5.2 A city-wide 3D model for Boston, MA, USA

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5.2.1 Introduction

This case study represents the lessons learned from two decades of refinement of a city-wide 3D model project initiated in 2002 as a collaboration between the Boston Planning and Development Agency (BPDA) and Paul B Cote Geographic Information Services (pbcGIS). The BPDA 3D city model provides designers and project review authorities with a common operating picture that includes unbuilt projects that are in the permitting pipeline. The city model also preserves information that reflects the shape of the city's neighbourhoods as they change over time. The latest refinement of the city model design has published a free toolkit and a framework for city model publishing that engages collaborators from the development community and neighbouring campuses and communities and supports archival and virtual/augmented reality applications. By sharing free tools, templates, documentation on the website citySchema.org (2022), pbcGIS and the BPDA hope to jump-start a culture of city model sharing and preservation across the Boston metropolitan area.

The BPDA is the planning and economic development agency for the City of Boston, Massachusetts, USA. By guiding physical, social and economic change in Boston's neighbourhoods, the BPDA seeks to shape a more prosperous, resilient and vibrant city for all. In May 2018, the BPDA launched a web-based 3D base model, a city digital twin (CDT) of the City of Boston, available for public use on the agency's website. The digital twin supports the BPDA's goal to implement new solutions to solve complex challenges facing Boston, while providing greater transparency and increased community engagement.

Figure 5.2.1 Boston Digital Twin – created using Esri scene viewer and published on ArcGIS Online

Boston was considered one of the first in the nation to launch a current realistic ArcGIS 3D smart model that integrates conventional GIS 2D data. The model builds on the city's commitment to ensuring city

data is open and accessible to the public and has begun to integrate data from the City's Assessing Department, the BPDA's Article 80 process and results from Climate Ready Boston.

Boston's digital twin and GIS planning tools were awarded the Special Achievement in GIS Award at the 2018 Esri User Conference, and the model was presented by Carolyn Bennett, Deputy Director of GIS, Boston Planning and Development Agency (BPDA's), at the American Planning Association (APA) National Planning Conference in New Orleans, LA, USA in 2018. Later that year, Bennett showcased the digital twin in the ArcGIS Urban AGOL web application at the Esri User Conference in San Diego, CA, USA in 2018.

5.2.2 Applications

In addition to being available for public use, the digital twin provides BPDA staff with tools that will create real world visualisations for planning Boston's urban context. The model is used to support planning initiatives and strategic planning areas, review development proposals, as well as conduct in-house urban design studies, shadow analysis and zoning development capacity modelling. It will also serve as a tool to better understand the impacts of climate change and sea level rise on Boston's built environment.

Boston has been undergoing a lot of new construction over the past decade. An historic city such as Boston needs to quickly understand the impacts of new development for both approved projects and proposed projects. The digital twin can help tell the story of Boston's development and how the city has changed overtime for planners, residents and policymakers.

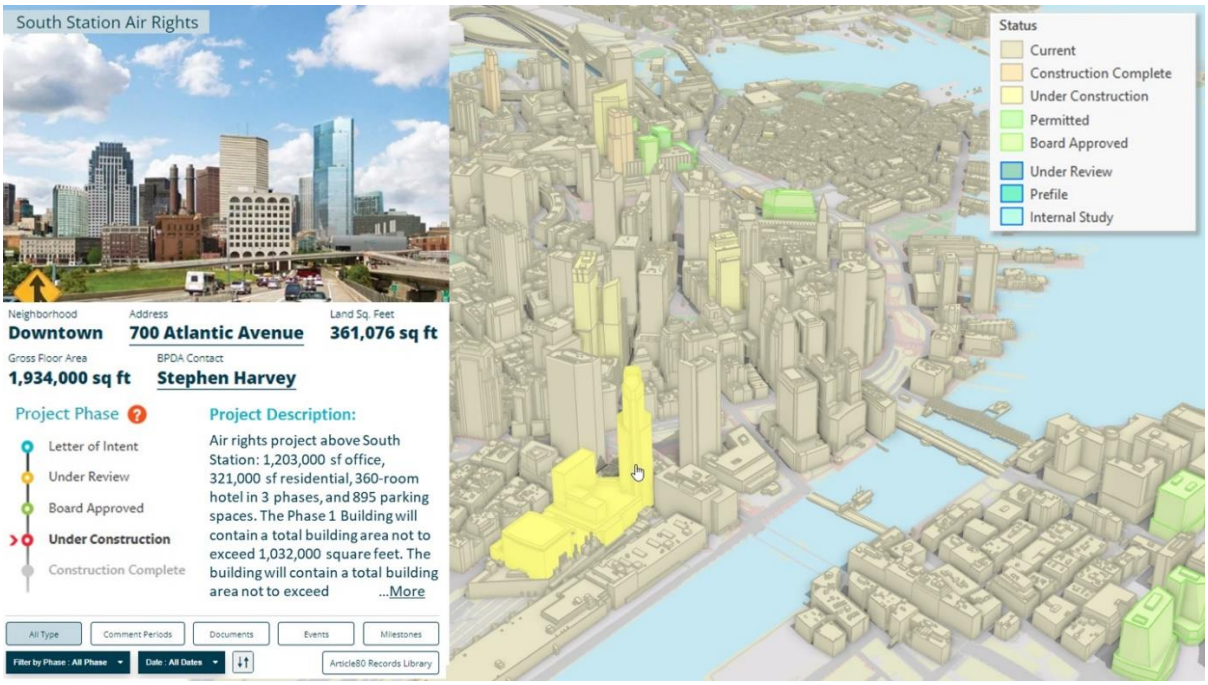

Figure 5.2.2 Models of proposed development projects link to official review documents

Within the BPDA, the model serves as a setting for visualising and evaluating physical design interventions proposed by developers or generated within the agency. The BPDA's project reviewers use the model through web-based scenes that facilitate investigation of view corridor impacts and analysis of shadows. Integration of the layers from the city's geographic information system allows reviewers to

understand the juxtaposition of project models with cadastral and regulatory information, such as land ownership and zoning as well as environmental impact information including projected sea level rise. Clicking on a project model in the web scene reveals the home page of the project that exposes the current review documents and status, see Figure 5.2.2.

Planning and review activities within the BPDA access the city model through web-based applications ArcGIS Online (Esri a) and ArcGIS Urban (Esri b). ArcGIS Urban incorporates Boston's zoning code and delivers metrics and indicators to evaluate projects and plans. ArcGIS Urban is used in community planning to communicate the outcomes of new zoning and allows users to visualise what the existing or proposed zoning envelope might look like and how changes in zoning affects density, lot coverage, floor area ratio and building height.

Using the digital twin to evaluate proposed zoning amendments and agency-sponsored planning initiatives also allows for collaboration between internal stakeholders, including inspectional services, public safety services and other planning organisations. Using the ArcGIS Urban application, analysts can apply new zoning rules to an entire neighbourhood and see the impacts before making any final zoning amendment decisions. Impacts of proposed zoning changes may be evaluated according to estimated impacts on population, households and jobs, as well as parking, energy use and carbon emissions. Metrics may be extracted to understand how regulatory changes may impact goals set by mayoral priorities on housing and climate resiliency.

Context for 3D Design

The digital twin allows planners, designers and reviewers to share a common operating picture of the existing built environment. Members of the design community and the general public are able to download tiled components of the city model in formats that are compatible with 3D design software. These editable models include unbuilt projects as they advance through the project review process. Making these models available as open data enables designers and other stakeholders to more effectively identify issues and opportunities.

Public information/participation

Members of the public access the city-wide 3D model through web scenes published using ArcGIS Online, a web-based publishing platform (Esri a). These 3D scenes provide an intuitive interface for 3D navigation, and layer control that permits the public to visualise models of approved projects. Clicking on a 3D model of a large project accesses the official project tracking page with the complete record of the project review proceedings. Other regulatory and environmental impact layers from geographic information systems (GIS), such as sea level rise scenarios, are also visualised in the context of these 3D web scenes.

Web-based sharing of the city model has the potential to make the public design review process more transparent, fostering collaboration and public feedback. This is important because these developments have had direct and profound impacts on the residents and neighbourhoods of Boston for decades. Digital twins can also be proponents of economic equity and inclusion in development by highlighting inequalities and development gaps and, at the same time, show the uniqueness and character of a neighbourhood.

Federated coordination of parallel overlapping city models

Architecture firms and adjacent municipalities maintain independent city models, many of which overlap in their context areas. Each of these models contain common information and private models

that represent plans in progress. Municipal and campus models are generally the most up-to-date and authoritative representations within each administrative territory.

Design firms assemble components of their own city models as a context for urban design questions that span across administrative boundaries. Integrating these independent models is a painstaking task that is compounded over time when it becomes necessary to discover, obtain and incorporate updates as they are made available in municipal models.

The citySchema.org repository catalogue (citySchema.org, 2022), described in more detail below, facilitates the assembly of independent models and discovery, download and registration that may be automated in a published subscribe pattern.

Historical/archival applications

Very long-term preservation and access to valuable cultural information is not the primary mission of municipal planning agencies. In time, the preservation of city model assets should come under the management of professional archivists and librarians.

The citySchema.org model collection schema is a vehicle for research that provides the necessary attribute fields for recording the provenance of models and references to the external sources that relate to the historical appearance and disappearance of structures. Temporal status attributes linked to models permit historical and alternative future scenes to be composed. Care has been taken in the design of the model collection schema that preserving historical observations of buildings is a routine and inexpensive outcome of managing the model collection.

Emerging historical and cultural preservation applications

There will be many applications in the future that incorporate city models. Each of these will benefit from a federated mechanism for accessing updates and historical information from a variety of web-based sources. For example, mobile augmented reality applications will eventually allow for the visualisation of historical structures and related documents and historical accounts spatially juxtaposed in a 3D georeferencing framework. Applications such as HistoryPIN.org (2022) demonstrate the information synergies that are created when historical documents are relayed in a geographic context.

The citySchema.org repository catalogue provides a framework for publishing city model assets that may be harvested and re-used by applications such as HistoryPin and others which could display 3D models just as they now display two-dimensional assets such as photographs. In time, 3D city models may also be used as a base model to enrich contextual understanding of documents and historical accounts.

5.2.3 Multi-agency collaboration

The applications described above involve diverse stakeholders with interests that span municipal boundaries and specialised technical domains. Currently the 3D city model fabric is fragmented, with independent municipalities and campus authorities being the most active and authoritative sources within their boundaries. For architects and urbanists, the difficulty of piecing together a continuous 3D model across these boundaries is necessary, and difficult.

Developing a city-wide 3D model poses new challenges for GIS technicians. Typical GIS datasets can be thought of as layers that cover the entire administrative territory. The 3D city model incorporates a collection of distinct building models, with their own unique provenance. The number of sources and the frequency of updates to the 3D city model collection calls for closer attention to issues of digital

asset management and documentation that are time-consuming to develop. Three dimensional models typically originate from specialised authoring tools with a variety of interoperability problems – including formats and coordinate systems.

Working together with the BPDA and the neighbouring City of Cambridge, Paul B Cote Geographic Information Services (2022) has developed a collection of generalisable tools that are shared for free at citySchema.org. The citySchema.org project has been created and shared as a means of reducing the costs of developing and linking together independent city model projects. It is hoped that the shared tools and documentation will accelerate the development of shared resources and expertise.

Free tools for city model development and stewardship

The experience of working with two neighbouring municipalities on city model development has led to the distillation of several patterns for developing and managing a 3D city model. These tasks fall to the staff of municipal GIS departments. The citySchema template establishes tried and true patterns for organising source material that, if followed, will protect critical model source data from the predictable hazards of hardware failure and the changing of project personnel.

It is expedient to implement data development procedures as repeatable scripts that call upon source data from a stable well-documented source management schema. Investing in well-documented, repeatable data development tools is worth the effort as the procedures are repeated and refined when updated source material becomes available. Because the anatomy of municipal GIS layers is similar from one city or campus to the next, the data organisation and development tools developed for the BPDA and the City of Cambridge may easily be adapted for use by others.

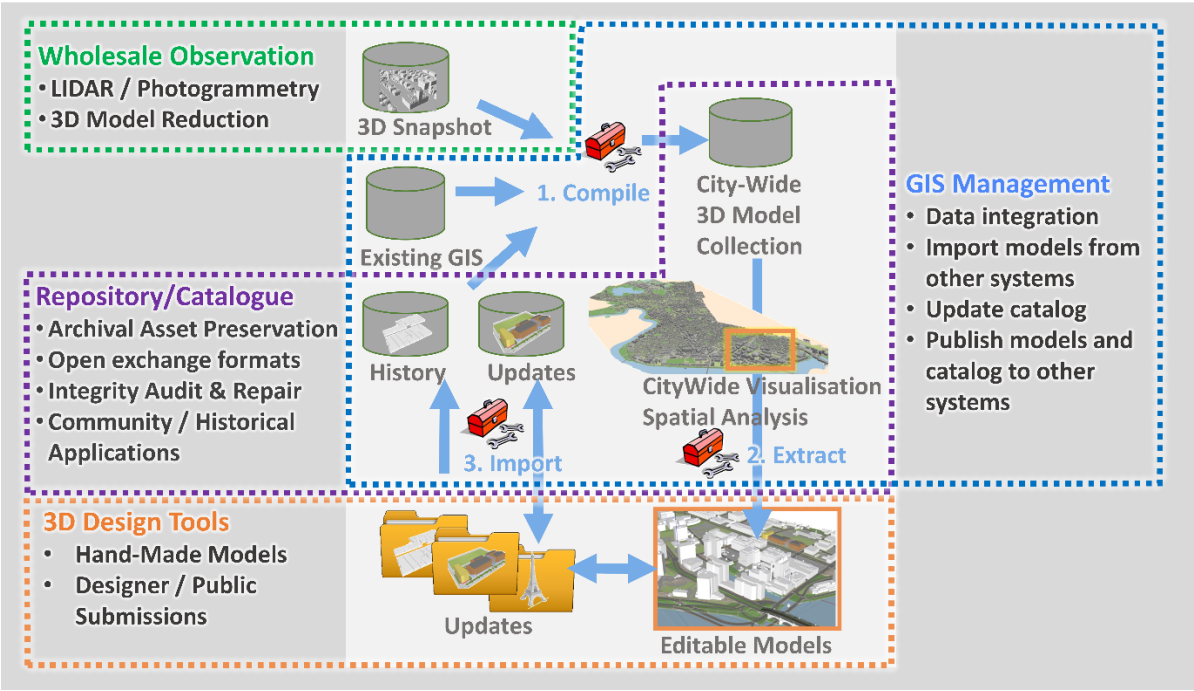

Figure 5.2.3 Architecture for city model development and sharing (citySchema.org, 2022)

The tools and templates shared at citySchema.org relieve an expensive barrier to entry for other agencies that wish to reduce the costs of their internal city modelling endeavours and to collaborate in a regional city modelling effort. When city models prepared by independent agencies share common development patterns, more potential for coordination and sharing is a by-product (see Figure 5.2.3).

Curating a collection of current and historical building models

The most active aspect of the city model development enterprise is the on-going management of a collection of 3D models of existing, proposed and historical buildings. During this process, individual building models are received and imported into a management schema that systematically preserves source files and creates the necessary descriptive metadata for each model.

Within the BPDA, the development of the city model involves frequent accession of new building models representing development proposals. During the review process, models of initial proposals may be superseded by revised models. If a project is approved, the status of the proposed model is promoted to 'Under Construction'. Such a model will stand in for the existing condition until the built condition is recorded by new photogrammetry. As models are promoted through the approval and construction process, models of existing structures often require modification. Models representing demolished or renovated structures are assigned appropriate status attributes and temporal attributes that preserve the historical record.

These procedures involve many moving parts and potential for errors, deletions and corruption that may go undetected until much later. Data curation procedures of this type call for a workflow that is auditable and reversible beyond the limits of an edit session. The citySchema workflows for model collection management ensure that original source models are filed in the source schema and that any operation can be traced and rolled back at any time. These procedures are facilitated with a guided workflow implemented with the ArcGIS Pro framework of geoprocessing and guided tasks. There is nothing about the model curation patterns that could not be re-created in any standard relational database management system.

5.2.4 Federated viewpoint on city model stewardship

There is no widely accepted reference model for federated collaboration in 3D city modelling, yet the problem has many aspects in common with well understood models for information-sharing across technically and spatially diverse agencies. The Reference Model for an Open Archival Information System (RM-OAIS) (Consultative Committee on Space Data Systems, 2012) has gained wide recognition among information management professionals in many fields as providing a means for many diverse contributors to collaborate on the development of coherent and sustainable systems for asset management and development.

A key pattern defined in the RM-OAIS is concerned with establishing content and technical standards for packaging digital assets for exchange among distinct technical communities. This is accomplished by the collaborative definition of archival information packages (AIP). AIP provides a means of integrating content, such as 3D models, with descriptive information concerning the identity and provenance of the models and information necessary for combining assets together in a coherent way.

Contributors and users of 3D city models occupy several distinct technical niches of a software ecosystem. Three-dimensional design tools used in the architecture, engineering and construction (AEC) industry employ hierarchical data structures for authoring and organisation of detailed 3D building

models. Software programmes for creating 3D models organise models with deeply hierarchical data structures that are limited in spatial extent. Software companies in the AEC space innovate and compete by offering proprietary data formats with productivity enhancing features.

GIS-based management tools for city models treat building models as indivisible data objects represented by rows in relational tables. The AEC community commonly uses broad-scale city model information from GIS, including terrain and ground plan. Because of the difficulty in using the GIS-based coordinates, AEC users clip out a collection of base-data and shift it to a local origin.

CitySchema.org has worked with the local stakeholders in the AEC, GIS and archival preservation communities to develop conventions for packaging and sharing city model assets that offer round-trip interoperability among the tools used in each of these technical niches. The submission guidelines are published at citySchema.org along with recommended workflows that maintain precise geographical referencing through the two-way exchange.

The citySchema repository catalogue

CitySchema.org tools and templates digest and publish the complete city model as a static website that embodies the RM-OAIS concept of a self-contained archival information package. The repository catalogue bundles together tiled terrain and ground plan models and collections of building models also segmented by tiles. The repository catalogue includes all the metadata necessary to describe the provenance of each component, including spatial and temporal envelope information necessary to compose the collection into a coherent city model reflecting a specific moment in time, see Figure 5.2.4.

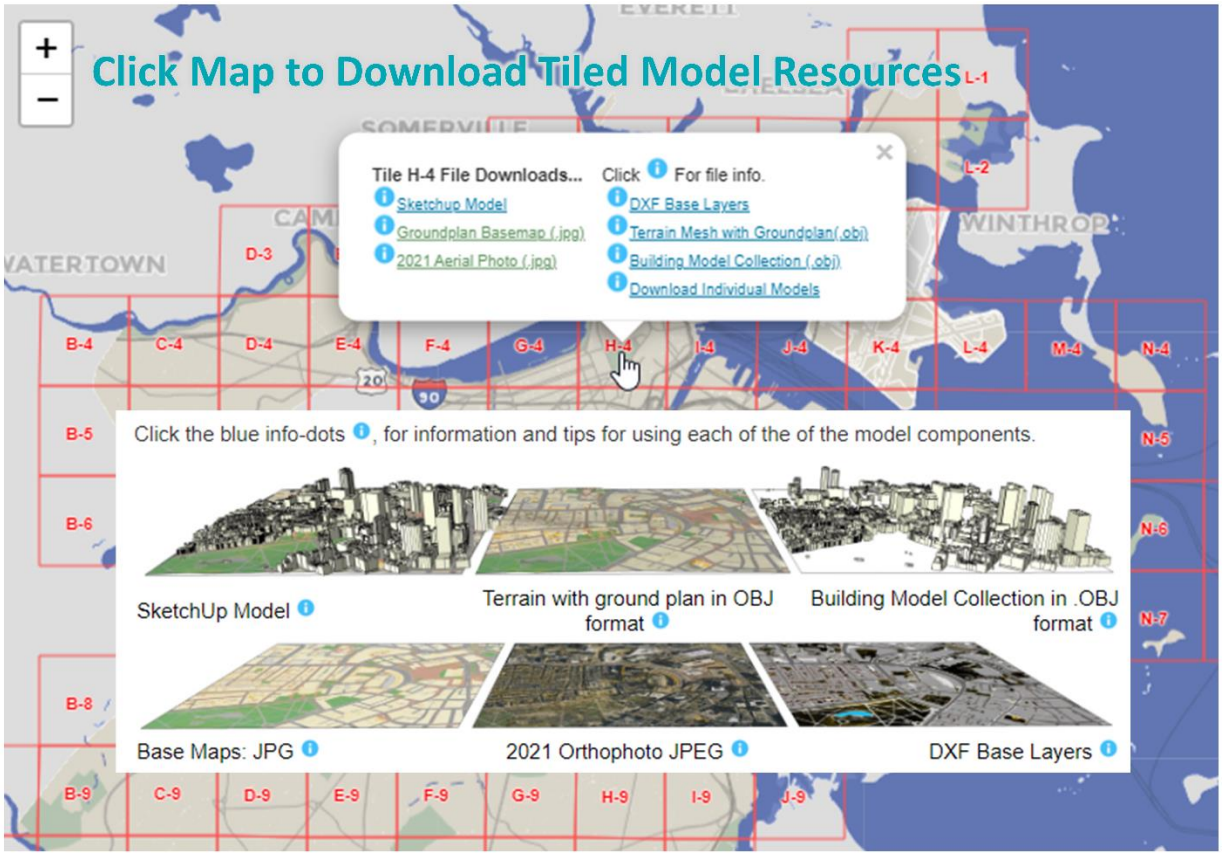

Figure 5.2.4 CitySchema repository catalogue (citySchema.org, 2022)

The repository catalogue includes a catalogue table, published as comma-delimited text and GeoJSON format that provides relative file system locations or URLs for each terrain model or building model asset. Figure 5.2.4 depicts how the catalogue file may be rendered as a human-readable map index that exposes each asset down to individual building models.

When placed in a web-accessible location, the URLs included in the catalogue provide web-endpoints for each model component which is offered in the Wavefront object exchange standard for 3D models (Wavefront, 1990). As a stand-alone file system that employs relative path referencing, the repository catalogue serves as a local repository for applications that need systematic access to models and their metadata for constructing optimised models for use in specialised design or augmented reality applications.

Automated harvest and subscription patterns

The citySchema repository catalogue framework provides a means for model aggregators to programmatically discover and harvest updates published by authoritative sources by comparing their last-retrieved catalogue information with updates posted by source repositories. The model identification framework employed by the repository catalogue allows any number of contributors to participate by publishing their own models and incorporate models published by other collaborators, while maintaining links back to source.

Currently, the repository catalogue has been implemented by the BPDA and by the City of Cambridge, MA, USA.

5.2.5 Conclusion and next steps

It seems inevitable that city digital twins will one day be a common web-based infrastructure that allows for the routine aggregation of information from recognised authoritative sources in third-party applications. Currently this prospect faces a chicken and egg problem. In the Boston metropolitan area there are already several independent city modelling projects that overlap. Some of these projects are based in GIS, some of them in commercial 3D design tools.

Despite the amount of time and resources devoted to these independent efforts, each is vulnerable to predictable hazards of complicated asset management routines designed by individual staff members or hired contractors that specialise in GIS or architectural design modelling. At the moment, there are no cultural archiving experts involved in the preservation and re-use of these irreplaceable packets of knowledge representing the changing shape of places and ideas about places.

The reason that successful federated city modelling enterprise is not more common to date is that developing the conventions for information sharing that span interdisciplinary domains are beyond the technical scope of the specialised participants. By sponsoring the citySchema project, developing OAIS-compliant tools and templates for city modelling and sharing them for free at citySchema.org, the BPDA and pbcGIS hope to bridge fragmentary purpose-specific city modelling efforts to a new epoch of multi-purpose, metropolitan-scale city digital twin applications.

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