Towards Drone-Based 3D City Information Modeling for Urban Analysis and Planning

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Abstract
City Information Modeling (CIM) has emerged as a digital extension of Building Information Modeling (BIM), enabling integrated representations of urban systems through 3D spatial data, semantic modeling, and temporal dynamics. While its potential aligns with the digital transformation of cities, CIM research remains fragmented by conceptual ambiguities and limited practical implementations. This paper addresses these gaps through a dual-method approach: (1) a PRISMA-BSMS-based systematic literature review of 159 CIM-related publications indexed in Scopus, and (2) an empirical case study applying UAV-based photogrammetry to generate a neighborhood-scale 3D model for Emniyettepe, Istanbul. By integrating bibliometric analysis with a UAV-to-CIM workflow, the study aims to bridge theory and application, offering insights into scalable, cost-effective, and replicable city modeling strategies for planning and research.

Keywords: City Information Model; City Information Modeling; bibliometric analysis; systematic review; PRISMA; Drone.

Introduction

By providing a digital paradigm that expands the capabilities of Building Information Modeling (BIM) beyond individual buildings to the city scale, City Information Modeling (CIM) has become a game-changing strategy for managing urban complexity. CIM, which has its roots in the combination of 3D geometry, semantic information, and temporal data, makes it easier to visualize, simulate, and coordinate urban elements in a single digital environment. Unlike traditional GIS platforms that primarily represent spatial data in static layers, CIM enables dynamic, object-based modeling that can support real-time analysis, stakeholder interaction, and lifecycle planning.

This shift toward integrated urban informatics positions CIM at the intersection of architecture, planning, computer science, and geospatial technologies. It incorporates data from Geographic Information Systems (GIS), remote sensing, BIM, and urban sensors while embedding social, economic, and environmental dimensions into city models. Accordingly, CIM is increasingly linked to discourses on smart cities, resilience, and data-driven urbanism, promising to enhance urban governance, infrastructure management, and participatory planning.

Yet, despite growing scholarly interest, CIM remains underdeveloped in both conceptual clarity and practical deployment. Existing literature is often fragmented—ranging from semantic data models and technical ontologies to simulation tools and design case studies—without convergence toward a standardized methodology. Furthermore, real-world implementations, especially at the neighborhood or district scale in developing contexts, remain scarce. This is largely due to high entry costs, challenges in integrating heterogeneous datasets, and the absence of open-access, scalable tools tailored to CIM.

By providing a digital paradigm that expands the capabilities of Building Information Modeling (BIM) beyond individual buildings to the city scale, City Information Modeling (CIM) has become a game-changing strategy for managing urban complexity. CIM, which has its roots in the combination of 3D geometry, semantic information, and temporal data, makes it easier to visualize, simulate, and coordinate urban elements in a single digital environment.

Building on this potential, the study follows a dual methodology. First, it conducts a systematic literature review using the BSMS (Bibliometric Analysis, Systematic Review, Meta-Analysis, and Storytelling) process, urban research–specific adaptation of the PRISMA framework. This step maps the evolution, themes, and gaps in CIM-related research. Second, it presents a field-based case study in Emniyettepe Neighborhood, Istanbul, where UAV photogrammetry is deployed to generate a localized CIM dataset and propose an adaptable workflow for future urban applications.

By bridging theory and practice, the study aims to inform both academic discourse and practical planning, contributing to the operationalization of CIM as a planning and design tool in diverse urban contexts.

Background and Theoretical Context

In order to facilitate the integrated modeling of urban systems, the interdisciplinary invention known as City Information Modeling (CIM) combines the fields of architecture, urban planning, geospatial science, and digital technology (Kolbe, 2009; Batty, 2007). CIM is a city-scale framework that uses semantically enhanced 3D models to visualize and manage urban form, infrastructure, and socio-environmental dynamics. It is theoretically and technically derived from Building Information Modeling (BIM). The capacity of BIM to manage the lifetime of buildings has led to its widespread adoption in the architectural and construction sectors; however, CIM extends this power by using layered spatial, temporal, and relational data to depict complex urban settings.

Buildings, roads, vegetation, and utilities are modeled as interactive entities with defined behaviors and attributes in CIM, in contrast to traditional Geographic Information Systems (GIS), which usually handle spatial datasets in a layered and frequently static manner. This method enables CIM to serve as a simulation and decision-support environment in addition to a geographic database. It may facilitate planning interventions, resilience strategies, infrastructure management, and public involvement through scenario modeling and digital twins.

In academic literature, CIM has been increasingly positioned within the larger framework of smart cities and urban digital transformation. Scholars have investigated the use of CIM in energy modeling, flood risk analysis, mobility optimization, heritage conservation, and sustainability evaluations. Gil et al. (2019), Biljecki et al. (2020), and Xue et al. (2022) are among the studies that emphasize the integration of CIM with cutting-edge technologies like blockchain, artificial intelligence (AI), the Internet of Things (IoT), and extended reality (XR) (Kitchin and Thrift, 2009). As a modeling tool, CIM may now be used as an operational platform for real-time urban management thanks to these interfaces.

Nevertheless, several critical challenges continue to limit the operationalization of CIM. These include:

1. The absence of widely accepted standards and workflows for CIM implementation;
2. The technical and conceptual difficulty of integrating multi-source and multi-scale datasets;
3. A lack of CIM-specific software ecosystems relative to the maturity of BIM platforms;
4. Expensive and technically difficult data collection techniques, such as satellite imaging and airborne LiDAR.

Despite the growing capabilities of UAVs and open-source modeling tools, existing literature lacks well-documented and replicable workflows that demonstrate how such data can be integrated into CIM frameworks at fine-grain scales. Most published examples focus either on theoretical frameworks or large-scale city-level models, often overlooking neighborhood- or district-scale implementations that are essential for detailed planning analysis.

This gap underscores the need for studies that not only evaluate the conceptual landscape of CIM but also present grounded methodologies for urban planners and designers. Addressing this need, the current study integrates a systematic literature review with an empirical UAV-based case study to offer a structured and replicable CIM workflow suitable for localized applications.

Methodology

This study applies a dual-method research design that combines a systematic literature review based on the BSMS process and a field-based UAV photogrammetry case study in Istanbul.

• Systematic Review Method (PRISMA-BSMS)

To investigate the current state of research on City Information Modeling (CIM), this study employed the BSMS review process—an urban-planning-specific adaptation of the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) framework (Page et al., 2021; Abusaada and Elshater, 2022; Elshater and Abusaada, 2022). The BSMS process enhances traditional review methodologies by incorporating:

1. Bibliometric analysis to quantify research output and trends;
2. Systematic review to identify themes and conceptual models;
3. Meta-analysis to detect methodological patterns;
4. Storytelling to frame the insights within urban and planning discourse.

The search was conducted in May 2024 using the Scopus database, chosen for its wide coverage of peer-reviewed literature and its compatibility with bibliometric tools. The query focused on terms such as "City Information Model," "City Information Modeling," and their plural and alternate spellings. The search string used was:

TITLE-ABS-KEY("city information model") OR TITLE-ABS-KEY("city information modeling") OR TITLE-ABS-KEY("city information models")

The inclusion criteria were articles, conference papers, books, and chapters; publications in English; and relevance to CIM as a modeling, planning, or design approach. A total of 159 documents published between 2009 and 2024 were identified. The full dataset was exported for analysis and cleaned to eliminate duplicates and irrelevant entries.

• Bibliometric and Thematic Analysis

To analyze the structure and evolution of City Information Modeling (CIM) literature, bibliometric and network visualization tools were employed to extract quantitative patterns and semantic associations from the selected corpus. Two primary software tools were utilized: VOSviewer (version 1.6.18) for keyword co-occurrence and author co-citation analysis, and CiteSpace (version 6.3.R4) for temporal and structural mapping of citation networks, keyword centrality, and cluster evolution.

The bibliographic data retrieved from Scopus—including titles, abstracts, author keywords, and indexed keywords—served as the foundation for this analysis. A thesaurus file was developed by the authors to standardize terminologies and merge synonymous terms (e.g., "CIM," "City Information Model," and "City Information Modelling" were unified under "City Information Modeling"). This step was essential to minimize fragmentation in keyword frequency and ensure consistency across the dataset.

For VOSviewer, a minimum occurrence threshold of five keywords was applied to filter the dataset and focus on terms with sufficient network weight. This threshold yielded 42 valid keywords. The software then generated a network visualization based on co-occurrence link strength, allowing identification of clusters that reflect thematic groupings in the literature. A similar threshold was applied for author co-citation analysis, using a citation count of 30 as the minimum threshold for inclusion.

CiteSpace was employed to assess the structural significance of keywords using centrality and degree metrics. The analysis was based on a g-index with a scaling factor of k=25 to balance citation volume and influence. This tool enabled the detection of pivotal keywords that serve as conceptual connectors between research themes, as well as the identification of burst terms and citation turning points that suggest emerging directions in the field.

Results and Discussion

• Publication Trends and Growth

The Scopus database had 159 papers about City Information Modeling (CIM) from 2009 until the middle of 2024, according to the bibliometric study. Peer-reviewed journal articles, conference proceedings, book chapters, and review papers are all included in this corpus, which shows how academic interest in CIM has grown over the last ten years. Figure 1 shows the number document count for the 159 documents by year, see figure (1).

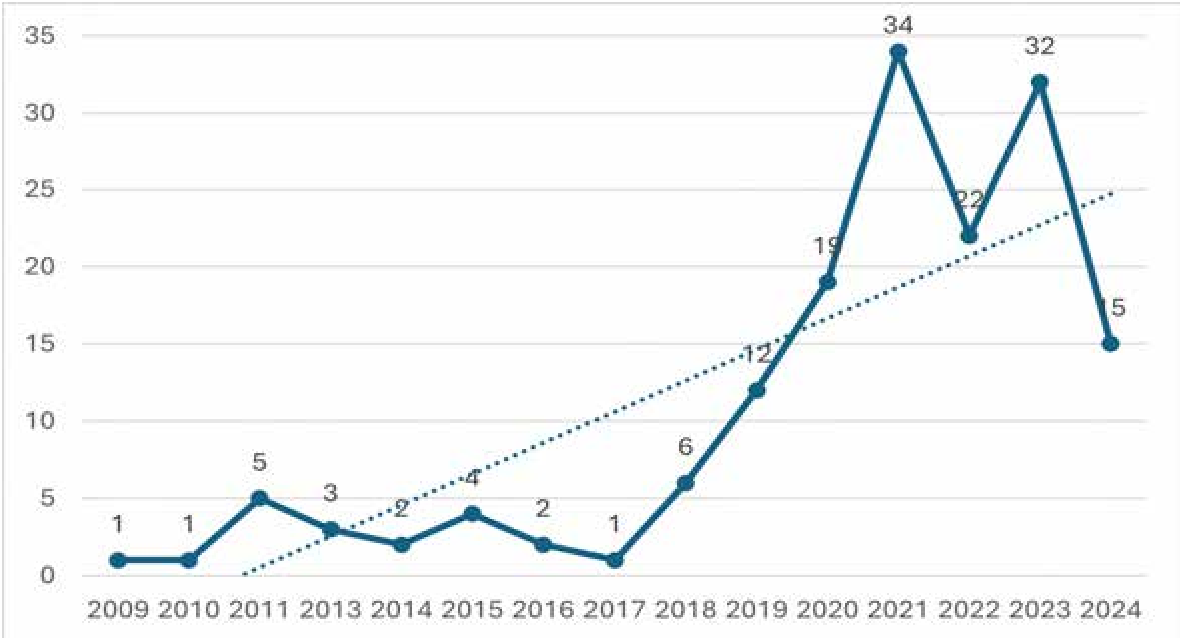

Figure (1): The document count for the 159 documents.

2009 was the first publication that was known to exist, and there was no rise in 2010. The number of publications increased 400%, or a high pace, from one to five in 2011. Following that, the trend experienced cyclical swings. 2013 had a 40% decrease, 2014 saw a little rebound, and 2015 saw a 33% fall. Interestingly, after a huge jump in 2018 (500% growth), the publications doubled in 2019 at a 100% growth rate. In 2021, 34 publications were released, a 79% increase over the year before. In 2022, there was a 35% decrease after this.

The number of publications as of mid-2024 indicates a preliminary 53% decrease from 2023. As more documents are indexed, this number is anticipated to alter by the end of the year. The average yearly growth rate for the examined time is almost 83%, if 2024 is excluded as an incomplete year. This indicates a persistent and growing interest in CIM, fueled by developments in digital twins, smart cities, and urban informatics.

• Geographical and Disciplinary Distribution

The geographic distribution of the 159 publications reveals a broad international interest in City Information Modeling (CIM). China leads the research output with 42 documents, followed by the United Kingdom and Portugal. These figures highlight the active engagement of both Eastern and Western academic institutions in advancing CIM scholarship. The prominence of China may be attributed to its parallel leadership in urban digitization, smart cities, and geospatial technology, while European contributions reflect strong ties between academic research and spatial planning practices.

In terms of disciplinary focus, the analysis reveals that Engineering and Computer Science dominate the subject areas. This suggests that CIM is still strongly rooted in technical and computational research, particularly in areas such as data modeling, digital infrastructures, and software development. However, substantial contributions from the Social Sciences and Environmental Science also point to an evolving interdisciplinary trajectory. These include topics like stakeholder engagement, participatory planning, and sustainable urban development—indicating a gradual integration of CIM into planning and policy-making discourses.

CIM's twin function as a technology platform for data integration and an urban planning decision-support system is reflected in this interdisciplinary collaboration. Because of this, scholars from a wide range of disciplines are coming together more and more around CIM to address issues of governance, resilience, and spatial justice in modern cities in addition to enhancing modeling accuracy.

• Citation Performance and Impact Indicators
The 159 documents retrieved from Scopus generated a total of 1,160 citations, underscoring the growing academic interest in CIM. When self-citations are excluded, the total citation count stands at 974, indicating substantial external engagement and cross-disciplinary relevance, see figure (2).

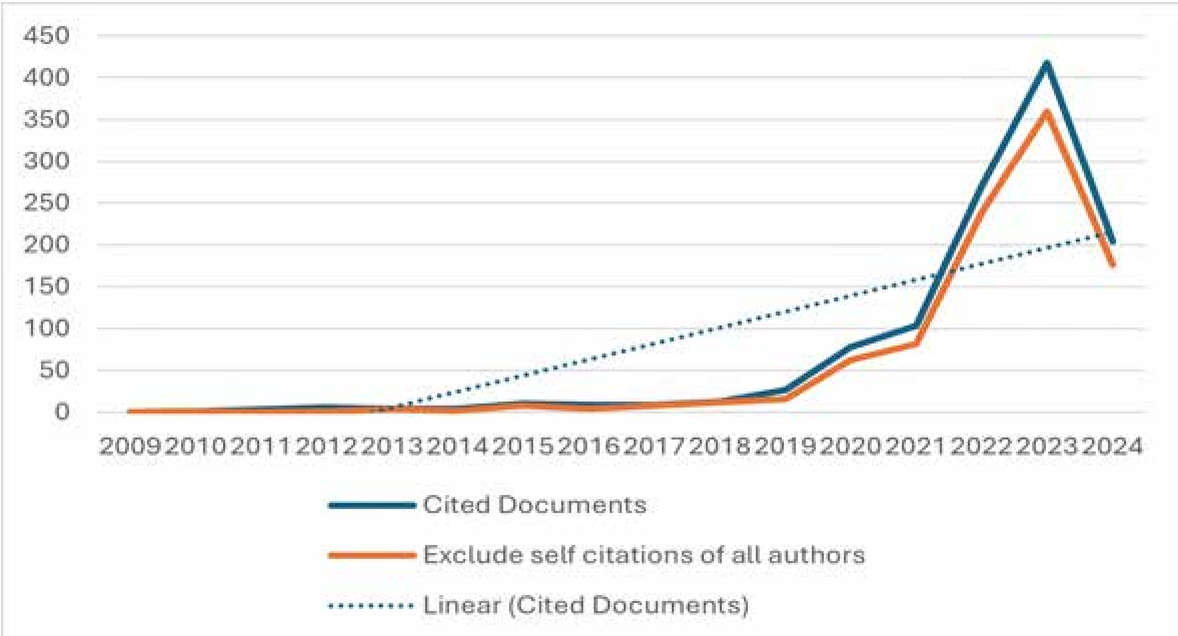

Figure (2): The citation count for the 159 documents, Self-citations included and excluded.

The annual citation trends reveal fluctuations typical of emerging research domains. After a slow start in 2009 and 2010, citations significantly increased in 2011 (200% rise). 2015 showed a 150% increase, regaining momentum after a 33% dip in 2013. Citations nearly doubled in 2019—a especially good year—and then increased by 163% in 2022. These peaks suggest that certain publications or themes triggered heightened academic attention at specific points in time.

The average annual attention rate, excluding the incomplete data for 2024, stands at approximately 77%, indicating consistent scholarly engagement with CIM topics. While 2024 data currently reflect a 53% decline, this is expected to adjust upward as new citations accrue throughout the year.

• Keyword Co-Occurrence and Clustering (VOSviewer Analysis)
To reveal underlying thematic patterns in the CIM literature, a keyword co-occurrence analysis was conducted using VOSviewer on the 159 Scopus-indexed documents. A custom thesaurus file was applied to harmonize keyword variants (e.g., "CIM," "City Information Model," and "City Information Modelling" were unified under "City Information Modeling") to avoid redundancy and improve consistency.

A threshold of five occurrences was set, resulting in 42 qualified keywords for inclusion. The resulting network visualization displays four major thematic clusters, each color-coded and indicating distinct lines of inquiry within CIM research:

• Cluster 1 (Red): Urban Modeling and GIS Integration
This largest and most densely connected cluster (14 keywords) includes terms like “three-dimensional modeling,” “urban design,” “urban planning,” and “geographic information system.” It represents the methodological backbone of CIM, highlighting the fusion of 3D spatial modeling with GIS technologies to support urban planning, simulation, and visualization.

• Cluster 2 (Green): Remote sensing and data systems
This cluster, which consists of 11 terms including “information systems,” “data acquisition,” and “remote sensing,” highlights CIM’s technological backbone. It shows interest in the collection, organization, and integration of urban data, especially via sensors and remote sensing technology.

• Cluster 3 (Blue): BIM-Driven Decision Support
With 10 keywords including “building information modeling,” “decision making,” and “urban growth,” this cluster illustrates how BIM methodologies are leveraged to inform policy and design decisions in urban contexts, extending BIM from architectural to city-scale applications.

• Cluster 4 (Yellow): Emerging Technologies and Sustainability
Terms such as “blockchain,” “sustainable development,” and “quality of life” are included in the smallest cluster (7 keywords). It covers themes that gaze ahead, examining how cutting-edge technologies and moral issues will shape urban futures.

While the thickness and number of connecting lines show the overall connection strength, or how frequently keywords appear in the same publications, node size in the network represents the frequency of keyword occurrence. The network’s node sizes reveal the frequency of keywords, with conceptual anchors such as “city information modeling” (74 occurrences), “information models” (68), and “building information modeling” (43) acting as prominent phrases. The overall link strength statistic emphasizes the importance of important phrases in the changing conversation by further quantifying the degree to which one keyword is related to others. The network map displayed in Figure 3 illustrates these interactions, with cluster colors, node sizes, and links reflecting co-occurrence strength, keyword frequency, and theme structure, see figure (3).

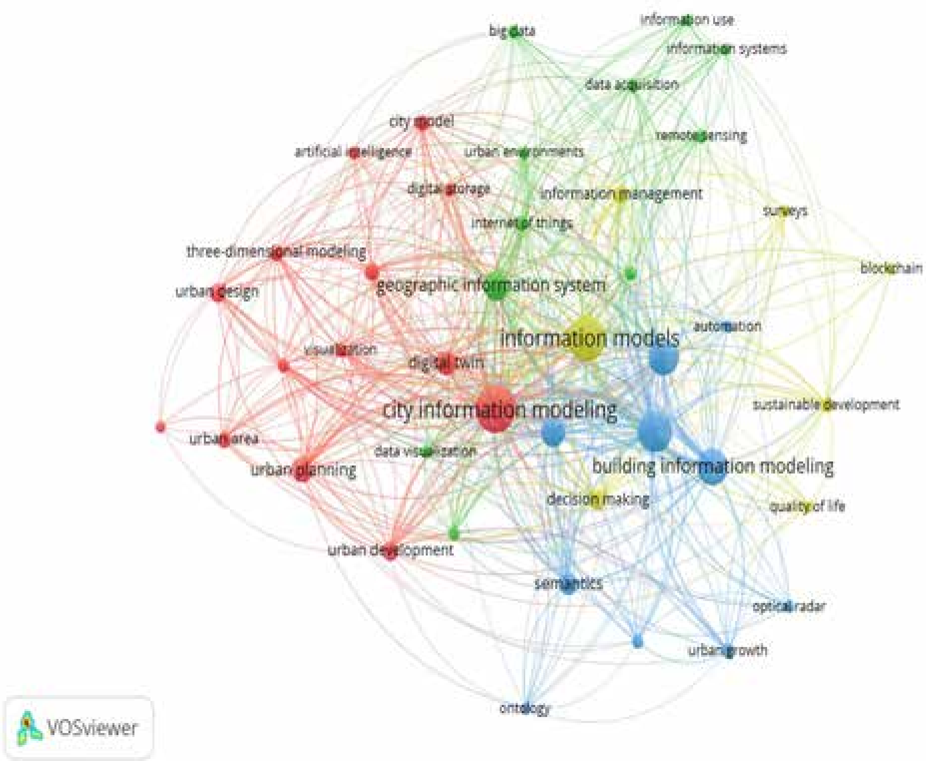

Figure (3): Analysis of the 159 documents retrieved from Scopus focusing on their keywords using VOSviewer (by authors).

• Author Co-Citation Network
To assess the intellectual structure of City Information Modeling (CIM) research, a co-citation analysis of authors was conducted using VOSviewer, with a citation threshold set at 30 citations. This approach identifies how frequently pairs of authors are cited together, highlighting core contributors and collaborative networks that shape the field.

The analysis resulted in a network visualization consisting of three author clusters, each representing a distinct epistemological orientation within the CIM discourse:

• Cluster 1 (Red): Multidisciplinary Pioneers
This largest cluster includes 13 authors with diverse disciplinary affiliations. Notable people include Biljecki, F. (56 citations; 1147 link strength) and Gil, J. (67 citations; 1171 total link strength), who are both acknowledged for their groundbreaking work at the nexus of spatial analysis, 3D modeling, and GIS. The cluster represents a wide range of study that combines planning techniques, data science, and urban informatics.

• Cluster 2 (Green): BIM-Oriented Scholars
Comprising 6 authors, this group is more tightly linked and focuses on extending Building Information Modeling principles to the city scale. Lu, W. (70 citations; 1110 link strength) and Xue, F. (65 citations; 1104 link strength) lead this cluster, contributing extensively to the development of semantic modeling, data structures, and BIM-to-CIM transition frameworks.

• Cluster 3 (Blue): Urban Design and Simulation Experts
With 5 authors, including Stoter, J. (59 citations; 1202 link strength) and Beirão, J. (43 citations; 733 link strength), this cluster specializes in spatial simulation, generative urban design, and visualization techniques. Their work bridges technical modeling and design-oriented inquiry, reflecting a synthesis between qualitative urbanism and quantitative modeling.

Across all clusters, the link strength metric reveals the intensity of co-citation relationships, underscoring the interconnectedness of leading scholars. The presence of well-known theorists such as Batty, M. (44 citations; 811 link strength) further reinforces the theoretical backbone of the field, see figure (4).

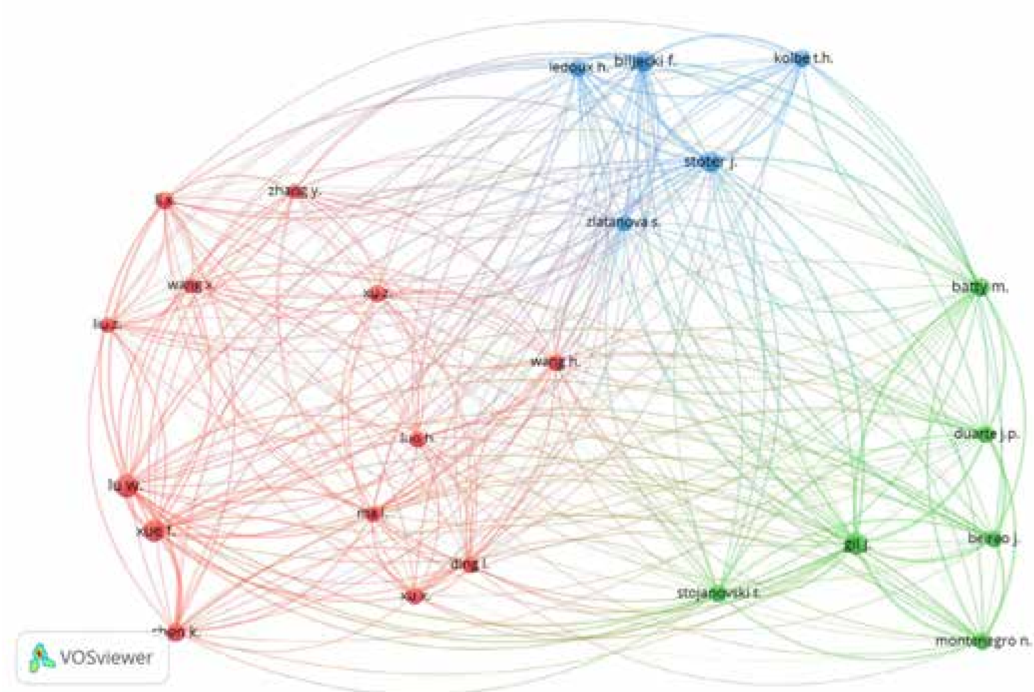

Figure (4): Network analysis based on co-citations of authors using VOSviewer (by authors).

• CiteSpace Keyword Network Analysis
To complement the bibliometric mapping of author contributions, a keyword co-occurrence analysis was conducted using CiteSpace software. This method enables a deeper understanding of thematic concentrations and emerging topics within the CIM literature by identifying central and highly connected keywords across the dataset. The analysis was based on keywords extracted from titles, abstracts, author keywords, and Keywords Plus. A g-index (k=25) was applied to define node inclusion thresholds, ensuring focus on the most influential terms.

The most frequently cited keywords reflect the foundational themes in CIM research:

Table (1): Keywords citation counts and node names by CiteSpace software (by authors).

Citation Counts	Node Name
67	information modeling
51	information theory
42	architectural design
29	cim
28	smart city
25	bim
20	digital twin
20	urban planning
15	gis
13	decision making

The importance of "Architectural Design" and "Information Modeling" attests to their function as conceptual pillars of the CIM discipline. The growing technical integration of CIM with urban digitalization and spatial analytics is indicated by keywords such as "Smart City," "Digital Twin," and "GIS."

Further insight is provided through degree and betweenness centrality metrics, which indicate the structural importance of each keyword within the network:

• Top keywords by degree (number of direct connections):
o BIM (55)
o Architectural Design (48)
o 3D Modeling (35)
o Big Data (33)
o GIS (29)

• Top keywords by centrality (influence as bridges between topics):
o BIM (0.33)
o Architectural Design (0.21)
o Information Modeling (0.19)
o Urban Development (0.19)
o 3D Modeling (0.17)

These metrics reveal that BIM functions as a pivotal bridge in the CIM discourse, connecting a wide range of subtopics from semantics and 3D environments to decision-making and sustainability. Similarly, architectural design serves as a core term linking design methodologies with information systems.

The keyword clusters derived from CiteSpace demonstrate that CIM research is shaped by three intersecting agendas:

• Technological Foundations: Emphasizing BIM, information modeling, GIS, and smart city tools.
• Design Integration: Highlighting architectural and urban design processes within digital frameworks.
• Analytical Expansion: Including big data, AI, and decision-support systems for adaptive urban planning.

UAV-Based Case Study and Workflow Development

This paper includes a field-based case study employing Unmanned Aerial Vehicles (UAVs) for 3D spatial data collecting in order to close the gap between theoretical investigation and real-world application in City Information Modeling (CIM). The objective is to assess the viability and efficiency of a UAV-to-CIM process that aids in neighborhood-scale urban planning. The Emniyettepe Neighborhood in Istanbul, Turkey's Eyüp District—an area experiencing significant urban change—has been chosen as the testbed for its execution.

• Study Area and Rationale

Emniyettepe was selected because of its diversified urban morphology, which comprises residential blocks, business corridors, green spaces, and underused areas, as well as its advantageous location close to Istanbul's central urban infrastructure. It is a typical model for testing UAV-based urban analytic technologies because of its diversity in land use and physical shape. The neighborhood's blend of public, commercial, and residential areas creates a diverse urban landscape, showcasing how flexible 3D modeling is for examining various urban typologies.

The region's usefulness as a case study is increased by its geographical and structural variety, which makes it possible to examine elements like building heights, terrain differences, and green areas. Additionally, the model could support future urban planning efforts, particularly if Emniyettepe is part of redevelopment projects or faces seismic risks, as seen across Istanbul. The practical benefits of choosing Emniyettepe include fewer regulatory hurdles for drone operations due to its moderate population density and lack of high-rise obstructions. By focusing on a moderately dense, underrepresented neighborhood like Emniyettepe, this project can showcase the scalability of drone-based modeling.

• Data Acquisition Using UAV and Photogrammetry

Data acquisition was conducted using a commercial-grade quadcopter UAV equipped with a high-resolution RGB camera. The choice of the drone depended on several aspects, firstly is its ability to capture high resolution 4k images, the images' size produced by the drone is 4000*3000 pixels, with 72 dpi resolution, all photos produced has geo-referencing according to the built-in GPS, with latitude, longitude and altitude measurements, the camera has gimbal that stabilize the image for less blurriness during the drone's motion and has the ability to capture different camera angle (oblique, aerial). Secondly, the DJI platform is compatible with different data processing tools like PIX4D mapper, Reality Capture, and Drone Deploy, Map Pilot Pro, along with its compatibility with the flight planning tools of the same platforms. Thirdly, the weight of the DJI Mavic air 2 is 570 grams, making the pilot license falls in the least license category according to the Turkish Civil Aviation Law. Lastly, the battery of the drone lasts for about 30 minutes, including the take-off and landing, giving about 18 minutes single flight maximum duration.

Flights were planned and executed under suitable weather conditions, adhering to Turkish civil aviation regulations. The photogrammetric mission covered approximately 1.2 square kilometers of urban fabric, capturing oblique images at an altitude of 80 meters. Flight paths were generated using Pix4Dcapture, ensuring 80% frontal and 70% side overlaps for accurate model generation. A total of 520 images were collected and processed in Pix4Dmapper, which generated a dense point cloud, digital surface model (DSM), orthomosaic, and 3D textured mesh. Ground control points (GCPs) were manually identified using local cadastral data to enhance the geospatial accuracy of the outputs. The final outputs serve as high-fidelity spatial datasets suitable for integration into CIM environments.

• Workflow Development: From UAV to CIM

The study proposes a replicable workflow that integrates UAV-derived data into CIM-compatible platforms. The workflow comprises the following key steps:

1. Flight Planning and Data Capture: Mission design with pre-defined overlaps and GCP targeting.

2. Image Processing: Use of Pix4Dmapper to generate georeferenced outputs, including point clouds and orthophotos.
3. Data Cleaning and Classification: Removal of noise points and classification into ground, vegetation, and structures.
4. Model Export and Conversion: Export of point clouds (.las/.xyz) and mesh models into interoperable formats (.obj, .fbx).
5. CIM Integration: Import into BIM/CIM platforms such as Autodesk Revit and InfraWorks. Point clouds are referenced using Dynamo scripts to support semi-automated model reconstruction.

This UAV-to-CIM pipeline not only enables spatially accurate modeling of existing urban conditions but also facilitates data-rich visualizations and planning simulations.

• Limitations and Technical Challenges
Several challenges were encountered during the field application. These include:

• Regulatory constraints: Flight restrictions in certain sub-areas limited full coverage.
• Data occlusion: Vegetation and narrow alleys reduced image clarity in specific zones.
• Model accuracy: While GCPs improved alignment, some distortions persisted at building edges.
• Software interoperability: Manual adjustments were required to align datasets across platforms.

Despite these constraints, the workflow proved robust in generating CIM-ready datasets with reasonable accuracy and scalability.

• Implications for Urban Planning Practice
The proposed UAV-to-CIM workflow offers a cost-effective and scalable alternative to traditional 3D city modeling methods. It enables planners, municipalities, and researchers to:

• Rapidly capture and model existing urban fabric.
• Conduct scenario testing for redevelopment or infrastructure projects.
• Integrate UAV-generated spatial data with semantic CIM databases.

This approach democratizes access to urban modeling tools, particularly for small and medium-sized cities or research institutions lacking access to high-end LiDAR or proprietary datasets.

Case Study: UAV-Based CIM in Emniyettepe, Istanbul
• Site Description and Rationale
The selected case study site for this research is the Emniyettepe Neighborhood, located within the Eyüpsultan District of Istanbul, Turkey. Emniyettepe lies at the intersection of historical legacy and contemporary urban transformation, making it a compelling environment for testing emerging City Information Modeling (CIM) techniques. The neighborhood features a mix of dense residential fabric, mid-rise housing blocks, narrow streets, and a variety of public infrastructure, characteristic of many transitional urban zones across Istanbul.

The rationale for selecting Emniyettepe is threefold. First, the neighborhood represents typical spatial conditions found in many post-industrial, middle-income areas of Istanbul, thus offering valuable insights for broader urban modeling applications. Second, it lacks recent comprehensive digital spatial documentation, presenting an opportunity to demonstrate the added value of UAV-based data acquisition in underrepresented urban zones. Third, its manageable geographic scale (approximately 0.3 km^2) allows for detailed photogrammetric data collection and processing within the constraints of low-cost UAV technology and limited flight windows.

The area is also experiencing increasing planning interest due to infrastructural upgrades and population pressures. These dynamics further justify the implementation of CIM as a tool for scenario testing, urban analysis, and participatory planning processes. The study shows how UAV-enabled processes may facilitate granular, scalable, and reproducible CIM creation in congested urban environments by concentrating on a neighborhood-level site, especially in situations where the available spatial data may be out-of-date, insufficient, or unavailable.

• UAV Data Collection Methodology

A consumer-grade UAV with an RGB camera was used to collect photogrammetric data in order to create a high-resolution spatial dataset for the Emniyettepe area. Early summer 2024 provided ideal illumination and little wind interference for the airborne survey, which was carried out in pleasant weather. Pix4Dcapture software, which allowed for automatic path construction based on terrain elevation, flying height, and necessary ground sampling distance (GSD), was used to pre-plan the flight mission.

As mentioned, several flights were performed in a duration of two days. Details of these flights are as following, (1) Flight Day One: Dates 2nd of January 2025, the images were taken between 4:53 pm and 5:44 pm, the total number of the images taken were 120 images. The flight aim was mainly for the testing of the Map Pilot Pro platform after the failure in connecting the mobile app with the drone using other platforms in a free trial version. Also the timing of the flight was not accurate, which caused the images to be losing brigtness. (2) Flight Day Two: Dates 3rd of January 2025, the images were taken between 4:47 pm and 5:27 pm, the total number of images taken were 160 images, since there isn't distortion in the orthomosaic map, only oblique photos were taken, whereas all georeferenced images can be combined in the processing, see figure (5).

A total number of two oblique flights were performed, drone altitude was set to be 60 meters, in order to capture all buildings' elevations, front and side overlaps were increased to be 80% and 80% respectively, the camera angle was set to be 30 degrees not looking at grid centre (camera face along the grid lines). No ground control points (GCPs) were used in this preliminary workflow due to logistical constraints and to test the capabilities of a GCP-free approach. However, image georeferencing was performed using the UAV's onboard GPS and IMU data. While this introduces a margin of spatial error compared to GCP-aided methods, it demonstrates the feasibility of lightweight data acquisition in constrained or resource-limited urban environments.

Following data acquisition, the image set was imported into Pix4Dmapper for processing. The software executed key photogrammetric steps including image alignment (structure-from-motion), dense point cloud generation, mesh reconstruction, and orthophoto production. The outputs included a classified point cloud, a 3D textured mesh model, a digital surface model (DSM), and a high-resolution orthomosaic map.

UAVs have been widely applied in surveying, archaeology, and environmental monitoring (Fahlstrom and Gleason, 1993; Sauerbier and Eisenbeiss, 2010). The UAV-based data collection workflow adopted in this study highlights the potential of cost-effective photogrammetry for producing CIM-compatible datasets at the neighborhood scale. It also underscores the accessibility of drone-based urban modeling for researchers and planning practitioners working with limited technical infrastructure.

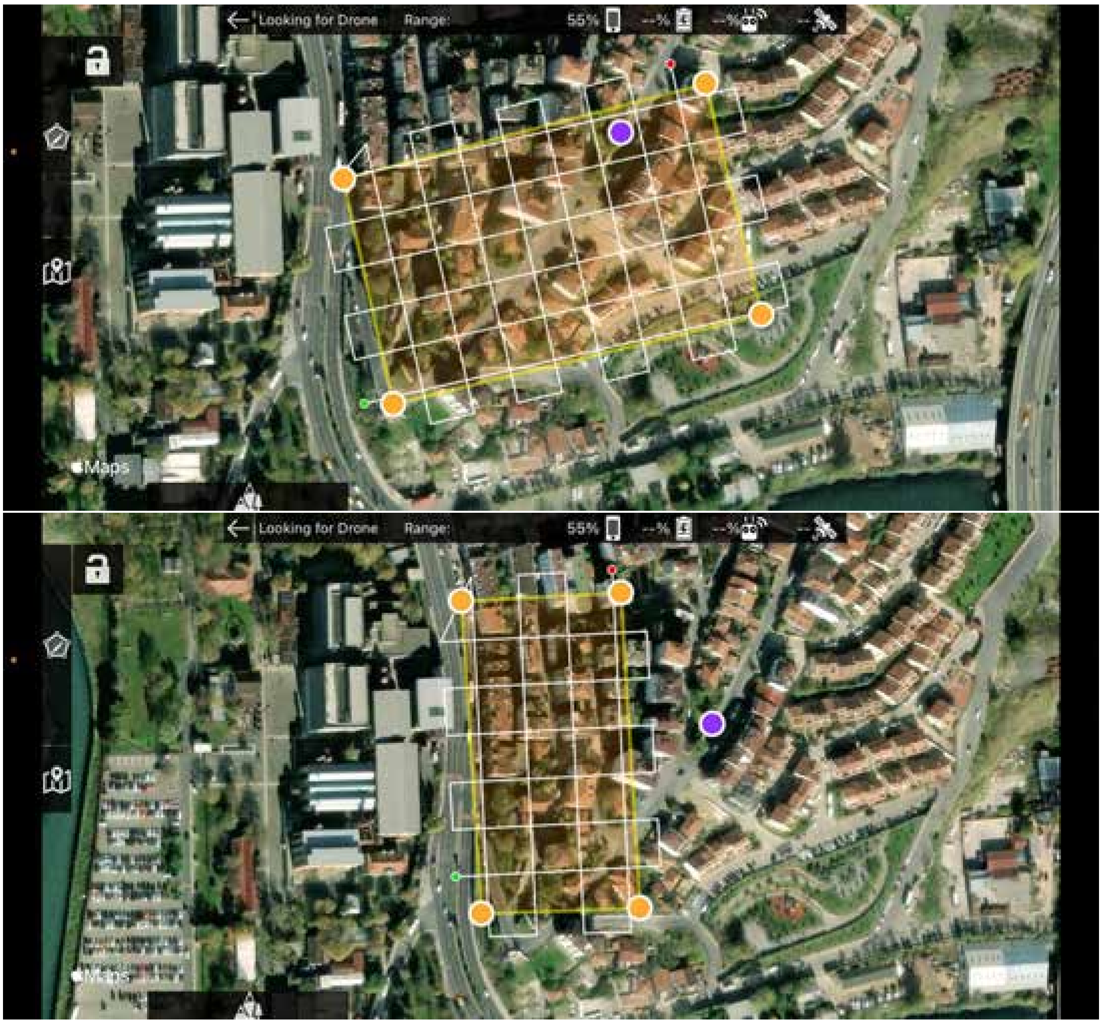

Figure (5): Map Pilot Pro platform.

• Point Cloud Processing and Model Preparation
Following UAV-based data acquisition, the image set was processed in Pix4Dmapper to generate a dense point cloud representing the Emniyettepe neighborhood's built and natural environment. This raw point cloud contained millions of georeferenced spatial data points, encoding x, y, z coordinates and RGB values for each sampled surface.

To prepare the dataset for integration into a City Information Modeling (CIM) workflow, several processing steps were undertaken:

o Noise Reduction and Point Cloud Cleaning
Initial filtering was performed to eliminate erroneous or floating points often resulting from poor lighting or reflective surfaces (e.g., glass facades, water puddles). The point cloud was then decimated to reduce density in less relevant areas while preserving critical architectural and morphological features. This process was conducted using CloudCompare, an open-source 3D point cloud processing software.

o Classification and Segmentation
Points were semi-automatically classified into ground, building, and vegetation categories using colorimetric and elevation-based rules. Manual adjustments were applied in areas where automated classification proved

insufficient, such as shadowed alleys or high-density tree canopies. Segmenting the point cloud into thematic layers allowed for greater control and selectivity during subsequent modeling operations.

o Mesh Reconstruction and Texturing
From the cleaned and classified point cloud, a 3D mesh was reconstructed using the Delaunay triangulation method in Pix4Dmapper. Textures extracted from original UAV images were overlaid on the mesh to enhance visual realism and enable context-aware urban analysis. The resulting textured mesh model provides an intuitive and scalable representation of neighborhood morphology.

o Format Conversion and BIM/CIM Compatibility
To enable downstream use in urban planning environments, the outputs were exported in open formats such as. LAS, .OBJ, and .FBX. Additionally, for future integration with Building Information Modeling (BIM) or CIM environments (e.g., Autodesk Revit, InfraWorks, or openCIM platforms), the processed point cloud was prepared for import into Dynamo scripts and Rhino-Grasshopper pipelines, facilitating procedural modeling and semantic enrichment. Through this multi-step approach, a photorealistic and spatially accurate 3D urban model was derived, serving as the foundation for neighborhood-scale CIM applications. The methodology underscores the adaptability of low-cost UAV workflows in producing structured urban datasets suitable for further analysis, simulation, and planning.

Drone-based imaging was conducted to capture high-resolution data for urban analysis, utilizing a DJI FC3170 camera. A total of 160 geolocated images were captured and processed using the Pix4D cloud platform, achieving 100% calibration success. The project was conducted using the WGS 84 / UTM zone 35N + EGM2008 height coordinate system, ensuring a consistent spatial reference for accurate mapping and analysis. The average Ground Sampling Distance (GSD) was 0.03617 meters, indicating the dataset's high spatial resolution and suitability for detailed 3D modeling and analysis.

The Pix4D platform's processing workflow highlighted exceptional quality checks throughout the project. The median number of keypoints per camera was 35,611, with an impressive 12,176 median matches per camera, demonstrating the robustness of image matching and calibration. Additionally, all 160 images were successfully geolocated, providing a solid foundation for generating accurate 3D models. The relative difference between initial and optimized camera parameters was 8.67%, further emphasizing the calibration process's precision. The dataset generated a 3D Ray Cloud comprising 774,731 points, which is critical for detailed reconstruction and urban feature analysis, see figure (6).

The quality checks also assessed absolute geolocation and orientation variances, with errors minimized across X, Y, and Z axes to ensure accurate spatial representation. Orientation errors for omega, phi, and kappa were similarly controlled, enabling precise 3D positioning and alignment of the images. The high density of observed keypoints and the low rate of weak matches validate the dataset's integrity and its potential for generating reliable outputs, such as Digital Surface Models (DSMs), Digital Terrain Models (DTMs), and orthomosaics.

Processing via the Pix4D cloud platform proved efficient and effective, particularly for a neighborhood-scale project. The integration of drone-based imaging with Pix4D facilitated the creation of detailed outputs for urban analysis. These include potential applications in infrastructure planning, land-use mapping, and environmental assessments (Shi et al., 2015). The ability to process a compact but detailed dataset underscores the feasibility of using drones for urban studies, with Pix4D providing a streamlined workflow for high-quality results.

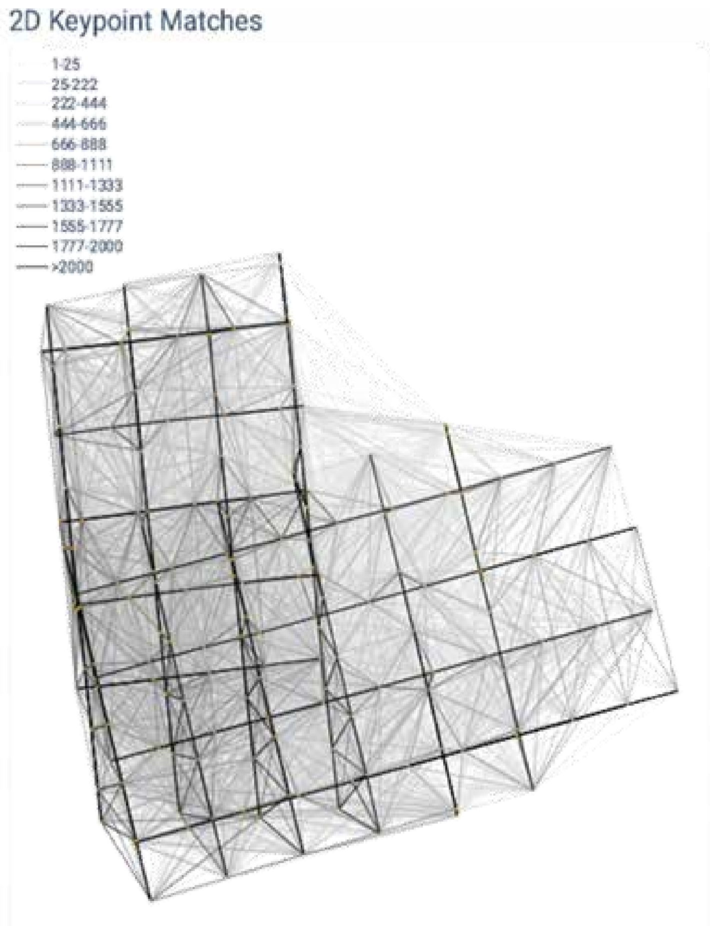

Figure (6): 2D key point matches of drone imageries.

• UAV-to-CIM Workflow and Integration

The processed point cloud and reconstructed 3D mesh were subsequently integrated into a City Information Modeling (CIM) workflow designed to support neighborhood-scale urban analysis and planning. This workflow aims to demonstrate how low-cost UAV photogrammetry can be translated into structured, analysis-ready models that are both visually rich and semantically informative.

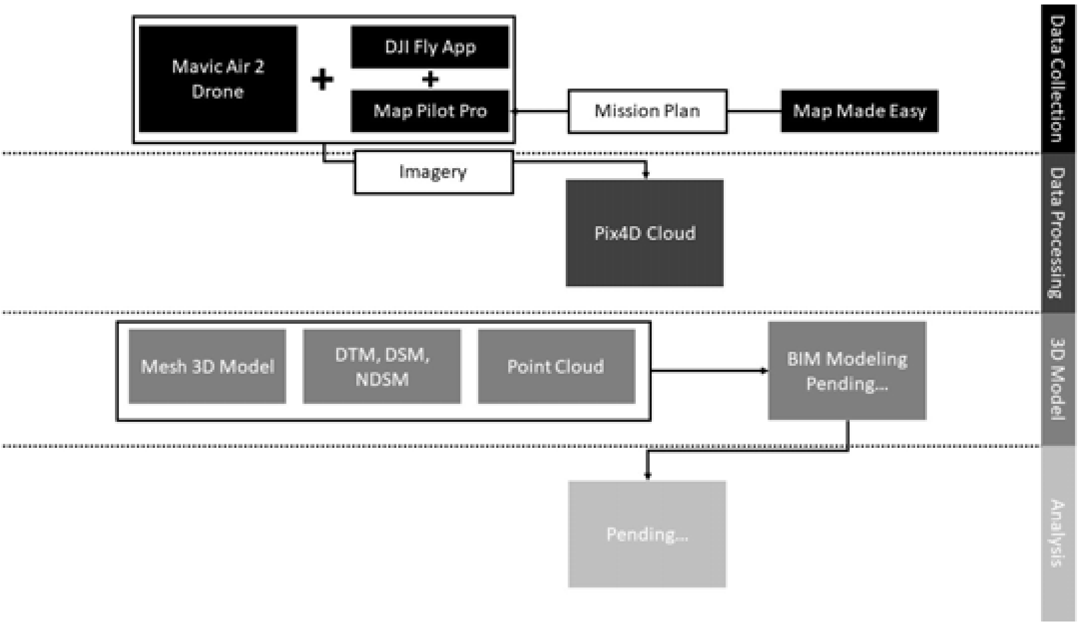

Figure (7): Workflow overview.

o Workflow Overview, see figure (7):
The UAV-to-CIM workflow developed in this study consists of five primary stages:

1. Aerial Data Acquisition (via UAV photogrammetry)
2. Image Processing and Point Cloud Generation (Pix4Dmapper)
3. Point Cloud Cleaning, Segmentation, and Mesh Reconstruction (CloudCompare & Pix4D)
4. Semantic Enrichment and Model Structuring (Rhino + Grasshopper)
5. CIM Visualization and Analysis (QGIS, Unity, or BIM tools)

This modular structure enables iterative refinement and potential expansion to include additional datasets such as cadastral layers, mobility networks, or environmental indicators.

o Semantic Modeling and Attribute Assignment
In order to transition from a visual 3D model to an information-rich CIM dataset, the mesh and point cloud were imported into Rhino and processed through Grasshopper scripts. Basic semantic attributes were assigned to key elements—such as building footprints, roof types, terrain surfaces, and vegetation clusters—allowing for basic querying and spatial categorization.

Where available, public GIS data (e.g., land use, parcel boundaries) were overlaid to spatially align real-world urban attributes with the drone-derived model. This integration facilitates early-stage urban assessments such as shadow analysis, density estimation, and accessibility studies.

o Use Case Scenarios and Planning Potential
The finalized CIM prototype enables a variety of planning-related applications, including:

• Neighborhood diagnostics: Visualizing built-environment morphology and open space distribution.
• Scenario testing: Modeling development options or simulating interventions at a detailed level.
• Stakeholder engagement: Enhancing communication with policymakers or community members through immersive and spatially accurate 3D models.

• Heritage documentation and resilience planning: Archiving current conditions of historically significant structures or assessing exposure to environmental risks (e.g., landslides, flooding).

The system remains scalable and open-ended, with potential for future automation via AI-based classification and integration with Internet of Things (IoT) urban sensing platforms.

• Workflow Limitations
Despite its strengths, the UAV-to-CIM workflow faces several challenges:

1. Data size and processing time: High-resolution point clouds and meshes require significant storage and computing resources.
2. Semantic limitation: Manual or semi-automated classification still relies on domain expertise and lacks standardized ontologies for CIM.
3. Scalability: While effective at the neighborhood scale, scaling to entire city districts requires adjustments in flight planning, data fusion, and computing infrastructure.

• Process Output
Below is a detailed overview of the generated outputs and their quality, as described in the quality report:

Point Cloud: The 3D point cloud generated during the processing included a total of 774,731 points, derived from the dense matching of 2D keypoints. The high number of observed 3D points reflects excellent feature extraction and matching. The distribution of 3D points indicates good coverage across the area, with keypoints observed in multiple overlapping images, increasing the accuracy and robustness of the reconstruction. The report indicates that most points were observed in 3-6 images, which enhances the reliability of their 3D coordinates. However, a small percentage of points were observed in more than 10 images, leading to high precision for specific features. The average ground sampling distance (GSD) of 0.03617 meters further underscores the high resolution and suitability of the point cloud for detailed urban analysis, see figure (8).

Figure (8): 3D point cloud.

Digital Terrain Model (DTM): The DTM created provides a clear representation of the terrain, excluding structures and vegetation. The processing used dense sampling and geoid-based height data (EGM2008) to ensure accurate elevation values. Given the GSD and the precise geolocation of input images, the DTM exhibits minimal vertical errors, as highlighted by the geolocation error checks.

The elevation of every element in the region, including plants, buildings, and other structures, is reflected in the Digital Surface Model (DSM). The DSM benefits from the high-resolution input images and accurate image matching, ensuring detailed height data for urban structures. Errors in height estimation were minimal, with the RMS error for geolocation at 0.826 meters, which is within acceptable limits for urban analysis, see figure (9).

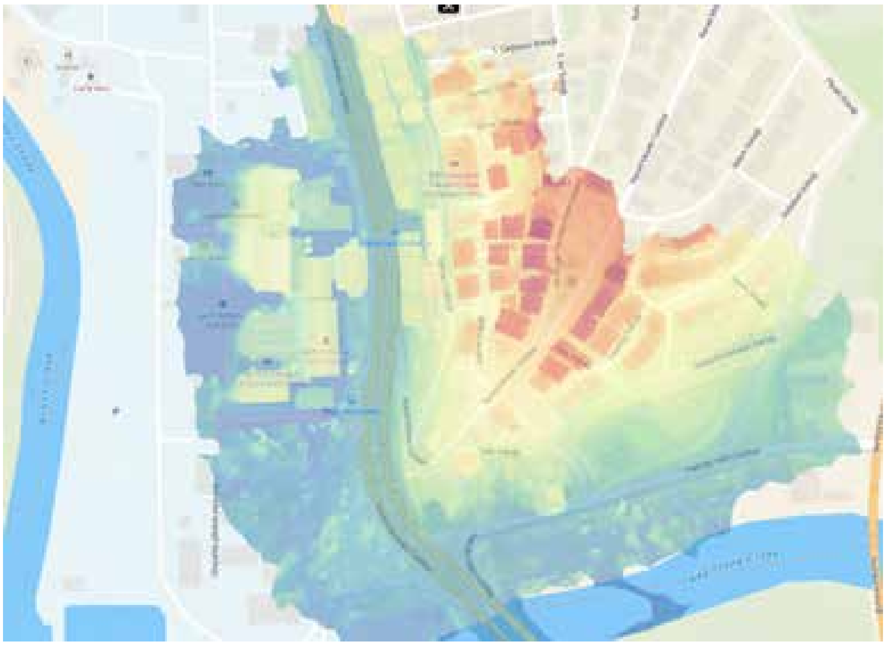

Figure (9): Digital Surface Model (DSM).

Orthomosaic: An orthomosaic was generated using the captured images, providing a georeferenced 2D representation of the area. The orthomosaic benefits from the high GSD, ensuring exceptional clarity and detail, with no major distortions noted in the quality checks, see figure (10).

Figure (10): orthomosaic was generated using the captured images.

3D Mesh Model: A 3D mesh model was created from the dense point cloud, integrating texture data from the input images. The mesh model captures the geometric and visual properties of the area, providing a detailed and realistic representation of the neighborhood (Nan and Wonka, 2017; Lafarge and Mallet, 2012; Oesau et al., 2016). The relative difference between initial and optimized camera parameters (8.67%) indicates successful alignment and calibration, ensuring the quality and accuracy of the mesh, see figure (11).

Figure (11): 3D Mesh Model.

The outputs generated from the drone data include high-quality DSM, DTM, point cloud, orthomosaic, and 3D mesh model, each with minimal errors and high precision. These deliverables provide a comprehensive basis for urban studies, including land use mapping, infrastructure assessment, and planning. The processing quality ensured by Pix4D highlights the effectiveness of the workflow for creating reliable and accurate models from drone imagery.

Findings and Discussion

This section synthesizes the insights derived from both the bibliometric literature review and the UAV-based field implementation. The dual-method approach provides a nuanced understanding of City Information Modeling (CIM), highlighting not only its theoretical evolution but also its practical feasibility in real-world urban contexts.

• Key Insights from the Literature Review

The systematic review conducted using the BSMS-PRISMA framework revealed several thematic and methodological patterns across the 159 CIM-related documents retrieved from Scopus:

1. Discipline Focus: While planning theory, social equality, and public engagement in digital modeling are covered in comparatively few publications, the bulk of CIM research are focused on the domains of engineering, computer science, and architecture.
2. Trends in Keywords: Words like “information modeling,” “BIM,” “smart city,” and “urban planning” showed up a lot, indicating a good desire to combine digital technology with urban administration. Emerging keywords like “digital twin” and “blockchain” signal the increasing diversification of CIM applications.
3. Author Networks and Citation Patterns: Co-citation and keyword network analyses identified a handful of pro-

lific authors (e.g., Gil J., Stoter J., Biljecki F.) who form intellectual clusters. These networks point to evolving research communities and schools of thought within CIM.
4. Gaps Identified: The review also exposed gaps, particularly in the standardization of CIM workflows, limited integration of environmental datasets, and lack of attention to citizen-centered or participatory modeling approaches.

• Key Insights from the UAV-Based Workflow
The practical application of UAV photogrammetry in the Emniyettepe Neighborhood demonstrated several capabilities and limitations of drone-based CIM integration:

o Feasibility and Accessibility: The UAV-based workflow proved effective in generating high-resolution, georeferenced 3D models using commercially available drones and software. This confirms the viability of cost-efficient data collection methods, particularly in under-resourced urban settings.
o Accuracy and Detail: The derived models captured detailed architectural and topographical features, suitable for various urban analyses such as land-use visualization, elevation profiling, and density assessment.
o Semantic Potential: While the point cloud and mesh were successfully processed into visually accurate models, the transition into fully semantically enriched CIM datasets remains partially manual. This presents a challenge for automation and scaling.
o Replicability: The proposed five-step UAV-to-CIM workflow is modular and adaptable, suggesting potential for deployment in other urban contexts with minimal reconfiguration.

• Theoretical and Practical Convergence
By pairing literature insights with real-world implementation, this study highlights the converging trajectories of theoretical research and applied urban modeling:

o From BIM to CIM: The strong conceptual link between BIM and CIM found in literature is mirrored in the UAV workflow, where BIM tools and logic were repurposed for urban-scale applications.
o Bridging Gaps: The empirical case study addresses gaps identified in the literature, particularly the need for standardized, low-cost, and scalable workflows for city modeling.
o Urban Planning Implications: For urban planners and policymakers, the findings suggest that CIM can be effectively initiated at the neighborhood scale, serving as a decision-support tool for both long-term planning and rapid diagnostics.

• Limitations and Considerations
Several constraints emerged during the study:

o Temporal Staticity: UAV-based models represent a static snapshot in time, limiting their ability to reflect dynamic urban processes without continuous data updates.
o Data Fusion Complexity: Integrating UAV data with other municipal datasets (e.g., cadastral, infrastructure, sensor data) remains technically and administratively challenging.
o Governance and Ethics: As CIM platforms increasingly incorporate detailed urban and citizen data, ethical concerns around surveillance, privacy, and data ownership must be addressed in future studies.
o Despite their benefits, UAV operations face evolving regulatory frameworks (Stöcker et al., 2017).

Conclusion and Future Work

This study investigated the evolving landscape of City Information Modeling (CIM) through a dual-method approach that combined a systematic literature review using the BSMS-PRISMA framework with a practical UAV-based case study in the Emniyettepe neighborhood of Istanbul. By identifying dominant patterns in the scholarly literature and assessing the viability of an approachable, reproducible workflow for urban-scale data modeling, the study sought to close the conceptual and practical gaps in CIM.

Although CIM has attracted increasing interest from a variety of fields, including engineering, computer science, and architecture, the literature analysis found that it currently lacks standardized tools, thorough frameworks, and extensive application in actual urban settings. In situations where traditional data sources could be out-of-date or unavailable, the UAV-based pilot research showed how drone photogrammetry might assist CIM operations in a technically possible and cost-effective way.

The study adds to the continuing discussion on the relevance, scalability, and integration of CIM within urban planning practice by contrasting bibliometric findings with actual application. The findings confirm that CIM is not merely a conceptual extension of BIM but a distinct paradigm requiring its own methodologies, toolchains, and interdisciplinary governance structures.

Future research should focus on several key directions:

1. Developing automated workflows for semantic enrichment of 3D models to reduce reliance on manual post-processing;
2. Using artificial intelligent powered platforms to generate 3D models using descriptive text and integrating them into CIM. (Liu et al., 2023)
3. Scaling the UAV-to-CIM framework to other urban environments to test generalizability and adaptability.

Final Remarks and Acknowledgements

It is important to note that the final conversion of the textured mesh model into a fully operational 3D City Information Model (CIM)—including semantic enrichment, object classification, and integration into BIM/CIM platforms like Revit—is still a pending task and constitutes a subsequent phase of this research. This work forms part of an ongoing thesis project, and further technical development and validation will be addressed in the upcoming stages. The author gratefully acknowledges Istanbul Technical University and Türkiye Scholarships (Türkiye Bursları) for academic support.

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