Empowering Smart Communities with a Digital Twin

Why detailed 3D city models are critical for enabling modern IoT solutions

A Technical Paper prepared for SCTE by

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1. The Case for a 3D Digital Twin

MSO's have two powerful and unique advantages towards delivering Smart City/Community programs – an expansive high speed, low latency network footprint and tremendous experience and expertise in the local markets they serve. However, delivering these expansive projects at scale, including Fiber-to-the-Premise/Home (FTTP/H), fixed wireless access, streetlight modernization, digital kiosks, parking, accessibility, and other intelligent Internet of Things (IoT) deployments presents unique challenges far different from the traditional cable business.

In the traditional business, a "best efforts" approach to data with uneven quality and currency, for example two-dimensional (2D) Geographic Information Systems (GIS) maps that are out of date, in many cases have been "good enough." In contrast, connected community programs require up-front three-dimensional (3D) information models covering buildings, sites, surface features, existing infrastructure, and ROW (right of way). These models need to be current, hyper-detailed, and comprehensive, and they must offer pinpoint accuracy. As a result, the traditional approach to data gathering with manual field walkouts is time inefficient, costly, and doesn't meet the new requirements for smart community planning, IoT engineering, and project execution.

To effectively address the "Smart City" challenge, a new and innovative approach to capturing field data – infrastructure, assets, and site conditions – is required to support the more precise requirements of fixed and wireless IoT deployments. This includes high resolution 360-degree imagery, dense LiDAR (Light Detection and Ranging) point clouds, and machine learning. Working with Cox2M, a division of Cox Communications, and building on the latest technologies, R&D efforts, and project experience across several relevant use cases, a blueprint for a smart community enablement platform emerged, largely enabled by the power of a detailed and accurate 3D digital twin.

This technical paper will outline the business rationale and specific use cases related to new MSO initiatives in fiber-to-the-home or -premise (FTTH/P), wireless, and private-public partnerships, and then dive into the technical requirements, challenges, and implementation of a 3D digital twin to accelerate and meet the end-to-end deployment needs of leading edge, connected community projects. Key learnings and best practices will be highlighted, along with performance metrics from actual projects – such as cycle time reduction, data quality improvements, and cost savings – that quantify the true benefits and impact of developing and integrating a 3D digital twin for field data automation.

2. Key Components of a Smart Community Planning and Engineering Solution

There are several high level requirements that are unique to smart community IoT planning and engineering (P&E) projects. These include the following key capabilities and attributes:

- 3D model of the real world
- High precision and accuracy
- Immersive online digital environment
- Integration with GIS and design tools
- Timeliness of information

Here is a deeper dive into the five essential components of the digital twin solution for smart community/IoT planning and engineering.

2.1. 3D model of the real world

Any assessment of the existing field conditions, such as infrastructure, relevant assets, surface features, and for that matter everything within the right of way (ROW), has to be presented in a three-dimensional context. This means both imagery and LiDAR are needed in order to produce a digital 3D representation of the true field conditions. The primary reason for this is that optimal placement of IoT-enabled devices and supporting connectivity (fixed and wireless) requires comprehensive and detailed horizontal and vertical references to address factors such as line of sight, clutter, visibility, accessibility, form and fit, and aesthetics. Even something as simple as taking measurements need to be performed in 3D space using x, y and z coordinates. A traditional 2D GIS map falls flat!

2.2. High precision and accuracy

Engineering smart kiosks, lighting, sensors, fixed wireless access (FWA), Wi-Fi coverage, and pre-connected FTTH cables and drops, requires very accurate site information and high precision reference data. GIS maps are typically based on legacy information that has been converted and/or migrated over time with poor positional accuracy, at best 2 to 3 meters but often much worse. Taking measurements, which are dependent upon the precision or relative accuracy of the data, cannot be trusted for engineering tasks. This means that a field survey, often referred to as “boots on the ground” or “field walkout”, is required but this takes a lot of time and expense. The results have worked adequately for traditional cable and telecom engineering for many years, but this approach does not deliver the on the imagery and 3D model requirements, and it does not provide an immersive digital twin (see next section).

2.3. Immersive online digital environment

An extremely important part of the smart community solution is the notion of a “virtual field walkout”. This refers to the ability for project stakeholders to visualize the real world environment from an application on a connected device such as a PC, laptop, tablet, or smart phone – in essence a digital twin. There are many benefits to having this capability, but the primary ones are:

1. Eliminate or reduce time, cost, and risk of “boots on the ground” field work
2. Ensure high quality measurements and calculations based on true 3D data
3. Collaborate and solve problems quickly and confidently
4. Avoid remedial work and mistakes related to poor or missing field information

Figure 1 – High Resolution Imagery & Extracted Assets

A large international engineering firm refers to high resolution street level imagery and LiDAR as "the single source of truth" for planning, high level design (HLD), low level design (LLD), and permitting.

2.4. Integration with GIS and design tools

Planning and engineering work is typically performed using GIS, computer-aided design (CAD) or other geospatially-enabled software tools. Digital field data must be integrated with these tools for productivity, accuracy, and completeness. There are two core requirements for the integration of a 3D geospatial digital twin with GIS and CAD.

2.4.1. Support for 3D data

The GIS or CAD platform being used for smart community/IoT projects must support 3D data management and visualization. Platforms that are used extensively for managing and designing in three dimensions include Esri ArcGIS and ArcGIS Online, and AutoCAD. In addition, the platform must allow high density LiDAR point cloud files and extracted 3D asset/feature vector data layers (points, lines and polygons) to be automatically loaded into the database.

2.4.1. Open API

There are two application programming interface (API) capabilities that are needed for effective integration of imagery/LiDAR and extracted 3D asset and feature data. The first is a 360-degree viewer plugin that works interactively within the system's user interface (UI) so that designers can perform tasks in an immersive 3D workspace. These sorts of plugins are normally set up using Java Script or Practical examples of this include recording measurements and placing proposed design elements in three-dimensional space with x, y and z coordinates. The second API capability that's important to the overall usability of digital field data for design and permitting is live rendering of third party data such as LiDAR, imagery, and vectors in real-time. This would be the approach used for data that is stored on the cloud and made accessible using a standard file format (such as LiDAR .LAZ, or vector DGB or Shapefile), or as an online internet protocol like WMS (web map service) for map tiles or WFS (web feature service) for geospatial data records.

2.5. Timeliness of information

Having the ability to capture field data where and when needed is critical to the overall smart community solution process, sequence of events, and project timeline. Ideally, field data for planning and engineering should be captured within 3-9 months of HLD/LLD and permitting, and no more than 12 months old. Similar to mobilizing field workers to inspect, survey and inventory field information, this means that imagery and LiDAR data capture needs to be mobilized early in the project cycle since it's required as input to planning, engineering and permitting activities. In essence, the field data needed to build a comprehensive 3D digital twin model of the real world must be performed on demand for the target area of interest (AOI).

3. Technical Considerations and Specifications

The foundation of creating a 3D digital twin of the outside plant (OSP) environment is the recording system. There are several options when considering field data capture, such as the method of capture, the type, frequency, resolution, accuracy, and level of effort.

Here is a simple matrix showing the available commercial options for field data capture supporting smart community use cases:

Table 1 – Commercial Data Capture Options

Data Capture Options	Type(s)	Method	Frequency	Resolution and/or Accuracy	Level of Effort*
Fixed Wing Aerial	Ortho & oblique imagery, LiDAR	Low altitude at slow speed, grid pattern flight plan	On a set schedule	30- to 150-megapixel imagery, 50 to 100 points-per-square-meter LiDAR, 0.1 to	Low

				1.0 meter positional accuracy	
Drone	Oblique & 360^0 imagery, some LiDAR options	Flown with ground-based pilot, requires permit or authorization	On demand	30-megapixel imagery, 500+ points-per-square-meter LiDAR, 0.2 to 0.5 meter positional accuracy	High
Street Level	360^0 & ortho imagery, LiDAR	Vehicle mounted, follow public and private roads, parking lots, etc.	On demand	30- to 100-megapixel imagery, ~1,000 to 2,000 points-per-square-meter LiDAR, 0.1 meter positional accuracy	Medium
Backpack/hand-held	Conventional & 360^0 imagery, LiDAR options	Heavy backpack, trolly or hand-held device	On demand	10- to 20-megapixel imagery, 1,000+ points-per-square-meter LiDAR, 0.2 to 1.0 meter positional accuracy	High

* Level of Effort is based on the time and cost per unit of measure, such as square miles or linear miles.

Based on the above criteria along with testing, trials and production projects performed by companies like Cox2M (a division of Cox Communications), Verizon OneFiber and Wireless, Ledcor Technical Services, Byers Engineering, and CalComm Consulting, street level imagery & LiDAR capture is best suited to the specific requirements of IoT and communications planning and engineering projects. The factors that have contributed to this conclusion are imagery/LiDAR resolution and quality, data capture flexibility, speed of capture and post-processing, overall cost, and ease of integration.

3.1. Street level imagery & LiDAR capture

The on-going evolution and recent innovations in vehicle-based street level imaging has enabled the creation of a geospatially accurate 3D digital twin. A great example of this is a recording system comprised of five individual cameras that fire off in sequence to the front, right, up, left, and rear as the vehicle crosses theoretical recording locations, also known as recording points, that are taken 5 meters apart as the vehicle drives and captures the AOI. The source images are merged using a patented process, creating a "GeoCyclorama" – a seamless, parallax-free, spherical, high-resolution, panoramic image taken at street level. At 5-meter (16.4 feet) intervals, the GeoCyclorama" is generated covering the entire road network for the target AOI. The resulting 100-megapixel resolution imagery, in which each pixel location is identified, provides users and systems with imagery that is both incredibly detailed and accurate.

Figure 2 – Example of Vehicle-Mounted 5-Camera, LiDAR and GPS System

The 100-megapixel resolution provides a full 14,400x7,200 resolution image. There is a 0.025 arc degree separation between pixels which translates to ~4.0mm at 10 meters, and ~6.5mm at 15 meters, between pixels. At 10 meters this is roughly a density of 62,500 pixels per square meter on a vertical plane such as a wall.

The LiDAR scanner is running the entire time so that the imagery and point cloud data capture is aligned and covering the exact same AOI. A high specification global positioning system (GPS) is integrated with the cameras and LiDAR sensor to ensure the best possible position identification and recording.

3.2. Imagery & LiDAR integration and positional accuracy

GeoCycloramas are high-resolution, parallax free images with a built in spatial component providing not only a precise location for each 360-degree image but an x, y & z coordinate for every pixel within the image. The patented capture technology allows for the precise pixel arc separation mentioned previously, which allows the system to accurately tie the imagery and LiDAR together. With the level of integration, the LiDAR point cloud is colorized based on the RGB (red, green, blue) values from the imagery. This is a very important part of the unique and innovative approach – any other process where imagery and LiDAR are collected separately will not deliver the accuracies and immersive capabilities of the GeoCyclorama, even if it’s possible to integrate them after the fact (which is extremely uncommon). During this post-processing stage, other positional improvements are applied through steps such as geospatial positioning alignment with a reference datum (control points) or external model, and relative positioning improvement (RPI) that utilize overlapping datasets to improve the data even further.

On average, the absolute positional (x, y & z location) accuracy is +/-10cm at 1 standard deviation. The relative accuracy, for example for taking measurements like pole spans, height of attachments, pavement width, concreate surface areas, is on average +/-2cm at 1 standard deviation.

3.3. Data analytics: asset and feature extraction

Extracting assets and other features from the imagery and LiDAR data is generally called data analytics. Data analytics tools and processes include a combination of machine learning (ML), artificial intelligence (AI), automation, partial automation, and human review and input from skilled analysts and subject matter experts (SMEs). Over time the algorithms improve, and the level automation increases based on lessons learned on production projects and as feature recognition libraries continue to be further developed.

Data analytics and extractions run through a proprietary and optimized platform that provides a host of automated, semi-automated, and manual tool sets to efficiently detect, extract and deliver a quality asset and feature-rich data analytics product. Over time the teams working on next-generation communications, IoT and smart city projects have built up an extensive library of ML models that can detect common infrastructure, roadway, roadside, architecture, and public works features from the 360-degree imagery and place the geometric representation accurately within the LiDAR point cloud data. The data analytics process has matured to become an entire workflow that includes project tracking, data management, automation, QA/QC, and client delivery to ensure that a quality product is maintained and that consistently meets the service level agreement (SLA) and required specifications.

To show the extent of the collective team's efforts, below are examples of some of the most widely used data analytics extraction assets and features, called data dictionaries:

Table 2 – Asset and Feature Extraction Examples

Pole Details	**Overhead**	**Ground Features**	**Right of Way**
Pole Base & Top	Span	Cabinet	Edge of Pavement
Material	Midspan	Manhole	Back of Curb
Cross Arm	Lowest Vertical Clearance	Handhole	Sign & Structure
Guy Wire POA	Power Vertical Clearance	Vault	Traffic Signal
Guy Wire Anchor	Primary Conductor	Pedestal	Bus Shelter
Equipment POA	Comms Cable	Wall	Sidewalk
Streetlight POA	Streetlight	Fence	ADA Ramp
Power POA		Building	Lane Markings
Comms POA			

4. Conclusion

The teams at Cyclomedia, Cox2M, and the other service providers and engineering firms – not to mention numerous local governments, cities, counties, and municipalities – have firsthand experience that collectively adds up to hundreds of projects and hundreds of thousands of miles of imagery and LiDAR data capture and processing. The use cases that have been successfully delivered include long-haul fiber, FTTH/P, 5G planning, pole inventory and engineering, joint use reconciliation, tax assessment, first floor elevations, sign condition and inventory, accessibility, and highway sign and roadway condition assessment. Several best practices have emerged and more continue to be developed all the time. The most important findings are summarized as follows:

> *Remote sensing technologies have advanced so much in the last 3-4 years that imagery and LiDAR solutions have become a viable alternative to manual field data capture, including use cases like pre-engineering walkouts, visual inspections, infrastructure and inventory surveys, and condition assessment.*
>
> *High quality and precise imagery, LiDAR and data analytics can replace 80-90% of traditional boots on the ground field data capture and accelerate project cycle times by 50% or more. Safety is improved while risk and liability are reduced.*
>
> *Street level data capture is best suited to smart community, communications, and IoT planning and engineering due to the close proximity to assets, infrastructure and features, high data quality, immersive experience (virtual fielding), speed and ease of capture, and flexibility of the AOI.*
>
> *Machine learning and automation are continuously able to handle more and more asset and feature extractions over time, but human subject matter experts are essential to training the routines, expanding the capabilities, and ensuring that quality and completeness goals are met.*
>
> *Street level data is a foundational component of creating a 3D digital twin city model to support smart community, IoT and communications planning, engineering, permitting, and construction.*

Cyclomedia and Cox2M are looking at short-term requirements to support additional assets and features along with closer integration with P&E workflows and tools. Longer term, the companies and other partners are looking to automate a greater number of assets and features, streamline the integration to the design and project management systems, and look to incorporate additional data sources into the analytics process. The Cyclomedia and Cox2M leadership teams welcome feedback from other SCTE, CableLabs, and NCTA members, and are open to development collaboration, lab testing and functional pilots to advance the 3D digital twin capabilities for smart community and IoT projects and evolving use cases.

Abbreviations

2D	Two-dimensional
3D	Three-dimensional
AI	Artificial Intelligence
AOI	Area of Interest
API	Application Programming Interface
FTTP	Fiber-to-the-Premise
FTTH	Fiber-to-the-Home
GIS	Geographic Information System
HLD	High Level Design
IoT	Internet of Things
LiDAR	Light Detection and Ranging
LLD	Low Level Design
ML	Machine Learning
OSP	Outside Plant
P&E	Planning and Engineering
ROW	Right of Way
RPI	Relative Positioning Improvement
SCTE	Society of Cable Telecommunications Engineers
SLA	Service Level Agreement
SME	Subject Matter Expert
UI	User Interface
WFS	Web Feature Service
WMS	Web Map Service

Bibliography & References

Wikipedia – Web Map Service. A standard protocol developed by the Open Geospatial Consortium in 1999 for serving georeferenced map images over the Internet. These images are typically produced by a map server from data provided by a GIS database. See https://en.wikipedia.org/wiki/Web_Map_Service.

Wikipedia – Web Feature Service. In computing, the Open Geospatial Consortium Web Feature Service (WFS) Interface Standard provides an interface allowing requests for geographical features across the web using platform-independent calls. One can think of geographical features as the "source code" behind a map, whereas the WMS interface or online tiled mapping portals like Google Maps return only an image, which end-users cannot edit or spatially analyze. See https://en.wikipedia.org/wiki/Web_Feature_Service.

