Building Cape Town's 3D City Model: Geospatial Foundations for an Urban Digital Twin (13989)

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SUMMARY

As early as 2010, the Geospatial Section identified the potential that 3D could present for the metro, and the need to build accurate base datasets that would allow the City of Cape Town (CCT) to build a three-dimensional City Information Model (3DCIM) from the ground up. The foundation of a 3DCIM must be the digital representation of the natural and built environment, as well as the full digital representation of land ownership and use rights. The following 3D geospatial datasets have been, or are currently being, developed and maintained to support the implementation of a 3DCIM:

(i) Annually updated Digital Elevation Models, including both surface and bare earth models,
(ii) A 5m Digital Terrain Model that is the legislated Ground Level Map 2019, providing the legal definition of so-called Existing Ground Level as used for determining the vertical in land use applications as per the Municipal Planning By-Law (MPBL),
(iii) Photogrammetrically captured high accuracy, high detail (LOD2.2) 3D building models that cover 35% of the metro's formal buildings with a focus on the higher interest areas of the CBDs and primary transport routes,
(iv) Automated feature extraction using deep learning of all the formal and informal (inclusive of backyarder dwellings) buildings into separate 3D building model datasets at a lower accuracy and level of detail (LOD1) but with full coverage to complement the LOD2.2 building models,
(v) Annual built environment change detection to identify change and maintain the datasets,
(vi) Automated production of 3D Development Envelopes for the full metro that are the spatial volumetric representation of the landowners use and development rights of a property according to the erf's zone as stipulated in the MPBL,
(vii) Tree classification in high density LiDAR data for realistic representation of the natural environment, and
(viii) 3D engineering model dataset that captures structures such as bridges or silos.

The value of this work is already evident in practical applications across the organization. Furthermore, significant research has been done on the best means of serving 3D data that is available to the CCT. The next phase of work focuses on expanding 3D coverage, improving

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interoperability, and developing a strategy for serving 3D data across departments. Through its methodical, data-driven approach, the Geospatial Section is laying the groundwork for an Urban Digital Twin that will enhance collaboration, transparency, and sustainability in Cape Town's future planning and governance.

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1 INTRODUCTION

Cities are complex systems that require coordinated planning, service delivery and decision-making. The City of Cape Town (CCT) faces increasing pressures linked to urban growth, housing demand, infrastructure provision and climate risk. Three-dimensional spatial data offers a practical means to improve how urban systems are understood, communicated and managed.

A 3D City Model (3DCIM) is a digital representation of a city's physical environment, including buildings, infrastructure and terrain, to support planning, analysis and visualisation (Cureton et al., 2023; Mazzetto, 2024). A 3DCIM is widely regarded as a precursor to an Urban Digital Twin (UDT) (Cureton et al., 2023), which integrates real-time data to simulate and optimise urban processes (OGC, 2024). The CCT's immediate focus is on establishing the foundational 3DCIM. The 3DCIM offers a practical, cost-effective way to manage Cape Town's urban environment, with the possibility of integrating real-time data to evolve into a UDT over time.

The development of a 3DCIM supports the CCT's Integrated Development Plan objectives (City of Cape Town, 2022), enabling better planning and service delivery, improved safety, inclusivity and transparency, and more efficient data-driven governance. Furthermore, it aligns with the United Nations' Sustainable Development Goals (SDGs), particularly SDG 9 (Industry, Innovation and Infrastructure), SDG 11 (Sustainable Cities and Communities) and SDG 13 (Climate Action) (United Nations, *no date*). Over the past decade, the CCT has made substantial progress in producing 3D-ready datasets such as aerial imagery, LiDAR, 3D building models and 3D zoning datasets. These datasets already support departmental workflows and decision-making while preparing for a future 3DCIM and prospective UDT capability.

Over the past three years, the City of Cape Town's Geospatial Section has made significant progress toward building the 3DCIM, improving and building datasets such as high-resolution aerial imagery, LiDAR data, Digital Surface Models (DSMs), Digital Terrain Models (DTMs), 3D building models, and 3D development envelopes (zoning models). This groundwork is providing CCT departments with tools to enhance their workflows and decision-making, while preparing for the full development of a 3DCIM. The 3DCIM will serve as a powerful tool for improving decision-making, infrastructure planning, and urban visualisation, as shown by existing use cases.

While the concept of an Urban Digital Twin (UDT), a dynamic, continuously updated digital representation of the CCT, remains a potential future evolution, the immediate focus is on establishing the 3DCIM as a foundation.

The challenge now lies in expanding the existing 3D datasets to cover the entire CCT, integrating these datasets into a cohesive model, and ensuring accessibility across departments and external stakeholders. By focusing on 3DCIM development, the CCT can leverage its geospatial data to enhance urban management without fully committing to the broader, more complex "smart city" concept, while aligning these initiatives with the CCT's strategic goals and Data Strategy.

2 THE GEOSPATIAL FOUNDATIONS FOR A 3D CITY MODEL

The Geospatial Section, which forms part of the Geomatics Branch, is responsible for the remote sensing and survey data management in the CCT. This function includes base data capture such as topographical data, digital elevation models, digital aerial photography, the management of the geospatial servers and databases, and dissemination of geospatial datasets and products to users, both internal and external to the CCT. The metropolitan area covers an estimated 2700 square kilometres.

The Geospatial Section has long recognised the potential value that three-dimensional spatial data and 3D interfaces could offer to the CCT. Since the early 2010s, the Section has been proactively working toward the development of a 3D City Model as a precursor to an UDT (Cureton, 2023). The Section has undertaken a range of preparatory activities to support what is viewed as an eventual and necessary evolution in the City's geospatial capability. This interest is shared across multiple departments within the CCT, with varying degrees of ambition: some envisage the future development of an Urban Digital Twin (UDT) or broader Smart City capability, while others focus on the more immediate benefits of a 3D City Model for planning, communication and decision-making. Within the CCT, the following definitions are accepted:

> *A **3D City Model** may be defined as a digital representation of a city's physical structures, terrain and infrastructure in three dimensions, used for planning, analysis and visualisation.*
> *An **Urban Digital Twin** (UDT) may be defined as a dynamic, virtual representation of a city's physical and functional systems that integrates real-time data to support simulation, monitoring and optimisation of urban processes (OGC, 2024).*

Regardless of the specific trajectory the CCT chooses to pursue, whether toward a 3D City Model or a UDT framework, the existence of high-quality 3D geospatial data remains a fundamental requirement. The development and maintenance of these datasets fall within the remit of the geospatial and land information sciences, and with this understanding, the Geospatial Section has focused on producing the foundational spatial data layers necessary to support three-dimensional urban modelling. In parallel, research and development has been conducted to evaluate and test optimal methods for serving 3D data within the CCT environment.

2.1 The CCT Core Geospatial Datasets

The Geospatial Section maintains a suite of 2D and 3D core geospatial datasets that provide direct and indirect inputs into the development of a 3DCIM. These core datasets include the following:

(i) Aerial Imagery: A 5cm resolution RGB orthophoto with a complementary near-infrared and digital surface model (DSM) data that is updated annually for the full metropolitan area. For every $5cm^2$ pixel, the CCT has values for RGB, IR, and height.
(ii) Oblique Imagery: A library of 5cm oblique aerial imagery (RGB) updated annually for all urban (developed) areas[2] and tied to the orthophoto for the primary function of assisting with desktop property valuations. This data has the potential to be a future input to a 3DCIM but is not currently being utilised for this purpose.
(iii) LiDAR: The high-density LiDAR data is captured annually for the full metro. The LiDAR dataset has a point density of 20 points per square metre and an absolute height accuracy of 15cm m (95% confidence) making it a valuable source of height information for the CCT. Multiple digital elevation models and contour datasets are extracted from this dataset annually. In future, the Section intends to implement the point cloud itself into a 3DCIM or UDT platform for an enriched 3D environment.
(iv) Historical Aerial Imagery: Scanned and rectified historical aerial imagery from the photogrammetric archives dating back to 1926. The spectral and spatial resolutions and coverage of each dataset are variable due to changing municipal boundaries and the purpose behind the original data capture.
(v) Heritage Maps: The scanned and georeferenced maps sourced from the CCT Heritage Branch. These maps date back to the early 19th century.

2.2 The Expansion of Existing 3D Datasets

The City of Cape Town maintains a set of geospatial datasets that support three-dimensional representation and analysis. These datasets vary in resolution, method of capture, and intended use, but collectively provide an initial 3D foundation upon which further modelling, visualisation and analytical workflows can be developed. A 3DCIM can be understood to be built from the ground up, and this is where the CCT has commenced its efforts. The Digital Terrain Model (DTM) represents the bare-earth surface with vegetation, buildings, and other raised objects removed and is a digital definition of the ground surface at the moment of capture. DTMs are particularly important because they define the spatial 'floor' on which all other 3D objects, features, and analytics are placed. In Cape Town, DTMs are derived annually from the latest LiDAR survey and function as the ground-level reference surface for 3D workflows. For 3D interfaces and applications, DTMs are typically consumed at a resolution of 1 to 2 metres. The aerial imagery is typically draped over the DTM to provide a natural looking surface for visualisation purposes.

In addition to the DTMs, the CCT acquires an annual Digital Surface Model (DSM) from the aerial imagery and derives a corresponding DSM from the LiDAR dataset. A DSM represents the top surface of all objects, including buildings, trees, vehicles and other structures. DSMs

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[2] Urban or developed areas versus rural or undeveloped areas that are typically used for agricultural purposes.

are crucial input datasets for automated feature extraction and downstream 3D building modelling. The LiDAR-derived DSM has superior vertical accuracy, while the image-derived DSM contains associated RGB and near-infrared values that support feature extraction. The Geospatial Section uses the DSMs as part of the development change detection workflows and as raw data for 3D model derivation, as discussed later.

The CCT maintains high-detail 3D building models, produced photogrammetrically from the annual 5 cm aerial imagery. These models are updated each year, with a minimum of 10 000 new models captured per cycle. The dataset has an approximate 30 cm positional accuracy and aligns with a Level of Detail (LOD) 2.2 specification as defined by Biljecki et al. (2016). LOD 2.2 is understood to mean that roof geometries are modelled with high fidelity while façade elements such as windows and doors are not fully represented (Figure 1). The models capture the roof geometry and drop the roof edge to the ground plane, meaning roof eaves are not captured volumetrically and the resulting building volumes are likely underestimated.

BuildingID *
P_0001056110_001_2018
P_0001084226_001_2017
P_0000975879_001_2013

Figure 1 (left): CCT photogrammetrically modelled 3D buildings to a LOD2.2
Figure 2 (right): 3D Building Model unique identifier based on CityGML standard.

The CCT models follow the Open Geospatial Consortium (OGC, 2024a) CityGML 3.0 standard as far as possible, providing geometric and semantic alignment with an internationally recognised 3D city model standard. CityGML compliance enables interoperability across software platforms and supports downstream analytical use cases relevant to Urban Digital Twins. Each building model is assigned a unique building identifier aligned with CityGML. The identifier embeds the SAP property key (see Figure 2), enabling the 3D building models to be joined directly to the CCT's property records. This establishes persistent object identity across GIS and SAP systems and allows transactional, spatial, and temporal data to be associated with a specific building instance. The unique identifier and the model attributes also include year of capture, year of demolition (where applicable, prior to archiving), method of capture and building height attributes (stored as relative height). Where possible, the building geometries are topologically closed to enable volumetric calculations. This semantic enrichment supports lifecycle tracking, interoperability, and analytical use cases relevant to Urban Digital Twins.

The building modelling programme commenced in 2013 and has resulted in approximately 35 percent coverage of buildings within the CCT area, targeted primarily at high-interest locations such as Central Business Districts and primary transport corridors. The CCT has an estimated 950 000 formal buildings across the metro that would need to be captured as a base dataset for a 3DCIM. The slow rate of capture has been due to budget constraints, limited specialised skill availability, and the resource-intensive capture methods. At present, no scalable solution to these constraints has been identified. These models are actively used by Development Management and Urban Design teams for evaluating development proposals, assessing urban form, and supporting policy interpretation and design review processes.

The annual capture of 10 000 new 3D building models does not include the ongoing maintenance on existing models that change due to development or demolition. To identify changes to the built environment, the Section runs annual development change detection using the DSM. By comparing successive years' DSMs, the team identifies new structures or modifications to existing buildings (see Figure 3). This product is used operationally, most notably by Valuations to identify unapproved developments and initiate investigations, demonstrating an applied 3D analytical capability within the CCT. The estimated number of changes to the built environment annually is approximately 60 000, far exceeding the current photogrammetric capacity of 10 000 models per year.

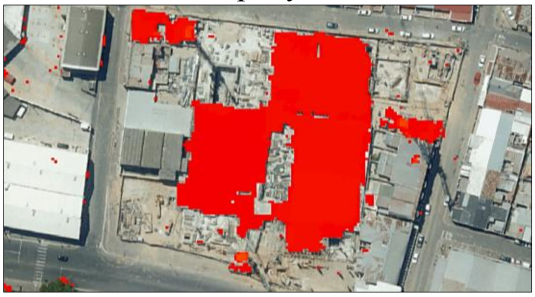


Figure 3: Change detection run annually on the built environment highlights new or amended buildings across the CCT.

In addition to the 3D building models, the CCT maintains a subsidiary dataset of 3D building parts. The concept of building parts is defined in the CityGML standard (OGC, 2024a) through the Building Part class, which allows complex buildings to be decomposed into structurally meaningful sub-components. The dataset is used for buildings with complex or distinct forms where sub-components can be identified. The parts are captured photogrammetrically, split and corrected for topology, and where possible are generated as topologically closed solids to support volumetric calculations. Breaking complex buildings into parts increases the success rate of volumetric calculations and supports analytical use cases such as massing and densification studies. Each building part inherits the parent building's unique identifier and is attributed with a part count to maintain hierarchical relationships.

The CCT also maintains a 3D engineering structures dataset, which contains 3D polygons representing electric substations, bridges, silos, and other infrastructure that does not fall under the classification of 'building'. These geometries are captured photogrammetrically to a high visualisation standard but are not intended to meet engineering-grade accuracy requirements. The 3D objects include thickness approximations, where applicable, and basic classifications (for example, “bridge”) to assist users. The thickness approximations are used to generate 3D Multipatch objects for use in 3D platforms. A Building Information Modelling (BIM) pilot project is currently being undertaken by an Engineering Branch within the City, and there is an expectation that this may support more detailed and accurate engineering structure data capture in future. The dataset is maintained on an ad-hoc basis in response to specific visualisation requirements, rather than through a citywide or programme-driven capture approach, due to resource constraints.

While the high-detail 3D building model dataset and the related 3D datasets, are highly valuable sources of 3D information, the limited coverage and resource-intensive production characteristics constrain its potential use for a citywide UDT. As discussed, high-accuracy modelling using traditional photogrammetric methods at the LOD 2.2 range is inherently resource-intensive, resulting in slow expansion rates relative to metropolitan demand. Preparing for a potential UDT requires a complete 3D building dataset as a foundational dataset, and this requirement was formally recognised as a need and a challenge in 2020.

To address the identified need for a full coverage 3D building model dataset, the Geospatial Section adopted a complementary approach that focuses on automated data extraction to accelerate coverage. This involves the use of existing datasets to generate 2D building footprint layers, which can then be extruded to generate lower LOD 3D building models suitable for broad-scale analysis. This strategy provides a pragmatic pathway toward citywide coverage while preserving a high-detail photogrammetric dataset for priority areas where accuracy and detail are operationally necessary.

2.3 The Development of New Foundational Geospatial Datasets

While the CCT maintains several core 3D-enabling datasets, the implementation of a 3D City Model requires additional geospatial layers that do not currently exist as authoritative datasets. To address these gaps, the Geospatial Section initiated a research and development programme in 2020 to create new 2D and 3D datasets that extend metropolitan coverage, improve semantic richness, and support three-dimensional analytical and visualisation workflows.

The focus of this work has been to achieve full municipal extent of buildings, including informal and incremental development; spatially represent land use and development rights as defined in the Development Management Scheme; establish a legally recognised elevation surface for defining Existing Ground Level; and incorporate elements of the natural environment into the 3D context. These developments collectively strengthen the 3D data foundations required for a future 3D City Model and prospective Urban Digital Twin environment and mark a transition from data capture for visualisation toward data modelling for analysis and decision-support. The work is composed of multiple complementary strands, each addressing a foundational requirement for a 3D City Model and prospective UDT environment.

These datasets are presently at varying levels of maturity, ranging from fully operationalised products in use by internal departments to prototypes and research workflows undergoing evaluation and scale-testing. Their collective purpose is to provide a complete, semantically meaningful, and updatable base from which a 3DCIM can evolve and be supported.

2.3.1 Automated Building Extraction

A key challenge for achieving metropolitan coverage of 3D buildings is the resource-intensive nature of photogrammetric capture. As noted, the City's LOD 2.2 building model programme delivers highly accurate and detailed geometries but expands slowly due to specialised skills, manual editing requirements, and cost. In 2020, the need for a complementary approach that could provide citywide coverage at a lower level of detail was formally identified. The Geospatial Section therefore initiated a research and development programme to investigate automated feature extraction methods using datasets already captured and maintained by the CCT.

The approach makes use of two annual datasets: the 5 cm aerial photography (RGB) and the high-density LiDAR point cloud. A Mask R-CNN deep learning method was implemented using the Deep Learning module in ArcGIS Pro to detect rooftop building footprints using two inputs: an RGB orthophoto and a normalised Digital Surface Model (nDSM) derived from LiDAR. From a methodological perspective, the optimal workflow would involve training a single multi-input model incorporating both datasets, as the two data sources are complementary. However, at the time of implementation, ArcGIS Pro did not support multi-input deep learning models, necessitating the use of two separate models: one trained on the RGB orthophoto and the other on the nDSM. Using two parallel models leverages the strengths of both data sources, with the optical model supporting visual feature recognition and the height model improving separation between buildings and other surfaces. Training data was derived from the City's detailed LOD 2.2 building models.

The output consists of raw 2D rooftop footprint candidates with a precision score of 0.85, recall score of 0.70 and an F1-score of 0.77 on the validation subset. These geometries exhibit irregularities and are therefore post-processed using a custom ArcGIS Model Builder geoprocessing workflow designed to remove noise, resolve geometry artefacts, and regularise outlines. The result is a comprehensive 2D building footprint dataset[3] representing approximately 950 000 buildings across the metropolitan area. The dataset is expected to be updated periodically to align with newly acquired LiDAR and/or aerial imagery datasets.

The second step involves the use of LiDAR height data to generate average building heights for each footprint, enabling the creation of LOD 1 3D building models. These models provide full citywide coverage at a lower level of detail and are suitable for broad-scale analytical and visualisation workflows. The LOD 1 models do not replace the higher accuracy and higher detail LOD 2.2 3D building models, which continue to be produced annually for priority areas, but rather serve as a complementary layer that satisfies the requirement for full coverage. In this configuration, the two datasets form a hierarchical complement: the manual

[3] It is important to note that this dataset represents roof extents and should not be confused with the building industry definition of a floor footprint.

photogrammetric dataset for high-interest areas requiring precision, and the automated dataset for complete municipal extent. This automated extraction pathway provides a pragmatic mechanism for maintaining and expanding the City's 3D building datasets on an annual cycle, which is an important requirement for future Urban Digital Twin environments.

2.3.2 Informal Structures and ADIs

Cape Town's built environment includes extensive informal and incremental residential development in the form of informal settlements and Additional Dwelling Units (ADIs or backyard structures). These areas are characterised by high spatial density, rapid temporal change and limited cadastral or planning representation. Despite their significance for municipal service delivery, housing planning, valuations, resilience and socio-economic analysis, these structures have historically been excluded from geospatial datasets due to the resource-intensive nature of manual capture and the limitations of traditional photogrammetric workflows at metropolitan scale.

To address this gap, the Geospatial Section partnered with UNITAC Hamburg to implement the Building and Establishment Automated Mapper (BEAM) tool on City-owned geospatial data. The BEAM model (UNITAC, no date) was trained on the City's high-resolution aerial imagery to detect rooftop structures associated with both informal settlements and backyard ADIs. The model produces 2D rooftop footprints, which are then extruded using LiDAR-derived height information to generate LOD 1 volumetric representations suitable for 3D environments and analytical workflows. The workflow has been successfully operationalised at metropolitan scale and is already being used by City departments for municipal workflows related to infrastructure and service planning, resilience, socio-economic analysis and future UDT applications.

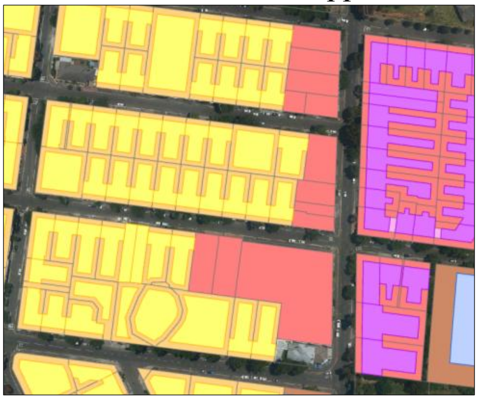
The inclusion of informal settlements and ADIs within the 3D data environment supports a more complete and equitable representation of the built form, improves the analytical capacity of municipal departments and ensures that future 3D City Model and UDT initiatives do not exclude or under-represent areas that are both spatially extensive and relevant to good governance.

2.3.3 The Zoning Development Footprints and Development Envelopes

A 3D City Model requires not only a representation of the physical built environment, but also the representation of the regulatory environment that shapes and constrains it. In Cape Town, development rights are defined through the City's Development Management Scheme (DMS) (City of Cape Town, 2015), which sets out how each property may be used and developed. These rules include setbacks, height restrictions, coverage limits, and other spatial provisions. Although the rules are inherently spatial, they exist primarily in textual and tabular form and are not represented in either a 2D or 3D geospatial format. This absence makes the application of the DMS interpretive and manual, and can present challenges for communication, transparency, and consistency in decision-making.

To address this limitation, the Geospatial Section initiated a programme to translate the DMS rules into spatial datasets. The DMS is a complex piece of planning legislation and contains provisions that are difficult to automate fully. Certain rules require subjective interpretation or discretion by planners, case officers, or the Municipal Planning Tribunal. These elements cannot be applied deterministically within a computational workflow and therefore are captured as attributes within the model output to ensure that they are explicitly noted by the applicant, user, or decision-maker rather than omitted or silently assumed. This approach enables the model to automate what can be automated while preserving the legal and interpretive integrity of the DMS.

The first phase focused on the 2D components of the DMS (see **Fejl! Henvisningskilde ikke fundet.**), specifically the setback rules that determine where within a land parcel building may occur. A custom rule-based geoprocessing model was developed to automatically generate 2D Development Footprints for each cadastral parcel. These footprints represent the portion of a property that is permissible for development in plan-view once the setback rules for the applicable base zone have been applied.



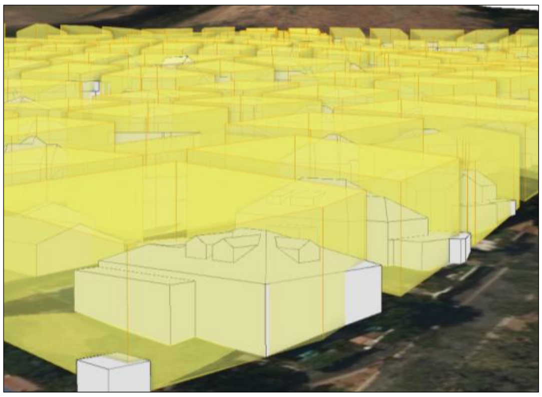


Figure 4 (left): Automated 2D Development Footprints; Figure 5 (right): Automated 3D Development Envelopes

The 2D Development Footprint dataset is presently available for internal testing and review and is being evaluated by Development Management for potential future integration into planning workflows. Although not yet in operational use, the spatialisation of setback rules has already demonstrated the potential to reduce reliance on manual interpretation, improve the consistency of planning outcomes and support clearer communication with applicants and practitioners. The Development Footprint dataset serves as the required base for the second phase of the work, which extends the rules vertically to create three-dimensional Development Envelopes that incorporate height controls.

The second phase extrudes the setback-derived Development Footprint by the maximum height permitted for the applicable base zone. In the DMS, maximum building height is defined as a vertical measurement from Existing Ground Level (EGL), with EGL determined from the City's Ground Level Map (see *2.3.4*). This amendment establishes a consistent height datum suitable for computational modelling. The resulting three-dimensional Development Envelope represents the spatial volume within which development may lawfully occur on a land parcel and provides a spatially explicit representation of development rights that can be queried, analysed and visualised in 3D environments (see **Fejl! Henvisningskilde ikke fundet.**).

The 3D Development Envelope dataset is currently in a testing and evaluation phase for full metropolitan implementation. However, it has been used extensively at small scales over the past several years to support development applications, Municipal Planning Tribunal hearings, legal and court proceedings, urban design studies, and the analysis of the impact of zoning rules on urban form. In these contexts, the envelopes have demonstrated clear value by improving clarity and communication between parties, reducing interpretive uncertainty, and enabling realistic visualisation of development potential within its spatial context. Scaling the workflow to citywide extent is currently constrained by hardware resources, and work is underway to assess performance, governance processes, and integration pathways for potential future adoption.

2.3.4 Ground Level Map 2019

Vertical measurements within the DMS require a legally unambiguous reference surface from which building height may be assessed. Historically, "Existing Ground Level" (EGL) was determined through the reconstruction of Natural Ground Level, often requiring site-specific survey evidence, historical interpretation, and professional judgement. While suitable in a conventional land use context, this approach presents challenges for digital 3D modelling, where a single consistent elevation surface is required for metropolitan-scale analysis. Furthermore, this approach slowed down development management processes and was expensive to the applicant.

Following a set of amendments to the Municipal Planning By-Law, the Ground Level Map (GLM) was introduced as the new legal basis for defining EGL. The GLM is defined in the DMS as: "*City of Cape Town Ground Level Map means a map approved in terms of the development management scheme, indicating the existing ground level based on floating point rasters and a contour dataset from LiDAR information available to the City*" (City of Cape Town, 2025). The GLM was finalised and approved in early 2024, establishing a digital elevation model as the legally recognised reference surface for vertical measurement in land use applications.

The GLM is derived from the City's 2019 LiDAR survey and consists of both a 5 m floating-point DEM and 2 m contour dataset (see Figure 6). The GLM enables EGL to be treated as an authoritative digital surface, providing consistency across cases and creating a crucial foundation for 3D zoning, massing, and height compliance analysis. While the GLM is still in the initial stages of operational adoption within planning workflows, its legal status provides a reproducible and citywide reference surface that is aligned with the needs of 3D City Model development.

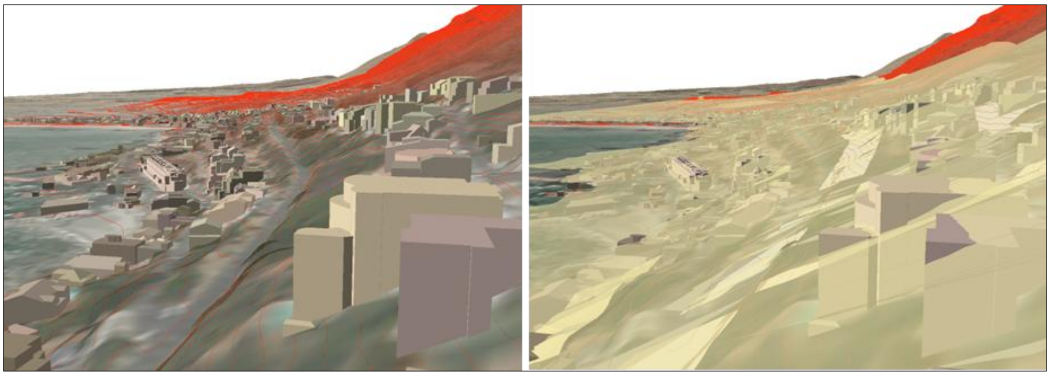


Figure 6: Ground Level Map 2019 5m DEM and 2m contours visualised in 3D (left) and then offset to show a parallel surface of the Single Residential height limit of 10m above EGL (GLM 2019) (right).

The GLM introduces a significant shift in the planning environment: it creates a unified elevation baseline that supports spatialisation, automation and transparency in development rights analysis. It also enables the application of height rules within 3D zoning envelopes to be processed algorithmically rather than through manual site-specific surveys, which is essential for full 3D City Model and prospective Urban Digital Twin implementations.

2.3.5 Tree Classification

Trees are a significant component of Cape Town's urban fabric and are relevant for environmental modelling, climate resilience, micro-climate analysis, and public realm planning. To incorporate vegetation into the 3D environment, the Geospatial Section is classifying trees from the high-density LiDAR point cloud. The classified points allow the extraction of two complementary datasets: 3D representations suitable for visualisation and modelling, and 2D canopy polygons for coverage analysis and policy work. The dataset is currently in the research and evaluation phase, with the intention to operationalise it for future 3D City Model and UDT applications.

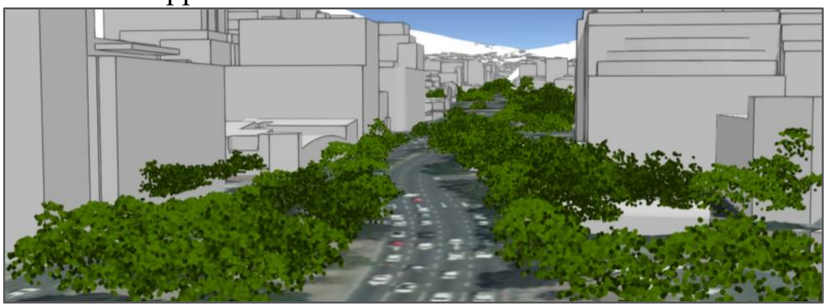


Figure 7: Inclusion of tree-classified LiDAR data for improved realism in 3D Scenes.

3 DISSEMINATING 3D DATA

While the Geospatial Section has focused on developing the foundational datasets required for a 3D City Model, an equally important challenge is ensuring that 3D data can be shared, consumed, and operationally integrated across departments. The CCT is an enterprise user of the ESRI platform, and current efforts therefore concentrate on leveraging the 3D capabilities available within this environment to evaluate how 3D data can be accessed and visualised at scale.

In 2022, a cross-departmental Web Scene Development Group was established to conduct research and development on serving 3D data via ESRI Web Scenes. The group began with five participants and expanded to more than eighty within eighteen months, indicating strong organisational interest and demand for 3D visualisation tools. The work involved testing data sources, data formats, rendering performance and user workflows across a range of planning and analytical tasks. Numerous Web Scenes have been built to assess the functionality and usefulness to various departments and addressing diverse needs.

A formal Web Scene Pilot was subsequently undertaken in collaboration with Business Applications, Corporate GIS, Land Use Management and Business Systems to examine data responsibilities, integration points and operational feasibility (see **Fejl! Henvisningskilde ikke fundet.**). The pilot confirmed that 3D visualisation provides meaningful value for planning-related workflows, particularly for development management, communication, and scenario testing. However, several constraints were identified, including system performance limitations, software restrictions, challenges in translating 2D datasets into 3D, and uneven GIS capacity across departments.

Work is ongoing to improve 3D data accessibility and user experience within the enterprise environment. A lightweight 3D viewer is currently under development to support consumption-based use cases without requiring 3D authoring skills, and further work is underway to establish data governance, update mechanisms, and performance optimisation strategies. These efforts demonstrate that the ability to serve and consume 3D data is as critical as the existence of the data itself, and that organisational appetite for 3D is already present. The next section documents the early use cases and benefits achieved across CCT departments, illustrating how 3D data is beginning to influence planning, analysis, and decision-making.

4 USE CASES AND EARLY BENEFITS

The availability of 3D datasets and visualisation platforms within the CCT has already enabled a range of practical applications across municipal functions. These early use cases demonstrate operational value, support improved communication and decision-making, and illustrate the relevance of a prospective 3DCIM environment.

4.1 Planning, Land Use and Design

Development Management, Urban Regeneration, Heritage and Urban Design teams have used 3D data to assess development proposals, understand bulk and massing, evaluate zoning compliance, and improve communication with applicants and affected parties. In the Bo-Kaap case (Business Tech, 2016) (see Figure 8), 3D visualisations were submitted during court proceedings to support assessment of visual impact and heritage considerations. In Dunoon, 3D models were used to communicate design intent for new public facilities and to assess growth associated with multi-storey small-scale residential units. A pilot Web Scene was also developed to represent heritage overlay zones, protected structures and proposed developments, providing improved contextual understanding during Development Management processes (see Figure 9). Across these applications, 3D representation enhanced clarity, reduced interpretive uncertainty associated with Development Management Scheme provisions and supported more transparent decision-making.

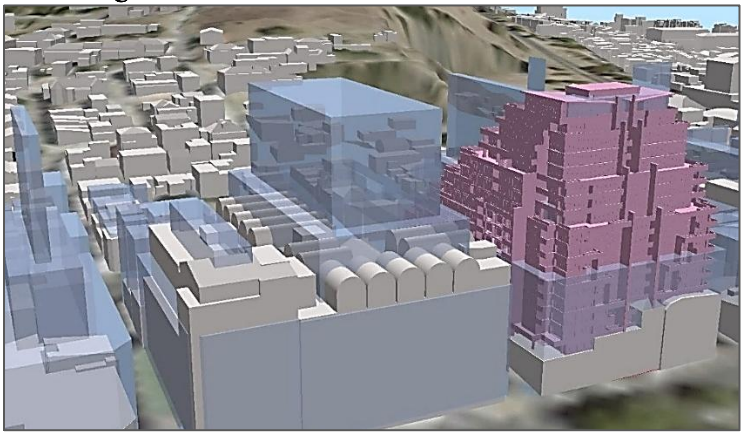


Figure 8: Bo-Kaap 3D Scene used to inform decisions of the Municipal Planning Tribunal and the Court.

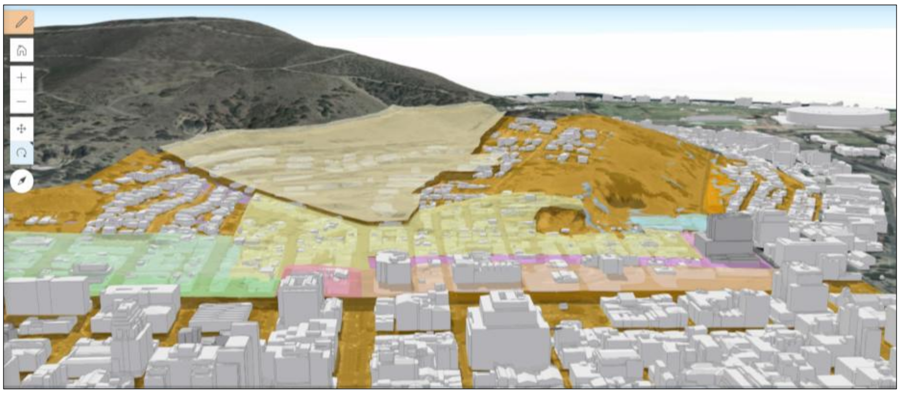


Figure 9: Heritage Web Scene visualising protected structures and overlay zones for contextual assessment.

4.2 Resilience and Environmental Management

Coastal Management used LiDAR-derived elevation models to model sea level rise scenarios and analyse climate-related risks along the coastline (see Figure 80). 3D data was applied to identify vulnerable areas, inform adaptation strategies, and support harbour and coastal development assessments. Additional environmental applications include solar feasibility studies on CCT-owned buildings and analysis of shadowing and future development rights using 3D zoning envelopes.

Figure 80: Sea Level Rise Study for Coastal Management

4.3 Infrastructure and Municipal Services

3D workflows supported operational tasks related to infrastructure, asset planning, and municipal service delivery. Facilities Management used 3D data to assess the feasibility of rooftop solar installations and to account for future overshadowing from adjacent development (Figure 11). During the drought period, 3D visualisation supported the communication of water consumption patterns at building level, improving situational awareness for planning units.

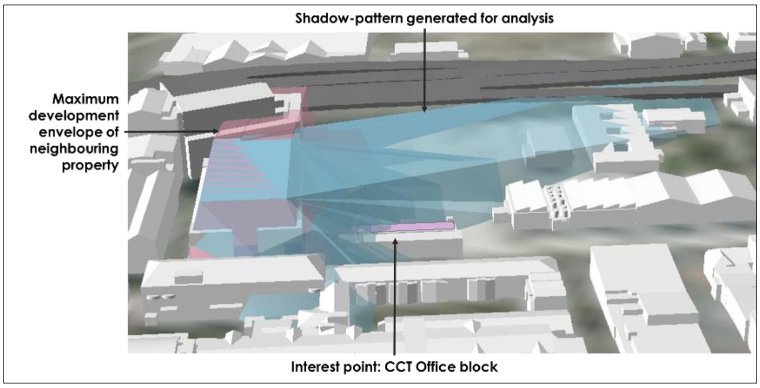


Figure 91: Shadow analysis to inform the positioning of solar panels on CCT building for Facilities Management

4.4 Operational Response and Field Preparedness

Safety & Security benefited from detailed 3D models derived from drone and geospatial data for specific sites of interest. These models were used for operational planning, providing detailed contextual understanding of layouts, access routes, and potential constraints. Future extensions include the use of 3D building and floor plan information to support pre-planning for operations and firefighting, improving risk mitigation and situational awareness.

4.5 Early Benefits and Implications for a 3DCIM

Across these thematic areas, early benefits include improved communication, reduced ambiguity in planning and regulatory processes, enhanced situational awareness for field operations, and more consistent interpretation of development rights. Notably, these outcomes have emerged despite partial 3D coverage, pilot delivery platforms and limited interoperability. This suggests that incremental deployment of 3D data can deliver tangible value in parallel to longer-term foundation building and indicates strong institutional demand for a fully integrated 3D environment.

5 CHALLENGES AND LIMITATIONS

The development of a 3DCIM within the CCT has been influenced by a combination of organisational, technical, and institutional constraints. The CCT faces a shortage of specialised geospatial and 3D modelling skills, requiring highly capable staff to manage multiple complex workflows simultaneously. This limits knowledge transfer, slows dataset maintenance, and reduces capacity for research and development, constraining the pace at which strategic datasets can expand. Technical constraints further affect scalability, including insufficient high-performance hardware for GPU-based processing and limitations in software support for 3D delivery platforms, such as the stalled rollout of Web Scenes in late 2023 despite continued 3D data creation. In parallel, departmental silos and limited data visibility contribute to duplicated efforts, missed reuse opportunities and higher integration costs, despite Corporate GIS standards for enterprise spatial data. Finally, organisational alignment and funding remain gradual; without a formal strategy or mandate for 3DCIM or UDT development, the work progresses but remains vulnerable to shifting priorities and cannot yet secure sustained investment or cross-departmental coordination at the scale required for metropolitan implementation.

6 DESIRED OUTCOMES AND FUTURE DIRECTIONS

The implementation of a 3D City Model within the CCT is expected to produce several strategic outcomes. In the near term, expanded 3D coverage, improved delivery mechanisms and institutional enablement would increase the availability, usability, and analytical value of 3D data across departments. In the longer term, full metropolitan coverage of buildings, development rights and elevation surfaces would enable advanced scenario modelling, more efficient service planning, and improved transparency in land governance.

To support this trajectory, several enabling actions are recommended. First, the development of a City-wide 3D strategy would provide organisational clarity, establish priorities, and align 3D data production with broader planning and digital objectives. Second, expanding specialised geospatial capacity, including skills in geomatics, 3D modelling, cloud delivery and analytical GIS, would increase the CCT's ability to scale production, operationalize new datasets and maintain them sustainably. Third, investment in high-performance computing, storage and software capabilities would address current bottlenecks associated with 3D data processing and digital delivery. Finally, improved mechanisms for data visibility, discoverability and sharing would reduce duplication, support cross-departmental collaboration, and create the basis for an integrated 3DCIM environment.

Collectively, these outcomes and enabling actions position the CCT to progress from early 3D visualisation toward analytical, decision-support and simulation capabilities consistent with future Urban Digital Twin environments.

7 CONCLUSION

The CCT has made considerable progress toward establishing the geospatial foundations required for a 3DCIM. Through the systematic capture, maintenance and development of high-accuracy elevation models, annual 3D building models, automated building extraction, zoning envelopes, and other 3D-enabling datasets, the CCT has begun to build the spatial infrastructure necessary for improved planning, analysis, and decision-support. Early departmental use cases have already demonstrated operational value, improving communication, strengthening evidence-based decision-making, and revealing the potential for 3D environments to reduce ambiguity in urban management processes.

Although these developments have occurred in the absence of an organisation-wide 3D strategy, and despite constraints related to skills, capacity, software and institutional alignment, the work illustrates that incremental, data-driven approaches can yield tangible benefits while laying groundwork for more advanced capabilities. As coverage expands and delivery mechanisms mature, 3D data use is expected to shift from visualisation toward analytical and scenario-based workflows, further strengthening the case for a metropolitan 3DCIM.

The CCT is therefore well-positioned to progress toward a fully integrated 3D environment, with the potential to support future Urban Digital Twin applications. Continued investment in 3D data production, platform enablement and institutional coordination will determine the pace at which this transition can occur and the extent to which the CCT can capitalise on the strategic value of three-dimensional geospatial information.

8 REFERENCES

Attaran, M. & Gokhan Celik, B. (2023). Digital Twin: Benefits, use cases, challenges and opportunities. *Decision Analytics Journal*. 6 (2023): 1-10.

Biljecki, F., Ledoux, H., Stoter, J. (2016): An improved LOD specification for 3D building models. *Computers, Environment, and Urban Systems*, vol. 59, pp. 25-37.

Business Tech (2016) *A look at the controversial new high-rise going up in Cape Town*. Business Tech. Available at: https://businesstech.co.za/news/finance/137117/a-look-at-the-controversial-new-high-rise-going-up-in-cape-town/ [Accessed: 25/01/2026].

ity of Cape Town (2022) *Integrated Development Plan (IDP) 2022–2027*. Available at: https://www.capetown.gov.za/Family%20and%20home/Meet-the-City/our-vision-for-the-city/the-citys-idp-2022-2027 [Accessed: 22/01/2026].

City of Cape Town. (2025) *Municipal Planning Amendment By-law 2025*. Available at: https://resource.capetown.gov.za/documentcentre/Documents/Bylaws%20and%20policies/Municipal_Planning_Amendment_Bylaw_2025.pdf [Accessed: 22/01/2025].

Cureton, P. and Hartley, E. (2023) 'City Information Models (CIMs) as precursors for Urban Digital Twins (UDTs): A case study of Lancaster', *Frontiers in Built Environment*, 9. doi:10.3389/fbuil.2023.1048510.

Esri. (2025) Model Builder: Quick Tour. [Online]. Available at: https://pro.arcgis.com/en/pro-app/latest/help/analysis/geoprocessing/modelbuilder/modelbuilder-quick-tour.htm [Accessed 05/09/2025].

Humby, L. 2021. *3D Property Objects in South African Local Government*. Master of Philosophy. University of Cape Town. [Online]. Available at: https://open.uct.ac.za [Accessed: 27/08/2025].

Mazzetto, S. (2024) A Review of Urban Digital Twins Integration, Challenges, and Future Directions in Smart City Development. *Sustainability*, 16, Article No. 8337. https://doi.org/10.3390/su16198337

Open Geospatial Consortium (OGC) (2024a) *CityGML 3.0 Conceptual Model*. OGC Standard. Available at: https://docs.ogc.org/is/20-010/20-010.html [Accessed: 22/01/2026].

Open Geospatial Consortium (OGC) (2024b) *Urban Digital Twins: Integrating Infrastructure, Natural Environment and People*. OGC Discussion Paper 24-025. Available at: https://docs.ogc.org/dp/24-025.html [Accessed: 20/01/2026].

United Nations (no date) *The Sustainable Development Goals*. Available at: https://sdgs.un.org/goals [Accessed: 20/01/2026].

United Nations Innovation Technology Accelerator for Cities (UNITAC) (no date) *BEAM (Building & Establishment Automated Mapper)*. Available at: https://unitac.un.org/en/beam [Accessed: 22/01/ 2026].

9 BIOGRAPHICAL NOTES

Lara Röttcher is a registered Professional Land Surveyor with a Master's in Geomatics from the University of Cape Town. Her postgraduate research investigated 3D cadastre and the representation of property objects in 3D City Models, contributing insights into how cadastral systems can better support land administration. She is currently Head of GIS & Surveys in the Property Transactions Department at the City of Cape Town, where she manages cadastral and geospatial functions that underpin municipal property governance. Previously, as Principal GIS Analyst, she led the City's Geospatial Section and initiated key 3D projects, including zoning models, automated building feature extraction, and foundational 3D datasets. Her work focuses on embedding 3D geospatial data into urban governance and decision-making.

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