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Research Article

The Birth and Life of Buildings: High-Resolution Analysis of Historical Building Trends through the Digitised Municipal Archive of Tel Aviv-Yafo

Elad Horn[1,✉], Or Aleksandrowicz[1], Daniel Rosenberg[1] & Ido Baum[1]

[1] BDAR Lab, Technion – Israel Institute of Technology, Israel

✉ Correspondence: Elad.Horn@campus.technion.ac.il

Abstract: Inconsistent temporal definitions of key events in a building's lifecycles, and especially of its "birth" date, usually impede a large-scale, high-resolution analysis of building trends and construction fluxes based on municipal building datasets. This study addresses this shortcoming by proposing a reproducible ontological dating formulation of major construction activities during a building's lifecycle using the building permit as the most common, reliable, and consistent indicator of a building's age. We tested this approach by analysing the Tel Aviv-Yafo Municipality's Engineering Administration Archive, which consists of around 5.3 million digitised documents spanning between 1920-2020 and arranged in more than 28,000 building files. We combined permit data with supporting taxation and construction completion documents to automatically extract the date of "birth" or major reconstruction of each of the dataset buildings. The resulting dataset enabled us to generate detailed diachronic maps of urban growth at the resolution of an individual building. Despite challenges such as data discrepancies and archival gaps, this analytical method highlights the value of working directly with raw administrative metadata to uncover valuable insights into historical transformations in the built environment. It also demonstrates the utility of building permits as critical indicators of economic and architectural activities. By applying this approach to urban-scale building datasets, it is possible to predict building ages with reasonable accuracy and, thus, to enhance the understanding of urban growth and transformation dynamics.

Keywords: Building age prediction, Building documentation, Building information databases, Architectural historiography, Spatial humanities, Tel Aviv-Yafo

Highlights:

- Definitions of key dates in a building's lifecycle are inconsistent across public databases.
- We propose an ontological formulation of a building birth date for large quantitative analysis.
- Automatic processing of building permit dates and quantities can reliably extract building ages.

1. Introduction

The built environment constantly changes as buildings are constructed, repaired, renovated, remodelled, refurnished, reconstructed, and demolished. But while we know from everyday experience that building existence is a temporal phenomenon, systematically defining what actions amount to the construction of a new building or its demise is not as straightforward as one could expect. This blurriness in definitions was acknowledged in recent studies on building age prediction and heritage discourse in spatial humanities (Ferreira-Lopes & Pinto-Puerto, 2018; Li et al., 2018; Sun et al., 2022; Zeppelzauer et al., 2018), including a study that noted that "[w]hile it is one of the key building attributes […], the year of construction of a building has not been given much attention in practice and research" (Biljecki & Sindram, 2017, p. 22). When attempting to investigate large databases of building information to explore the historical transformations of a city's physical development, this conceptual blurriness becomes a genuine impediment to extracting meaningful and reliable quantitative insights. Without clearly and consistently defining the moments of "birth" and "change" of most buildings in such databases, analysing the historical trends embodied in them stands on shaky grounds.

In this study, we explored the theoretical ambiguities, blurry definitions, and technical challenges that complicate the seemingly straightforward definition of major moments in a building's life, both within academic discourse and across professional and regulatory domains (Figure 1). We then attempted to distil coherent definitions of a building's moment of inception that may serve as a strong indicator for significant construction activity concentrated on a single building plot. In defining this moment, the proposed system considers a building's visual appearance, impact on the built landscape, and structural integrity as the most important spatial variables that indicate significant construction activity. Consequently,

we suggest determining a building's moment of "birth" based on the type of certification documents contained in municipal building files, highlighting the significance of carefully studying the local properties of building certification systems in large-scale and high-resolution analyses of building stock trends.

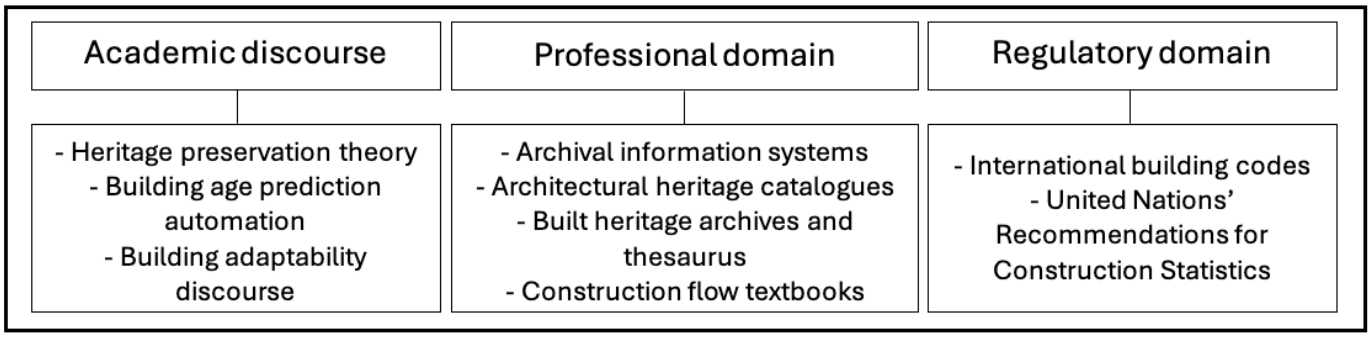

Figure 1. Knowledge domains and sources for determining a building's moment of "birth".

This study presents a reproducible ontological formulation defining a building's moments of "birth" to support large-scale, high-resolution historical analysis of construction trends and cycles. The study also aims to rectify a critical gap in the methodological foundations of architectural historiography that has direct implications within the broader domain of the spatial humanities. This gap impedes different types of diachronic analysis of the evolution of the built environment, especially when studying how the ups and downs in the economy affect the building stock. To explore the coherence, practicality, and challenges of the suggested methodology, we applied it to the historical analysis of a large dataset of planning and construction documents archived and digitised by the Tel Aviv-Yafo Municipality's Engineering Administration. Based on the documents' classifications, we automatically extracted years of increased building activities on each plot to recreate the city's timeline of construction and expansion.

2. Background: The Ambiguity of Dating a Building's Birth

Dating of buildings, alongside their location, designer, size, and style, is a fundamental feature of historical databases dedicated to documenting the built environment (Szekely, 2017). One should, therefore, expect to find a clear and standardised building dating methodology underlining such databases. However, guides to the creation and maintenance of built heritage archives only superficially address the question of building dating. For example, the International Council on Archives (ICA) guide for architectural records vaguely describes the "life" of a building as what happens after the "acceptance of the building and the final payment" (2000, p. 30), while the Getty Research Institute's Art and Architecture Thesaurus (2021), a seminal guide for archiving architectural works, does not provide dating conventions for key moments in a building's lifespan, including its "birth". Similarly, the Core Data Index to Historic Buildings and Monuments of the Architectural Heritage (Thornes & Bold, 1998) mentions the need to date the construction phases of a building without clearly describing how these dates should be defined and based on which documentation.

Reflecting the ambiguity of building dating in archival guidelines, many built heritage archives use ad-hoc temporal building attributes whose definitions are not based on common standards or guidelines and are neither transparent nor reproducible. For example, *Archipedia*, an online database maintained by the Society of Architectural Historians, uses date attributes such as "design and construction," "converted," "renovated," "additions," and "restoration" (*Archipedia*, 2024). Other archives use other attributes in their building dating chronology, such as "design" and "completion" year (*Finnish Architecture Navigator*, 2020), or "built", "additions", and "alterations" (*Philadelphia Architects and Buildings Project*, 2024), or simply indicate "dates" that seem to be significant in a building's life (*Het Nieuwe Instituut Collection*, 2024). None of these archives has explicit definitions for the temporal attributes they use. These persistent inconsistencies and ambiguities in terminology across architectural archives and databases impose difficulties in cross-examining and comparing data.

Some large standardisation and regulatory systems, which usually rely on clear and reproducible uniform definitions, have addressed the questions of "birth", "death", and temporal changes of buildings, though not always in a consistent manner. For example, the U.S. International Building Code (IBC) self-referentially considers an existing building as "a building erected prior to the date of adoption of the appropriate code, or one for which a legal building permit has been issued" (International Code Council (ICC), 2021). On the other hand, the United Nations' 1997 International Recommendations for Construction Statistics acknowledged the complexity of defining the year or period of construction. It suggested that when parts of a building are constructed at different times, the primary year of construction should refer to the largest part, and in cases where multiple buildings are involved, the year of the main structure should be recorded (United Nations Department of Economic and Social Affairs, 1997, p. 268 par. 4.538). While helpful, such definitions are open to inconsistent interpretations because they lack specific references to building documents and systematic definitions of how to relate to the data these documents contain.

Moving away from regulatory documents, dating buildings based on their physical presence has increasingly attracted scholarly interest during the last decade, particularly with advances in machine vision technologies. Researchers have explored various methodologies to estimate building age, concentrating on the analysis of street-view imagery (Li et al., 2018; Ogawa et al., 2023; Sun et al., 2022; Zeppelzauer et al., 2018) alongside morphological characteristics (Rosser et al., 2019), use of airborne light detection and ranging (LiDAR) data (Tooke et al., 2014), geographic information systems (GIS) data (Biljecki & Sindram, 2017; Ogawa et al., 2023), and historical maps (Van Hoesen & Letendre, 2013). These efforts address the common challenge of incomplete or inaccurate temporal data for building stocks across diverse geographic and urban settings. However, most of these methods are not able to provide precise building "birth" dates since they are interested in the general periodisation of decades-long building trends and fashions (Li et al., 2018; Zeppelzauer et al., 2018). More recent approaches to built heritage documentation,

which have used a combination of historical GIS, graph models, and advanced data analysis methods of spatiotemporal phenomena, were nevertheless unable to determine specific dates of birth (Ferreira-Lopes & Pinto-Puerto, 2018; Ferreira-Lopes & Pires Rosa, 2023). More importantly, these studies typically do not address the conceptual ambiguities of determining a "birth" date for a building.

Another issue generally left under-discussed in current literature is how to account for changes made to buildings after their initial completion. For example, Sun et al. (2022) acknowledged that the primary limitation and source of error of their study was "the bias of data collection", explaining that the dataset they analysed ignored "renovation, expansion and addition" actions when determining the year of construction (Sun et al., 2022, p. 11). Zeppelzauer et al. (2018) expressed a similar sentiment. Certain building modifications, depending on their scale and size, may be regarded as fundamentally changing the original building to a point of total reconstruction despite integrating elements of the original building into the new project. Such modifications, while not involving full-scale demolition of the original building, require considerable investment that cannot be overlooked when analysing large-scale building trends. The lack of conceptual clarity on whether a building can be regarded as new even when it consists of some elements of an older building can become a source of significant error in analysing large datasets of historical building stocks, especially in locations where building preservation involves adding significant built volumes or a complete reconstruction of interior spaces.

3. Building Permits as Indicators of Building Age

To formulate a reproducible definition of a building's birth date, one should first understand the common temporal elements in the construction of a typical building. In modern times, this process usually follows this path: allocating and purchasing a parcel of land; forming an alliance of owner and construction professionals; planning and authorising the building; acquiring permits for construction and coordination with authorities; demolition of former structures on the ground; breaking the ground and placing the foundations; building the structural elements, interiors partitions, and facades; finishing the building and land development; obtaining a license for building occupation; delivery to tenants; adding conversions, additions, renovations, and restorations; and finally partly or complete demolition of the structure (Allen, 2005, pp. 227–238; Merritt & Ricketts, 2000, pp. 1.4-1.7). To propose a reproducible formulation based on this generic construction process, we first explored and analysed the theoretical ambiguities, fuzzy definitions, and technical challenges that complicate the seemingly straightforward definition of a building's lifespan.

3.1. The Birth of a Building

In Edward Allen's 2005 textbook *How Buildings Work*, he suggested that a "building begins as a concept of need in someone's mind. If the need is a simple one and the person dexterous and ambitious, the steps needed to realise the concept are simple and direct" (2005, p. 227). However, this conceptual starting point is rarely documented and thus difficult to track in large-scale archives. The earliest identifiable moment might be the first meeting between a developer and an architect or the signing of a contract between them, yet documentation of such actions is rarely kept in archives, either. Another optional starting point is when construction begins, as noted by Historic England (2018, p. 6), which calculates a building's age from when the ground is first broken.[1] Similarly, the Israel Central Bureau of Statistics (2024) marks the start of construction with excavation for foundations. However, the documentation of this action is normally not mandatory and it is less likely to be found on public records. What leads to it, though, is usually a specific archived binding legal document: the building permit. Following a definition appearing in a Eurostat analysis, a building permit can be described as "an authorisation to start work on a building project, and as such is the final stage of authorisation prior to the start of work" (Visocka, 2010, p. 2).

Administrative records provide additional potential birth markers, such as the date of the first or last municipal tax payment (Daniels & Peyceré, 2000, p. 30). These dates, while well-documented and important for historical records, do not capture the full planning and construction timeline, which can span months or even years. Consequently, they may not fully reflect the administrative, economic, and architectural systems already in place.

Other factors considered in determining a building's age include various stages of construction or demolition. According to the United Nations guidelines for population and housing censuses, each census must define "whether buildings under construction are to be recorded and, if so, at what stage of completion they are to be considered eligible for inclusion. Buildings being demolished or awaiting demolition should normally be excluded" (2017, p. 267). These guidelines further suggest that in defining the "[y]ear or period of construction," the focus should be on the major part of the building if constructed at different times, and "[w]here living quarters comprise more than one building (living quarters with detached rooms, for example), the age of the building that contains the major part of the living quarters should be recorded" (2017, p. 268). These guidelines consider factors like the completion stage and occupancy type and rate, providing detailed insights into a building's history and usage. However, this information often relies on personal accounts from occupants or census personnel, making it susceptible to bias and inconsistencies.

3.2. Building Transformations

Determining when changes to a building render it "new" is critical for understanding its lifecycle. This requires identifying significant transformations that mark the end of one iteration of a building and the start of another. The criteria for these transformations vary across different databases and archives. For instance, some refer to correcting construction flaws, maintenance, major repairs, renovations, or extensions (Daniels & Peyceré, 2000), while others mention additions, alterations, termination, or demolition. Not only are these criteria not uniform, but also not clearly defined.

The Getty Thesaurus provides more detailed guidelines on building changes. It distinguishes between "additions" (substantially increasing area, height, or volume) and "alterations" (changes without increasing volume) (The Getty Research Institute, 2021). The International Building Code (2021) uses a "50 percent rule" to classify substantial changes as an addition and defines substantial damage based on whether the cost "equals or exceeds 50 percent of the market value of the structure before the improvement or repair is started." These definitions help categorise reconstructions, repairs, or additions as substantial improvements and encourage us to consider buildings as evolving components within an economic system.

[1] According to Historic England's Principles of Selection for Listed Buildings, a building less than 30 years old can be listed if "[t]he Secretary of State calculates the age of a building from the point at which the ground was first broken."

Similarly, the United Nations 1997 statistical recommendations define new construction as an entirely new structure or significant extensions to an existing structure "whether or not the site was previously occupied" while distinguishing between capital repairs, which typically require a construction permit, and regular maintenance (United Nations Department of Economic and Social Affairs, 1997, p. 27). According to these guidelines, when changes to a building reach an economic threshold that requires a permit, it signifies the transition to a new building, marking the end of the previous one. In our eyes, this approach, relying on statutory permission, offers more consistency and clarity in defining the different phases of a building's lifecycle than other definitions.

3.3. Municipal Administration Archives

Considering our interest in studying diachronic trends in the construction economy, we concluded that municipal administrative documentation is the best consistent source for building dating because of its permanency and orderly collection. Due to their consistency in preserving building documentation, municipal archives of planning, construction, and architectural administrations provide invaluable repositories and thus insights into the processes underlying building realisation in cities. In contemporary times, these processes typically entail the systematic submission of consistent paperwork, including licensing, permits, tax records, reports, and other administrative documents. Once submitted to local planning authorities, these documents are processed and archived and may become available to the public.

Traditionally, historians browse administrative archives manually by searching through individual building files and scrutinising each document to reconstruct a structure's past. If properly recorded, these documents could be scanned and digitised to form a digital database to allow a different approach to historical research (Esmaeili et al., 2014; Münster et al., 2019). This is based on the assumption that, as Szekely pointed out, regardless of data persistence, the importance of administrative archives is that they are primarily responsible for preserving the integrity of historical documents, not their authenticity or truthfulness (Szekely, 2017, p. 11). Accordingly, the reinterpretation of data and metadata within these archives has the potential to illuminate related topics beyond the structured archival arrangement of documents (Szekely, 2017, pp. 11–12).

Among all the construction-related documents kept in municipal archives, the building permit is probably the single most important type of documentation to shed light on a building's lifespan, at least in places where the execution of major building activities without a building permit is regarded as a legal offence. A further emphasis was placed on the significance of the building permit since it appears that, in most cases, granting this type of official approval signals a substantial change in a building's form, scale, or economic value.

While issuing a building permit may precede actual construction for a significant time (Bruno & Corea, 2019), it nonetheless signifies a level of planning maturity and effectively delineates the historical context in which a building emerges. It should also be noted that "not all the granted permits lead to real building works (not all projects end up being carried out) and […], construction activity can last long, making it difficult to connect the output to the obtained licenses" (Bruno & Corea, 2019, p. 418). While not free of constraints, the permit emerges as an effective, faithful, and persistent document to reflect economic and stylistic transformations that are key focal points for an architectural-based research agenda.

For our study, we, therefore, defined a building's "birth" as the moment when the first building permit is issued for construction on an unobstructed parcel of land. This permit marks the formal approval of the building process and serves as the earliest official record of significant architectural and economic activity on a plot. Building permits are also issued to approve the construction of a new building in place of an older one or for additions or modifications to an existing building. For the sake of differentiation, we defined building permits issued on a specific plot beyond the original permit as "reconstruction" permits, a term that covers three major building activities involving considerable investment in obstructed plots: demolition of an old building and construction of a completely new building in its place; addition of floors or wings to a building; and extensive changes to the facades of a building.

4. Case Study: Comprehensive Dating of Building Using a Municipality Engineering Database

To explore the coherence, practicality, and benefits of relying on municipal archives and building permits for large-scale dating of buildings, we systematically analysed the contents of a large database archived and digitised by the Tel Aviv-Yafo Municipality's Engineering Administration (Table 1). This database contains 5.3 million planning and construction documents related to 27,662 parcels that went through building and rebuilding from 1920 to 2020. The data is stored in digital building files containing planning, architectural, taxation, and regulatory documentation of building activities. Besides the importance of the White City of Tel Aviv as an emblem of the Modern Movement in architecture, Tel Aviv-Yafo serves as an adequate case study for this historical and quantitative research as its building records have been digitised, catalogued, and made publicly available through an online archive.

4.1. Archival Data Acquisition

The Tel Aviv-Yafo Municipality's Engineering Administration Archive (2024) underwent a thorough scanning and digitisation process some 15 years ago and is accessible as a public and free online service.[2] The easy-to-use archive website states that a "single file consolidating all building-related documents allows for reliable documentation over time of all the events related to the building." Building files can be searched by inserting the building address, plot number, building file number, or other administrative serial numbers into the service search engine. The archive grants access to all attainable building files, including most of the city's residential buildings and some of its public and commercial buildings. Other files that are not open to the public include schools, army and police facilities, urban infrastructures, embassies, small and temporary structures (such as bus stops), large factories, and other structures that require any level of confidentiality.

To trace the complete lifecycle of all the buildings in a city according to the proposed methodology, one should first obtain a digital dataset of all building files, including document types and dates. In the case of the Tel Aviv-Yafo Municipality, such a dataset is not readily available for public distribution. Since no batch download function was available via the archive's internet site, and manually copying each metadata table was implausible, we opted to automate the manual data acquisition process of all open records.

[2] The online archive might not be available outside Israeli communication networks and in that case may be accessed through a virtual private network (VPN) service.

Table 1. Case study workflow, outcomes, and tools and software used.

	Stage	Outcome	Tools and software
1	Data acquisition	Scraping all building file metadata from the online archive	- Python3 - PyCharm - CSV files - The Tel Aviv-Yafo Municipality's Engineering Administration Archive (online) - Municipal public GIS platform (iView)
2	Manual examination of the archive data and files	Allocating the most persistent documents to reflect major building transformations into three categories	- The Tel Aviv-Yafo Municipality's Engineering Administration Archive (online) - Microsoft Excel
3	Assessing reliability of the three document categories	A high degree of reliability for the three categories peaks in indicating significant dates	- Python3 - Microsoft Excel
4	Data contextualising	Exploring the scope and limitations of the dataset, periodisation of data	- Python3 - Microsoft Excel
5	Automating Building Dating	Developing a code that finds significant dates for each building file	- Python3 - CSV files - Microsoft Excel

Following an examination of the archive's database structure, we composed a web automation script to obtain the complete available dataset systematically that would not harm its structure and integrity.[3] The script repeated the actions a single user would take to perform an online search and obtain the complete data for a single building file. It was written in Python3, a standard and general-purpose programming language, using PyCharm, an integrated development environment for data science and web development. Such a process of importing data from websites into files or spreadsheets is known as data scraping or web scraping and is potentially possible if the website structure does not prevent it purposefully.

In the case of the Tel Aviv-Yafo building files archive, the scraping process that took place from April to June 2021 included the following actions: launching a Chrome browser; inserting the archive's web address; authorising the service terms of use; adjusting the mode of search for "block and parcel"; inserting specific numbers of block and parcel; identifying and choosing the required building; copying the metadata list that contains 25 documents to a CSV (comma-separated value) file; continuing to the next list page; repeat copying the building file metadata lists to termination; creating a unified CSV data file for the building file. To perform a streamlined scraping of the dataset, we automatically entered the block and parcel numbers into the search engine. These were obtained from the municipal public GIS platform operated by iView (2024).

The complete publicly available archive database was scraped into CSV files titled with their building file number. Out of 41,872 searched city parcels, we retrieved 28,701 building files with accessible documents that were considered for this study as we used strictly open and online accessible data. These represent 5,293,515 metadata entries, averaging 191 documents per building file. Each metadata entry mainly consisted of these fields: file ID number; block number; parcel number; file date (day/month/year); document type; permit serial number (largely missing); document file size (in kb); page number and row number. Following the scraping and initial data handling processes, we found that 19.23% of the 5.3 million metadata entries were not dated and, therefore, could not be used for analysis. This is likely due to an absence of clear dates on the original documents or human error in data processing.

[3] The web automation script can be downloaded from GitHub code repository: https://github.com/bdar-lab/TLVArchive

4.2. Identifying and Categorising Document Types for Building Dating

Each digitised building file may comprise dozens to several hundred documents. Each document is recorded with a metadata entry containing the issuing date, type, class, file size, and serial identifications. An online viewer and client-side download is available for each listed document separately, linked to a scanned PDF file or a born-digital document. If dated, the documents are arranged chronologically and classified under one of 68 document types. To locate the files that were more commonly and constantly used and thus could be reliably compared across periods, we organised them by their appearance frequency and quantity (Table 2). We found 14 document types that have been used throughout most of the dataset period and constitute more than 1 percent of all documents. These document types amount to 82 percent of the dataset, or 3.5 million documents.

Table 2. Document types by amount (more than 1% of total document) and persistence over time.

	Document type title	Use period[4]	Total amount	% of total
1	Incoming and outgoing letters, objection letters, notices to beneficiaries, resignation	1921-2019	586,411	13.81
2	Municipal levy assessment notice, construction fees, payment vouchers	1923-2020	435,091	10.25
3	Title deed (Tabu), identification documents, publications, affidavits, and other	1922-2020	381,865	8.99
4	Appeal committee, sub-committee, licensing authority, district committee	1925-2030	318,147	7.49
5	Letters/inquiries, internal correspondence, and others	1923-2020	305,922	7.20
6	Completion certificate file + completion certificate[5]	1924-2020	280,281	6.61
7	Approval of stations - on A4 documents and on plans	1923-2020	235,812	5.55
8	Business licensing - general	1924-2016	205,552	4.84
9	Application (specifications and invoices)	1924-2016	186,974	4.4
10	Signed written permit	1923-2020	152,053	3.58
11	Sanitary plans, sewer connection	1925-2016	139,130	3.28
12	Signed permit plan	1924-2020	136,606	3.22
13	Stability calculation, engineer's affidavit	1925-2017	88,358	2.08
14	Unsigned plans	1923-2019	45,752	1.08
	Total		**3,497,954**	**82.38%**

To better understand the basic nature of these document types, we analysed eight building files consisting of 1,601 dated documents, their overall structure, and specific content. These files were selected because they represent significant moments in Tel Aviv's construction history, spanning from the 1920s to recent decades, and have been thoroughly documented in local historiography (Duvshani, 1993; Ravid, 2008). The selection was also intended to reflect a range of building types and uses, ensuring that our analysis accounted for diverse urban development contexts. To evaluate which document types best indicate a building's major transformative events, we qualitatively assessed each type for its importance, reliability, and consistency. Out of 14 document types, two were found irrelevant to the building process ("business licensing - general"; "approval of stations"), while four others were incoherent with their documents' content or structure ("unsigned plans"; "stability calculation, engineer's affidavit"; "title deed (Tabu), identification documents, publications, affidavits, other"; "letters/inquiries, internal correspondence, other"). The other eight types were directly related to construction processes and could potentially and reliably provide evidence of significant

[4] Document types that have been recorded for more than ten documents per year.
[5] Due to the interchangeability of the two types, we combined them.

building or construction activities. To this list, we added the document type "completion certificate" despite its scarcity (0.42% from all the database documents) since it seemed to have a high level of importance and reliability. Together, the chosen documents were assessed and arranged in chronological order (Table 3), which generally reflects the common path of building planning and construction actions as described by Allen (Allen, 2005) and Merritt and Ricketts (2000).

Table 3. Document types by construction chronology and reliability assessment.

	Document type	Content description	Reliability, consistency, importance
1	Signed written permit	Building permits that are usually signed and dated	Very high importance and reliability in combination with other certifications
2	Signed permit plan	Permits, drawings, signed logs	High reliability, medium importance since there is no uniformity in the number of documents; in earlier years, several documents were indexed for each permit separately, usually accompanying the written permit
3	Appeal committee, sub-committee, licensing authority, district committee	Usually, requests for change licenses and small demolitions in existing buildings	Reliability is chronologically dependable, with little importance as it usually refers to minor changes
4	Completion certificate	Completion of construction certificates	High importance and reliability, low consistency
5	Municipal levy assessment notice, construction fees, payment vouchers	Bills and fees for individual operations during the life of the lot: demolition, construction, addition, closing, construction of partitions, etc.	High importance and consistency, such payments were usually made shortly before or after the construction operation, low reliability as not always related to construction taxes
6	Completion certificate file	Supervision and inspection of materials and installations, concrete test certificates, completion certificate portfolio, construction completion audit	High importance and reliability, low consistency
7	Sanitary plans, sewer connection	Submission and approval documents for sanitation in the building - a graphic drawing or front cover of submission folders	High importance and reliability in correlation with other certifications
8	Application (specifications and invoices)	Cardboard folders - plan for building a house/request for a permit	High importance, low consistency, and reliability, as these are requests that are not certain to have been carried out
9	Incoming and outgoing letters, objection letters, notices to beneficiaries, resignation	Various correspondence regarding licensing, approval of plans and tenant and owner complaints	High reliability, but lacking consistency in the level and type of information

Closely reading the eight building files also revealed some anomalies. These were related to the database structure, including years of peak documentation that turned out to be insignificant to building processes such as local neighbourly complaints letters or business taxation. To overcome such inconsistencies, we focused on documents that recorded actions distinctively related to construction activities and eliminated the other, less relevant ones that were identified in Table 3. Eventually, we focused on three categories of documents: permits, taxation, and construction completion, which comprise 23.89% of all archived documents (Table 4). In the completion category, we included an occupancy confirmation form ("form 4" and "Form 1", comprising 0.42% of total documents) that have been in use since 1993, as they complemented the two other documents that have been in constant use. These documents cover obligatory moments in the building's administrative authorisation process and thus represent building birth and reconstruction dates most accurately.

To assess the reliability of the three document categories in indicating birth and reconstruction years, we systematically inspected a larger sample of 100 building files containing 6,883 dated documents. Although not randomly selected, these files were chosen from a limited pool of

several hundred buildings that were well-documented in architectural monographs (Aleksandrowicz, 2024; Duvshani, 1993; Hoffmann & Horn, 2021; Karmi-Melamede, 2018; Ravid, 2004, 2008), in which the reliability of dating was high. These files represent a diverse geographic distribution across Tel Aviv-Yafo and encompass buildings designed by a variety of architects over an extensive period. This selection method aimed to include a representative range of building types and construction periods that could provide a solid basis for testing our predictions.

Table 4. Document types by three categories.

	Category	Document type	% of total
1	Permits	Signed written permit; Signed permit plan	6.8
2	Taxation	Municipal levy assessment notice, construction fees, payment vouchers	10.25
3	Completion	Completion certificate file; Completion certificate; Form 4; Form 1	7.02
	Total		**24.07%**

No.	1	2	3	4	5	6	7	8	9	10
Street name	Nahalat Binyamin	Allenby	Allenby	HaYarkon	Montefiore	Herzl	Maze	HaMagid	Maze	Bograshov
Number	17	90	96	102	31	72-74	27	5	46	2
Building file ID	30170	40900	40960	271020	100310	20720	140270	730050	140460	260020
Total documents in file	480	542	411	466	330	308	337	517	377	373
Total dated documents of 3 categories	74	65	70	68	84	33	93	182	63	71
Important years estimation	1927-1931 1937-1939 1947	1928-1929 1934-1937	1933-1934 1937-1938 1941-1943 1947	1926-1928 1930-1934 1938-1943	1926-1927 1977-1979 1983-1985	1935-1937 2006-2009	1932 1998-1999 2000-2002	1930-1931 1933-1934 1957 2001-2003	1932 1941	1932-1933
ground-truth birth years	1926-1931	1928	1934-1935	1926	1925	1925	1934-1935	1930-1931	1932-1933	1925
	23/7/1991	21/2/1991	3/2/1990	9/7/2013	15/10/2012	12/1/2009	07/11/2002	31/7/2007	15/10/2012	25/12/1932
Color codes:	9/6/1991	21/2/1991	19/12/1976	15/12/2011	15/10/2012	04/02/2008	07/11/2002	31/7/2007	4/8/2005	26/07/1990
Permits	17/7/1989	8/6/1987	5/12/1972	15/12/2011	24/9/2012	17/12/2007	07/11/2002	31/7/2007	13/1/1999	13/06/1990
Taxation	9/7/1986	8/12/1985	4/12/1972	7/7/1993	13/9/2012	19/08/2007	15/04/2002	30/7/2007	13/1/1999	03/05/1989
Completion	3/6/1982	12/11/1985	22/6/1972	2/6/1991	13/9/2012	26/12/2006	25/03/2002	30/7/2007	22/12/1998	19/02/1989
	16/3/1979	14/10/1985	16/5/1972	21/6/1990	13/9/2012	5/12/2006	11/03/2002	23/7/2007	20/12/1998	24/10/1987
	16/10/1973	3/1/1985	15/5/1972	20/6/1990	9/1/2012	10/06/1997	26/02/2002	27/7/2006	13/10/1998	05/07/1985
	20/9/1973	16/7/1972	13/5/1972	11/6/1990	13/09/1992	24/6/1993	26/02/2002	1/1/2004	7/8/1994	22/04/1985
	19/8/1973	16/7/1972	12/7/1968	20/2/1990	21/04/1985	13/4/1978	04/02/2002	1/1/2004	13/4/1994	21/04/1985
	14/8/1973	29/5/1972	8/7/1968	15/2/1990	03/04/1985	13/4/1973	30/10/2001	1/1/2004	13/1/1993	17/04/1985
	13/8/1973	29/5/1972	18/6/1965	22/7/1987	20/03/1985	5/10/1969	30/10/2001	23/12/2003	7/1/1992	19/03/1985
	4/7/1973	22/3/1965	8/11/1962	9/6/1987	14/02/1985	26/9/1969	16/10/2001	22/12/2003	7/1/1992	05/03/1985
	8/2/1973	22/3/1965	2/7/1956	28/5/1987	12/02/1985	9/9/1968	16/10/2001	22/12/2003	5/11/1990	20/02/1985
	1/2/1973	16/2/1958	2/7/1956	23/10/1957	06/01/1985	5/5/1963	11/10/2001	22/12/2003	16/9/1990	29/09/1967
	8/7/1970	16/2/1958	14/6/1956	23/10/1957	17/12/1984	15/3/1963	11/10/2001	17/09/2003	16/8/1990	29/09/1967
	3/3/1970	13/6/1957	7/4/1951	21/06/1943	4/12/1984	15/3/1963	08/08/2001	17/09/2003	16/7/1990	25/09/1967
	14/11/1969	11/11/1937	28/11/1947	16/10/1938	26/10/1984	14/3/1963	26/07/2001	17/09/2003	25/3/1990	11/07/1967
	13/11/1969	11/11/1937	23/07/1947	12/8/1938	17/10/1984	21/9/1949	26/07/2001	04/09/2003	28/1/1990	19/05/1967
	5/11/1969	6/3/1936	26/6/1947	12/8/1938	14/10/1984	28/1/1937	26/07/2001	04/09/2003	3/9/1989	17/05/1967
	21/6/1964	6/3/1936	10/6/1947	12/8/1938	03/10/1984	28/1/1937	26/07/2001	03/08/2003	14/8/1989	16/05/1967
	10/4/1964	6/3/1936	4/5/1947	12/8/1938	14/07/1984	13/1/1937	24/07/2001	17/07/2003	28/6/1989	10/02/1967
	31/3/1964	6/3/1936	28/4/1947	12/8/1938	21/06/1984	4/3/1936	23/07/2001	2/7/2003	21/6/1989	11/01/1967
	15/5/1959	3/3/1936	28/4/1947	12/8/1938	4/6/1984	1/3/1936	23/07/2001	29/6/2003	20/6/1989	12/08/1966
	9/1/1959	12/4/1935	16/1/1947	12/8/1938	4/6/1984	31/10/1935	23/07/2001	24/6/2003	1/6/1989	12/07/1966
	31/3/1947	12/4/1935	16/1/1947	12/8/1938	30/5/1984	30/10/1935	19/07/2001	23/6/2003	18/5/1989	30/12/1965
	31/3/1947	12/4/1935	11/9/1945	12/8/1938	30/5/1984	27/10/1935	18/07/2001	23/6/2003	18/5/1989	08/11/1965
	11/3/1947	12/4/1935	4/12/1944	15/1/1936	08/03/1984	9/9/1935	18/07/2001	26/05/2003	8/5/1989	08/11/1965
	25/11/1942	12/4/1935	22/01/1943	9/5/1934	08/03/1984	13/8/1935	18/07/2001	21/05/2003	8/5/1989	11/01/1965
	26/2/1939	12/4/1935	16/12/1941	11/4/1934	08/03/1984	28/2/1929	15/07/2001	11/05/2003	13/4/1989	11/07/1964
	26/2/1939	28/2/1935	6/8/1941	10/11/1933	04/03/1984	22/2/1926	4/7/2001	02/02/2003	21/6/1988	26/03/1961
	13/4/1938	23/3/1934	1/8/1941	20/5/1932	02/03/1984		10/6/2001	20/01/2003	29/1/1988	16/03/1961
	13/4/1938	23/3/1934	30/7/1941	20/5/1932	20/10/1983		10/6/2001	18/12/2002	6/1/1988	16/03/1961
	13/02/1938	23/3/1934	28/7/1941	20/5/1932	20/10/1983		10/6/2001	18/12/2002	1/10/1987	25/12/1960
	1/2/1938	23/3/1934	11/5/1941	20/5/1932	25/7/1983		4/6/2001	18/12/2002	1/10/1987	20/11/1960
	1/2/1938	23/3/1934	22/4/1941	20/5/1932	29/4/1983		4/6/2001	18/12/2002	13/8/1987	31/10/1960
	23/1/1938	23/3/1934	14/4/1938	16/5/1932	26/4/1983		4/6/2001	18/12/2002	29/12/1986	31/10/1960
	21/10/1937	23/3/1934	14/4/1938	11/10/1931	01/04/1983		4/6/2001	10/12/2002	18/12/1986	31/10/1960
	30/09/1937	26/11/1931	1/4/1938	11/10/1931	25/03/1983		1/6/2001	05/12/2002	18/12/1986	25/10/1960
	12/08/1937	26/11/1931	31/3/1938	11/10/1931	24/12/1982		8/1/2001	2/12/2002	4/2/1986	07/08/1950
	26/7/1937	2/4/1929	22/3/1938	10/12/1930	27/08/1981		19/12/2000	28/11/2002	10/6/1985	26/05/1950
	26/7/1937	2/4/1929	24/01/1938	16/10/1930	07/02/1979		19/12/2000	07/11/2002	10/6/1985	26/03/1950
	19/7/1937	2/4/1929	16/12/1937	16/10/1930	24/4/1978		22/3/2000	07/11/2001	6/6/1985	03/02/1950

Figure 2. Classification of construction documents from a sample of 100 building files.

For each of the sample's building files, we manually extracted their permits, taxation, and completion documents and chronologically colour-coded them in a table according to their category (Figure 2). Based on the sheer number, chronology, and order of these documents, we subjectively estimated each building's birth and reconstruction years, assuming that major construction activity is reflected in a peak in document quantities at a specific time. These predictions were compared with the "ground-truth" data from the historical monographs. The comparison demonstrated that peaks in document quantities of specific document types can indicate the key dates in a building's life with high certainty. Most prediction errors were related to construction activities in the 1920s due to a lack of documents. These results suggested that we could develop a method that could automatically identify these key dates by tracing the temporal fluctuations in the quantities of these three document categories in each building file.

The practical insight from this inquiry underscored that within our case study's planning systems, statutory documents directly relating to construction activities are probably the most systematically recurring documentation in the municipal building files. Within these, it appeared that the most reliable and consistent document category was the building permit due to its direct connection to the actual start of construction. Supplementary documents such as completion certificates and taxation records added robustness to the analysis, especially when they appeared close to the permit date. These documents, when found within a narrow time frame around the issuance of the permit, reinforced the permit's indication of the building's construction year.

4.3. Contextualising the Data

To explore the scope of the final dataset, we plotted a histogram showing document quantities for each year between 1920 and 2020 (Figure 3). While Tel Aviv was founded in 1909 as a neighbourhood in Jaffa, we chose 1920 as a starting point since only a handful of documents in the entire archive were catalogued with earlier dates. This correlates with the establishment of Tel Aviv as an independent "township" a short time after the establishment of the British civilian administration in Mandatory Palestine (Golan, 2023).

The overall dataset trends can be divided into four different periods: from 1920 to the mid-1940s; mid-1940s to mid-1980s; mid-1980s to 2003; and 2003-2020 (Figure 3). These four periods seem to reflect socio-political and economic transformations in Tel Aviv-Yafo. Following its independence from Jaffa, Tel Aviv expanded north and east, while its population increased significantly with Jewish immigration (the Fifth Aliyah) in the 1930s. This growth is reflected in a significant increase in submitted documents between 1933 and 1937. As a result of World War II, this growth slowed between 1939 and 1944 but resumed with the massive settlement of the newly established Israeli state after 1948. It is reasonable to assume that the city's economic and construction activities were impacted by such events, as the quantitative analysis of the database demonstrates.

Figure 4 shows the annual fluctuations in the number of documents categorised as permits, taxes, or construction completion certificates, following the three document categories we identified as the most relevant for documenting construction activities. This figure highlights another structural issue related to changes in submission methods and types of documents over the years. For example, the quantities of "signed permit plan", a document type describing the architectural drawings used for certification, peaked throughout the 1930s, consistent with the historical narrative of the city's growth and expansion. However, this did not correlate with the quantities of the "signed written permit" type, even though the two document types typically have similar quantities, with each certification plan leading to the issuing of a written permit. Reviewing the "signed permit plan" documents, we noticed that building permits in the 1930s were divided into several individual drawings that were catalogued separately, while later permits were consolidated into a single lengthy document. This prompted us to consider the changes in administrative legislation pertaining to the submission and cataloguing of documents and their impact on data reliability.

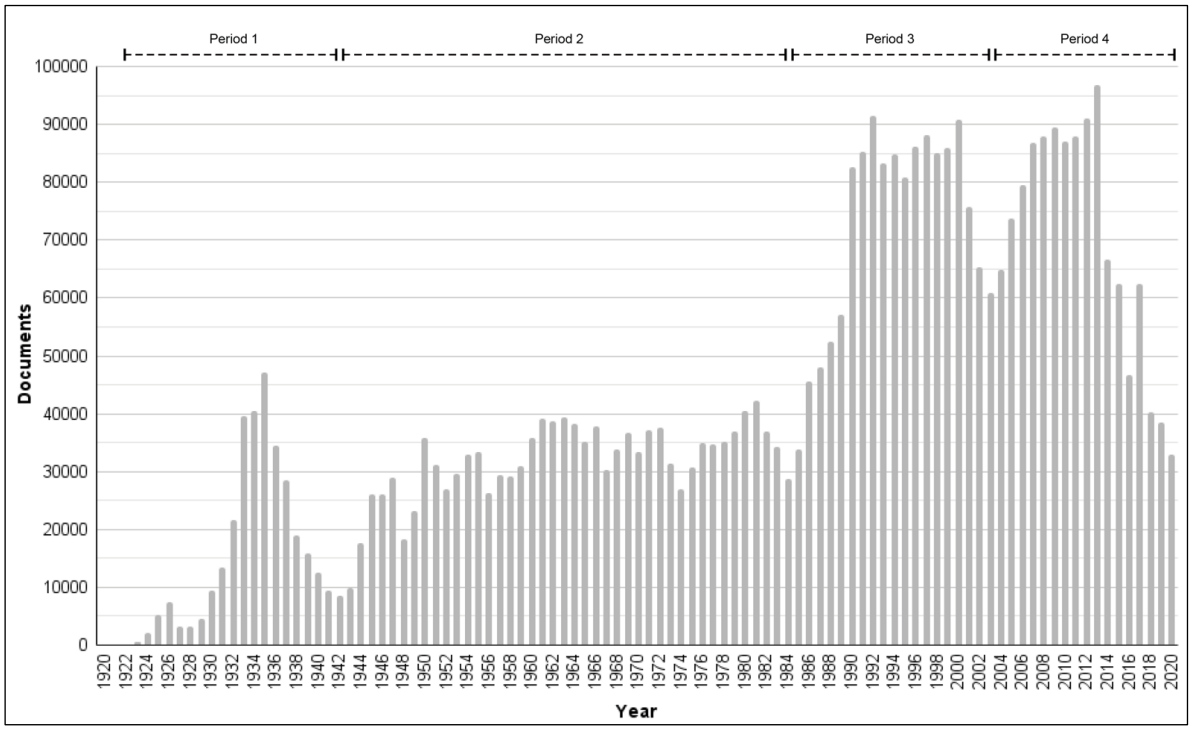

Figure 3. Documents per year: the Tel Aviv-Yafo Municipality's Engineering Administration Archive.

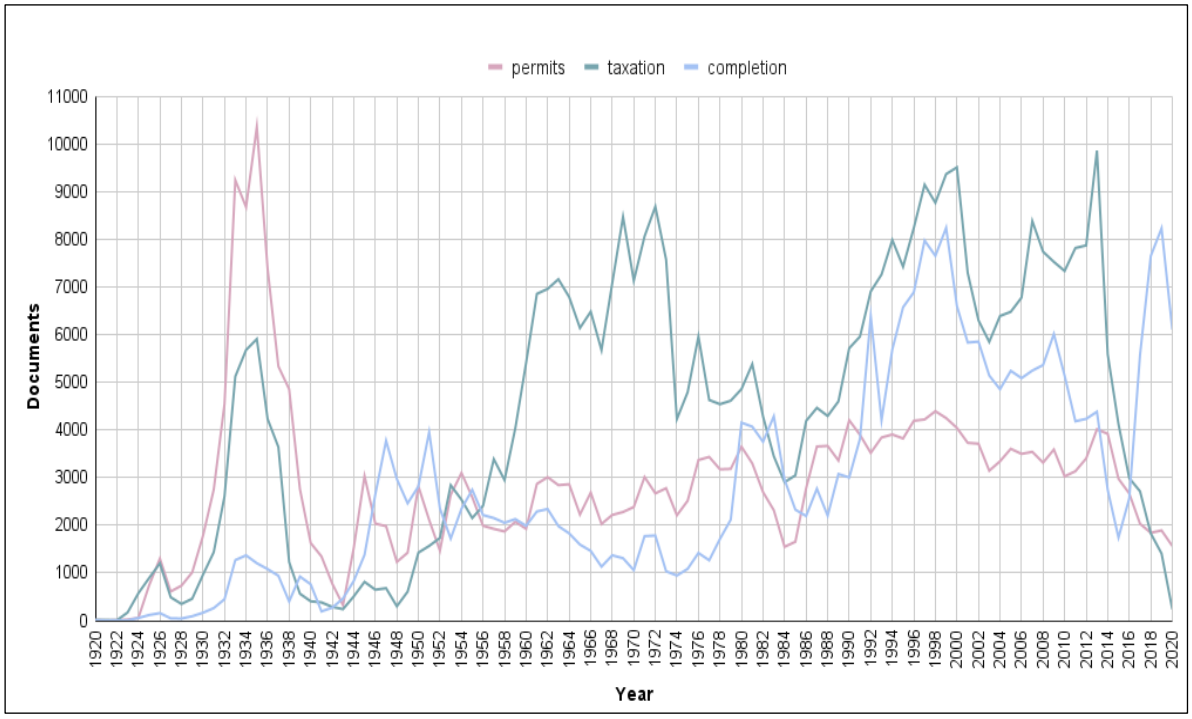

Figure 4. Documents per year by category: permits, taxation, completion.

4.4. Automating Building Dating Using Predictive Modelling

To automate the building dating process, we developed a code that estimates the "birth" and reconstruction years for each building file based on the quantity, frequency and date of the municipality's archival documents.[6] The analysed documents were selected and grouped according to the three primary categories (Table 4), each representing a different aspect of the construction lifecycle: permits, taxation, and completion. To account for variations in documentation practices over time, the model divided the historical data into four distinct periods: 1920–1925, 1926–1943, 1944–1985, and 1986–2021. These periods differ slightly from those defined in Section 4.3 to better reflect the different administrative and documentation patterns. For the latter three periods, we used ground-truth construction year data of 150 building files from 1926 to 2021 to weigh the relative value of peaks in each of the three document categories in accurately predicting "birth" and reconstruction years. For the 1920–1925 period, predictive weights were not applied due to sparse bureaucratic records, and predictions relied solely on the presence of a permit, which proved mostly effective.

For each of the three latter periods, a minimum weight threshold was determined by identifying the lowest weight necessary to predict a construction year. Each year's score summed the predictive category weights within a 3-year window of the target year, prioritising years with higher cumulative weights as more likely to represent actual construction events. Subsequent years with weights exceeding the threshold were spaced at least 10 years apart from any previously identified years to avoid clustering and improve temporal accuracy. To address the differences in documentation practices across periods, we applied distinct predictive approaches tailored to each timeframe and validated them through an iterative process. For 1926–1943, predictions were based on the minimum weight threshold, as validated by ground-truth data. In the 1944–1985 and 1986–2021 periods, the model required an additional condition for accuracy: the presence of either a permit or completion category in proximity to the target year. This requirement reduced false positives by focusing on documents indicating key construction milestones.

Running the model on the ground-truth dataset of 133 sample buildings, we were able to determine that the model performed relatively well. Of the 150 predictions, 127 key dates (84.6%) were accurately predicted within an error margin of 0 to 2 years, with an absolute deviation from zero of 2.08 years (see distribution of deviations, Figure 5). We further validated another random sample of 43 building files comprising 110 predictions. Each building file was manually examined, and its significant years were extracted and compared against the model's automated predictions. The manual year extractions resulted in a four-year proximity of 83.7% accuracy for the first year of major construction activity and 88.9% for the subsequent major reconstruction years.

Running the validated prediction model on the entire building file database resulted in 22,838 buildings with an identified "birth" (or original construction) year (which we nicknamed "Y1"). We were also able to identify the first ("Y2", 13,158 buildings), second ("Y3", 4,953 buildings), and third ("Y4", 988 buildings) reconstruction years of buildings, indicating substantial expansion or significant modification that took place after a "birth" event. 6,055 building files did not have sufficient documents or did not have a permit to enable us to predict their significant years distinctively. We observed that for buildings constructed before the 1980s, predictions for years beyond Y2 often became irrelevant as it introduced many false positives. To enhance the model's precision, we restricted predictions for Y3 and Y4 to buildings from 1980 onwards, accepting a slight trade-off in accuracy to reduce false positives. Eventually, the manual analysis of Y3 achieved 77.8% accuracy within a four-year range, while Y4 predictions demonstrated a higher accuracy of 90%. The significance of the second-, third- and fourth-year data lies in its ability to highlight less frequent but potentially impactful changes in a building's lifecycle. These data points can reveal reconstruction, major renovations, repurposing, or other notable changes that might not be as common but are crucial for understanding the evolution of the city's infrastructure and construction

[6] The web automation script can be downloaded from GitHub code repository: https://github.com/bdar-lab/TLVArchiveAnalyzer

economy (Figures 7, 8, 9, and 10). By incorporating these years, the analysis gained a more comprehensive view of trends in construction activity and their long-term implications on urban development.

Figure 6 exemplifies the prediction method and shows an accurate prediction of the building's significant years by considering condensed administrative periods (y1, 1932) while ignoring times of taxation activity only (1975, 1979, 1988, 1994) or periods that precede major construction activities (2001) that resulted in later significant modifications (y2, 2004).

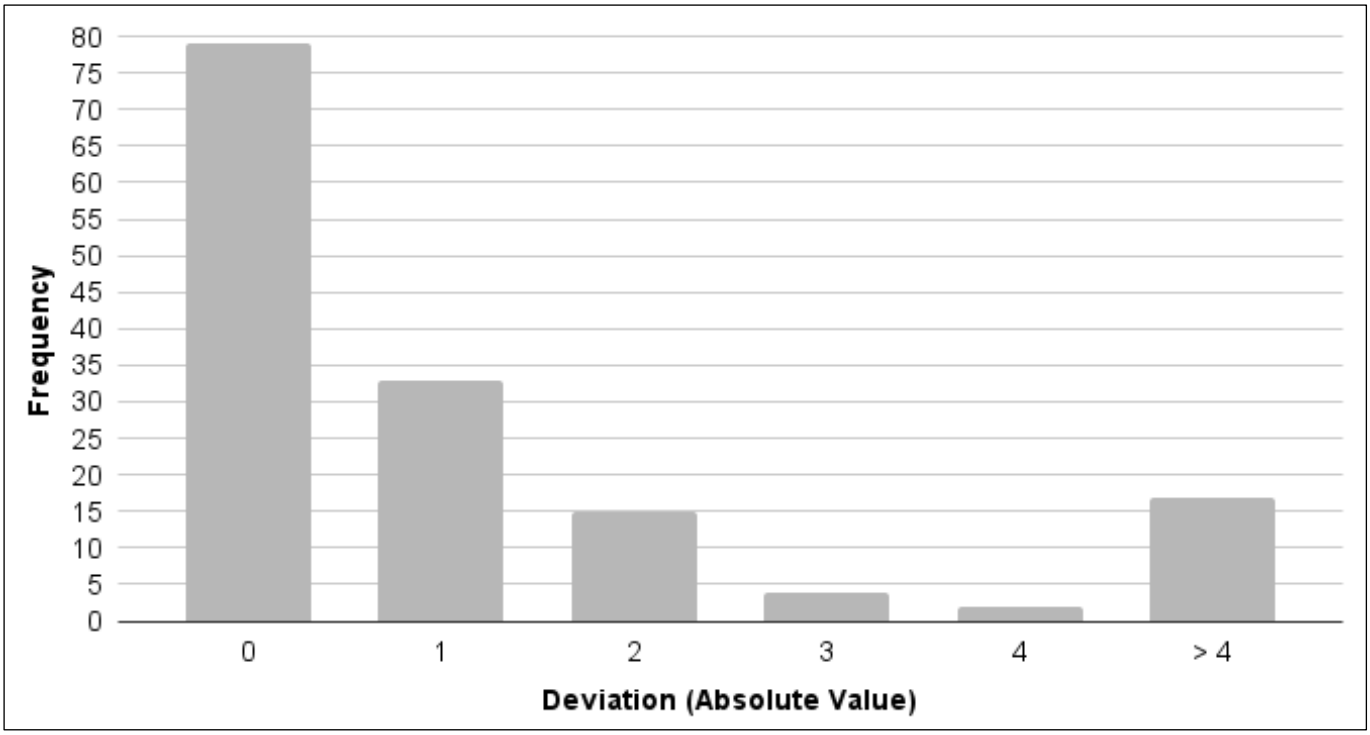

Figure 5. Distribution of prediction deviations from ground-truth years (absolute values).

Figure 6. Yearly document trends for a single building file (1 Yehuda ha-Levi St.), showing predicted birth (y1) and reconstruction (y2) years.

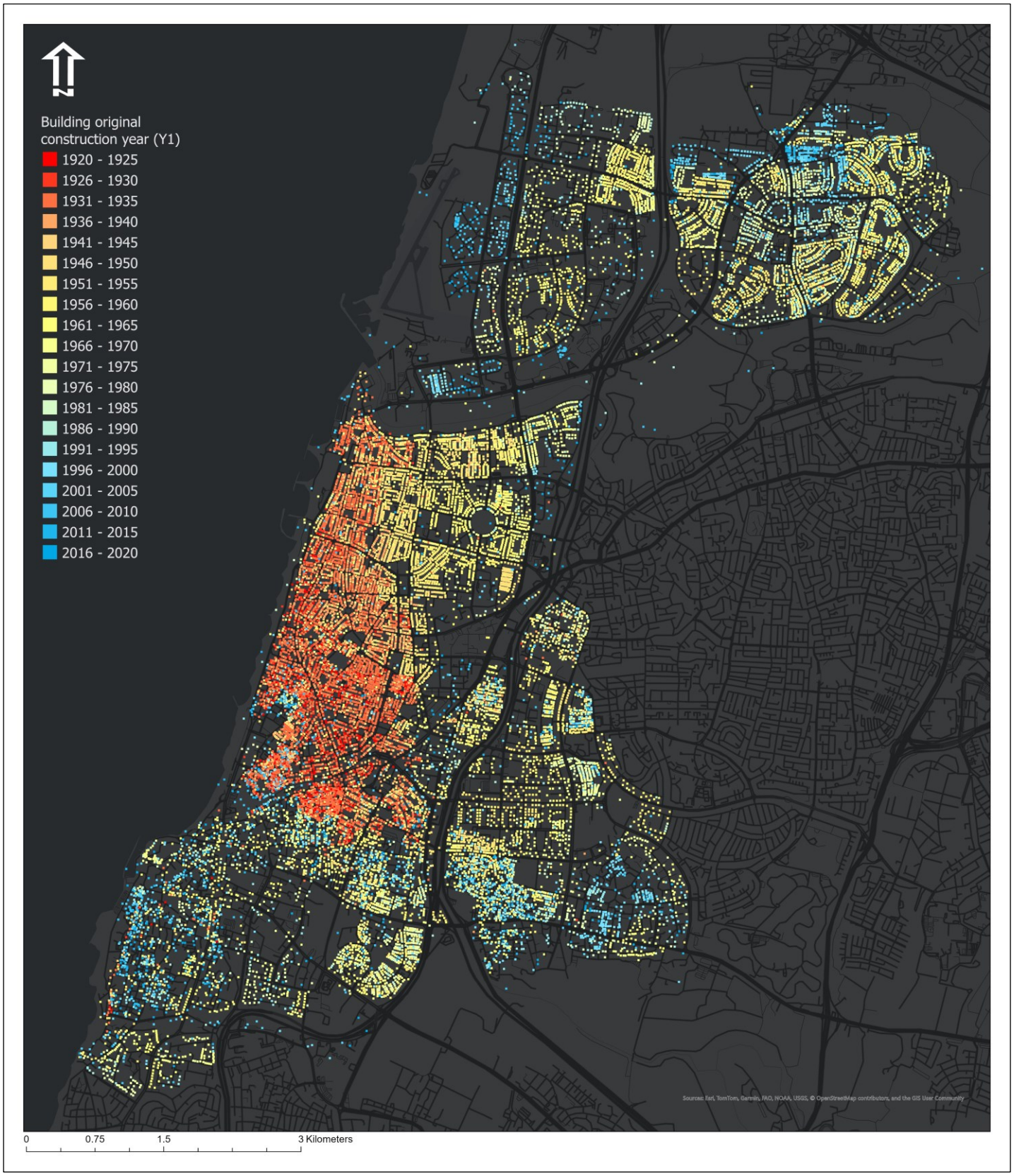

Figure 7. Construction chronology in Tel Aviv-Yafo, 1920-2020: (Y1) building birth years.

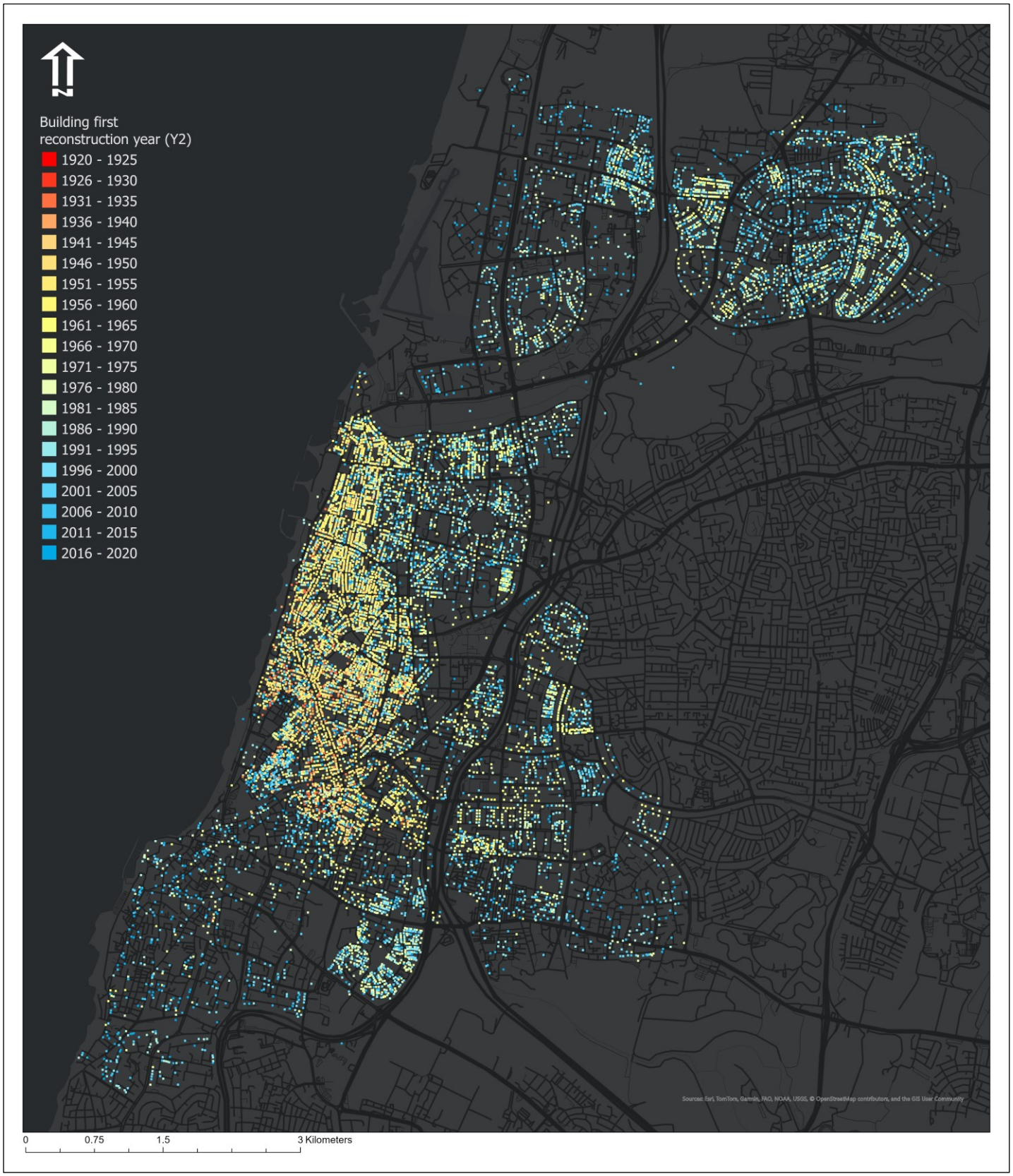

Figure 8. Construction chronology in Tel Aviv-Yafo, 1920-2020: (Y2) building reconstruction years.

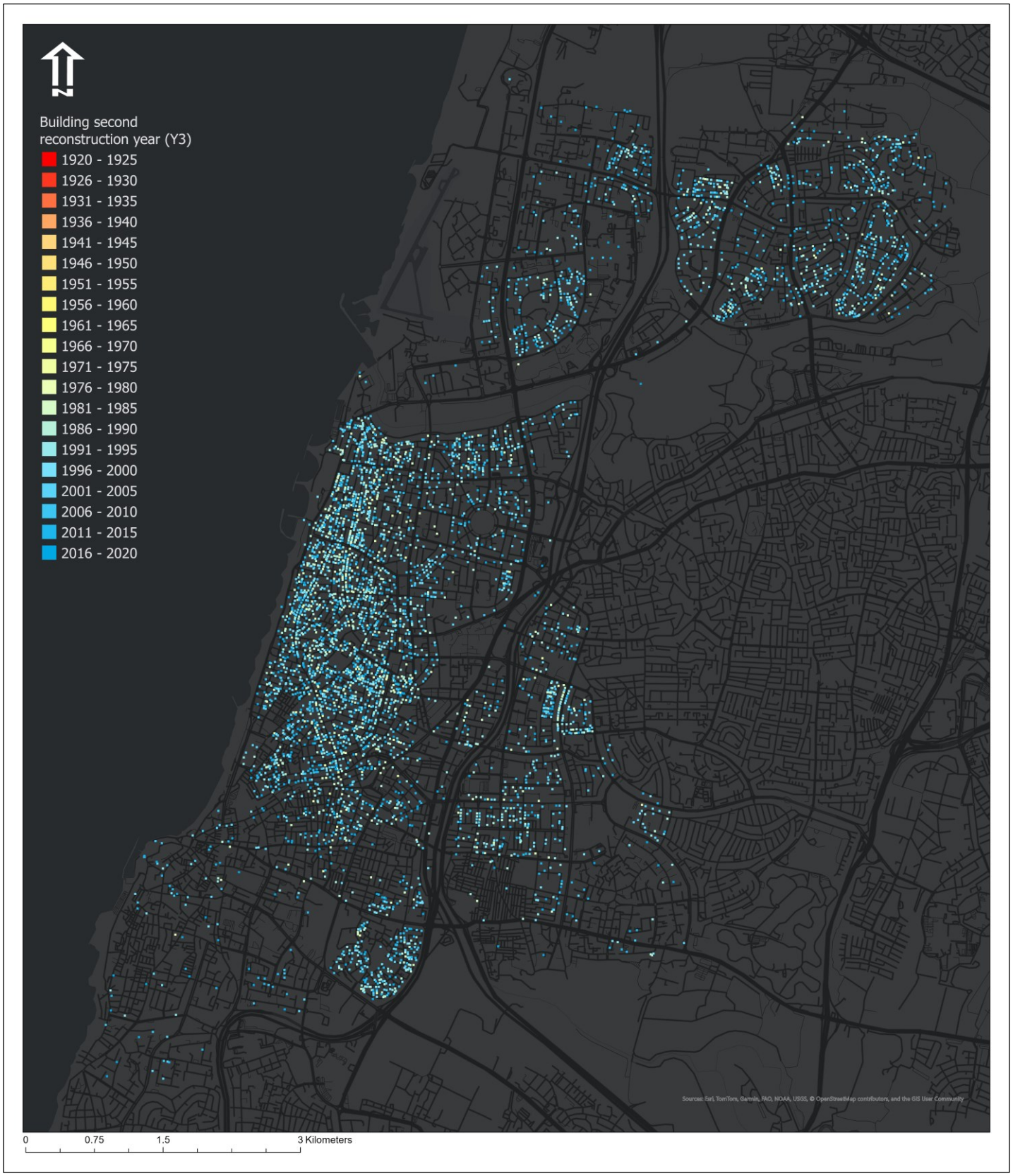

Figure 9. Construction chronology in Tel Aviv-Yafo, 1920-2020: (Y3) building reconstruction years.

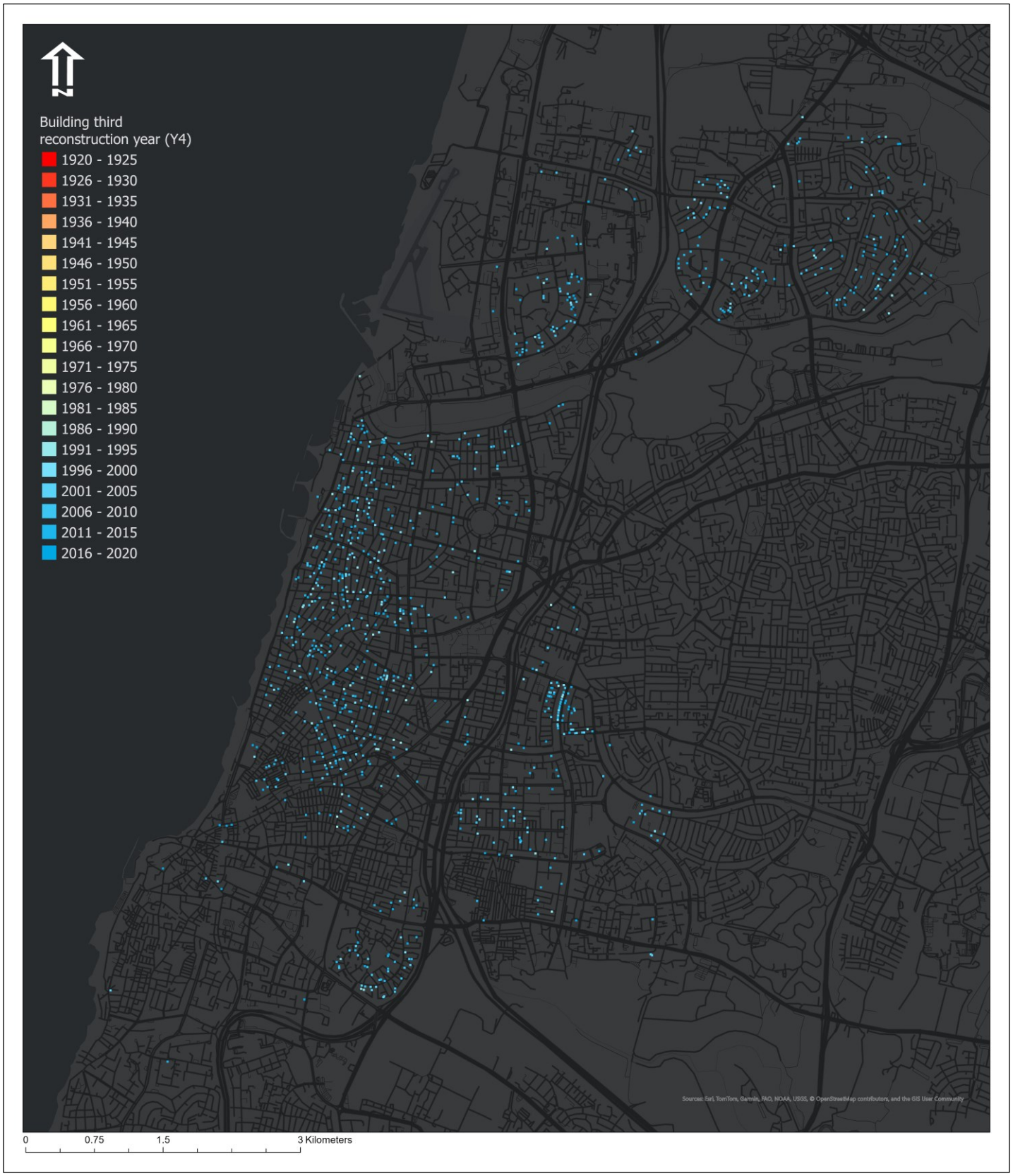

Figure 10. Construction chronology in Tel Aviv-Yafo, 1920-2020: (Y4) building reconstruction years.

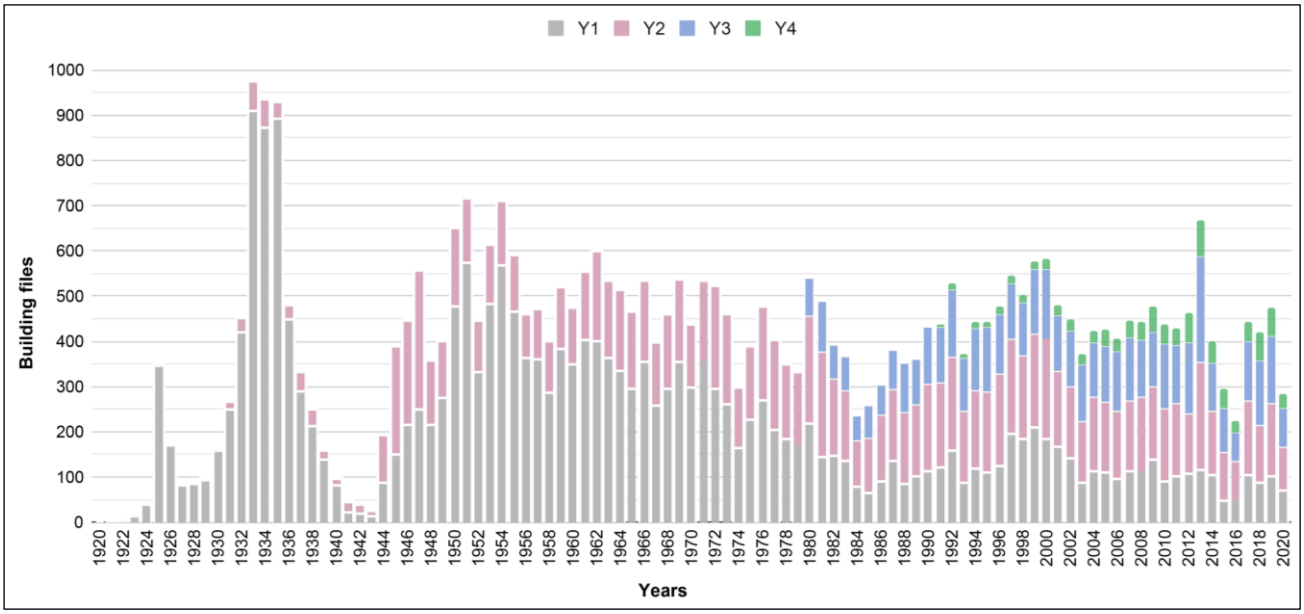

Figure 11. Overall automatic prediction of birth and reconstruction years (Y1, Y2, Y3, Y4) for building files per year.

5. Discussion

5.1. Building Dating in Municipal Archives

This study focused on formulating a consistent and reproducible definition of a building's birth and reconstruction dates throughout a large building database. One of the fundamental challenges identified in the process was the inconsistency in how different archives and databases record different temporal attributes related to a building's lifespan. This conceptual inconsistency poses significant challenges for researchers attempting to compare data across different sources and geographies or conduct comprehensive analyses of urban and architectural development trends. Acknowledging this gap, we proposed a structured methodology that can be modified based on the unique nature and context of the analysed databases.

A more fundamental challenge is the ontological definition of a building's "birth", which has to be answered with clarity while acknowledging that there cannot be a singular, definitive definition of the term. The question of when a building is "born" is inherently complex and varies depending on legal, architectural, and cultural contexts, as well as the available documentation. Our aim in this study was to counter this complexity and present a framework that can be adapted according to the specific needs of different geographic locations and research agendas.

In our case, selecting the building permit as a primary marker for the "birth" and "reconstruction" of a building, we were able to generate a detailed building age dataset of a city with a good level of confidence. Combined with two other categories of statutory documents stored in the archive we analysed, the reliance on building permit dates offers a practical formulation that can be used to determine city-scale construction trends. While we recognise that building permits are just one approach and that municipal records may vary significantly across locations, the consistent availability and formal role of permits in documenting construction approval make them an effective marker for major construction events, as exemplified by the results of our model validation process for the earlier periods. In later periods, since 1986, we have seen a decline in permit dominancy as documentation practices enforced a larger presence for the other two document categories, alongside a general surge in document submission quantities. A building permit, reinforced with taxation and completion records, offers a specific year of issuance, yielding more precise results than conventional building age prediction methods, which often use broader intervals, such as decades. However, our process was not perfect and could benefit from an elaborated periodic-specific cleaning procedure to eliminate false positive results (e.g. constructing a fence, enclosing a balcony) and from integrating complementary methods, like change detection in historical remote sensing imagery.

Alongside proposing a practical methodology for building dating, our study suggests a bottom-up approach to locating critical economic changes in the construction economy as they are manifested at the scale of separate building plots. Here, the building permit is a key document marking when resources are allocated for development and when demand for new infrastructure is high. Mapping the building plots for which permits are issued can provide insights into the geographic distribution of market demands and urban planning priorities at specific times. Building permits also reflect larger economic changes by revealing shifts in construction activity, investment levels, and development trends. Additionally, fluctuations in the number of permits issued can provide insights into financial cycles, such as booms and recessions, affecting the real estate, construction, and architectural industries. An increase in the number of permits issued often correlates with economic growth and increased real estate development, while a decrease can signal economic downturns or regulatory changes. For example, an increase in reconstruction permits in Tel Aviv-Yafo since the mid-1980s, as shown in Figure 11, correlates with recent understandings of the urban renewal trend in the city's recent history (Aleksandrowicz, 2024; Hoffmann & Horn, 2021).

5.2. Challenges and Limitations in Classifying and Standardising Data

While quantitative analyses of municipal archives and building documents offer valuable insights, they are not without challenges, as Bruno and Corea (2019) demonstrated in their study of building permits as indicators for production in construction. A primary issue is the inconsistency

and incompleteness of archival records. Our dataset revealed substantial gaps in consistent documentation, particularly in the first half of the 1920s, and did not cover all the buildings within the current city boundaries. These inconsistencies are not unique to our study; they reflect common issues in municipal archives, such as uneven documentation quality and underrepresentation of certain areas. For example, building permit records for parts of Jaffa before its administrative integration into Tel Aviv in 1950 are notably sparse, often due to poor record-keeping rather than actual historical underdevelopment; in later periods, these geographic disparities are minimal (Figures 7, 8, 9, and 10). This geographic disparity can skew the analysis, making it difficult to draw comprehensive conclusions about urban development trends and calling for the use of alternative documents for certain areas and periods.

Such limitations highlight a broader issue in relying solely on quantitative analysis, which, while seemingly objective, can inadvertently perpetuate the biases and gaps in the source material. For instance, relying on quantitative data to determine significant periods of urban change assumes the availability and accuracy of such data across all periods and regions, which is not always the case. Therefore, such a study requires critical engagement with the data to identify and account for such biases, ensuring a more complete appreciation of the results. The accuracy of any prediction model similar to ours would, first and foremost, be limited by an archive's consistent organisation and its archiving system, methods, and norms.

The lack of standardisation in data entry and classification poses another complication to such analyses. Administrative and legislative data has often not been properly attained, recorded, or standardised in municipal institutions, as Münster et al. (2019) and Ammon (2018) have noted. For example, the absence of a single, unified identifier for buildings, coupled with the variability in address and parcel number assignments, necessitated meticulous data merging and cleaning efforts in linking building files with their corresponding addresses and parcel numbers within a GIS framework. Furthermore, buildings on corner parcels or within large complexes often have multiple associated addresses, complicating the analysis. Similarly, a single parcel might contain multiple buildings, or a building might span several parcels, further complicating data uniformity. Such practical issues of inconsistencies are part of common data handling and cleaning processes and should be executed with precision.

Periodisation adds another layer of complexity to data handling. Historical cataloguing and classification methods are affected by legislative and administrative trends and conventions, necessitating context-specific interpretive frameworks for different periods. For example, the surge in building permits in 1930s Tel Aviv required a different evaluation technique than that of earlier or later periods. Recognising and adapting to these historical contexts is essential for accurately interpreting data and addressing the variability in documentation practices over time. Although this context dependence might limit direct comparisons across archives, effectively managing these factors allows for a more robust understanding of urban growth and transformation dynamics.

6. Conclusion: What Can a Quantitative Reading of Municipal Engineering Archives Tell Us about Urban History?

The advent of large-scale digital databases and data analysis technologies has enhanced our capacity to investigate historical questions with a level of precision previously difficult to achieve. Municipal archives, particularly those that have been digitised, serve as rich data repositories that could reveal intricate details about urban development. However, this approach complements rather than replaces traditional historical narratives, which have often relied on anecdotal evidence or interpretations. While data-driven analysis offers the potential for a more objective and comprehensive understanding of past trends, it is important to acknowledge the limitations inherent in these datasets, as highlighted by recent studies (Sun et al., 2022; Zeppelzauer et al., 2018). Discrepancies in data collection methods, inconsistencies in record-keeping, and gaps in archival coverage pose challenges that must be addressed. Despite these challenges, our study demonstrates the potential of working directly with raw administrative data. By cleaning and analysing this data, we can mitigate some of its intrinsic limitations and uncover valuable insights that might otherwise be obscured.

This study also highlights significant gaps in the ontological clarity and methodological rigour within architectural historiography and urban studies, particularly regarding the temporal aspects of buildings. The lack of consistent definitions for the “birth” and “reconstruction” of buildings in existing databases presents an obstacle to conducting reliable high-resolution diachronic analyses of building stocks. Our approach proposes an explicit and reproducible definition of a building’s birth and reconstruction, emphasising the role of official certification documents in marking significant construction activities. While this method offers a more accurate prediction of building birth and reconstruction years for large-scale, quantitative analyses, it is important to recognise that this framework might need to be adapted when applied to other urban contexts.

The implications of this study extend beyond the confines of academic discourse into practical applications in urban planning and architectural conservation. Understanding the timelines of building construction and modification can contribute to identifying periods of significant urban growth or decline, estimating building renovation potential, and aiding in planning future developments. Additionally, GIS-based mapping, as demonstrated in this study, can inform heritage conservation decisions and highlight the practical value of large data-driven GIS mapping, particularly in participatory conservation of heritage areas, as recently demonstrated by Salimi et al. (2025). The proposed methodology provides a tool for architectural historians and urban planners to more accurately map the evolution of the built environment, such that it is not based solely on contemporary data such as images and GIS data but rather builds on reliable processing and insight extraction from archival metadata.

This study also contributes to the emerging field of spatial humanities, particularly within the context of architectural historiography. By leveraging digitised municipal archives and advanced data extraction techniques, the study showcases the potential of digital tools for uncovering new insights into historical urban development. The methodological framework proposed here can serve as a model for future spatial humanities projects, encouraging the integration of data-driven approaches in the study of architectural history and urban studies.

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Data Availability Statement: Data might be available upon a reasonable request.

Conflicts of Interest: The authors declare no conflict of interest.

References

Aleksandrowicz, O. (2024). *From within the box: the architecture of Bar Orian [in Hebrew]*. Babel Publishers.

Allen, E. (2005). *How buildings work: the natural order of architecture* (3rd ed.). Oxford University Press. https://doi.org/10.1093/oso/9780195161984.001.0001

Ammon, F. (2018). Digital humanities and the urban built environment: Preserving the histories of urban renewal and historic preservation. *Preservation Education & Research*, *10*, 11–31.

Archipedia. (2024). Society of Architectural Historians. https://sah-archipedia.org/content/FAQs

Biljecki, F., & Sindram, M. (2017). Estimating building age with 3D GIS. *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *4*(4W5), 17–24. https://doi.org/10.5194/isprs-annals-IV-4-W5-17-2017

Bruno, G., & Corea, C. (2019). Do building permits act as a leading indicator of Italy short-term production in construction? *Electronic Journal of Applied Statistical Analysis*, *12*(2), 416–428. https://doi.org/10.1285/i20705948v12n2p416

Daniels, M., & Peyceré, D. (Eds.). (2000). *A guide to the archival care of architectural records: 19th-20th centuries*. ICA - International Council on Archives.

Duvshani, G. (1993). *Architect Yehudah Magidovits [in Hebrew]*. Ministry of Defense.

England, H. (2018). *Principles of Selection for Listed Buildings* (Issue November). https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/757054/Revised_Principles_of_Selection_2018.pdf

Esmaeili, H., Woods, P. C., Thwaites, H., & Hashim, K. (2014). Digital archiving of architectural heritage. *Reinventing Cities and Places: Proceedings of the International Urban Design Conference on 'Cities, People and Places*, 97–107. https://www.academia.edu/34815708/Digital_Archiving_of_Architectural_Heritage

Ferreira-Lopes, P., & Pinto-Puerto, F. (2018). GIS and graph models for social, temporal and spatial digital analysis in heritage: The case-study of ancient Kingdom of Seville Late Gothic production. *Digital Applications in Archaeology and Cultural Heritage*, *9*. https://doi.org/10.1016/j.daach.2018.e00074

Ferreira-Lopes, P., & Pires Rosa, M. (2023). Metodología de captura y análisis de datos del patrimonio inmueble industrial de la Eurociudad del Guadiana. *Ge-Conservacion*, *24*(1), 56–68. https://doi.org/10.37558/gec.v24i1.1205

Finnish Architecture Navigator. (2020). https://finnisharchitecture.fi/

Golan, A. (2023). Boundary making in the formative years of Tel Aviv Township, 1920–1923. *Urban History*, *50*(4), 757–772. https://doi.org/10.1017/S0963926822000177

Het Nieuwe Instituut Collection. (2024). https://zoeken.nieuweinstituut.nl/en

Hoffmann, J., & Horn, E. (2021). *POMO: Architecture of Privatization [in Hebrew]*. The Avie and Sarah Arenson Built Heritage Research Center, The Technion.

International Code Council (ICC). (2021). *International Building Code 2021 (IBC): Chapter 2 Definitions*. https://codes.iccsafe.org/content/IBC2021P2/chapter-2-definitions

Israeli Central Bureau of Statistics (ICBS). (2024). *Israeli Central Bureau of Statistics: Definition Glossary*. https://www.cbs.gov.il/en/Pages/All-Terms.aspx?k=Construction+begun

IView. (2024). *Tel Aviv-Yafo GISN*. https://gisn.tel-aviv.gov.il/

Karmi-Melamede, A. (2018). *My Father, Dov Karmi [in Hebrew]*. Babel Publishers.

Li, Y., Chen, Y., Rajabifard, A., Khoshelham, K., & Aleksandrov, M. (2018). Estimating building age from Google street view images using deep learning. *Leibniz International Proceedings in Informatics, LIPIcs*, *114*(September). https://doi.org/10.4230/LIPIcs.GIScience.2018.40

Merritt, F. S., & Ricketts, J. T. (2000). *Building design and construction handbook* (6th ed.). McGraw-Hill Professional Publishing New York, USA.

Münster, S., Apollonio, F. I., Bell, P., Kuroczynski, P., DI Lenardo, I., Rinaudo, F., & Tamborrino, R. (2019). Digital cultural heritage meets digital humanities. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRS Archives*, *42*(2/W15), 813–820. https://doi.org/10.5194/isprs-archives-XLII-2-W15-813-2019

Ogawa, Y., Zhao, C., Oki, T., Chen, S., & Sekimoto, Y. (2023). Deep learning approach for classifying the built year and structure of individual buildings by automatically linking street view images and GIS building data. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, *16*, 1740–1755. https://doi.org/10.1109/JSTARS.2023.3237509

Philadelphia Architects and Buildings Project. (2024). https://www.philadelphiabuildings.org/pab/app/pj_display_alldates.cfm/5854

Ravid, B. (2004). *Joseph Berlin, Architect: Between little Tel-Aviv and the White City [in Hebrew]*. Binyan VeDiyur.

Ravid, B. (2008). *Josef Tischler: Architect and town planner [in Hebrew]*. Bauhaus Center Tel Aviv.

Rosser, J. F., Boyd, D. S., Long, G., Zakhary, S., Mao, Y., & Robinson, D. (2019). Predicting residential building age from map data. *Computers, Environment and Urban Systems*, *73*(August), 56–67. https://doi.org/10.1016/j.compenvurbsys.2018.08.004

Salimi, H., Fadaei Nezhad Bahramjerdi, S., & Tootoonchi, R. (2025). The Role of Geographic Information Systems (GIS) in Participatory Conservation of Heritage Areas. *European Journal of Geography*, *16*(1), s1–s11. https://doi.org/10.48088/ejg.si.spat.hum.h.sal.1.11

Sun, M., Zhang, F., Duarte, F., & Ratti, C. (2022). Understanding architecture age and style through deep learning. *Cities*, *128*(May), 103787. https://doi.org/10.1016/j.cities.2022.103787

Szekely, I. (2017). Do Archives Have a Future in the Digital Age? *Journal of Contemporary Archival Studies*, *4*(2), 1. http://elischolar.library.yale.edu/jcas/vol4/iss2/1

Tel Aviv-Yafo Municipality. (2024). *The Tel Aviv-Yafo Municipality's Engineering Administration Archive*. https://handasa.tel-aviv.gov.il/Pages/default.aspx

The Getty Research Institute. (2021). *Art & Architecture Thesaurus® Online*. http://vocab.getty.edu/page/aat/300004792

Thornes, R., & Bold, J. (1998). *Documenting the cultural heritage*. Getty Publications. https://books.google.co.il/books?hl=en&lr=&id=HYL9EAAAQBAJ&oi=fnd&pg=PP1&ots=7js7v1Tn1x&sig=_4Gd-zJCBEv7PQ_RmC7uu0smktw&redir_esc=y#v=onepage&q&f=false

Tooke, T. R., Coops, N. C., & Webster, J. (2014). Predicting building ages from LiDAR data with random forests for building energy modeling. *Energy and Buildings*, *68*(PARTA), 603–610. https://doi.org/10.1016/j.enbuild.2013.10.004

United Nations Department of Economic and Social Affairs. (1997). *International recommendations for construction statistics (Series M, No. 47, Rev. 1)*. https://unstats.un.org/unsd/distributive_trade/SeriesM_47rev1E.pdf

United Nations Department of Economic and Social Affairs. (2017). Principles and Recommendations for Population and Housing Censuses, Revision 3. In *Statistical Papers* (Vol. 3, Issue March). UN. https://doi.org/10.18356/bb3ea73e-en

Van Hoesen, J., & Letendre, S. (2013). Characterizing the spatiotemporal evolution of building-stock age in Poultney, Vermont: A GIS-based approach to improve thermal efficiency in historical buildings. *Environment and Planning B: Planning and Design*, *40*(4), 630–643. https://doi.org/10.1068/b38085

Visocka, S. (2010). An analysis of building construction based on building permits statistics. In *Eurostat: Statistics in Focus 55/2010*. https://ec.europa.eu/eurostat/web/products-statistics-in-focus/-/ks-sf-10-055

Zeppelzauer, M., Despotovic, M., Sakeena, M., Koch, D., & Döller, M. (2018). Automatic prediction of building age from photographs. *ICMR 2018 - Proceedings of the 2018 ACM International Conference on Multimedia Retrieval*, *3206060*(c), 126–134. https://doi.org/10.1145/3206025.3206060

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