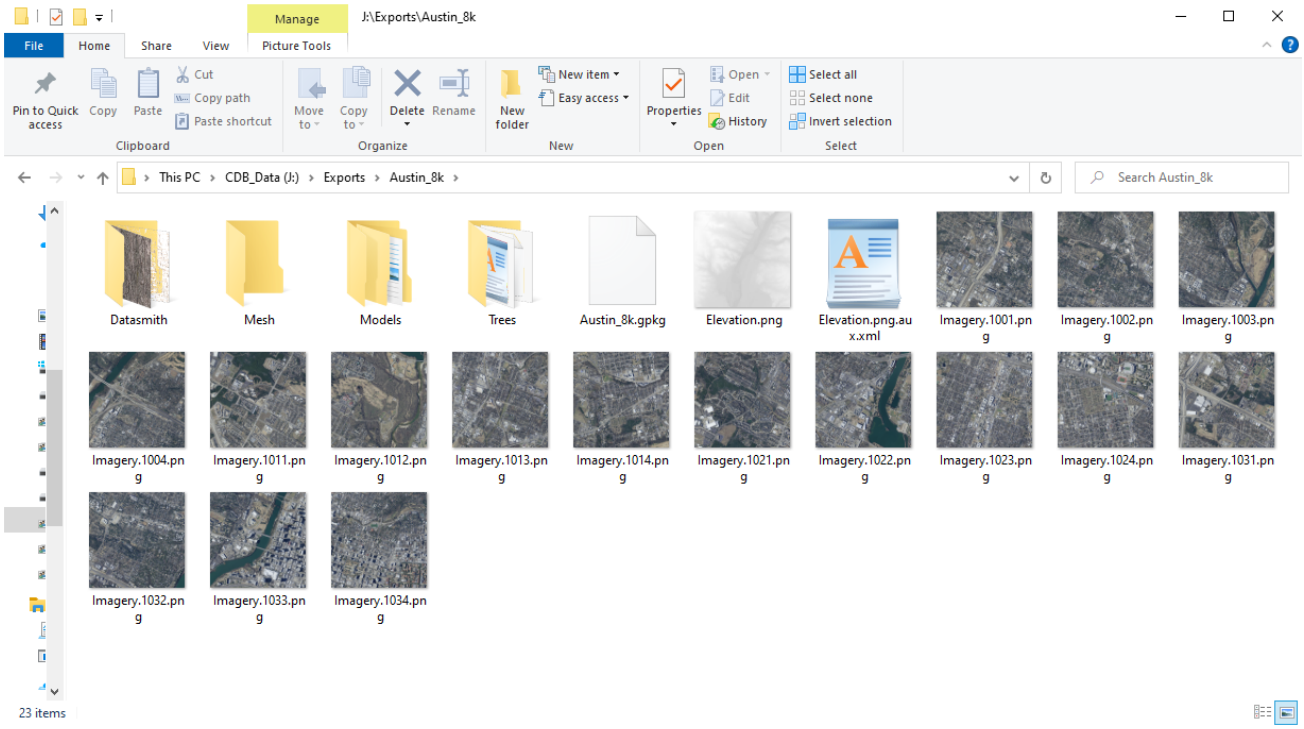


Figure 69. Windows Explorer shows the files exported by Unreal Datasmith.

12.10.1. Importation of the Datasmith output into Unreal

Once the Datasmith export process completed the Unreal Engine Editor is used to import the data and covert it to native Unreal assets. To do this the user presses the Datasmith button on the Top of the Application window and navigates to the .udatasmith file in the Datasmith directory shown in the graphic below.

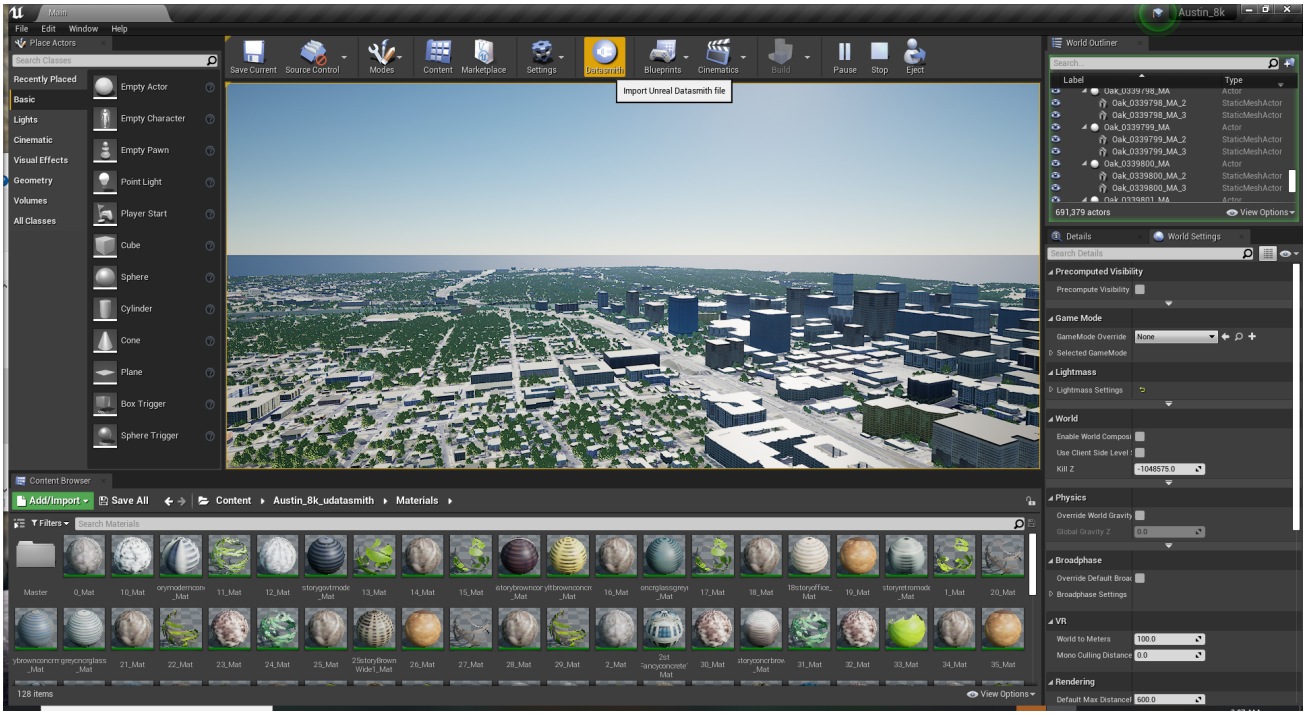


Figure 70. Datasmith import into Unreal Engine 4.26.1 is shown in this render.

12.11. Technical Challenges

12.11.1. OpenSceneGraph glTF Creation

Issues with glTF creation in the osg software being used for conversion.

- The unexpected issues encountered in creating glTF could be considered and gap in technical capabilities.
- This gap was address by correcting the issues and publishing the updates.

Tile content issues in the San Diego CDB

- Tile Model Geometry limits exceeded
- Tile Model Reference counts exceeded

C++\CLI Integration with Unity

- SimBlocks software development team evaluated if using a C\CLI interface on top of some C code to call the functions from C#; however after some testing it was determined this would not be possible with Unity as the engine does not allow loading managed C++ modules.
- As an alternative, using other ways to interoperate between C++ and C# was successful.

Debugging External DLLs in Unity

- When a Plugin loads an external DLL, Unity will enter into an unstable state, making the Editor unusable. A workaround was to build the standalone player, which makes debugging more difficult.

Texture flickering, mipmap issues.

- Some texture flickering is noticeable, and SimBlocks team is currently investigating a mipmap solution.

12.12. Future Work

- Showing transportation elements is still an outstanding task.
- Reduce GeoPackage size by sharing textures between models
- Reduce GeoPackage size and loading time by using DXT/hardware texture compression
- Improve Unity rendering performance by batching models and sharing materials and textures

Chapter 13. Component Implementation: Steinbeis

13.1. Overview

In the ISG Sprint Year 2, the Steinbeis team developed various data visualization clients, including Unreal Engine (UE), Unity 3D, web client, and smartphone fetching the 3D data from the GeoVolume server. Steinbeis has used the 3D building models of the University of Applied Sciences Stuttgart (HFT Stuttgart) and its surrounding area as a use-case. These were modeled with interiors and are available in different formats such as skp or x3d. Those formats can be converted to gltf/glb or 3D Tiles. Measurements of the CO2 concentration inside the rooms were integrated. These measurements come from the Sensors placed in rooms that are managed with the SensorThings API.

Moreover, the dynamic data from the moving sensors from different types of vehicles were integrated into visualization clients. They can access and render these datasets from SensorThings to simulate 3D urban mobility. The dynamic moving data such as taxi, air-taxi movement, and eBike movement was managed and delivered through the OGC SensorThings API standard. At the same time, the concept and implementation used the GeoVolumes API for managing the 3D geospatial resources.

The overall system architecture of Steinbeis' implementation is illustrated in Figure 71.

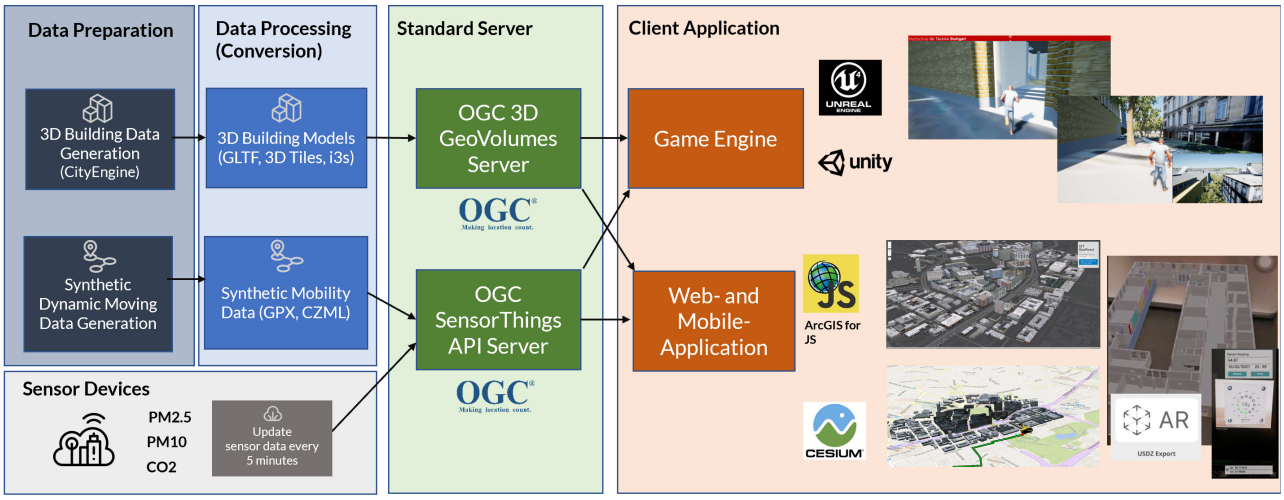


Figure 71. The system architecture of Steinbeis' implementation allows for importing of GeoVolumes and SensorThings data into third-pary display technologies.

13.2. Server Side

13.2.1. GeoVolumes Server

In the OGC ISG Sprint Year 1 [https://www.ogc.org/projects/initiatives/isg-sprint-yr1], Steinbeis successfully implemented a GeoVolumes API server to deliver 3D geospatial resources supporting

3D Tiles, I3S, and Terrain and available online [http://steinbeis-3dps.eu/3DGeoVolumes]. The data available on this server included New York City and San Diego. In this OGC ISG Sprint Year 2 the GeoVolumes server was expanded with the data around the HFT Stuttgart area, Germany and organized the 3D content by the usage of the data in the client as follows:

I. 3D model of HFT Stuttgart building in LoD-4.

II. 3D building models for the surrounding area of the HFT Stuttgart in LoD-1.

III. The combined models of I. and II.

The GeoVolumes server collections can be rendered in HTML as shown in Figure 72. The same result in JSON format is also available. Either format can be accessed via the same URL, but with a different search string

- HTML [https://steinbeis-3dps.eu/3DGeoVolumes/collections/?f=html]
- JSON [https://steinbeis-3dps.eu/3DGeoVolumes/collections/?f=json]

Figure 72. Steinbeis GeoVolumes Server output showing links and resultant images.

13.2.2. SensorThings Server

In this sprint, two SensorThings servers are developed to manage the environmental data (e.g. CO2, PM2.5, and PM10) from the sensors around the HFT Stuttgart area and the mobility routes around the Stuttgart area. Both servers can be accessed via http://193.196.138.56/frost-luftdata-api/ and http://193.196.138.56/sta-isg-sprint/ respectively.

The data modeling of the SensorThings API server for air quality data is shown in Figure 73. In this server, when the sensor system is attached to the building which existed in the CityGML model, the `gml_id` of the related CityGML object can be linked and stored in the SensorThings' Thing entity. This concept is called CityThings [https://doi.org/10.1177/2399808320983000].

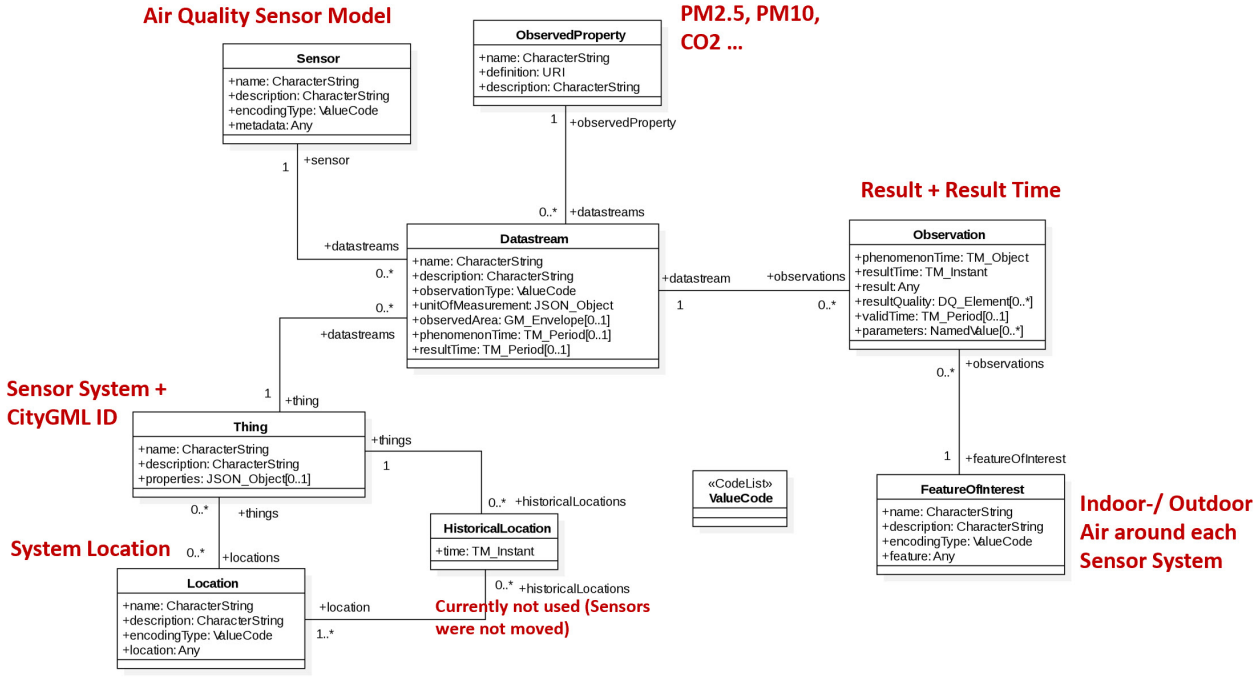


Figure 73. Steinbeis' SensorThings API Server data model is shown for static (non-moving) air quality sensors.

The data modeling of the SensorThings API server for mobility routes is shown in Figure 74. In this server, the SensorThings Location and HistoricalLocation entity are used for managing the route data of each vehicle. These entities were used to visualize synthetic eBike and air taxi routes in Stuttgart city.

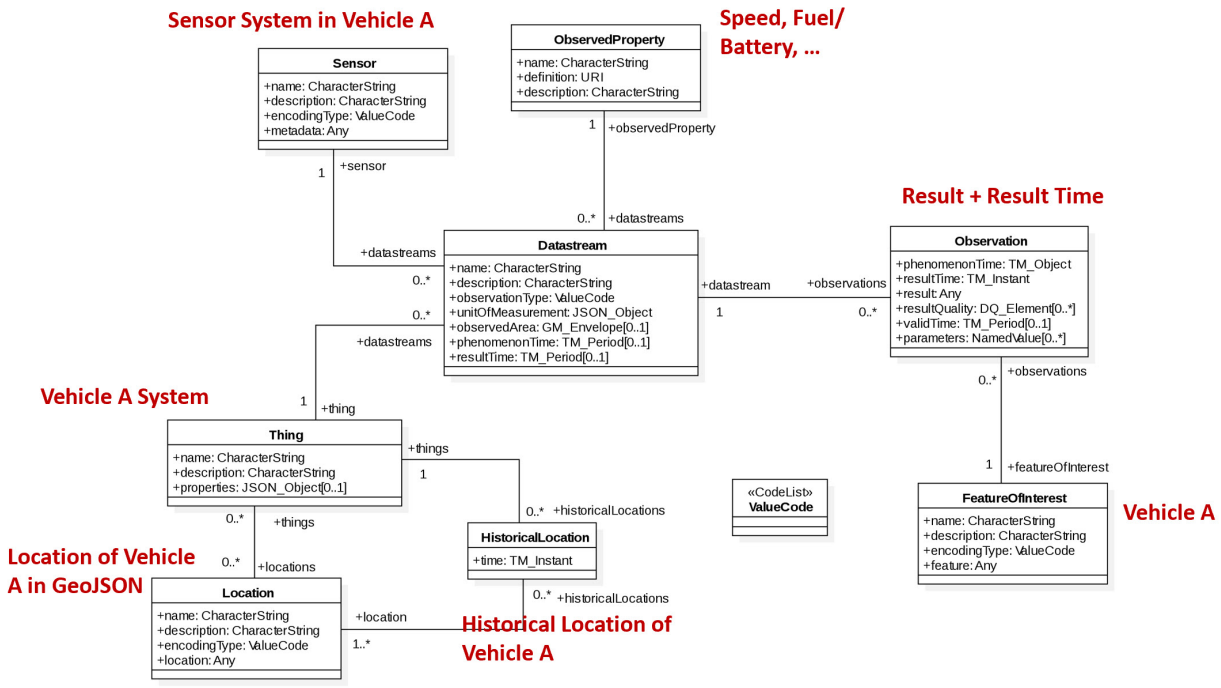


Figure 74. Steinbeis' SensorThings API Server data model is shown for moving air quality sensors.

13.2.3. 3D Building Data Generation

Introduction

As mentioned above, three types of 3D building datasets were used for the OGC ISG sprint year 2.

I. 3D model of HFT Stuttgart building in LoD-4

II. 3D building models for the surrounding area of the HFT Stuttgart in LoD-1

III. The combined models of I. and II

3D model of HFT Stuttgart building in LoD-4

The 3D model of HFT Stuttgart building 2 in LoD-4 is originally available in Trimble Sketchup (skp) format. For its use in the ISG sprint, data conversion from skp to glTF was done using Feature Manipulation Engine (FME).

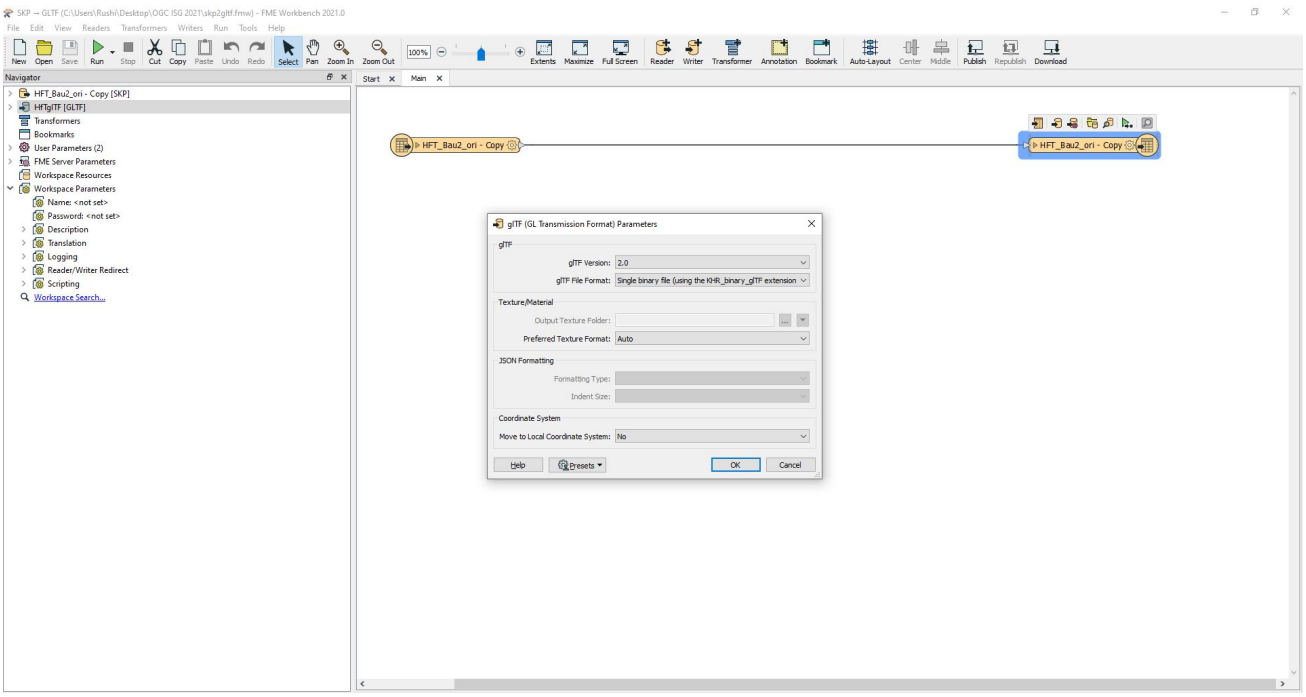


Figure 75. FME screen shot showing the processing of a Trimble Sketchup to glTF conversion.

The glTF output was produced in version 2.0 as a single binary file (glb). For its later use in ArcGIS CityEngine, the glTF model was imported using CityEngine's inbuilt glTF importer.

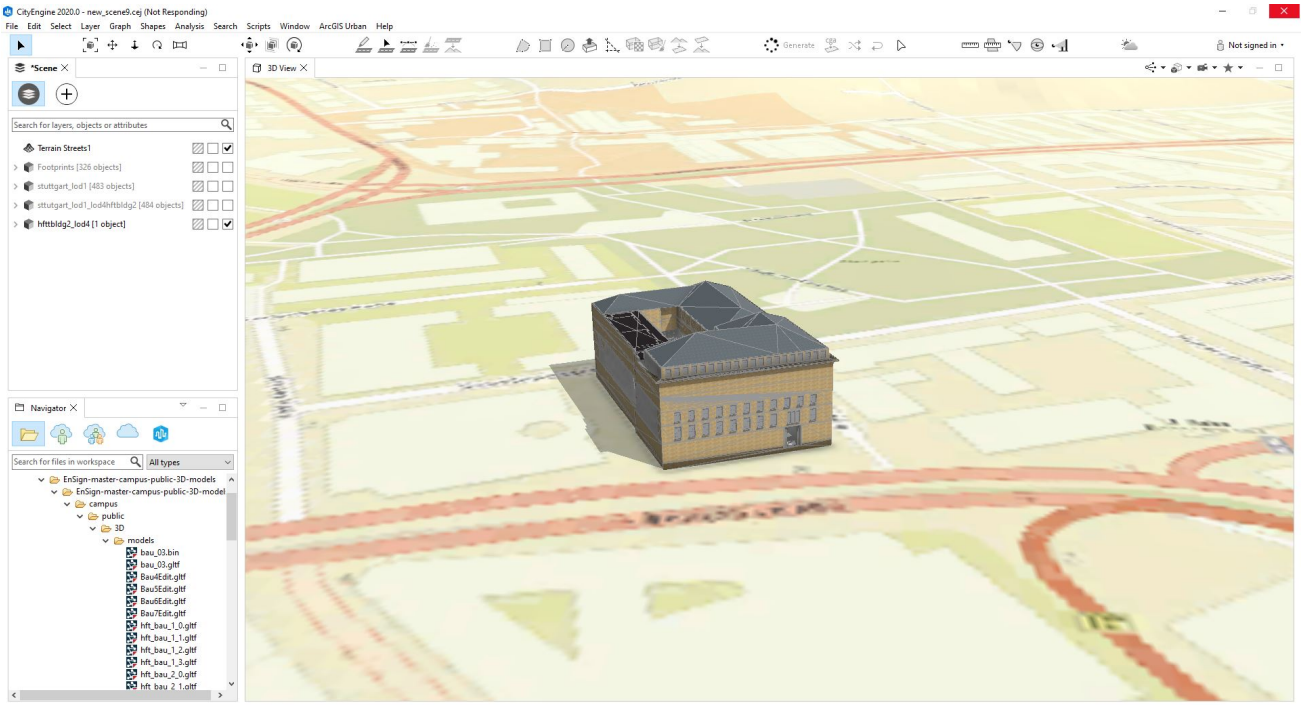


Figure 76. An example of a glTF model of HFT Stuttgart building imported into ArcGIS CityEngine.

The output glTF file was found to have incorrect surface normals in some parts of the model. Further investigation found that the surface normals were preserved if the same model was converted to COLLADA (dae) using Trimble Sketchup's built-in COLLADA exporter. This issue was further confirmed by Ecere, who collaborated with the Steinbeis team to integrate the LoD-4 model of HFT Stuttgart within their visualization library / VR / AR applications and CDB X GeoPackage prototype producer. Further, to investigate the issue different glTF exporters such as the freely available glTF exporter plugin [https://extensions.sketchup.com/extension/052071e5-6c19-4f02-a7e8-fcfcc28a2fd8/gltf-exporter] of Trimble Sketchup and CityEngine's built-in glTF exporter were used. Unfortunately, each tool produced different glTF output in terms of data quality. Hence together with Ecere, a joint recommendation to improve the glTF data conversion pipeline from commonly used data formats such as Trimble Sketchup (skp), COLLADA (dae), 3D multipatch shapefiles/FileGeodatabase (shp, FileGDB) is suggested. For the moment, the incorrect surface normals from few parts of the original model were manually fixed for the use case development.

3D building models for the surrounding area of the HFT Stuttgart in LoD-1.

To generate 3D buildings around the HFT Stuttgart building, CityEngine's built-in connection to Open Street Map (OSM) was used. First, the building footprints of the neighboring buildings were fetched from the OSM dataset. These building footprints were then extruded to LOD-1 building models with generic textures using CityEngine's built-in shape grammar rule file of Building_From_OpenStreetMap.cga.

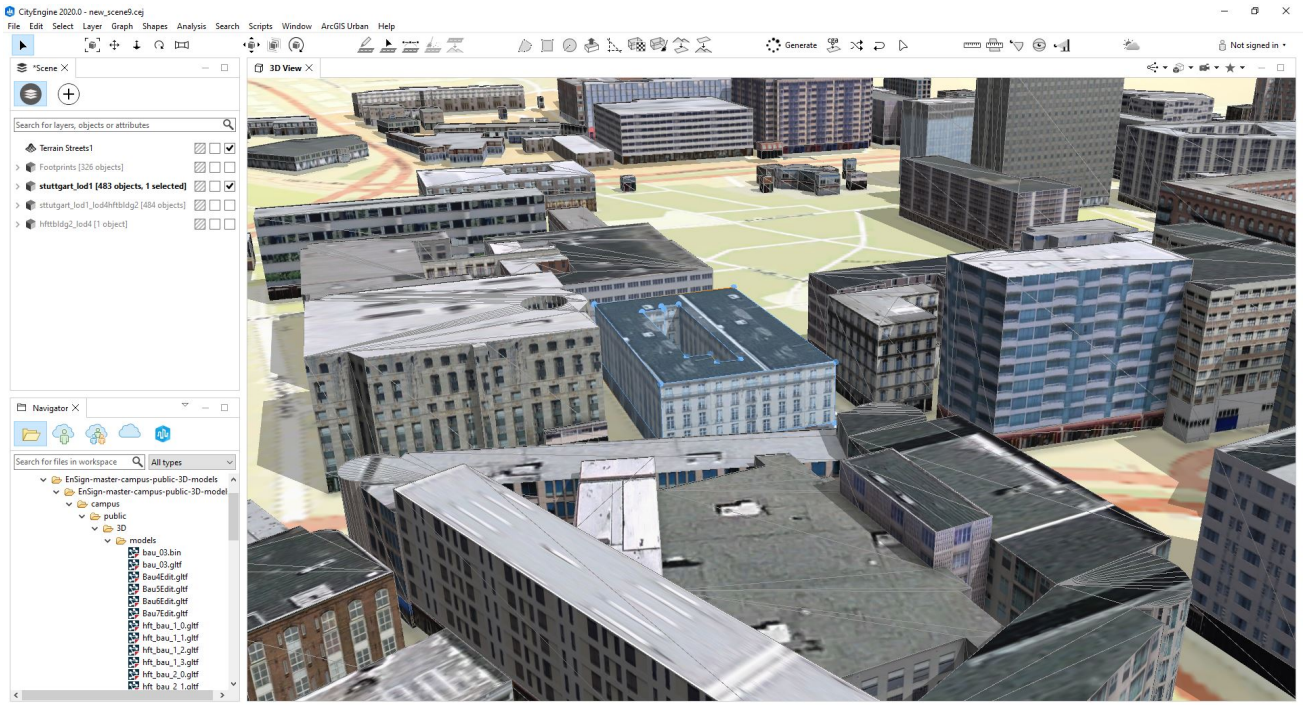


Figure 77. LOD-1 of 3D building models with generic textures displayed using ArcGIS CityEngine.

The combined models of I. and II

For the combined used on the client side, both models I and II were merged inside CityEngine. The LOD-1 model of the HFT Stuttgart building was replaced with the imported LOD-4 glTF model.

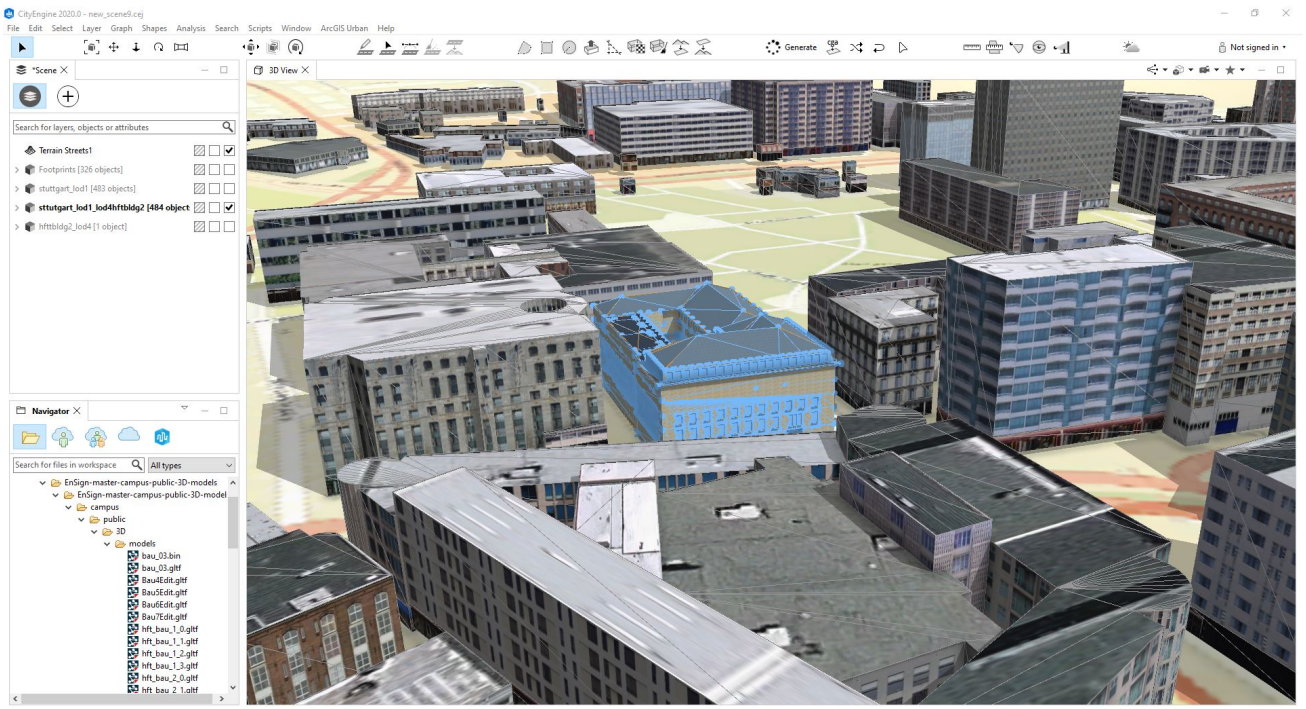


Figure 78. ArcGIS CityEngine display of a LOD-4 building model of HFT Stuttgart surrounded by LOD-1 building models.

To preserve the georeferenced coordinates and textures, the combined model was exported to FileGDB. Using ArcGIS Pro and FME, FileGDB was converted to Scene Layer Package (slpk – i3s)

and 3D Tiles respectively. The overall data conversion flow diagram is illustrated in Figure 79.

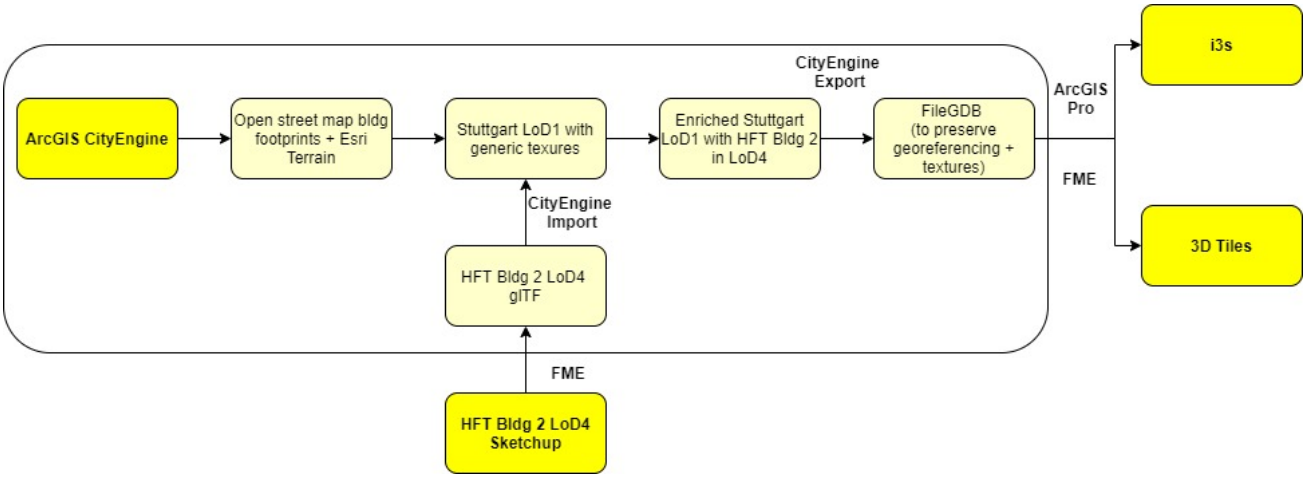


Figure 79. The data conversion pipeline from ArcGIS CityEngine to I3S and 3D Tiles is shown in this processing pipeline.

13.3. Client Side

The focus of the client side is to provide an overview of the compatibility between the different standards. On the frontend different tools were used for the visualization. CesiumJS and the ArcGIS Client are Javascript-based libraries for Web-Visualization. Unreal Engine and Unity are game engines that allow for the creation of applications in the field of desktop games, as well as AR and VR applications. The Android Augmented Reality column is an application developed with Unreal Engine. In the iOS Augmented Reality application, the native tool in the Apple iOS devices is used to visualize 3D and AR content without having to download special apps.

Showing Overview with the Matrix table and explain each block.

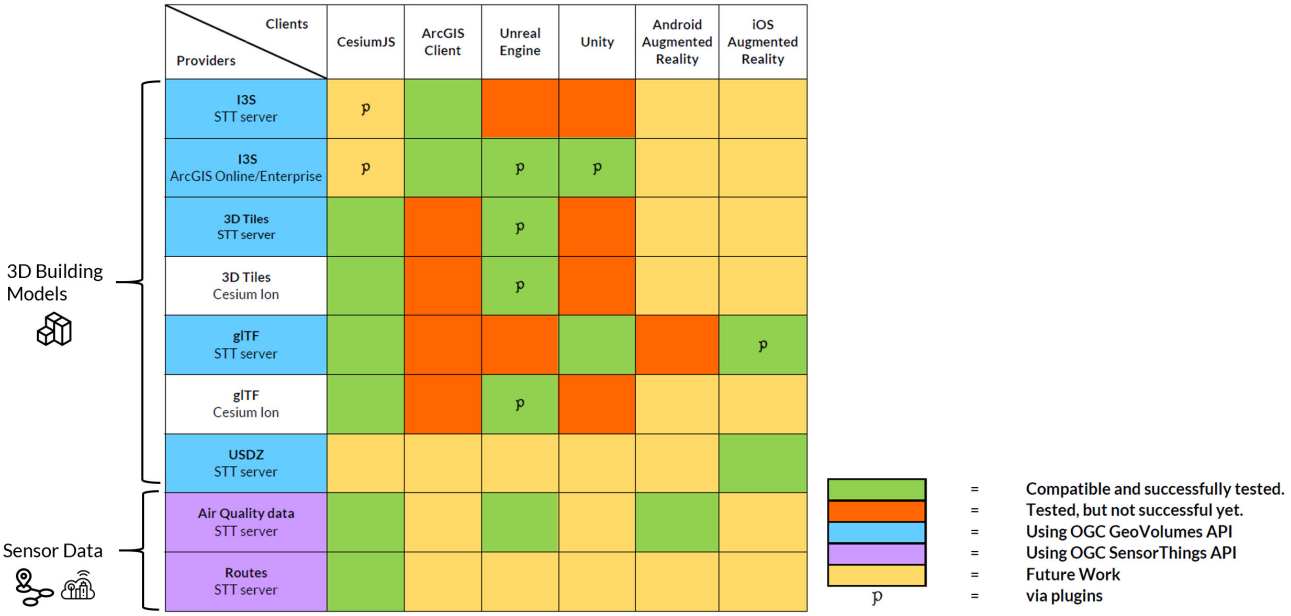


Figure 80. The compatibility matrix between clients (columns) and server providers (rows) is displayed as color-coded cells. Green indicates compatibility, orange is incompatible, and yellow is future work.

13.3.1. Game Engines

Unreal Engine

The Unreal Engine 4 developed by Epic Games [https://www.unrealengine.com/en-US/] was used in this sprint to test out the compatibility with the different datasets and the different methods of providing them. For this use case a third-person (view) project was set up in the developer environment. To access the data the plugin listed below was used. This is provided in the Epic Games Store Marketplace.

Unreal + 3D Tiles

3D Tiles are a Standard for 3D Data Streaming supported by the OGC and developed by Cesium. To access a 3D Tiles Dataset in UE4, Cesium developed a plugin called "Cesium for Unreal". The main function of the Plugin is to load assets from Cesium Ion, such as the Cesium Terrain, into the game world. Since the Plugin was designed to load 3D Tiles from Cesium Ion, the process is straightforward. Only the Asset ID and the key are required. But it also opens the door for loading datasets in different ways. In a recent update the process for this is made more accessible because it has an option to switch between the Asset ID & Key and a URL field. The URL can point to a 3D Tileset from a Geovolumes Server. This was successfully tested with an implementation of the GeoVolumes Server on the Steinbeis Server.

https://steinbeis-3dps.eu/3DGeoVolumes/collections/Stuttgart/Stuttgart_3DBuildings_LoD1_HfTLoD4_unreal/tileset.c4u.json

It also allows to loading 3D Tiles from a local source. For that purpose, the URL field has to be used and point to a location on a local drive. To indicate that the URL has to start with the file:/// protocol prefix.

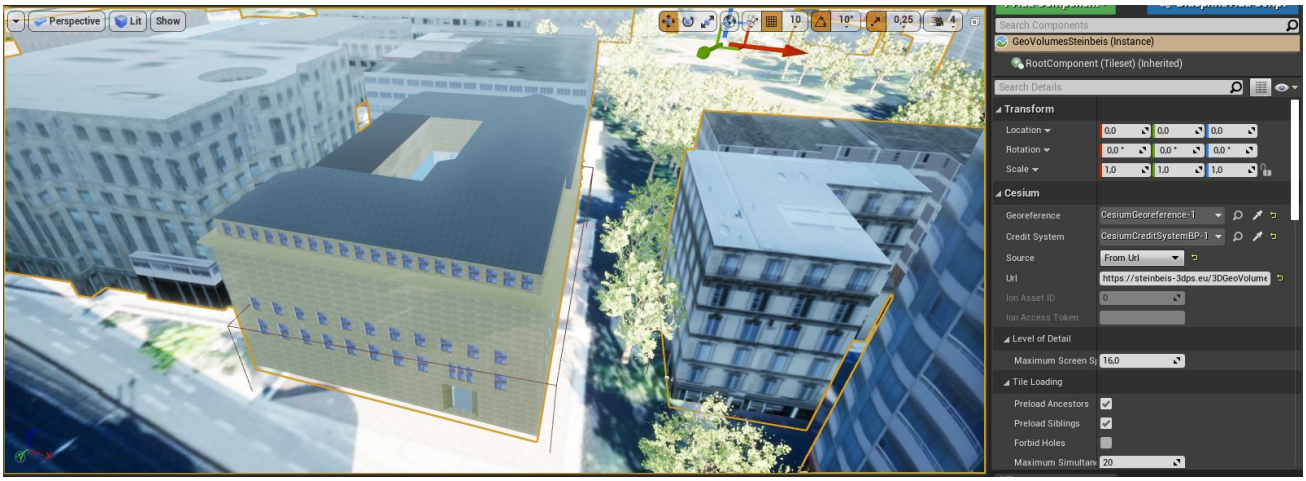


Figure 81. Unreal Engine displaying loaded 3D Tiles from GeoVolumes Server.

Loading 3D Tiles into Unreal Engine requires that the coordinate system needs to be in line with UE's expectations. Because the test dataset did not fit those requirements, it needed to be converted. An Open Source Tool [https://github.com/tomap-app/rtcCenter2transform] (the PLATEAU project) is available to convert 3D Tiles into Relative to Center (RTC) format. The conversion is also indicated in the URL with the c4u ending generated by the conversion tool. A first effort to

host this tool on a server for on-the-fly conversion failed but, with further investigation, seems plausible. This would be a great addition to the GeoVolumes Server because the tilesets wouldn't have to be hosted in two different formats (RTC and regular Coordinates) but instead could be converted on the fly and accessed through additions in the URL.

Before Conversion	After Conversion

<pre>"boundingVolume" : {
"box" : [
4157169.143514174,
671422.7367559096,
4774754.532228447,
846.1180383828469,
0,
0,
0,
983.3672450176673,
0,
0,
0,
703.838994808495
]
}</pre>
	<pre>"boundingVolume": {
	"box": [
	-3.955821495503187,
	-1.57150904845912,
	0,
	846.1180383828469,
	0,
	0,
	0,
	983.3672450176673,
	0,
	0,
	0,
	703.838994808495
	]
	}</pre>

Table 9. RTC Conversion 3DTiles

Unreal + I3S

To use I3S Tiles in UE4, the "ArcGIS Maps SDK for Unreal Engine" is needed. It is in beta and can be downloaded from the ESRI Early Adopter [https://earlyadopter.esri.com/key/ArcGISforGameEngines] site. It currently cannot be downloaded from within the Epic Games Marketplace. To use the plugin, it needs to be placed in the plugins folder of an Unreal Engine C++ Project. Upon installing it, a message shows that the plugin is developed for Unreal Engine version 4.25, which is the previous release of the UE. The plugin then provides a graphical user interface and possibilities over C++ programming to add I3S to the game world. They can be managed as Layers.

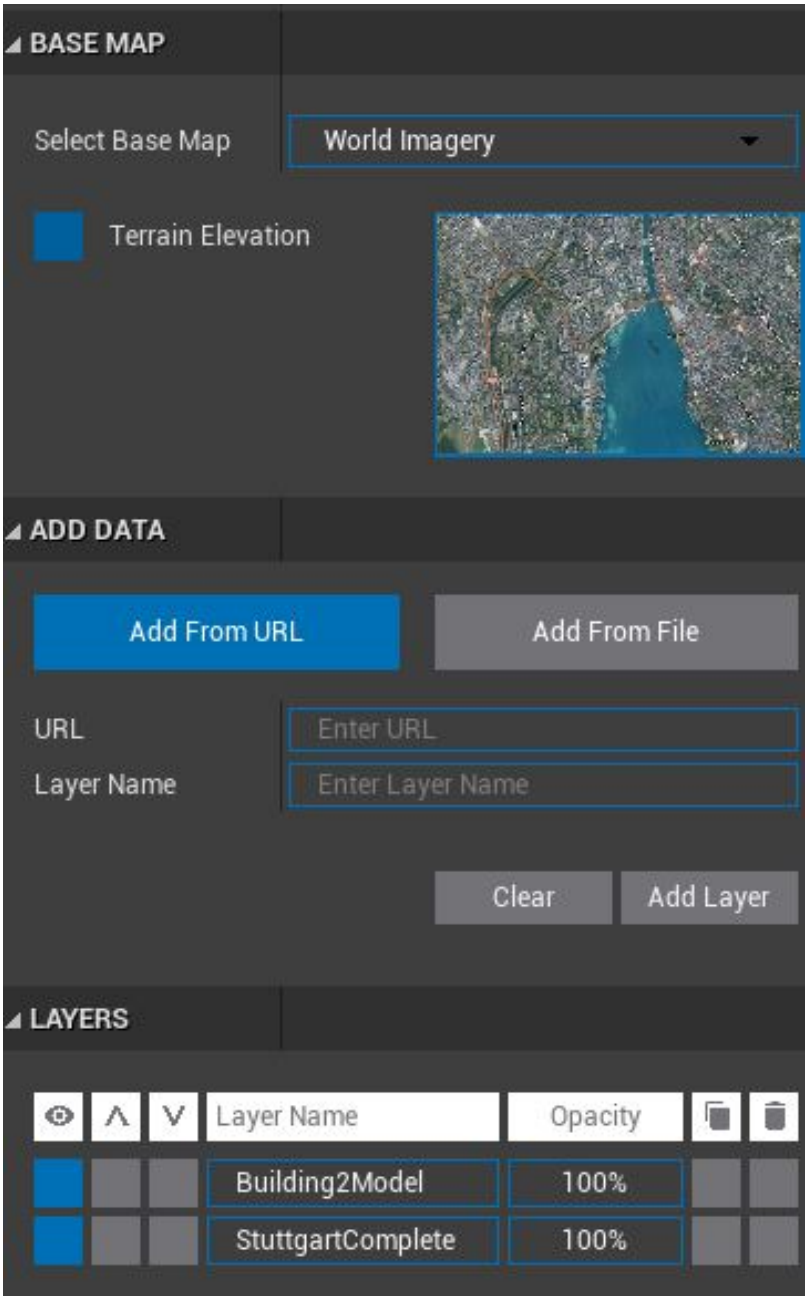


Figure 82. ArcGIS Maps SDK running in Unreal Engine4.

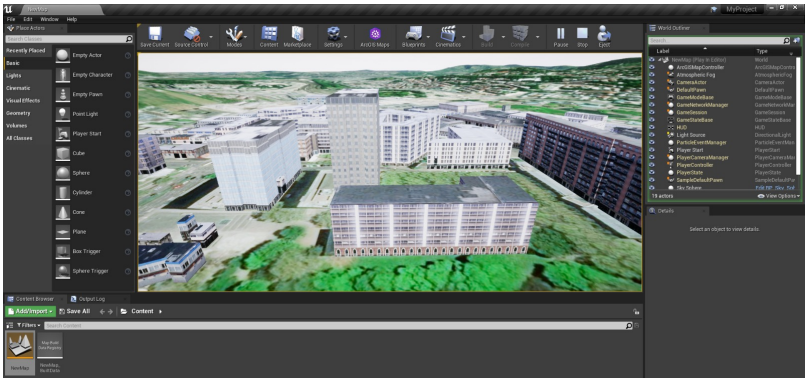


Figure 83. Visualizing i3s 3D models in Unreal Engine.

As shown in Figure 83 and the compatibility matrix (Figure 80), the streaming of the I3s from an ArcGIS server works with this solution.

To further investigate the interoperability between the Unreal Engine and the I3S format an I3S service was implemented based on the SLPK (Scene Layer Package) format, which is based on the I3S specification and realized as a compressed/portable version of an I3S file structure. The Steinbeis I3S service was implemented with Node.js and comprised all the endpoints necessary to access the I3S payloads: Node, Shared, Features, Geometries, Attributes, and Textures. Although the ArcGIS JavaScript Client was compatible with the Steinbeis I3S service, Unreal Engine wasn't able to fetch the payloads from the Steinbeis service. Since an API key is needed to access the I3S datasets hosted in the ArcGIS Enterprise Portal, Unreal Engine expected a portal item and not an I3S dataset hosted in a third-party server.

As of the end of the Sprint, there is no clear path on how to include I3S streamed from the Steinbeis server

In comparison to the Cesium Plugin, the ArcGIS Maps SDK works differently and does not show directly in the Editor Window. This makes using it with views like a 3rd Person more difficult. Also, it requires a C++ project, whereas the Cesium plugin can also be used with a Blueprint Project.

Unreal + glTF

The possibility of including glTF Models into UE4 is given by multiple plugins such as the Datasmith Plugin, the glTFRuntime Plugin, and the glTF Exporter. The Datasmith and the glTF Exporter are published by Epic Games directly. In this Sprint, the glTF Exporter was tested with different glTF models. This is shown in the Compatibility Matrix. With this plugin, it is not possible to load glTF models from the Steinbeis Server into UE4. In future work, it can be tested if glTF models can be loaded from Servers with glTFRuntime Plugin or over C++. There is a workaround to convert the glTF model in Cesium Ion to 3D Tiles and then use the model in Unreal Engine. This still allows for streaming the model from a server, but the location has to be specified in Cesium Ion. If the model is imported via the glTF Exporter, then it can be placed directly in the Unreal Engine viewer.

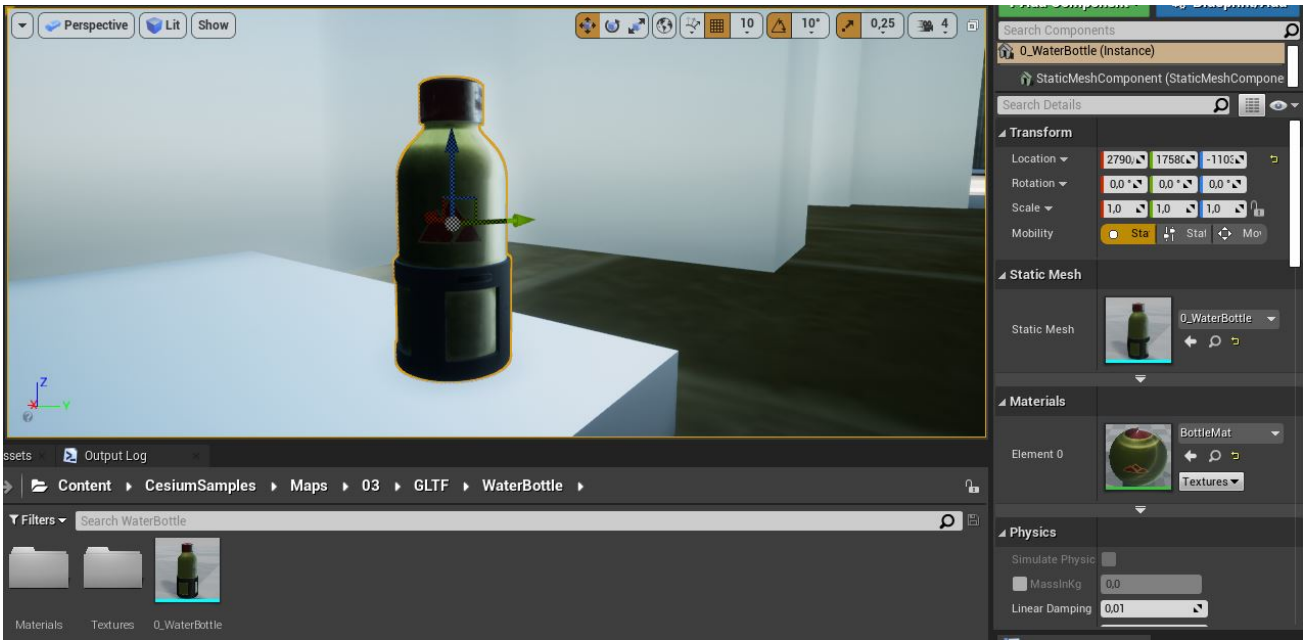


Figure 84. A local glTF model imported into Unreal Engine.

The tests were carried out with a glTF 2.0 Model of the University of Applied Sciences (HFT Stuttgart) and an official glTF 2.0 model of a Waterbottle.

Unreal + SensorThings

The Sensor Things Server can be connected to a UE4 project like other Rest APIs. The Epic Games Marketplace provides different plugins for that purpose. For this Sprint the VaRest Plugin was tested since it can be used for free. It provides some functions in the blueprint system of UE4 that allow it to connect to SensorThings and request observations. It was tested with the air quality sensors in Stuttgart.

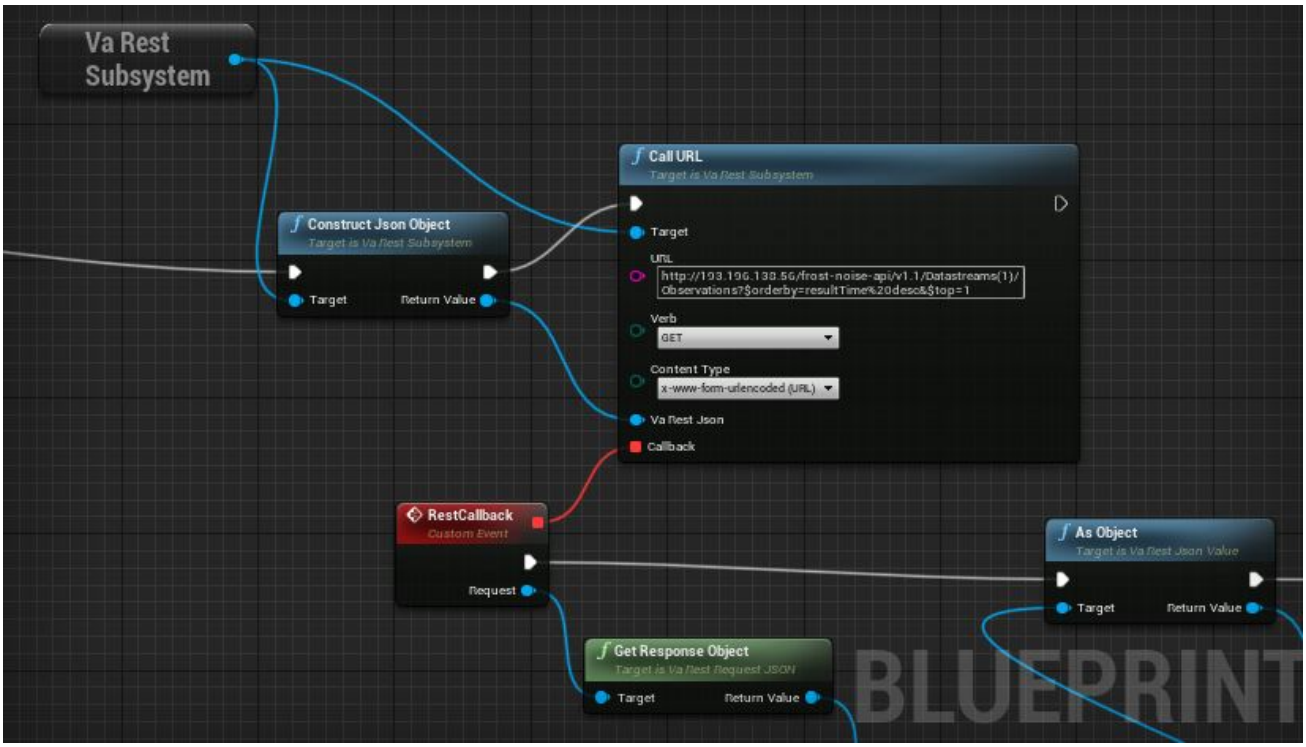


Figure 85. The connection to SensorThings using VaRest shown in Unreal Engine's Blueprint visual scripting system.

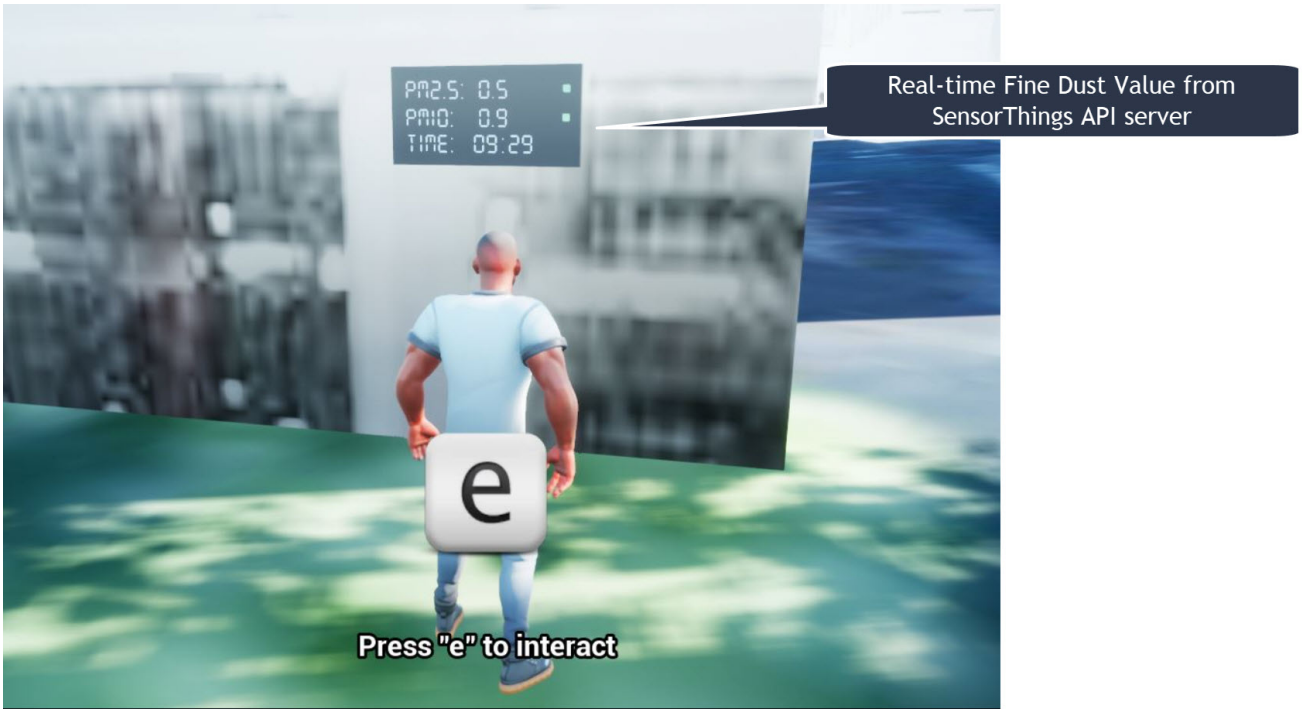


Figure 86. Demonstration of connecting real-time fine dust sensor data in the Unreal Game Engine using SensorThings API.

Unity

Unity + I3S

Compatibility between the Unity game engine and I3S is achieved via a Unity plugin developed by ESRI. An ESRI Early Adopter account is required in order to download the plugin and an API key to access the ESRI online services. The I3S plugin for Unity supports two of the available project templates in Unity, i.e., High Definition Render Pipeline and the Universal Render Pipeline. Installation of the plugin is managed by locally importing it as a Unity package. The user can choose to use the plugin either as a graphical user interface (GUI) or a C# scripting interface. In order to activate the GUI, the user has to add the I3S plugin as a prefab in the scene hierarchy. The various GUI sections allow the user to customize the camera position (Latitude, Longitude, Height) and direction (Heading, Pitch, Roll) in a global coordinate reference system, the base map among different map tile servers, the addition of I3S data via a remote URL or local file as a layer and the added layers management by controlling their visibility, ordering, naming, opacity, duplication, and deletion. The addition of I3S layers hosted on the ArcGIS Enterprise Portal was seamless and error-free in Unity. An attempt to investigate the interoperability between the I3S plugin for Unity and the Steinbeis I3S server resulted, similar to the Unreal Engine, in failure for the same reason.

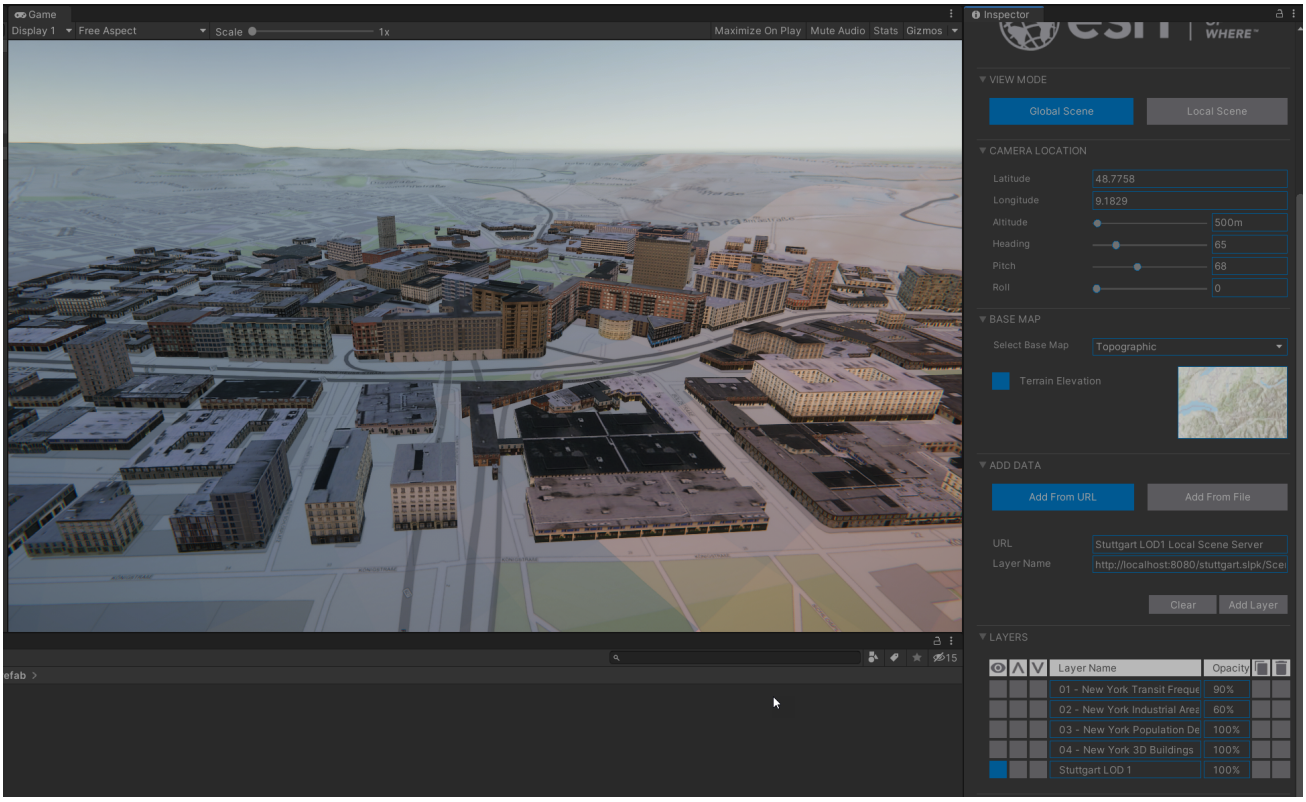


Figure 87. A visualization of the I3S 3D building model service is shown in Unity3D.

13.3.2. Web Visualization

In the ISG Sprint Year 1 a client application based on the CesiumJS framework was successfully developed to load collections from the input 3D GeoVolumes API URL and render of the geospatial contents from the loaded collections and containers. This client is online [http://steinbeis-3dps.eu/STT3DClient/index.html] and was used in the ISG Sprint Year 2 to test and evaluate new 3D data of the HFT Stuttgart area on the GeoVolumes server. All data on the Steinbeis GeoVolumes server mentioned in the GeoVolumes Server section above are tested and shown in Figure 88.

Figure 88. The GeoVolumes Server is visualizing different 3D building model data in the area of HFT Stuttgart.

Extending to the above web clients, the mobility route data were integrated such as synthetic eBike and air taxi routes from the Steinbeis SensorThings API server as shown in Figure 89.

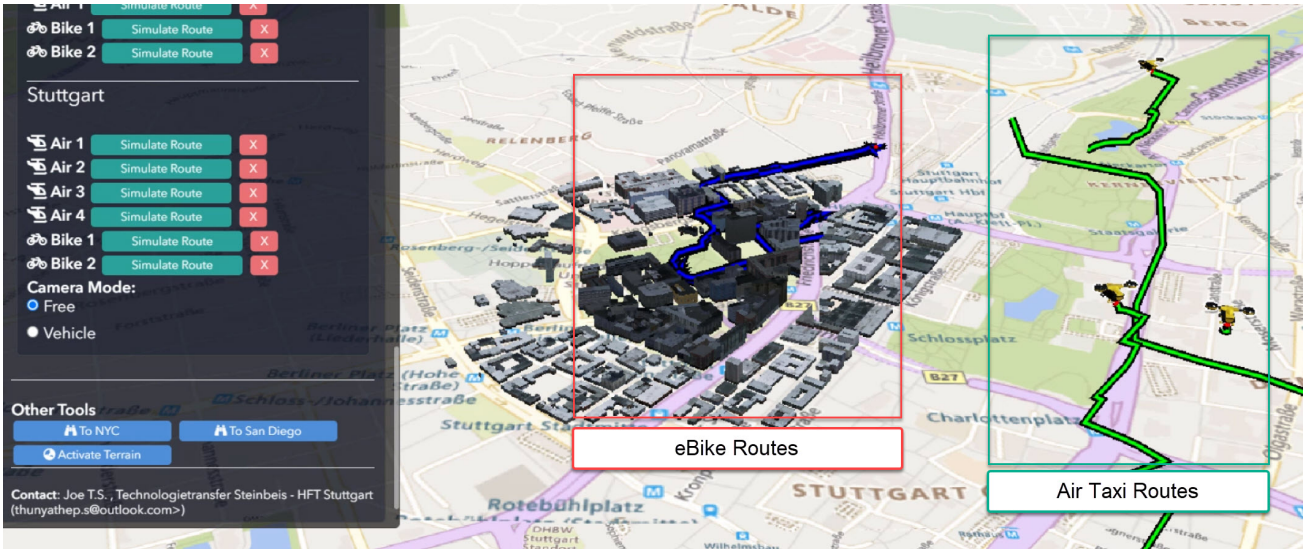


Figure 89. The same GeoVolumes server visualizing different 3D building model data and SensorThings routes in the area of HFT Stuttgart.

Moreover, the ArcGIS for JS library was used to evaluate the I3S services from a GeoVolumes server. The I3S services hosted on ArcGIS Online (for example, arcgis.com) and Steinbeis' own developed I3S service (for example, https://steinbeis-3dps.eu/scenelayers/hftbldg2/layers/0) were used.

13.3.3. Mobile Visualization

Android + Unreal Engine

The Mobile Augmented Reality Application was developed with the Unreal Engine and Google's ARCore. As described above Unreal Engine has good compatibility with local glTF models and SensorThings API. The application is designed to recognize an image of a sensor as a marker. When the marker is in view, it shows the real-time measurements of the air quality sensor by requesting it from the SensorThings server. Additionally, the application searches for planes where a glTF model of the HFT Stuttgart model can be placed by the User.

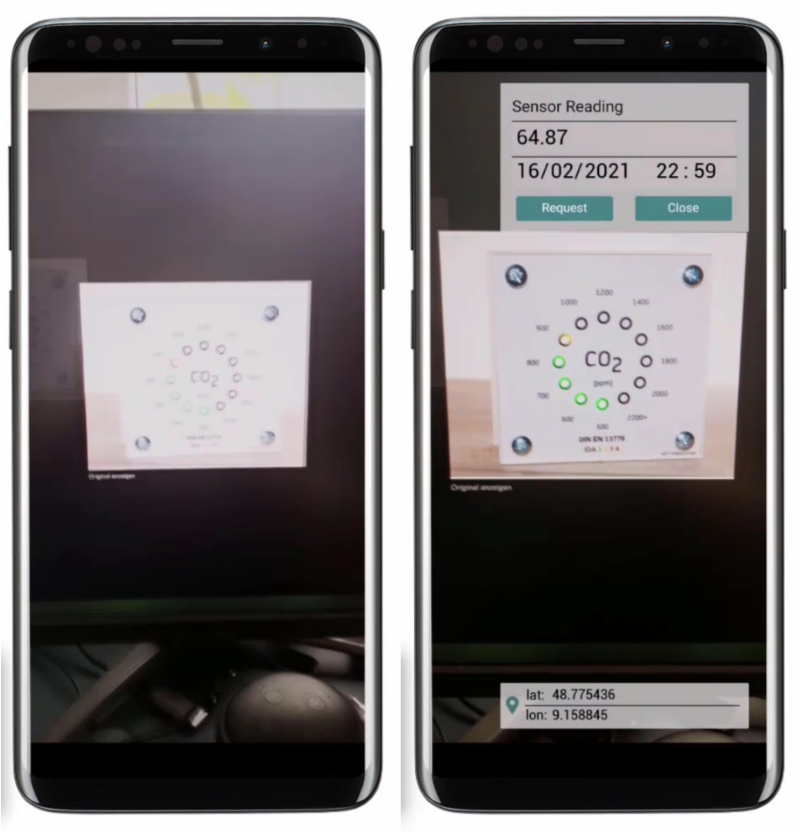


Figure 90. Visualization of a sensor reading in an AR Android Application built using Unreal Engine.

iOS + GeoVolumes

3D data in USDZ format can be visualized directly in iOS devices without extra tools or plugins, as example in Figure 91 showing the HFT Stuttgart building models on the iPhone XR via the GeoVolumes API. Steinbeis explored two ways to visualize USDZ 3D data in iOS devices. First, the 3D data was preprocessed by converting them to USDZ format, then uploaded to the Steinbeis GeoVolumes server. The data was loaded and visualized directly in iOS devices from the Steinbeis GeoVolumes server. Second, the data in glTF format were loaded from the server and converted on-the-fly to USDZ format with the 3rd party software (https://github.com/google/usd_from_gltf). It was found that the first method is more efficient as the USDZ can be loaded on iOS devices directly while the client loading time of the second method is highly depended on the server performance to convert glTF to USDZ.

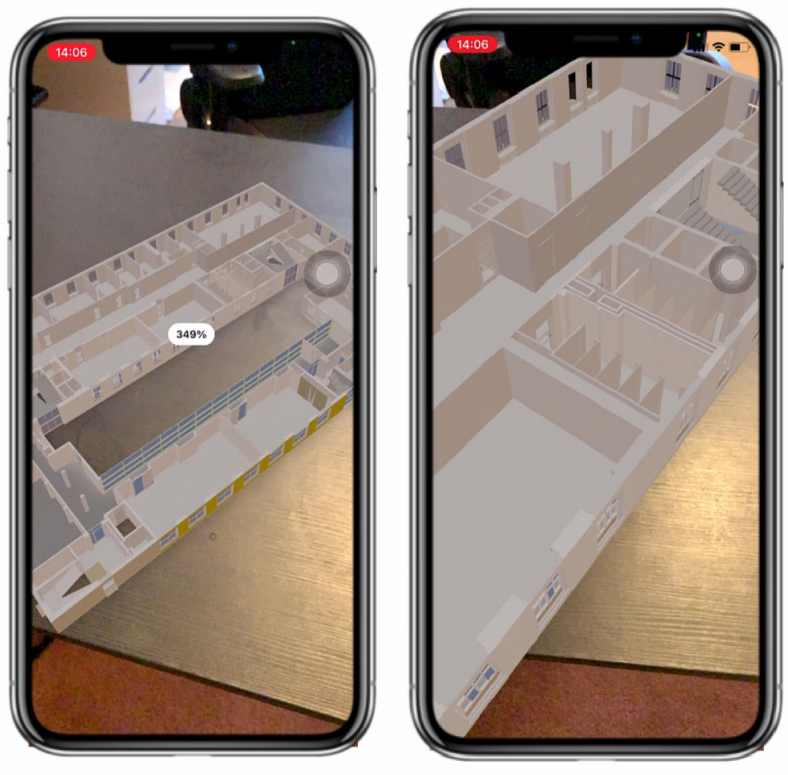


Figure 91. 3D building models are visualized using an iOS device with data from a GeoVolumes server.

Chapter 14. Recommendations for the Future

NOTE

Draft

This section is not complete. The bulleted lists will be turned into prose with references to the detailed descriptions. Additional items may be added based on additional reviews of the participant material.

14.1. Introduction

This section discusses (**#**) recommendations for future Sprints. These are split into general recommendations, mostly dealing with conducting the Sprint; and potential future projects driven by sponsors or liaison relationships with other organizations.

The *NOTE* mechanism is used to highlight all recommendations. All of the *NOTES* come after the discussion on that topic.

14.2. General Recommendations for Future Sprints

14.2.1. Total Time

In comparison to ISG Year 1 Sprint, the time allocated for this Sprint from intiial work on the Request for Proposals to final report was 20% (2 months) less with most of the difference being in the time to prepare the final report. Future sprints should allow at least 3 months for writing the final report and review by interested DWG/SWGs. This would be allocated 1 month for participant contributions, 1 month for OGC writing and editing, and 1 month for DWG/SWG review.

NOTE

Recommendation

Allow at least 3 months from the conclusion of the Sprint work to write, edit, and review the final (Engineering) report.

14.2.2. Sprint Work Schedule

ISG Year 2 Sprint happened over two weeks. The particiapnts liked the additional week (compared to Year 1); however, the two weeks were split by the member meeting. A split-week sprint might be useful; however, splitting the sprint because of a member meeting caused difficulties with the participants and OGC staff as there were multiple demands for time in the week prior to the Members Meeting. There was some appreciation for having the Sprint work weeks separated. We were unable to separately determine if having separate work weeks was good or bad because of the contained Member Meeting.

NOTE	Recommendation
	Do not have the Sprint work week(s) immediately before a member meeting

14.3. Topics of Future Work

14.3.1. Introduction

This section discusses opportunities for follow-on work. The criteria for including potential projects here was that the work needed to be more investigative in nature and less performance improvement or engineering a solution where the characteristics of the solution are known.

In particular, the process of data conversion has been studied farily extensively in these two Sprints. The process of conversion is well understood and locations of performance gains have been identified. While improving conversion is an important process, it was felt that the parameters were sufficiently well known so it did not need to be handled in a future sprint.

The remaining sections identify protential projects that involve relationships or interactions with other organizations, OGC internal work, or work in support of a sponsor mission.

14.3.2. OGC Internal Work

This Sprint used a large number of data sources (See **Appendix C**). Only two were initially made available and provided by OGC (San Diego and New York CDB datasets). The participants took it upon themselves to identify and collect additional datasets to test or illustrate their work. [Appendix-C] lists all sources used in the Sprint with as much ancillary data as could be obtained and recorded. It would help future OGC projects of all sizes and members to create and maintain a catalog of datasets that can be used for OGC activities. It was out of scope for this Sprint to develop or suggest a structure or model for such a repository.

NOTE	Recommendation
	OGC should develop a catalog of datasets for future projects and members.

14.3.3. External Organizations

OGC and Khronos Group already have a formal liaison. That relationship should be cultivated and expanded to increase the cross-flow of glTF requirements and features. Khronos' OpenXR and WebGPU Working Groups may also prove of productive, through their impact is not as immediate as 3D Formats (glTF). Other organizations that might have an impact on OGC work include World Wide Web Consortium (W3C), especially with their working group listed below.

- **Khronos Group** - advancenments to glTF
    - Support for multiple external files to represent different appearances

- Support for multiple meshes to represent different configurations (e.g., damage)
- Improved support for general animation
- Improved support for rigid animation (attachment/pivot points)
- Point cloud support
- Improved geometric compression (perhaps documentation would be sufficient)
- Improved image compression (may be a matter of tool support)

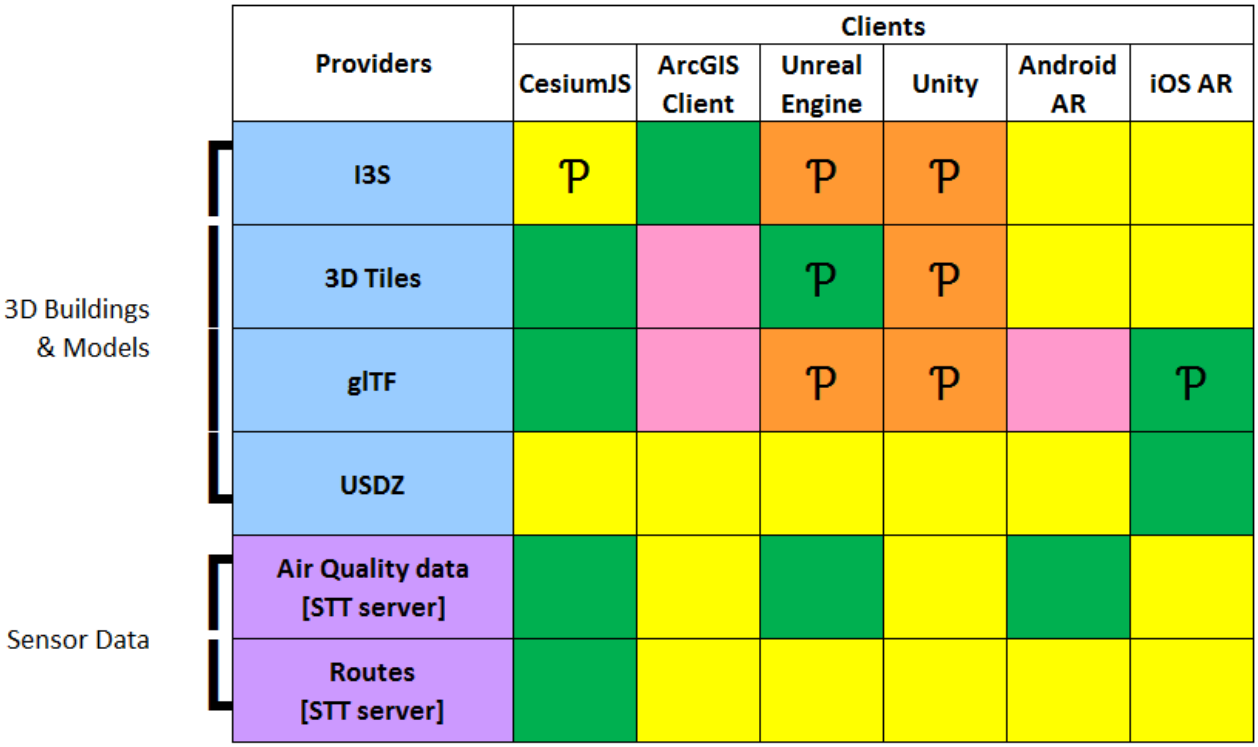
- **World Wide Web Consortium** - web technologies
  - Immersive Web [https://www.w3.org/groups/wg/immersive-web]
  - Web of Things [https://www.w3.org/groups/wg/wot]
  - Accessibility Guidelines [https://www.w3.org/groups/wg/ag]

NOTE

Recommendation

Increase communication between OGC and Khronos Group to speed up geospatial requirements for glTF and adoption of glTF in the geospatial community.

14.3.4. OGC Specification Interactions



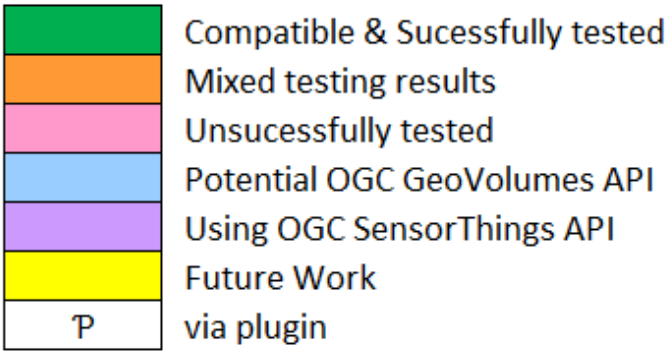


Figure 92. The chart summarizes work done by some of the participants. The right-most four columns cover non-OGC applications (two for game engines and two for mobile libraries - ARCore (Android) and ARKit (iOS)). The stylizied **P** *indicates interfaces that are known to require plugins. The yellow boxes indicate areas that have not been investigated. Nost of the recommendations cover these areas.*

This chart shows potential interaction between participants (OGC members and external organizations) and OGC standards and APIs. Of particular interest are the columns on the right side for non-OGC systems: Unreal Engine, Unity, and AR applicatiopns using the standard device libraries for Android and iOS. Steinbeis and SimBlocks have already made some effort to address these interfaces, but there is a lot of fertile landscape for investigation.

It is a sign of the maturity of the OGC specifications that this Sprint identified many tasks (either performed or recommended) that cross areas of interest. A task may appear in more than one section. This reflects the need of those areas to approach the problem from different directions and develop a cross-area solution.

14.3.5. Recommendations for CDB Integration

- Include glTF as a prototype modeling format in an upcoming version of CDB (perhaps V1.3)
- Work closely with Khornos Group to add needed functionality to glTF

	Recommendation
NOTE	Include glTF as an optional prototype modeling format in an upcoming release of CDB.

14.3.6. Recommendations for Moving Features and Sensors Integration

In ISG Year 1 Sprint, Steinbeis showed integration from simulated moving IoT can be integrated using OGC's SensorThings API. In Year 2, they showed that real-world IoT sensors can also be integrated. Where appropriate the OGC GeoPose standard should be used to quantify position and orientation over time.

- Digital twin, both to report and control
- Smart city, especially transportation networks

- Work more with moving models and how to store time-based and time-sensitive information. Perhaps this is good work for a cross-over effort with GeoPose.

NOTE

Recommendation

Use a Sprint to investigate integration of SensorThings and GeoPose to remotely track moving objects or people of interest displaying the results in a virtual or augmented reality environment.

14.3.7. Recommendations for Total Access Integration

includes Building Information Models/Management, sensor integration, indoor/outdoor traversal

NOTE

Recommendation

Use a Sprint to duisplay a building environment with indoor and outdoor components. The display environment needs to include extensive use of metadata and IoT (SensorThings API) to highlight features not readable visible.

Appendix A: OGC Standards/Specifications and Scenarios

A.1. OGC Specification / Scenario Cross Reference

Standard/Specification	**Scenarios**			
	1 A&B (*Conversion*)	**2** (*Indoor/ Outdoor*)	**3** (*Moving Objects*)	**4** (*New Capabilities*)
glTF V2 [https://github.com/KhronosGroup/glTF/tree/master/specification/2.0#contents]	**X**	**X**	**X**	**X**
Khronos glTF Extensions [https://github.com/KhronosGroup/glTF/tree/master/extensions/2.0/Khronos]	**X**	**X**	-	**X**
Vendor glTF Extensions [https://github.com/KhronosGroup/glTF/tree/master/extensions/2.0/Vendor]	**X**	**X**	-	**X**
CDB [https://www.ogc.org/standards/cdb]	**X**	**X**	**X**	**X**
OpenFlight (*PDF download*) [https://portal.ogc.org/files/19-065]	**X**	-	**X**	**X**
3D Tiles [https://www.ogc.org/standards/3DTiles]	**X**	**X**	-	-
CityGML [https://www.ogc.org/standards/citygml]	**X**	**X**	-	-
GeoPose Standards WG [https://www.ogc.org/projects/groups/geoposeswg]	-	**X**	**X**	-
GeoVolumes (Draft) [https://docs.ogc.org/per/20-030.html#_draft_specification]	**X**	-	-	-
Indexed 3D Scene Layers (I3S) [https://www.ogc.org/standards/i3s]	**X**	-	-	-
IndoorGML [https://www.ogc.org/standards/indoorgml]	-	**X**	-	-

Indoor Mapping Data Format (IMDF) [https://docs.ogc.org/cs/20-094/index.html]	-	**X**	-	-
Moving Features [https://www.ogc.org/standards/movingfeatures]	-	-	**X**	-
Routing Standards WG [https://www.ogc.org/projects/groups/routingswg]	-	-	**X**	-
SensorThings [https://www.ogc.org/standards/sensorthings]	-	**X**	**X**	-

Table 10. OGC Specification/API Cross Reference with Scenarios

This table is intended to be used as a guide in determining which Standards and specifications can be used with the various scenarios. Particular use cases may or may not use the indicated Standard/specification.

Appendix B: Feature Comparison: glTF and OpenFlight

B.1. Modeling Formats Comparison

The analysis and table were presented to all potential bidders in the Call for Proposals. FlightSafety proposal included providing a more detailed and nuanced analysis. Their results are presented in thire Participant report section.

Feature	Description	OpenFlight	glTF
Transformations	Move, rotate, and scale the contents	**Group**	**Nodes**, **Scenes** [https://github.com/KhronosGroup/glTF/tree/master/specification/2.0#scenes]
Geometry	The means to define the geometry of a model	**Mesh**, **Vertex**, **Face**, **Subface** - Allows the specification of arbitraty planar convex polygons to define a surface. Not all of these nodes are required to create geometry, but at least two are.	**Meshes** [https://github.com/KhronosGroup/glTF/tree/master/specification/2.0#meshes] - This is collection of verteces and indicies that only create a triangulated surface.
Appearance	The means to put a color, texture, or material on a geometric surface	**Mesh**, **Face** - Limited to basic coloring and image textures	**Materials** [https://github.com/KhronosGroup/glTF/tree/master/specification/2.0#materials] - Physically Based Material support including advanced PBR features.
Animation	*The means to change geometry and/or appearance of the model over time. There are several sub-types that are listed separately.*		

Feature	Description	OpenFlight	glTF
Key Frame	Specifies a collection of important (key) frames.	**Group** - Specifies a collection of frames where each collection is displayed in total replacing the contents of the previous frame. This is like discrete key frames (no interpolation between frames).	**Animations** [https://github.com/KhronosGroup/glTF/tree/master/specification/2.0#animations] - This node supports all animation types in glTF. Generally this is done by linearly interpolating between the key frames for the specific type of animation desired.
Skeletal	Specifies how the surface moves over a collection of joints in response to the movement of those joints.	*n/a*	**Skins** [https://github.com/KhronosGroup/glTF/tree/master/specification/2.0#skins], **Animations** [https://github.com/KhronosGroup/glTF/tree/master/specification/2.0#animations] - Provides data for weighted geometry vertices (skin) and moves them according the animation of the joints.
Morph	Specifies a starting and ending geometry, typically down to the level of individual vertices. The system linearly interpolates between the two based on some externally supplied value.	**Vertex**, **Morph Vertex**	**Morph Target** [https://github.com/KhronosGroup/glTF/tree/master/specification/2.0#morph-targets], **Animations** [https://github.com/KhronosGroup/glTF/tree/master/specification/2.0#animations]

Feature	Description	OpenFlight	glTF
Articulation	Specifies allowed animation within fixed limits at fixed points in the model.	**Degree of Freedom**	**AGI_articulations** [https://github.com/KhronosGroup/glTF/tree/master/extensions/2.0/Vendor/AGI_articulations], **Animations** [https://github.com/KhronosGroup/glTF/tree/master/specification/2.0#animations]
LOD	Level of Detail allows a model to exist at several detail levels. The display system chooses which detail level to display based on the distance to the object and potentially other factors.	**Level of Detail**	**MSFT_lod** [https://github.com/KhronosGroup/glTF/tree/master/extensions/2.0/Vendor/MSFT_lod]
Switch	This feature allows zero or more models to be displayed from the collection. This is a generalized version of LOD and is frequently used for before & after displays.	**Switch**	**KHR_materials_variants** [https://github.com/KhronosGroup/glTF/tree/master/extensions/2.0/Khronos/KHR_materials_variants] provides this functionality for appearance on the same geometry. Except for the LOD indicated above, there is no explicit functionality for this capability.
Lighting	*This feature provides lighting for the model and scene. It may or may not illuminate other objects. Subtypes are listed separately.*		
Glow Lights	This feature is small glowing light sources that do not illuminate other objects.	**Light Point**	This is typically done with an emmsive color or texture on geometry. There is no explicit support in the foramt.

Feature	Description	OpenFlight	glTF
Punctual Lights	This includes point, spot, and directional lights that illuminate other objects.	**Light Source** - The reference does not provide any indication that directional lights are supported.	*n/a* - Support for light interaction with the model appearance is supported; however, the format does not include light definitions. See **Notes, Lighting** for addtional details.
IBL	Image Based Lighting (IBL) is used to illuminate a PB Material model. This provides light from 4pi steradians with the proper coloring for each angle. It is typically used to light an individual location in a scene.	*n/a*	**EXT_lights_image_based** [https://github.com/KhronosGroup/glTF/tree/master/extensions/2.0/Vendor/EXT_lights_image_based] (see **Notes, Lighting**)
Camera/ Viewpoint	The location where a virtual camera is put into the scene for viewing the contents. Typically several charateristics of the camera are available for definition including (but not necessarily all) lens, zoom, projection type (**perspective** or **orthographic**)	*n/a*	**Cameras** [https://github.com/KhronosGroup/glTF/tree/master/specification/2.0#cameras] (see **Notes, Viewing**)
Text	The ability to add text to the scene without creating specialized geometry for it.	**Text**	*n/a*
Audio	The ability to add sound to an object (model) or environment.	**Sound**	**MSFT_audio_emitter** [https://github.com/KhronosGroup/glTF/pull/1400] There are discussions as to how appropriate this is for glTF in the standardized version.

Feature	Description	OpenFlight	glTF
Inclusion	The ability to include secondary files or datasets as directly as part of the scene. These inclusions do not modify existing objects or features.	**External reference**	*n/a*
Metadata	The ability to associate data about the node (metadata) with a node. This is usually structured and provides for easy expansion.	**Comment** - This is unstructured plain descriptive text.	**KHR_xmp_json_ld** [https://github.com/KhronosGroup/glTF/pull/1893] - Public, but currently unratified extension to provide a structure to store metadata in **various nodes.**
Instancing	The ability to create multiple display objects from a single source object. The geometry, apperance, and animatation is the same between the instances.	**Instancing**, **Replication**	**EXT_mesh_gpu_instancing** [https://github.com/KhronosGroup/glTF/tree/master/extensions/2.0/Vendor/EXT_mesh_gpu_instancing]

Table 11. OpenFlight - glTF Comparison

A high-level comparison of the modeling portion of OpenFlight and glTF. The structural elements of both formats were ignored.

Notes

1. ***Lighting:*** *glTF does support lights; however, the trend is not to have models with lights as they need to interact with something physical to be seen. The lighting is typically supplied by the system handling the display of the glTF model. Model illumination is typically done with IBL. It is possible to include IBL with a model using EXT_lights_image_based [https://github.com/KhronosGroup/glTF/tree/master/extensions/2.0/Vendor/EXT_lights_image_based].*

2. ***Viewing*** *Typically cameras are contained and managed in the scene environment to account for different uses of the model. There is no reqirements that the model camera must be used.*

Appendix C: Datasets Used in ISG Year 2 Sprint

C.1. Introduction

A description of the datasets used during the Sprint. At a minimum, there should be overview images plus a complete set of metadata in terms of accessing the data and its license.

C.2. Datasets

Data set	Overview	Format	Size	Owner	License
Austin		GeoPackage	951MB((4km2)	Multiple - See Notes	PD
Berlin	-	*unk*	*unk*	*unk*	*unk*
Honolulu, HI	-	CDB	*unk*	*unk*	*unk*
Miami, FL	-	*unk*	*unk*	*unk*	*unk*
New York CDB	-	CDB	*unk*	Provide by FlightSafety	*unk*
Paris		GeoPackage	4.41GB(4km2)	Multiple - See Notes	Mixed
San Diego CDB		GeoPackage (From CDB)	32.9GB(GLTF-Binary) 2.27GB(OpenFlight)	Created By CAE USA Inc	*tbd*
Stuttgart		OpenStreetMap	*unk*	OpenStreetMap contributors	*unk*
Yeman	-	*unk*	*unk*	Provided by Presagis	*unk*

Table 12. Details of data sets used by the participants during the Sprint.

C.2.1. Austin Notes

Please See SimBlocks section of the ER Section GeoPackage Content Creation (Austin Tx) for Unreal Engine and Unity for a complete description of all datasets and processes used for Austin TX.

- Texas Natural REsource Information System
  - Source Imagery: https://data.tnris.org/collection/f84442b8-ac2a-4708-b5c0-9d15515f4483
  - Web Map Service (WMS): https://imagery.tnris.org/server/services/StratMap/StratMap19_NCCIR_CapArea/ImageServer/WMSServer
- Source Elevation: https://apps.nationalmap.gov/downloader/#/
  - Incorrect link: https://elevation.nationalmap.gov/arcgis/services/3DEPElevation/ImageServer/WCSServer
- Building Footprints https://austintexas.app.box.com/s/8ah8itbha7u6lis9eipypnz5ljvwta4t
- Tree Locations https://data.austintexas.gov/Locations-and-Maps/Tree-Inventory/wrik-xasw

C.2.2. Honolulu Notes

C.2.3. Berlin Notes

- Used in OGC Testbed 13

C.2.4. Miami Notes

C.2.5. New York CDB Notes

C.2.6. Paris Notes

Imagery: Bing Virtual Earth (for Paris resolution appears to be ~0.5 Meter/Pixel

Elevation: Shuttle Radar Topography Mission (SRTM) (Sample rate ~30m)

Paris GIS Information:

Basic Site Home — Paris Data (https://opendata.paris.fr/pages/home/)

Note: The site is in French. To get descriptive information on the data layers from this site you will need to download the PDF files and load them in google docs and have google docs do the translation. For the site itself use chrome and let google translate it.

Building Footprints Volumes bâtis — Paris Data (https://opendata.paris.fr/explore/dataset/

volumesbatisparis/information/)

Notes: Building Hight Information is described by number of floors in building. In general assume 4.3 M per floor but in truth this is quite variable.

Trees Les arbres — Paris Data (https://opendata.paris.fr/explore/dataset/les-arbres/information/?disjunctive.typeemplacement&disjunctive.arrondissement&disjunctive.libellefrancais&disjunctive.genre&disjunctive.espece&disjunctive.varieteoucultivar&disjunctive.stadedeveloppement&disjunctive.remarquable)

This dataset contains an inventory of trees in the city of Paris containing species of tree and height in meters.

Note: There are some spikes in the tree height information. Not all trees are in the inventory

Note: Both Building Heights and Trees were downloaded as GeoJSON.

Note on other layers available on basic site. There are many layers available that we may use in the future for enhancements such as street furniture, traffic signals and possibly additional building information that will allow automated selection of building templates.

- Building Footprints https://opendata.paris.fr/explore/dataset/volumesbatisparis/information
- Tree Locations https://opendata.paris.fr/explore/dataset/les-arbres/information/?disjunctive.typeemplacement&disjunctive.arrondissement&disjunctive.libellefrancais&disjunctive.genre&disjunctive.espece&disjunctive.varieteoucultivar&disjunctive.stadedeveloppement&disjunctive.remarquable
- Elevation (SRTM) https://earthexplorer.usgs.gov/

C.2.7. San Diego CDB Notes

- source CDB https://gsa-temp-public.s3.us-east-1.amazonaws.com/CDB_san_diego_v4.1.zip
- GTLF GeoPackage *url*
- OpenFlight GeoPackage *url*
- GeoPackage Files *url*
- Other versions of the San Diego CDB
  - the original one provided by CAE (specified above)
  - the GeoPackage(s) created by SimBlocks based on earlier CDB Interoperability Experiments
  - the CDB X GeoPackage datastore prototype that we produced for the CDB X Tech Sprint

    - Additional information at https://github.com/sofwerx/cdb2-eng-report/blob/master/11-tiling-coverages.adoc or https://portal.ogc.org/index.php?m=projects&a=view&project_id=466&tab=2&artifact_id=95315

C.2.8. Stuttgard Notes

- Street data: (c) OpenStreetMap contributors. https://openstreetmap.org/
- Ecere sourced the data from a GeoFabrik (https://download.geofabrik.de/) OSM PBF extract of Baden-Württemberg (https://download.geofabrik.de/europe/germany/baden-wuerttemberg-latest.osm.pbf), and converted this to our GNOSIS Map Tiles and our GNOSIS Data Store.
- Detalied HfT building interiors created by HfT students in Sketchup.

C.2.9. Yemen Notes

C.2.10. Global Datasets

- Viewfinder Panoramas: worldwide elevation data from Jonathan de Ferranti: http://www.viewfinderpanoramas.org/Coverage%20map%20viewfinderpanoramas_org3.htm
- NASA Visible Earth Blue Marble: https://visibleearth.nasa.gov/collection/1484/blue-marble
- *ESA Gaia's Sky in colour https://sci.esa.int/web/gaia/-/60196-gaia-s-sky-in-colour-equirectangular-projection (Gaia Data Processing and Analysis Consortium (DPAC); A. Moitinho / A. F. Silva / M. Barros / C. Barata, University of Lisbon, Portugal; H. Savietto, Fork Research, Portugal.) CC BY SA 3.0.

Appendix D: Display Applications

D.1. Introduction

A description of the display applications. This section needs to highlight the use of Unreal/Unity and other display applications. Use of an application by a particiapnt developed by another one should also be highlighted.

D.2. Client Display Applications

Particiapnt	Unity	Unreal Engine	Android	iOS	CesiumJS	GNOSIS
Cesium	-	-	-	-	-	-
Ecere	-	-	-	-	**X**	**X**
FlightSafety	-	-	-	-	**X**	-
InfoDao	-	-	-	-	-	-
SimBlocks	**X**	**X**	-	-	-	-
Steinbeis	**X**	**X**	**X**	**X**	**X**	-

Table 13. This table lists the applications used by the participants. It's intent is to highlight game engine, mobile applications, and cross-use of display tools.

Appendix E: Revision History

Date	Editor	Release	Primary clauses modified	Description
19 August 2021	L. Daly	.1	all	Draft version released to CB SWG

Table 14. The revision history of this document starting with the initial release outside of the creating organization (ISG Year 2 Sprint)

Appendix F: Bibliography