

Politecnico di Torino

Master of Science in architecture for Sustainability

MASTER'S THESIS

Creating interactive dashboards and visualization strategies for sustainable design scenarios in cities and integrating approaches to create a digital twin of Torre Littoria.

Supervisors: Prof. Anna Osello

Prof. Matteo Del Giudice

Candidate:Fatemeh Barati

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Abstract

This thesis investigates the integration of Building Information Modelling (BIM), Geographic Information Systems (GIS), environmental analysis, and interactive visualization to support the sustainable transformation of historic buildings and their urban environments. Torre Littoria in Turin, Italy, is selected as the case study due to its architectural significance, its relationship with the historic urban fabric of Via Roma, and the challenges associated with introducing sustainable interventions within a heritage-sensitive context.

The research develops an integrated BIM-GIS workflow for connecting building-scale information with the surrounding urban context through different digital environments. A BIM model of Torre Littoria is developed to support building-scale environmental analysis, while GIS-based methods are used to represent and analyse the surrounding urban environment. The workflow addresses BIM-GIS interoperability by considering the transfer, simplification, and spatial integration of building and urban data. Environmental analyses are subsequently used to evaluate three sustainable intervention scenarios: electrochromic glazing, photovoltaic integration, and vegetation enhancement in selected outdoor areas.

The scenarios are evaluated according to their environmental performance, spatial characteristics, heritage constraints, and regulatory considerations. Revit is used for building-scale modelling and solar analysis, while QGIS/UMEP is used for urban context and, outdoor environmental analysis. ArcGIS Pro is employed to organize, spatially relate, and visualize the resulting datasets. Finally, ArcGIS Online and Experience Builder are used to develop an interactive web-based environment in which the case study, analytical results, and intervention scenarios can be explored and compared.

The resulting framework demonstrates how BIM-GIS integration and interactive visualization can support context-sensitive decision-making for sustainable interventions in historic urban environments. Rather than identifying a single universally optimal intervention, the research provides an integrated workflow for comparing alternative strategies according to their environmental performance, spatial context, architectural characteristics, and heritage constraints.

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List of Abbreviations

Abbreviation	Full term
BIM	Building Information Modelling
GIS	Geographic Information Systems
BIM-GIS	Building Information Modelling-Geographic Information Systems
DT	Digital Twin
UMEP	Urban Multi-scale Environmental Predictor
SOLWEIG	Solar and Longwave Environmental Irradiance Geometry
PV	Photovoltaic
BIPV	Building-Integrated Photovoltaics
EC	Electrochromic
SHGC	Solar Heat Gain Coefficient
Tmrt	Mean Radiant Temperature
SVF	Sky View Factor
QGIS	Quantum Geographic Information System
IFC	Industry Foundation Classes
RVT	Revit project file format
GIS-BIM	Geographic Information Systems-Building Information Modelling

Chapter 1 Introduction

1.1 Research Context and Problem

Cities have always been understood and transformed through different forms of representation. Maps, plans, sections, elevations, perspectives, and written documents have been used to describe the built environment and support decisions about its development. These forms of representation changed over time according to available technologies, the type of information that needed to be communicated, and the political, social, and technical conditions of each period. Representation can therefore be understood not only as a way of describing reality, but also as a tool for interpreting it and supporting future decisions.

Digital technologies have expanded this role by allowing architectural and urban information to be connected within more complex environments. Three-dimensional models, georeferenced databases, environmental simulations, and interactive visualization can combine geometry with additional information and analytical results. Rather than replacing traditional forms of representation, these technologies extend them. Historical drawings, maps, surveys, and photographs remain important sources for understanding existing buildings, while contemporary digital tools make it possible to reorganize this information according to current analytical needs (Del Giudice, 2018).

At the same time, sustainable transformation of the built environment requires information from different spatial scales. Building characteristics such as façades, glazing, roofs, terraces, and materials influence environmental performance at the architectural scale, while surrounding buildings, street geometry, vegetation, open spaces, and urban morphology affect solar access, shading, and outdoor conditions at the urban scale. BIM and GIS can support these different levels of information, but they are based on different geometries, semantic structures, levels of detail, coordinate systems, and analytical purposes. Their integration can therefore involve simplification, transformation, or loss of information during data exchange (Wang et al., 2019; Zhu & Wu, 2022).

These challenges become more significant in historic urban contexts, where sustainable interventions cannot be evaluated only through environmental performance. Architectural significance, heritage constraints, visual impact, spatial character, and the identity of the place must also be considered. The concept of genius loci is relevant in this context because it emphasizes the physical, historical, cultural, and experiential qualities that contribute to the identity of a place (Norberg-Schulz, 1980). Sustainable transformation should therefore improve environmental conditions without weakening the relationship between a historic building and its urban context.

Torre Littoria in Turin provides a relevant case for investigating this condition. The building is closely connected to Via Roma, Piazza Castello, the Sant'Emanuele block, the portico system, the internal courtyard, and the surrounding historic fabric. Its environmental behaviour and potential transformation cannot therefore be understood only at the scale of

the individual building. The research problem addressed by this thesis is consequently the fragmentation of architectural, urban, historical, and environmental information across different scales and digital environments. A more integrated representation is needed to connect these elements and support the evaluation of sustainable interventions within a sensitive historic context.

1.2 Research Gap

Existing research has demonstrated the potential of BIM, GIS, Digital Twin approaches, environmental analysis, and sustainable retrofit as separate or partially connected fields. BIM-GIS integration studies have shown that combining detailed building information with urban-scale spatial data can support planning and sustainability applications. However, interoperability remains a recurring challenge because differences in geometry, semantics, data structures, and levels of detail may lead to simplification or loss of information during data exchange (Wang et al., 2019; Zhu & Wu, 2022).

At the same time, many Digital Twin applications in the built environment focus on operational monitoring, infrastructure management, sensor integration, or real-time data. Other studies address environmental analysis or sustainable retrofit mainly at either the building scale or the urban scale. Fewer studies combine these aspects within a single workflow that connects detailed building information, urban context, environmental analysis, scenario comparison, and interactive visualization.

This gap is particularly relevant in historic urban contexts. Sustainable interventions in protected or architecturally significant buildings must respond not only to environmental performance, but also to heritage constraints, visibility, architectural identity, and the relationship between the building and its surrounding urban fabric. There is therefore a need for integrated approaches capable of linking building and urban scales while also supporting the comparison of sustainable interventions within these constraints.

The present thesis addresses this gap by testing an integrated BIM-GIS and Digital Twin-oriented workflow for Torre Littoria. The contribution lies not in applying these technologies as isolated tools, but in examining how historical and architectural information, urban spatial context, environmental results, sustainable scenarios, and interoperability issues can be brought together within a common representation for context-sensitive decision support.

However, limited research has explored how these approaches can support context-sensitive sustainable retrofit decisions in architecturally protected historic buildings.

This thesis addresses this gap by developing an integrated BIM-GIS-based workflow that combines building information, urban context, environmental analysis, and scenario evaluation to support sustainable retrofit decisions for Torre Littoria.

1.3 Aim and Objectives

The main aim of this thesis is to create a new digital image of the city by connecting building-scale and urban-scale information within an integrated digital environment that supports environmental analysis and the comparison of sustainable intervention scenarios.

To achieve this aim, the thesis pursues the following objectives:

- To establish a conceptual connection between historical forms of urban and architectural representation and contemporary digital approaches to the built environment.
- To develop and integrate building-scale and urban-scale digital information for Torre Littoria and its surrounding historic context.
- To examine the interoperability of the BIM-GIS workflow by identifying how geometry, attributes, and analytical information are preserved, transformed, simplified, or lost during data exchange.
- To analyse selected environmental conditions and compare sustainable intervention scenarios, including electrochromic glazing, photovoltaic integration, and vegetation-based strategies, while considering heritage compatibility, regulatory constraints, and the architectural and urban context.
- To develop an integrated and interactive visualization that brings together architectural information, urban context, environmental results, and alternative scenarios, allowing their relationships and differences to be explored and compared.
- To evaluate the feasibility of sustainable interventions by integrating environmental performance with heritage and regulatory constraints.

1.4 Research Questions

Based on the research problem and the objectives defined above, the thesis is guided by the following research questions:

1. How can BIM and GIS be integrated to connect building-scale and urban-scale information for Torre Littoria, and what interoperability limitations emerge during the exchange of geometry, attributes, and analytical data?

2. How can environmental analysis results be linked to architectural and urban spatial information in order to evaluate the relationship between Torre Littoria and its surrounding built environment?

3. Which sustainable intervention strategies are feasible for Torre Littoria considering environmental performance, architectural and heritage constraints, regulatory requirements, and the characteristics of the urban context, and how can the selected scenarios be compared and represented in order to identify the most appropriate solutions?

Chapter 2 Literature Review

2.1 Evolution of urban and architectural representation: from historical maps to digital representations

The representation of cities and buildings has always been closely related to the ways in which the built environment is understood, documented, and transformed. Maps and architectural drawings are not simple reproductions of physical reality. They select and organize information according to a specific purpose, scale, cultural context, and available technology. Representation has therefore developed together with changes in society, construction practices, and the information required to support architectural and urban decisions.

Before the introduction of digital technologies, spatial information was mainly communicated through drawings, maps, engravings, plans, elevations, sections, and perspectives. Each of these methods described a different aspect of space. Plans provided information about position and spatial organization, elevations represented the visible characteristics of façades, sections explained vertical relationships, and perspectives communicated depth and volume. The development of descriptive geometry, particularly through the work of Gaspard Monge in the eighteenth century, provided a more systematic method for translating three-dimensional objects into two-dimensional representations. This contributed to the development of architectural drawing as a technical language through which geometric and construction information could be communicated more precisely (Del Giudice, 2018).

Historical urban maps reveal a similar effort to communicate complex spatial conditions using the representational tools available at the time. Many maps combined planimetric information with pictorial or perspectival elements in order to represent not only streets and urban blocks, but also buildings, roofs, monuments, defensive structures, and other elements that contributed to the character of the city. Such representations were not produced exclusively for geometric documentation. They could also communicate urban hierarchy, territorial organization, political intentions, or a desired image of the city.

Turin provides a particularly clear example of the relationship between representation and urban transformation. Its urban structure developed through successive phases of expansion and modification, and historical maps recorded changes in streets, blocks, squares, public buildings, and the relationship between the old city and its later extensions. The historical documentation collected in *Torino nell'Ottocento e nel Novecento* demonstrates how maps from different periods can be compared to reconstruct changes in the urban fabric and understand the processes that produced the present form of the city (Scarzella, 1995). The twentieth-century transformation of Via Roma similarly illustrates how drawings, plans,

elevations, photographs, and urban maps were used together to document existing conditions and communicate new architectural and urban interventions (Moglia, 1995).



Figure 2.1

Historical view of Piazza Castello and Torre Littoria in Turin.
Source: Giorgio Mondadori e Associati, Via Roma: Cinquant'anni di storia, immagini e vita di Torino, p. 66.

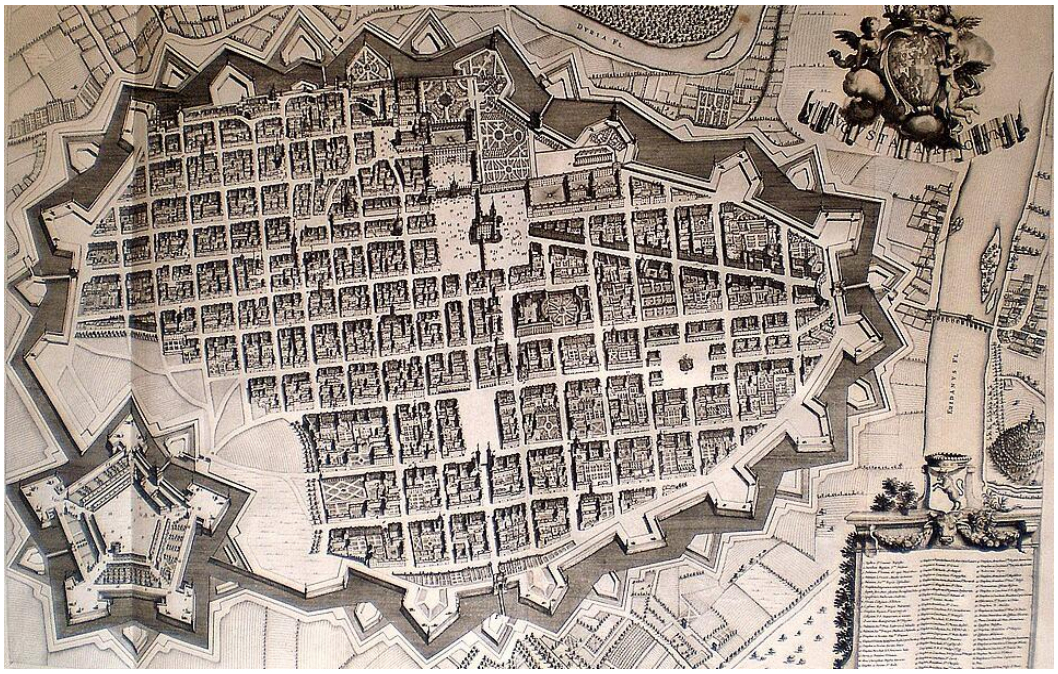


Figure 2.2

Historical map of Turin in 1674, illustrating the representation of urban form through a combination of cartographic and pictorial elements. Source: Wikimedia Commons (n.d.), "Torino's map (1674)".

At the building scale, knowledge was also distributed across several independent forms of documentation. Plans, elevations, sections, structural drawings, construction details, photographs, specifications, and archival documents represented different aspects of the same architectural object. Understanding the complete building therefore required the interpretation and combination of several sources. This condition is particularly relevant for existing and historic buildings, where original drawings may be incomplete and where later modifications can create differences between the documented design and the current physical condition.

The documentation of Torre Littoria illustrates this process. Historical drawings, photographs, structural information, and archival sources provide complementary information about its geometry, construction system, and architectural development. Del Giudice (2018) demonstrates how such heterogeneous historical documentation can be interpreted and translated into a digital information model of the building. In this process, the digital model does not replace the historical sources; rather, it provides a new environment in which information previously distributed across different documents can be reorganized and related.

The transition toward digital representation can therefore be understood as part of a longer evolution rather than as a complete break with traditional methods. As the complexity of buildings and cities increased, representation was required to communicate not only form and dimensions but also a growing amount of technical, spatial, environmental, and descriptive information. Digital environments respond to this condition by allowing geometry to be associated with additional information and by creating relationships between different datasets and scales. Del Giudice (2018) describes information modelling as a natural renewal of architectural representation through digital technologies, extending the traditional role of drawing toward the organization of both graphical and alphanumeric information.

This transformation is also occurring at the urban scale. Historical maps remain important sources for understanding the evolution and identity of cities, but their information can now be georeferenced, compared, combined with contemporary spatial datasets, and incorporated into digital analytical environments. Recent research has explored the transformation of historical maps and documents into multidimensional knowledge models using GIS and other computational methods, demonstrating how historical information can contribute to contemporary analysis rather than remaining only as archival documentation (Lyu & Deng, 2025).

Digital representation therefore changes the way the image of the city can be constructed and used. Traditional representations were primarily document-based and relatively static, while contemporary digital environments can connect geometry, spatial information, historical knowledge, analytical results, and alternative conditions. The objective remains related to a long-established purpose of representation: making the city understandable. What changes is the capacity to connect different forms of knowledge and to examine relationships that were previously distributed across separate documents.

In this thesis, the concept of a new digital image of the city is understood within this historical continuity. It does not refer simply to the production of a more realistic three-dimensional model. Instead, it refers to the possibility of connecting building-scale and urban-scale information, historical knowledge, and environmental results within a common representation. The digital tools examined in the following sections are therefore considered as contemporary methods for extending the role of urban and architectural representation from documentation toward integrated analysis and comparison.

2.2 Digital Approaches in the Built Environment

The increasing complexity of buildings and cities has encouraged the development of digital approaches capable of organizing, analysing, and connecting different types of spatial and technical information. These approaches operate at different scales and with different purposes. Building Information Modelling provides detailed object-based information at the building scale, while Geographic Information Systems support georeferenced spatial analysis and the management of urban-scale datasets. Their integration can connect architectural information with the wider urban context, while Digital Twin approaches extend this relationship by combining digital models with additional data, analysis, and interactive visualization. The following sections examine these approaches individually and then consider their integration and interoperability.

2.2.1 Digital Twins in the Built Environment

The concept of the Digital Twin originated in industrial and manufacturing applications, where a digital representation was connected to a physical asset in order to support monitoring, analysis, and lifecycle management. The concept has since expanded into the built environment and is increasingly applied to buildings, infrastructure, and urban systems. In this context, a Digital Twin is not simply a three-dimensional representation, but a digital environment in which information about a physical asset can be organized, analysed, updated, and communicated.

An important distinction concerns the level of connection between the physical and digital environments. Kritzinger et al. (2018) distinguish between a digital model, a digital shadow, and a Digital Twin. A digital model has no automatic data exchange with the physical asset. A digital shadow includes an automated one-way flow of data from the physical object to the digital representation, while a Digital Twin involves a more integrated relationship in which information can flow between the physical and digital systems. This distinction is important because the term Digital Twin is often applied to projects that function primarily as digital models or visualization platforms rather than fully connected operational systems.

In the built environment, Digital Twins can combine several types of information. Geometric and semantic representations may be provided through BIM or other three-dimensional

models, while additional datasets can include sensor measurements, environmental information, historical documentation, simulation results, and operational records. Analytical processes can then be used to evaluate current conditions, compare alternatives, or predict future performance, while visualization platforms allow this information to be explored and communicated. Recent research therefore treats the Digital Twin as an integrated information environment rather than as a single model or software application.

The potential applications of Digital Twins vary according to scale and purpose. At the building scale, they can support monitoring, maintenance, energy management, structural assessment, and refurbishment. At the urban scale, they may connect buildings, infrastructure, public spaces, mobility systems, and environmental information. Their value lies particularly in the possibility of relating heterogeneous datasets to spatial objects and using them to understand conditions that cannot be represented through geometry alone.

Digital Twins are also relevant to sustainable transformation because they can provide a common environment for linking environmental information with existing building and urban conditions. BIM-IoT research, for example, shows that Digital Twin approaches can support real-time monitoring, lifecycle management, and the evaluation of building performance, although interoperability, standardization, data integration, cost, and technical complexity remain important challenges.

However, not every research application requires a fully operational Digital Twin with continuous sensor data and bidirectional communication. The required level of integration depends on the objectives of the study. A research prototype may instead combine digital models, spatial information, environmental analysis, scenarios, and interactive visualization without maintaining a continuous live connection with the physical asset. Such systems should be described carefully so that their capabilities are not overstated.

This distinction is directly relevant to the present thesis. The research does not develop a fully operational Digital Twin with real-time sensors or automatic control. Instead, it adopts a Digital Twin-oriented approach in which building-scale and urban-scale information, environmental analysis results, sustainable intervention scenarios, and visualization are connected within a common digital framework. The purpose is therefore not to reproduce the complete functionality of an operational Digital Twin, but to investigate how an integrated digital representation can support the comparison and interpretation of information across different scales.

Table 2-1

Classification of digital representation approaches and their relation to the methodology developed in this thesis.

Concept	Data connection	Main characteristics	Relation to this thesis
Digital Model	No automatic data exchange	Static digital representation containing geometric and semantic information	Revit BIM model developed for Torre Littoria
Digital Shadow	One-way data flow	Digital representation updated through external data inputs	Environmental and spatial analyses derived from BIM/GIS data
Digital Twin	Bidirectional and real-time data connection	Continuous interaction between physical and digital systems	Not implemented due to the absence of real-time sensor integration
Digital Twin-oriented approach	Integrated information from multiple sources	Combines different datasets and analytical workflows to support decision-making	Proposed methodology integrating BIM, GIS, environmental analysis and scenario evaluation

2.2.2 Building Information Modelling

Building Information Modelling (BIM) represents a shift from conventional drawing-based documentation toward an object-based digital environment in which geometric and non-geometric information can be organized within the same model. Building elements are not represented only through lines or surfaces, but as parametric objects associated with properties, relationships, materials, and other descriptive information. BIM can therefore support a more integrated representation of a building, allowing graphical and alphanumeric data to be connected and managed within a common information structure.

This characteristic is particularly relevant for existing buildings, where knowledge is often fragmented across different sources. Historical documents, drawings, photographs, surveys, point clouds, material information, and on-site investigations may all contribute to the reconstruction of the building. Osello and Cassis (2026) describe BIM-based workflows for the built heritage in which information from historical research, geometric surveys, laser scanning, parametric modelling, and environmental simulations is progressively integrated into a shared digital model. In this context, BIM becomes not only a geometric representation but also a framework for organizing multidisciplinary knowledge about the existing asset.

The application of BIM to historic buildings has led to the development of Historic Building Information Modelling (HBIM). HBIM extends the principles of BIM to heritage assets, where

the model may incorporate information about historical development, construction systems, materials, surveys, conservation conditions, and archival documentation. Previous studies emphasize that this process is more complex than BIM modelling for new construction because information can be incomplete, heterogeneous, or uncertain, and the model must often be reconstructed from multiple independent sources (Murphy et al., 2009; Volk et al., 2014).

For this reason, the amount and reliability of information included in an existing-building BIM model should be related to its intended use. Osello and Cassis (2026) refer to the use of different levels of geometry, information, and reliability in BIM modelling of existing buildings. This is particularly important in heritage contexts, where producing unnecessary geometric detail may increase modelling effort without contributing to the objectives of the analysis. The model should therefore contain the level of representation and information required for the specific investigation rather than attempting to reproduce every physical component with the same degree of detail.

BIM also provides a basis for environmental and performance-related analysis. Information associated with building components can be used in simulations concerning energy performance, materials, structural behaviour, or other aspects of the building. In the Digital Twin-oriented workflows discussed by Osello and Cassis (2026), BIM acts as one of the principal information sources that can be connected with simulations and other digital systems. This relationship is particularly relevant for Green Building applications, where geometric and semantic building information can support the evaluation of environmental performance and alternative interventions.

However, BIM is primarily oriented toward the detailed representation of individual buildings. When building information must be related to streets, surrounding buildings, vegetation, infrastructure, or wider urban conditions, a different spatial scale and information structure is required. Osello and Cassis (2026) emphasize that building and urban scales are interdependent and that the transition between them represents an opportunity for integrating models, data, and simulations. In this context, BIM provides the detailed architectural information, while GIS supports the representation and analysis of the wider spatial environment. The characteristics of GIS and the challenges involved in connecting the two systems are discussed in the following sections.

2.2.3 Geographic Information Systems

Geographic Information Systems (GIS) are digital environments designed to collect, manage, analyse, and visualize information associated with geographic locations. Unlike conventional databases, GIS organize information according to spatial reference, making it possible to examine not only the characteristics of individual objects but also their position and relationships with surrounding elements. Spatial data can therefore be combined through layers representing buildings, streets, land use, vegetation, infrastructure, topography, environmental conditions, and other components of the urban environment.

GIS are particularly suitable for urban and territorial analysis because they operate across wider spatial scales than building-oriented modelling systems. Wang et al. (2019) describe GIS as a macro-scale approach capable of managing geospatial information about the external environment of buildings, while BIM primarily represents detailed information at the scale of the individual building. This distinction allows GIS to support the analysis of relationships between individual architectural objects and broader urban systems, including street networks, neighbouring buildings, public spaces, landscape elements, and infrastructure.

An important capability of GIS is the integration of heterogeneous datasets within the same spatial reference system. Vector data, raster data, elevation models, environmental datasets, historical maps, and other georeferenced information can be overlaid and analysed together. This makes GIS useful not only for visualization but also for identifying spatial patterns and relationships. Applications in the built environment include urban planning, land-use analysis, infrastructure management, environmental assessment, risk analysis, heritage management, and the evaluation of urban morphology and outdoor environmental conditions.

GIS can also support sustainability-oriented analysis. Spatial information describing urban geometry, vegetation, land cover, solar conditions, and other environmental variables can be combined to investigate how the configuration of the city influences environmental performance. Wang et al. (2019) note that GIS-based simulation methods can contribute to the evaluation of energy performance, carbon emissions, solar availability, and other parameters relevant to sustainable urban development. In this sense, GIS provides an analytical context in which the environmental behaviour of individual buildings can be related to surrounding urban conditions.

The role of GIS becomes particularly relevant when the built environment is studied across multiple scales. Osello and Cassis (2026) emphasize that urban and building scales are interdependent and that the transition between them should not be considered only as a difference in representation detail. At the urban scale, GIS can describe and analyse spatial phenomena across a wide area, while at the building scale more detailed geometric and semantic information is required. Their integration therefore provides an opportunity to connect data, models, and simulations across different levels of representation.

GIS is also increasingly applied to cultural and historic built environments. Georeferenced historical information can be combined with contemporary spatial datasets in order to document changes, analyse relationships between buildings and their surroundings, and support conservation and management activities. Colucci et al. (2022), for example, demonstrate the use of GIS together with HBIM to organize heritage information at different spatial scales within a common spatial database. Their work shows that GIS can provide the urban and territorial context required to interpret individual heritage assets while maintaining links with more detailed building information.

Despite these capabilities, GIS generally represents buildings with less architectural and semantic detail than BIM. When detailed building information must be transferred into a geospatial environment, differences in geometry, data structures, semantic organization, coordinate systems, and levels of detail can create interoperability problems. For this reason, the complementary relationship between BIM and GIS is important, but their integration requires careful management of data exchange and information transformation. These issues are examined in the following section.

2.2.4 BIM-GIS Integration and Interoperability

BIM and GIS provide complementary representations of the built environment. BIM offers detailed geometric and semantic information about buildings and their components, while GIS manages georeferenced information and spatial relationships at urban and territorial scales. Their integration, often referred to as GeoBIM, aims to connect these different levels of information so that individual buildings can be interpreted together with their surrounding streets, infrastructure, vegetation, public spaces, environmental conditions, and other urban elements. This combination has increasingly been investigated for applications related to planning, sustainability, cultural heritage, infrastructure management, and Digital Twins (Wang et al., 2019).

The relationship between BIM and GIS can take different forms according to the purpose of the application. In some workflows, BIM remains the main environment and GIS contributes contextual information. In others, GIS becomes the primary environment and selected BIM information is transferred to support urban-scale analysis. A third approach combines information from both environments without requiring all data and analyses to be managed within a single software platform. Wang et al. (2019) emphasize this complementary relationship between detailed building information and wider geographic context.

Interoperability refers to the ability of different systems to exchange information and to make meaningful use of the transferred data. In BIM-GIS workflows, interoperability therefore involves more than the successful visualization of a three-dimensional model. Geometry, attributes, semantic relationships, coordinate information, and analytical results may all be affected during data exchange. Differences between BIM and GIS in data structures, geometric representations, semantics, levels of detail, and spatial reference systems can result in information being preserved, transformed, simplified, or lost.

Zhu and Wu (2022) identify BIM-to-GIS as one of the most frequently investigated directions of information exchange. Their review distinguishes geometry conversion and semantic transfer as two major interoperability tasks. Although several standards, conversion methods, and software solutions have been developed, maintaining both geometric consistency and semantic information across the two environments remains a significant challenge.

Open standards such as Industry Foundation Classes (IFC) and CityGML have been widely investigated as possible mechanisms for BIM-GIS integration because they provide structured

representations of building and urban information. IFC is primarily oriented toward detailed building information, while CityGML represents urban objects at different spatial levels. Mapping between these structures can support information exchange, but differences in their underlying schemas mean that direct correspondence between objects and attributes is not always possible.

In practical workflows, other methods may also be used when the objective of the transfer is primarily geometric. Formats such as OBJ can transfer three-dimensional form between modelling and spatial-processing environments, but they do not preserve the complete semantic structure of a BIM model. This distinction highlights the difference between geometric interoperability and information interoperability: a building may be transferred successfully as geometry while object properties, relationships, and other BIM information are partially or completely lost.

Another possible approach is to access building models directly within geospatial environments rather than converting them completely into a different data model. In such cases, the building information may remain available for reference and visualization, while the GIS environment provides the wider spatial context and analytical framework. However, direct access to a model does not necessarily imply that the original BIM functionality or editability is maintained. These different approaches demonstrate that BIM-GIS integration is not based on a single universal workflow, but on the selection of an exchange strategy according to the information and analyses required.

The relationship between different scales is particularly important in existing and historic environments. Colucci et al. (2022) demonstrate how BIM and GIS can be integrated to organize heritage information at multiple spatial levels, connecting detailed building information with roads, vegetation, raster data, and wider geographic context. Similarly, Osello and Cassis (2026) describe the transition between building and urban scales as an opportunity to integrate models, datasets, and simulations rather than simply as a change in geometric detail. In this perspective, BIM and GIS perform different but complementary roles within a broader digital representation of the built environment.

Their complementary nature also means that integration does not require every analysis to be transferred to or reproduced within the same environment. Building-scale analyses may remain within the BIM environment when they depend on detailed building geometry and component information, while GIS can support analyses that rely on wider spatial relationships and urban context. The results can then be connected at a later stage. This approach can reduce unnecessary data conversion and limit the loss of information associated with transferring detailed building data into a less detailed spatial representation.

Despite substantial progress, full BIM-GIS interoperability has not yet been achieved. The effectiveness of an integrated workflow should therefore be evaluated not only according to whether models can be transferred or visualized, but also according to which information remains reliable and usable after the exchange. This is particularly relevant for workflows

combining environmental analysis, historic-building information, and multiple spatial scales, where the quality of transferred information directly influences subsequent interpretation and comparison.

For this thesis, BIM-GIS integration is consequently understood as both a technical and an informational process. The objective is not to place all data and analyses within a single software environment, but to connect building-scale and urban-scale information while using each environment according to its analytical strengths and critically examining how information changes during transfer. This understanding provides the conceptual basis for the methodological workflow developed in the following chapters.

2.3 Related Works

The previous sections introduced the main concepts and digital approaches relevant to this research. This section reviews previous studies that are more directly related to the objectives of the thesis. The selected works are examined according to three main themes: environmental analysis across building and urban scales, sustainable retrofit of existing and historic buildings, and BIM-GIS and Digital Twin applications. The purpose is not only to describe existing approaches, but also to compare their methods, scales, data structures, analytical capabilities, and limitations in order to identify the open issues that remain relevant to the present research.

2.3.1 Environmental Analysis at Building and Urban Scales

Environmental performance in the built environment is influenced by factors operating at both building and urban scales. Previous studies have examined variables such as orientation, solar exposure, glazing properties, urban morphology, sky view factor, façade materials, and vegetation to understand how they affect thermal behaviour and outdoor comfort.

At the urban scale, Dehghan Lotfabad et al. (2025) investigated the effect of vertical greenery on outdoor thermal comfort in Via della Consolata, Turin. The study combined remote sensing and numerical simulation to evaluate air temperature, mean radiant temperature (Tmrt), Universal Thermal Climate Index (UTCI), and carbon emissions. The results showed that green walls can reduce radiant heat during peak summer conditions and improve outdoor thermal comfort, although their effect varies seasonally. The study also identified urban morphology and low sky view factor as important conditions influencing microclimatic performance.

Urban geometry and orientation have also been examined as important environmental parameters. Studies comparing different building or street orientations show that solar access and shading vary significantly according to orientation and surrounding morphology. These relationships influence both building exposure and pedestrian conditions,

demonstrating that environmental performance cannot be evaluated independently from the spatial configuration of the urban context.

At the pedestrian scale, Jung et al. (2026) investigated the effect of façade materials on thermal comfort in a dense urban corridor using ENVI-met simulations and machine-learning analysis. The study evaluated physiological equivalent temperature (PET), mean radiant temperature, and air temperature, and found that façade materials can significantly affect pedestrian heat exposure. Green walls and high-reflectance materials improved thermal conditions, while materials with greater heat-storage capacity produced higher heat stress. The authors also note that retrofitting existing buildings may be limited by architectural and legal constraints.

At the building scale, Amaral et al. (2015) investigated the relationship between glazing type, window size, and orientation using dynamic simulation. Single-, double-, and triple-glazed windows were compared according to thermal performance, solar heat gain coefficient, and orientation. The results showed that glazing performance changes significantly according to façade orientation and opening size, and that no glazing type can be considered independently from the solar conditions of the façade.

More recent research has similarly emphasized the importance of glazing properties and seasonal conditions. Studies comparing double and triple glazing show that insulation performance, solar heat gain, opening area, and ventilation interact differently across seasons. These findings support the use of façade-specific environmental analysis rather than applying a single glazing strategy uniformly to all orientations.

Overall, the reviewed studies show that environmental performance depends on a combination of building-scale characteristics and urban-scale conditions. At the building scale, glazing, orientation, and façade properties influence solar gains and thermal behaviour, while at the urban scale, morphology, sky view factor, vegetation, and surface characteristics influence shading and pedestrian thermal comfort. These studies provide an important basis for identifying the environmental parameters that should be considered when evaluating sustainable interventions, while the selection of specific retrofit strategies requires additional consideration of feasibility, heritage conditions, and regulatory constraints.

2.3.2 Sustainable Retrofit of Buildings

Sustainable retrofit studies investigate how existing buildings and urban areas can improve environmental performance through interventions that modify the building envelope, introduce renewable energy systems, or enhance outdoor environmental conditions. The effectiveness of these strategies depends not only on technical performance, but also on building type, scale, climate, cost, architectural compatibility, feasibility, and regulatory constraints.

At the district scale, Yamamura et al. (2017) developed a GIS-BIM-based urban energy planning system and applied it to twelve communities along Tokyo’s Yamanote railway line.

The study compared three approaches: converting large buildings toward nearly zero-energy standards, applying lower-cost long-tail energy-saving measures to smaller buildings, and combining both strategies. The results showed that retrofit effectiveness depends on the characteristics of the building stock and that combining different levels of intervention across a district can be more effective than focusing only on major upgrades in large buildings.

Adaptive glazing represents another retrofit strategy at the building-envelope scale. Research on smart windows has investigated the use of electrochromic glazing to dynamically control solar transmission according to environmental conditions. Gugliermetti and Bisegna (2003) examined the visual and energy performance of electrochromic windows in a Mediterranean climate, while later studies evaluated different control strategies for reducing solar gains while maintaining indoor comfort. These studies show that electrochromic glazing can provide more flexible solar control than conventional fixed glazing, although its effectiveness depends on orientation, climate, control strategy, and façade characteristics.

Photovoltaic integration is widely investigated as a retrofit strategy that combines the building envelope with renewable energy production. Kuhn et al. (2021) reviewed a broad range of Building-Integrated Photovoltaic solutions, including roof and façade systems, coloured modules, glazing-integrated systems, and different constructional configurations. Their review shows that BIPV can be adapted to different architectural conditions, but its feasibility depends on the combined consideration of energy performance, architectural integration, system design, and construction requirements.

These considerations become more restrictive in historic and protected contexts. Lucchi et al. (2022) analysed the legislative and authorization frameworks for photovoltaic technologies in historic buildings and protected areas in Italy and Switzerland. The study found that although technological development has increased the availability of visually integrated and customizable PV solutions, implementation is still strongly influenced by heritage regulations, authorization procedures, and stakeholder acceptance. In Italy, fragmented and complex authorization processes were identified as an important barrier. The study therefore demonstrates that technical solar potential alone is not sufficient to determine the feasibility of PV interventions in protected buildings.

Vegetation-based interventions have also been investigated as retrofit and climate-adaptation strategies. Dehghan Lotfabad et al. (2025), in a case study in Turin, examined the use of green walls as a measure for improving outdoor environmental conditions. Their work shows that vegetation can be considered as a retrofit option not only for its cooling potential, but also in relation to urban morphology, seasonal performance, and site-specific conditions. This highlights the importance of evaluating vegetation-based strategies according to local feasibility and context rather than treating them as universally applicable solutions.

Taken together, these studies demonstrate that sustainable retrofit can involve substantially different types and scales of intervention. Adaptive glazing modifies solar transmission through the building envelope, photovoltaic systems introduce on-site renewable energy

production, vegetation can influence outdoor environmental conditions, and district-scale strategies can combine measures according to the characteristics of different buildings. Their effectiveness is therefore highly context-dependent.

For existing and historic buildings, the reviewed literature also shows that environmental performance cannot be the only criterion for selecting an intervention. Architectural compatibility, visual impact, regulatory requirements, feasibility, and the characteristics of the existing building must also be considered. The literature therefore provides a range of potential retrofit strategies and evaluation criteria, while the selection of appropriate interventions for a specific case study requires these findings to be combined with case-specific analysis and constraints.

2.3.3 BIM-GIS and Digital Twin Applications

Previous studies have applied BIM-GIS integration through different technical strategies depending on the scale, purpose, and type of information involved. These applications range from energy management and heritage maintenance to web-based visualization and Digital Twin development. Comparing these workflows is useful because they show that integration can be achieved through direct software connections, shared databases, web platforms, or sensor-based systems, each with different strengths and limitations.

Barrile et al. (2023) developed an integrated BIM-GIS system for the energy management of buildings. The workflow combined a BIM model developed in Revit with a geospatial environment in Autodesk InfraWorks, while ArcGIS data were accessed through the Autodesk Connector for ArcGIS. The study used the integrated environment to represent the building together with surrounding buildings and transport infrastructure and to support energy-related planning. The workflow demonstrated the practical value of connecting detailed building information with geographic context, but also showed that interoperability between BIM and GIS environments remained incomplete and that not all BIM information could be preserved during the integration process.

Barrile et al. (2024) extended this investigation by comparing several approaches for BIM-GIS integration in the context of urban sustainability. Their study examined commercial integration through InfraWorks, immersive VR/AR/MR environments, and a more flexible implementation based on Cesium. The authors found that commercial software can simplify the visualization of BIM models within their geographic context, while immersive environments can improve communication and spatial understanding. However, these approaches may provide limited analytical functionality or flexibility. The Cesium-based solution was proposed as a more customizable environment for integrating structural and geospatial information, including temporal data. The study therefore highlights the continuing trade-off between ease of use, information depth, analytical capability, and interoperability.

A different integration strategy was developed by Colucci et al. (2022) for the planned maintenance of historic built heritage. Instead of simply transferring a BIM model into GIS, the

authors created a shared PostgreSQL/PostGIS spatial database containing information at different Levels of Detail. Urban and territorial information, building elements, vegetation, raster data, and maintenance records were organized within the same database. Dynamo was used as a bidirectional bridge between Revit and PostgreSQL, allowing selected BIM parameters to be exported, updated, and transferred back to the BIM model. This approach improved the connection between architectural and geographic information and allowed users to query information at different scales. At the same time, the study identified incompatibilities related to formats, geometry, software, standards, and Levels of Detail, demonstrating the complexity of maintaining structured information across BIM and GIS environments.

Web-based integration has also been investigated as a method for making combined BIM and GIS information more accessible. Varlık and Dursun (2024) developed a three-dimensional web client that displayed BIM models, photogrammetric city models, and infrastructure information within a common environment using Cesium and virtualcityMAP. Their work demonstrated that web platforms can support the combined visualization of heterogeneous urban datasets without requiring users to operate the original modelling software. However, the authors also identified technical difficulties associated with processing and displaying complex 3D data on the web, as well as continuing interoperability problems caused by differences in BIM and GIS data formats and Levels of Detail.

Digital Twin applications introduce an additional level of integration by linking digital models with monitoring or time-dependent information. A recent study developed for the Certosa Metro Station in Turin used QGIS, CAD, Revit, InfraWorks, Python, and Autodesk Tandem to create a georeferenced Digital Twin environment for structural health monitoring. Virtual sensors representing accelerometers, tiltmeters, inclinometer chains, and topographic benchmarks were linked to the BIM model, while synthetic datasets were processed in Python and transferred to Autodesk Tandem through an API. The study demonstrated how BIM and geospatial information can be extended through dynamic monitoring data, but also identified difficulties related to parameter mapping, data formatting, platform reliability, and interoperability between multiple software environments.

These studies demonstrate that BIM-GIS integration does not follow a single technical model. Direct software connections provide relatively simple workflows but may reduce information depth. Shared databases can preserve and update structured data more effectively but require more complex data modelling and synchronization. Web-based environments improve accessibility and visualization, while Digital Twin platforms allow time-dependent information to be connected to digital models but introduce additional requirements for data management and interoperability.

A recurring limitation across the reviewed applications is the difference between successful visualization and complete information integration. A BIM model may be correctly positioned and displayed in a GIS or web environment while part of its original semantic structure, parameters, relationships, or analytical information is lost or simplified. Conversely,

approaches designed to preserve richer information generally require additional databases, conversion processes, scripts, or middleware.

Overall, previous applications demonstrate the potential of BIM-GIS and Digital Twin approaches for connecting building information with urban context, supporting environmental and energy applications, managing historic assets, and communicating complex information through interactive environments. At the same time, they reveal continuing challenges related to interoperability, preservation of information, scale differences, data updating, and the integration of analytical outputs. These recurring limitations provide an important basis for identifying the open issues addressed in the following section.

Table 2-2

Synthesis of selected related studies and their relevance to the thesis

Reference	Focus	Scale	Main contribution	Relevance to this thesis
Amaral et al. (2015)	Glazing, orientation and façade performance	Building	Shows how glazing and façade configuration affect performance	Supports the electrochromic glazing scenario
Gugliermetti & Bisegna (2003)	Electrochromic windows	Building	Examines adaptive glazing for controlling solar gains	Supports the use of electrochromic glazing as a retrofit option
Kuhn et al. (2021)	Building-integrated PV	Building	Reviews opportunities and challenges of BIPV integration	Supports the PV scenario and technology selection
Lucchi et al. (2022)	PV in historic and protected buildings	Heritage / Building	Examines PV integration under heritage constraints	Supports PV feasibility in the heritage context
Dehghan Lotfabad et al. (2025)	Vertical greenery and thermal comfort	Urban / Pedestrian	Shows the influence of vegetation and urban morphology on outdoor conditions	Supports the vegetation scenario and pedestrian-scale analysis
Jung et al. (2026)	Façade materials and outdoor comfort	Urban / Pedestrian	Links façade conditions with outdoor thermal performance	Supports the connection between building envelope and urban comfort
Wang et al. (2019)	BIM–GIS integration	Building + Urban	Presents BIM and GIS as complementary systems	Supports the BIM–GIS integration framework
Zhu & Wu (2022)	BIM/GIS data exchange	Building + Urban	Identifies geometry, semantic and interoperability challenges	Supports the interoperability assessment
Colucci et al. (2022)	BIM–GIS for historic heritage	Heritage / Building + Urban	Demonstrates BIM–GIS integration across heritage scales	Supports the heritage-oriented BIM–GIS workflow
Barrile et al. (2023; 2024)	BIM–GIS and urban applications	Building + Urban	Explores integrated digital environments for spatial and environmental data	Supports the integrated digital workflow
Kritzinger et al. (2018)	Digital Twin concepts	General / Industrial	Distinguishes Digital Model, Digital Shadow and Digital Twin	Supports the Digital Twin-oriented positioning
Lai et al. (2024)	Urban Digital Twins	Urban	Discusses integrated digital environments for decision support	Supports the thesis as Digital Twin-oriented rather than operational
Proposed methodology	Sustainable retrofit evaluation of Torre Littoria	Building + Urban	Integrates BIM, GIS, environmental analysis and scenario comparison	Represents the integrated contribution of this thesis

2.4 Open Issues Emerging from the Literature

The reviewed studies show significant progress in environmental analysis, sustainable retrofit, BIM-GIS integration, and Digital Twin applications. However, several recurring issues remain only partially addressed, particularly when these approaches are applied together in historic urban contexts.

A first issue concerns the separation between building and urban scales. Building-scale studies often focus on parameters such as glazing, façade orientation, and solar exposure, while urban-scale studies analyse morphology, vegetation, sky view factor, shading, and pedestrian conditions. Although both levels are relevant, they are frequently examined through separate models and analytical environments, making it difficult to represent their relationships within a common framework.

A second issue concerns BIM-GIS interoperability and the preservation of information. Differences in geometry, semantics, coordinate systems, data structures, and Levels of Detail can lead to information being transformed, simplified, or lost during data exchange. Colucci et al. (2022), for example, identify incompatibilities between formats, geometries, standards, LoDs, and software as important challenges in BIM-GIS integration for historic heritage. This shows that successful visualization of a BIM model within GIS does not necessarily mean that its original information structure has been preserved.

A third issue concerns the translation of environmental analysis into feasible retrofit decisions. Previous studies provide evidence on environmental parameters and on strategies such as smart glazing, photovoltaic systems, vegetation, and energy-retrofit measures. However, good environmental performance alone is not sufficient to determine whether an intervention is appropriate for an existing or historic building. Architectural compatibility, visual impact, heritage constraints, regulations, and technical feasibility must also be considered.

A further issue concerns the integration of analysis, scenario comparison, and visualization. BIM-GIS and Digital Twin applications demonstrate that heterogeneous information can be combined within shared databases or interactive environments, but many studies focus mainly on monitoring, maintenance, energy management, or visualization. Fewer approaches connect building and urban information with environmental results and alternative retrofit scenarios within the same workflow.

Overall, the main open issue is therefore not the absence of individual tools or sustainable strategies, but their fragmentation across scales, disciplines, and digital environments. Building-scale modelling, urban spatial analysis, environmental evaluation, heritage knowledge, and retrofit strategies are well established individually, while their coordinated use within a common workflow remains less developed. These open issues provide the basis for the methodological approach adopted in this thesis.

Chapter 3 Methodology

3.1 Methodological Framework

The methodology adopted in this research was structured as an iterative workflow that integrated multiple sources of information, analytical scales, and digital tools. Instead of following a purely linear sequence, the process involved continuous evaluation and refinement of intermediate results, allowing adjustments to the workflow whenever technical or methodological issues emerged. The different stages of the research were therefore interconnected, with data preparation, environmental analysis, scenario development, and visualization progressively informing each other.

The methodology draws together historical and architectural documentation, site observations, geospatial and climatic data, regulatory and heritage constraints, user needs, and insights from the literature. Building-scale information and solar analysis were carried out mainly in Revit, while the urban-scale spatial and environmental analyses relied on QGIS, UMEP, and SOLWEIG. Results from both scales, combined with contextual constraints and evidence from the literature, then shaped the definition and evaluation of sustainable intervention scenarios. Finally, the BIM model, GIS data, environmental results, and scenario outputs were brought together in ArcGIS Pro, allowing them to be visualized and compared, and forming the basis for the new digital representation of Torre Littoria and its urban context.

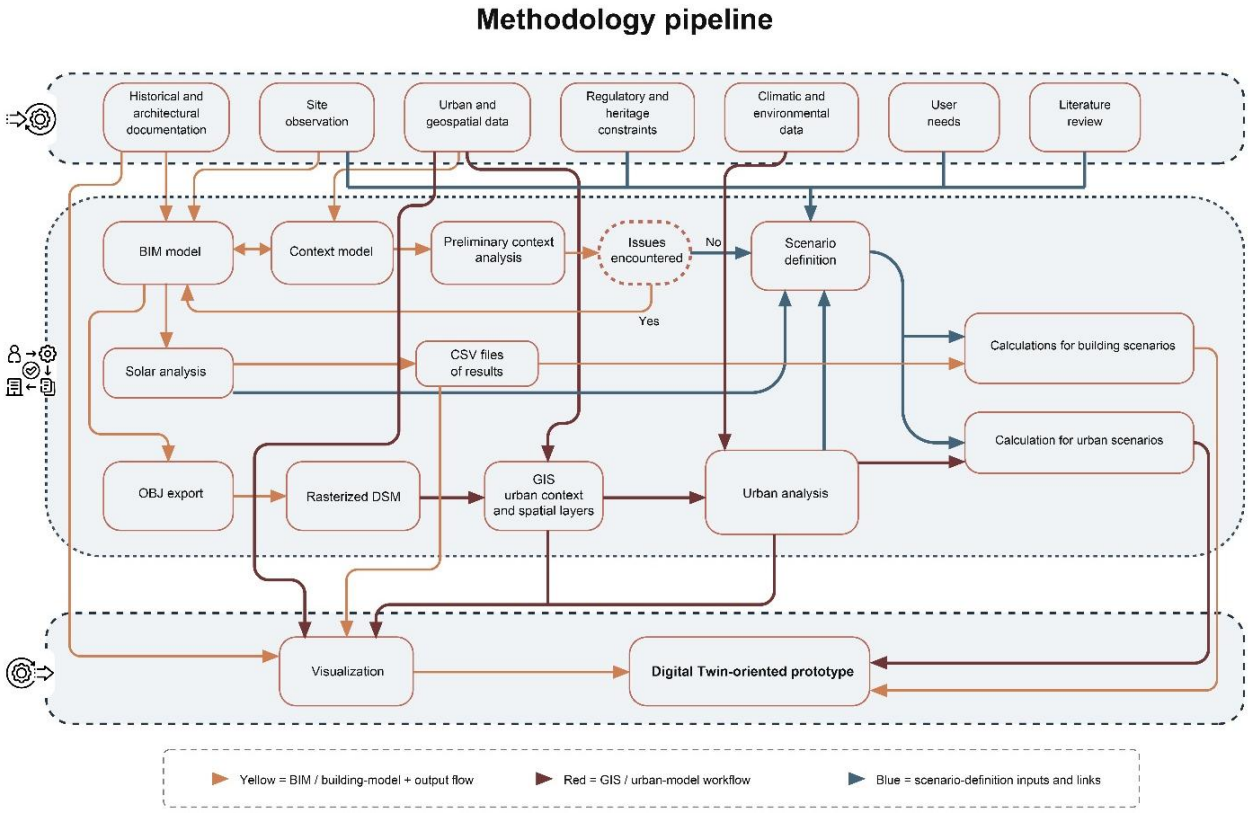


Figure 3.1

Overall methodological workflow of the research, showing the main inputs, analytical processes, iterative data exchanges, scenario development, and final integration. Source: author.

3.2 Case Study: Torre Littoria



Figure 3.2

Figure 3.2. Historical and present-day views of Torre Littoria within the Sant'Emanuele block: (left) original representation of the building during the reconstruction of Via Roma; (right) contemporary view of Torre Littoria. Sources: left image, Collezioni Storiche del Politecnico di Torino (n.d.); right image, Bruna Biamino (2010), MuseoTorino.

Torre Littoria is located in the historic centre of Turin, close to Piazza Castello and along the northern section of Via Roma. This area is characterized by continuous building fronts, internal courtyards, public squares, and an extensive system of porticos that contributes strongly to the architectural identity of the city centre. Within this predominantly horizontal urban fabric, Torre Littoria appears as a distinctive vertical landmark and creates a strong contrast with the surrounding buildings.

The tower was developed as part of the reconstruction of the northern section of Via Roma during the early 1930s. This large urban transformation aimed to give the street a more coherent architectural character through coordinated façades, continuous porticos, regulated building heights, and improved connections between the surrounding streets and public spaces (Moglia, 1995). The project was developed within the Sant'Emanuele block, which had been acquired by Società Reale Mutua Assicurazioni as part of the redevelopment of this section of Via Roma.

Torre Littoria was designed by architect Armando Melis de Villa in collaboration with engineer Giovanni Bernocco. The complex combines a lower building body that follows the scale and continuity of Via Roma with a tower rising above the block. During the development of the project, modifications to the portico configuration and the opening towards Via Viotti reduced part of the available building volume. Part of this volume was subsequently transferred

vertically, contributing to the final development of the tower (Attisano, 2025). Completed in 1934, the building reaches approximately 85 m in height and became one of the most recognizable early high-rise buildings in Turin.

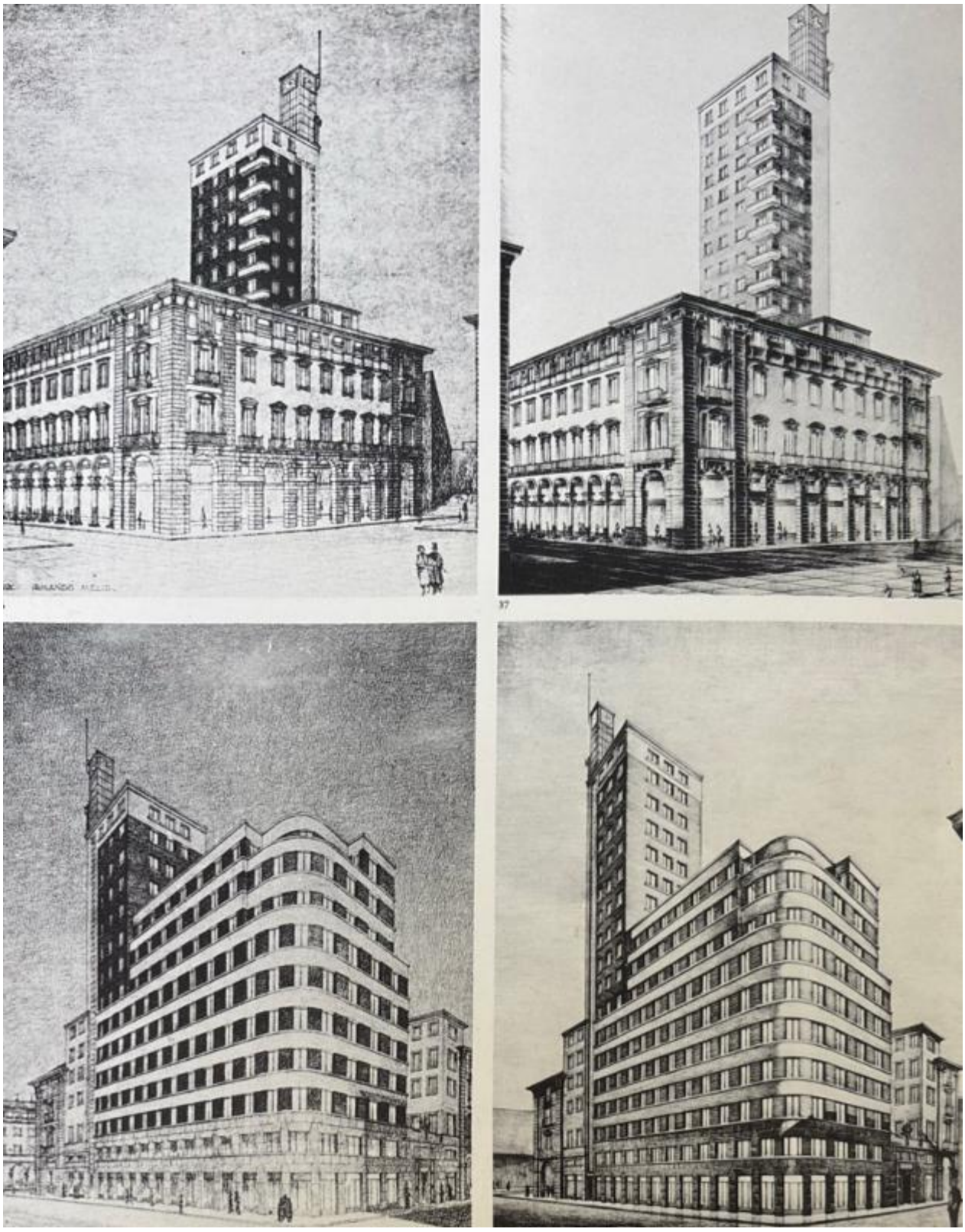


Figure 3.3

Figure 3.3. Historical design proposals for Torre Littoria, showing alternative architectural configurations developed during the design process. Source: Via Roma: Cinquant'anni di storia, immagini e vita di Torino, p. 38.

The building was also technically innovative for its period. Its main load-bearing structure was constructed in steel, with columns, beams, and bracing forming the structural frame. Historical drawings and technical documentation preserved in the Fondo Melis de Villa provide detailed information about the original plans, elevations, sections, and structural configuration of the complex (Melis de Villa & Bernocco, 1935; Del Giudice, 2018). These documents are particularly important for understanding the relationship between the tower and the wider Sant'Emanuele block.

The case study therefore includes not only the tower itself, but also its immediate architectural context. The lower wings, porticos, internal courtyard, balconies, terraces, and surrounding streets form part of the existing spatial configuration of the complex. In particular, the porticos are part of the continuous urban system developed along Via Roma during its twentieth-century reconstruction, contributing to the architectural continuity of the street, while the internal courtyard creates a more enclosed and private environment within the block.

The present condition of the complex is also the result of more recent renovation projects. Documentation associated with Studio Pomero shows interventions involving the internal courtyard and other common and external areas of the Sant'Emanuele block, including landscape elements, entrances, façades, and the relationship between the courtyard and the surrounding residential wings. The courtyard currently contains existing trees, planted areas, pedestrian paths, and landscaped spaces, and this condition forms part of the current character of the complex (Studio Pomero, n.d.).

The tower itself also underwent a significant residential transformation developed by Benedetto Camerana Studio following a competition in 2017. The project, completed in 2019, introduced contemporary residential layouts, updated building services, home-automation systems, acoustic improvements, and measures for thermo-hygrometric comfort while largely maintaining the external architectural character of the building (Benedetto Camerana Studio, 2020).



Figure 3.4

Interior views of Torre Littoria after renovation: (left) view of the internal courtyard and its relationship with the surrounding residential façades; (right) view of the vertical relationship between the courtyard space and the tower façade. Source: Author's photographs (2026).

The current post-renovation condition of Torre Littoria is used as the reference condition for this thesis. Its historical and architectural significance, its vertical relationship with the surrounding urban fabric, the presence of the internal courtyard and portico system, and the coexistence of original and contemporary layers make it a particularly suitable case study for investigating sustainable transformation within a sensitive historic context.

3.3 Stakeholders, Users, and Requirements

The proposed digital environment is designed to support the work of architects, designers, engineers, environmental specialists, building owners or asset managers, and heritage or municipal authorities involved in the analysis and potential transformation of Torre Littoria. The final visualization environment is based on ArcGIS Pro, ArcGIS Online, and Experience Builder. Building-scale information, urban context, environmental analysis outputs, and sustainable intervention scenarios are integrated within the ArcGIS environment and presented through a web-based interface developed in Experience Builder. The published application can be accessed through a dedicated web link, allowing users to view and interact with the final digital representation without requiring an ArcGIS account. An ArcGIS account is required for the authoring, management, and editing of the underlying ArcGIS content and web application. This distinction allows the final visualization to be shared with a wider range

of professional stakeholders while maintaining controlled management of the datasets and analytical outputs.

Architects and designers require an integrated understanding of both the building and its urban context. For these users, the system should make it possible to relate the BIM model to spatial and environmental information, identify relevant areas of the building and its surroundings, and compare alternative intervention scenarios within the existing architectural context.

Engineers and environmental specialists require more analytical information, including solar-analysis results, spatial data, urban environmental outputs, and the assumptions used in the evaluation of the proposed scenarios. For these users, it is important that analytical results remain connected to the building elements or urban areas to which they refer.

Building owners and asset managers are mainly interested in understanding which interventions may be technically feasible and how alternative solutions compare. The integrated visualization should therefore support the interpretation of analytical results without requiring the user to work separately with the different software environments used during the research.

Heritage and municipal authorities represent another important user group because the suitability of interventions in Torre Littoria cannot be assessed only through environmental performance. Architectural compatibility, visibility, existing conditions, and regulatory and heritage constraints must also be considered when evaluating the feasibility of a proposed intervention.

Based on these users, the main requirements of the digital environment are to connect building- and urban-scale information, maintain the spatial relationship between environmental results and the elements they describe, support the comparison of sustainable scenarios, and provide a clear visualization of the existing condition and proposed interventions. These requirements guide the selection and preparation of the input data and the subsequent development of the BIM-GIS workflow.

3.4 Input Data and Data Preparation

The development of the research workflow required information from different sources and at different spatial scales. For this study, the main inputs were organized into three groups: building documentation and contemporary site observation, spatial and environmental context data, and regulatory and heritage constraints. Each group supported a different stage of the methodology and was prepared according to its subsequent use in the BIM, GIS, environmental-analysis, and scenario-evaluation processes.

Building documentation provided the main reference for understanding both the historical and current condition of Torre Littoria. The collected material included original plans,

elevations, sections, technical descriptions, historical publications, photographs, and documentation related to later renovation works. Original documentation by Melis de Villa and Bernocco, together with archival material discussed by Del Giudice, supported the interpretation of the geometry, façades, structural organization, and relationship between the tower and the wider Sant'Emanuele block. Recent documentation associated with Studio Pomero and Benedetto Camerana Studio was instead used to understand the current post-renovation condition, particularly the courtyard, common spaces, landscape elements, and residential transformation of the tower.

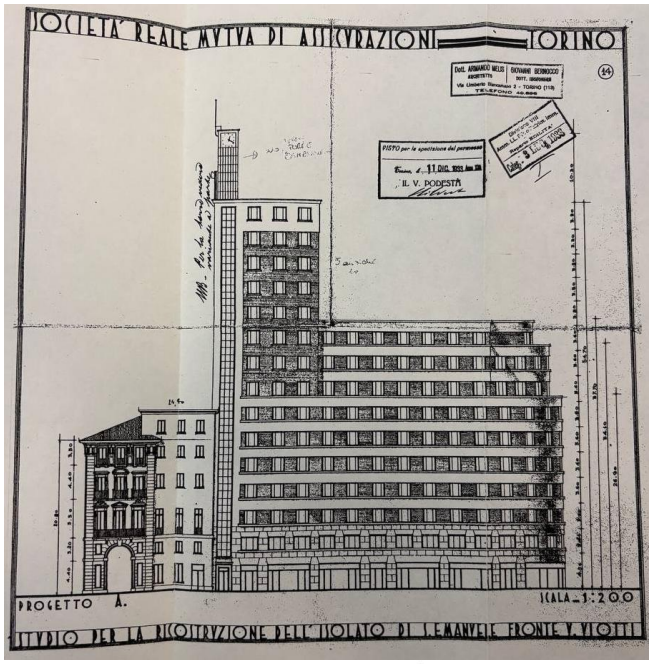


Figure 3.5

Historical documentation of Torre Littoria within the Sant'Emanuele block. Source: Lazzarino, L. (n.d.), Tesi di Laurea, Politecnico di Torino.

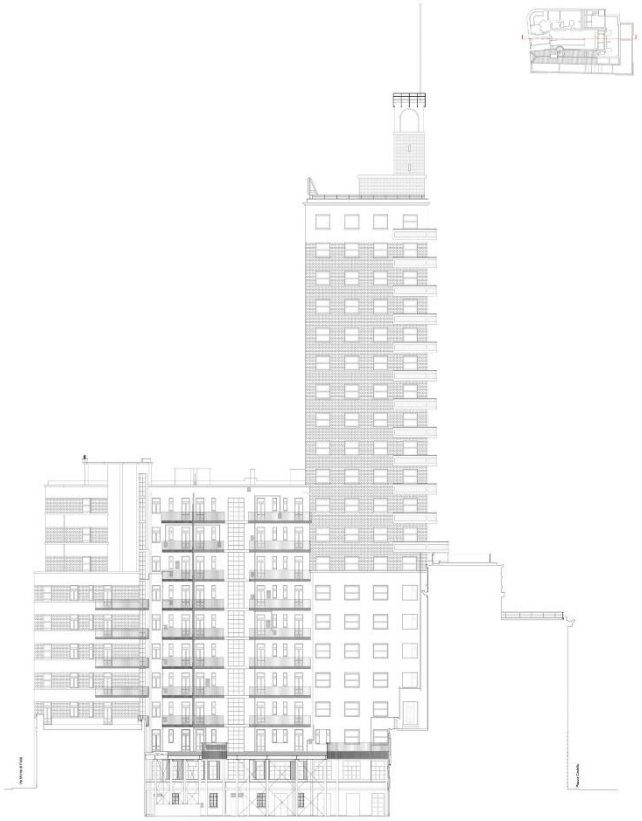


Figure 3.6

Contemporary document of the Torre Littoria complex after renovation. Source: Studio Pomero (2019), Torre Littoria Isolato S. Emanuele / La "piazzetta ritrovata".

These documentary sources were complemented by direct site observation. Photographs and observations collected during the site visit were used to compare the available drawings and project documentation with the current condition of the building and its surroundings. Particular attention was given to the façades, porticos, courtyard, existing vegetation, roof and terrace configuration, and the relationship between the building and Via Roma. Contemporary information concerning the ongoing 2025-2026 pedestrianisation and redevelopment of Via Roma was also considered. Municipal documentation describes the repaving of the street, removal of architectural barriers, new pedestrian facilities, benches, bollards, bicycle infrastructure, and selected planters. Site observation nevertheless indicated that vegetation remains relatively limited along the immediate Via Roma frontage compared with the more vegetated internal courtyard of the Sant'Emanuele block. This contrast contributed to the interpretation of the existing site condition. (Città di Torino, 2025-2026).

The second group consisted of spatial and environmental context data. Geolocation information was used to establish the position and orientation of Torre Littoria and to relate the BIM model to its urban surroundings. Urban and land-use data were collected from the Geoportale of the City of Turin and were used to develop the GIS context, including surrounding buildings, streets, pedestrian areas, vegetation, and other spatial elements required for the urban-scale analysis.Climatic information was incorporated through the EPW weather file used in the UMEP/SOLWEIG workflow. These inputs provided the geographical and climatic basis necessary to connect the individual building with its wider environmental context.

The third group consisted of regulatory and heritage constraints. Because Torre Littoria is located within Turin's historic centre and forms part of the Via Roma complex, possible interventions are influenced by heritage protection, municipal planning regulations, visibility from public space, architectural compatibility, and the permitted level of alteration to different building elements. These constraints were therefore considered from the beginning of the scenario-development process rather than being applied only as a final verification. Their role was to help distinguish between environmentally promising interventions and solutions that could also be considered compatible with the architectural and regulatory conditions of the case study.

The regulatory review was supported by the cartographic documentation of the Turin PRG, particularly the maps concerning the historic centre and the classification of its architectural characteristics. These maps were used to locate Torre Littoria within the wider protected urban fabric and to interpret the planning and architectural conditions affecting the building and its surroundings. Together with the corresponding regulatory provisions, the PRG documentation provided a spatial reference for identifying the constraints that had to be considered during the selection and evaluation of the retrofit scenarios.

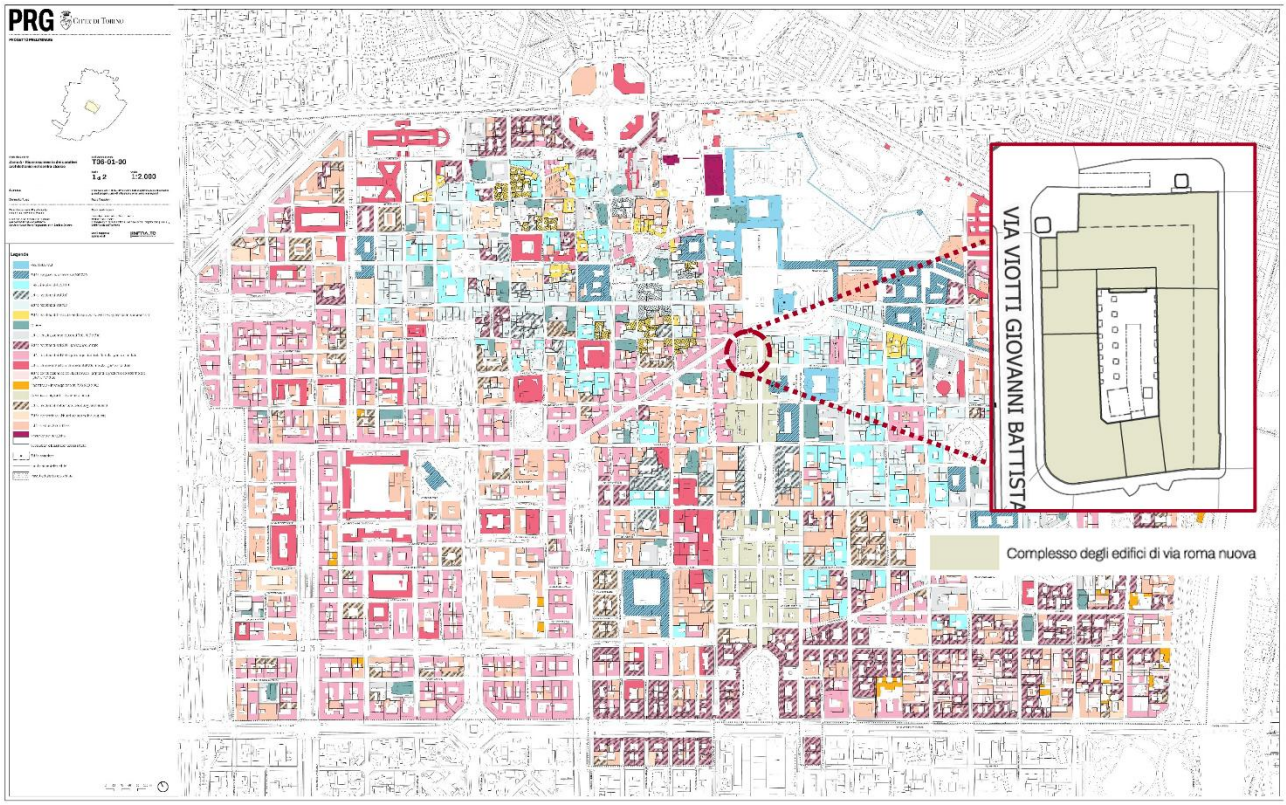


Figure 3.7

PRG map of the historic centre of Turin showing the classification of architectural characteristics within Zona A. Source: Città di Torino, PRG, Tavola T06-01-00.

The preparation of these inputs established the common information basis for the following stages of the methodology. Historical documentation and site observations supported the development and verification of the building model; spatial and environmental data supported the GIS and environmental analyses; and regulatory and heritage constraints informed the definition and later evaluation of feasible intervention scenarios.

3.5 Data Modelling and Processing

Following the collection and preparation of the input data, the next stage of the methodology focused on the development and processing of the building- and urban-scale digital information. Different software environments were used according to the type of information and analysis required: Revit was used for the building model and building-scale solar analysis, while QGIS, and UMEP/SOLWEIG supported the preparation and analysis of the surrounding urban context. The workflow therefore involved several data exchanges rather than a single software environment. The technological workflow shown in Figure 3.8 summarizes the main software, data formats, analytical processes, and connections through which the different datasets were progressively developed and later integrated in ArcGIS Pro.

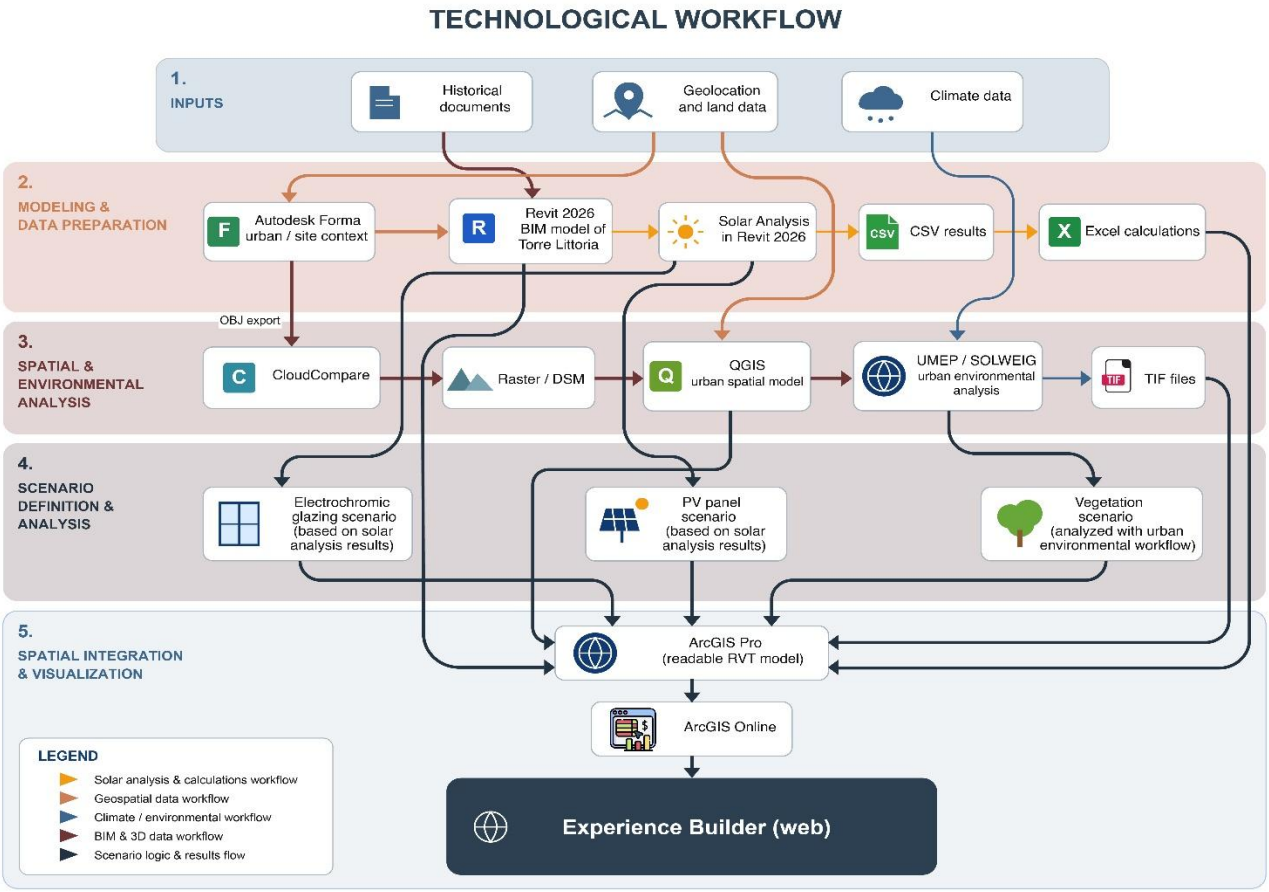


Figure 3.8

Technological workflow showing the software environments, data exchanges, environmental analyses, scenario development, and final integration used in the research.

3.5.1 BIM Model Development

The BIM model of Torre Littoria was developed in Autodesk Revit 2026 and represents the current post-renovation condition used as the baseline of the research. The modelling process was based on the available historical plans, elevations and sections, technical documentation, renovation material, photographs, and observations collected during the site visit. Historical documentation was particularly important for understanding the original configuration of the tower and its relationship with the lower volumes of the Sant'Emanuele block, while more recent documentation was used to interpret changes introduced through later renovation works. Previous research on Torre Littoria also demonstrated the value of information modelling for reconstructing and organizing heterogeneous archival information related to an existing historic building (Del Giudice, 2018).

The objective was not to produce a complete as-built or highly detailed HBIM reconstruction of every architectural and structural component. Instead, the level of modelling detail was defined according to the requirements of the environmental analyses and the subsequent BIM-GIS workflow. The model was developed at an analysis-oriented level of development broadly corresponding to LOD 300 for the architectural elements relevant to the research. The

principal geometry, dimensions, position, orientation, façades, openings, roofs, terraces, porticos, and other externally relevant elements were therefore represented with sufficient detail to support solar analysis, data extraction, and integration with the urban-scale environment. Interior elements that did not influence the external geometry or the analyses were simplified or excluded.

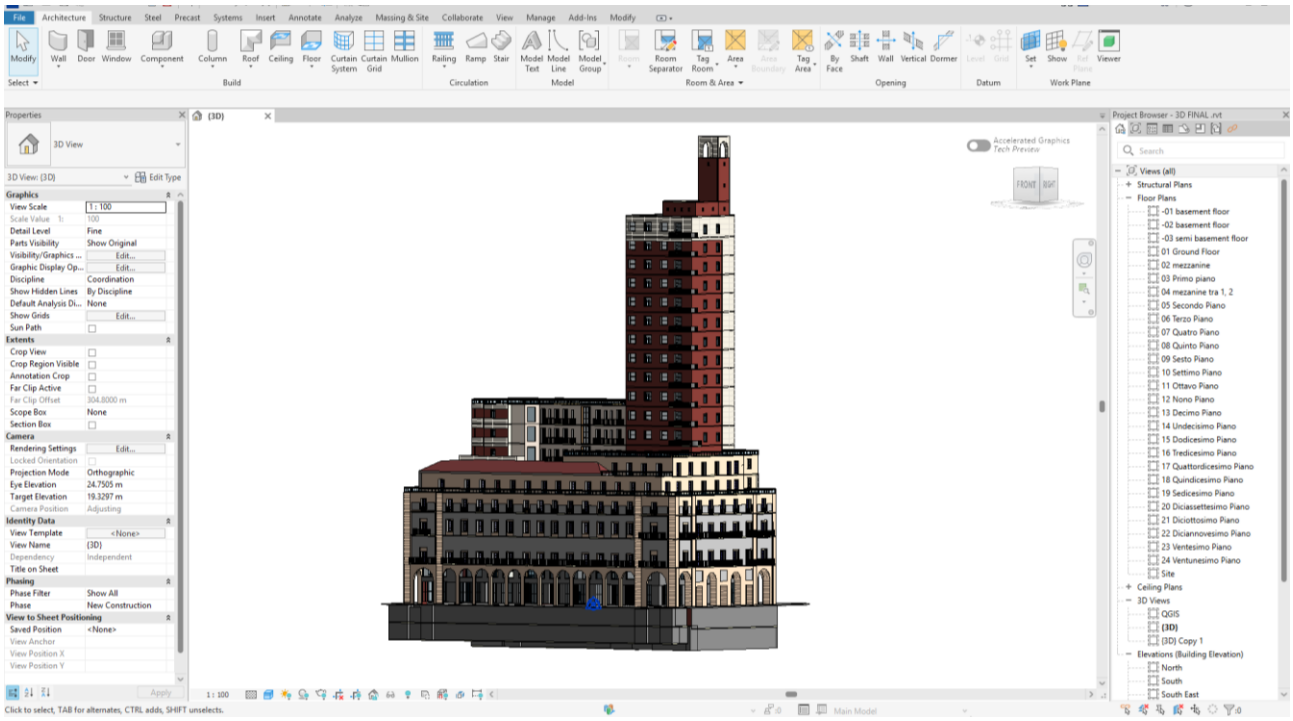


Figure 3.9

Revit BIM model of Torre Littoria developed for environmental analysis and BIM-GIS integration. Source: author.

Particular attention was given to the vertical configuration of Torre Littoria. The building was organized through separate Revit levels in order to represent the changing geometry of the tower, its lower volumes, setbacks, terraces, and roof surfaces. Externally exposed floor slabs and terrace surfaces were maintained in the model because they contribute to the external form, height profile, and shadow behaviour of the building, while fully enclosed intermediate floor elements that did not affect the external geometry were not considered essential for the analytical model.

Façade openings were represented as identifiable BIM elements rather than only as graphical openings. Windows, curtain-panel elements, and relevant doors were organized through Revit schedules so that they could later be related to the results of the solar analysis. The elements were classified according to characteristics relevant to the research, including façade orientation, their position within the lower or tower portions of the building, and whether they faced the external urban context or the internal courtyard. This organization was particularly important for the subsequent evaluation of the electrochromic-glazing scenario, since the intervention could be associated with specific groups of openings according to their solar exposure.

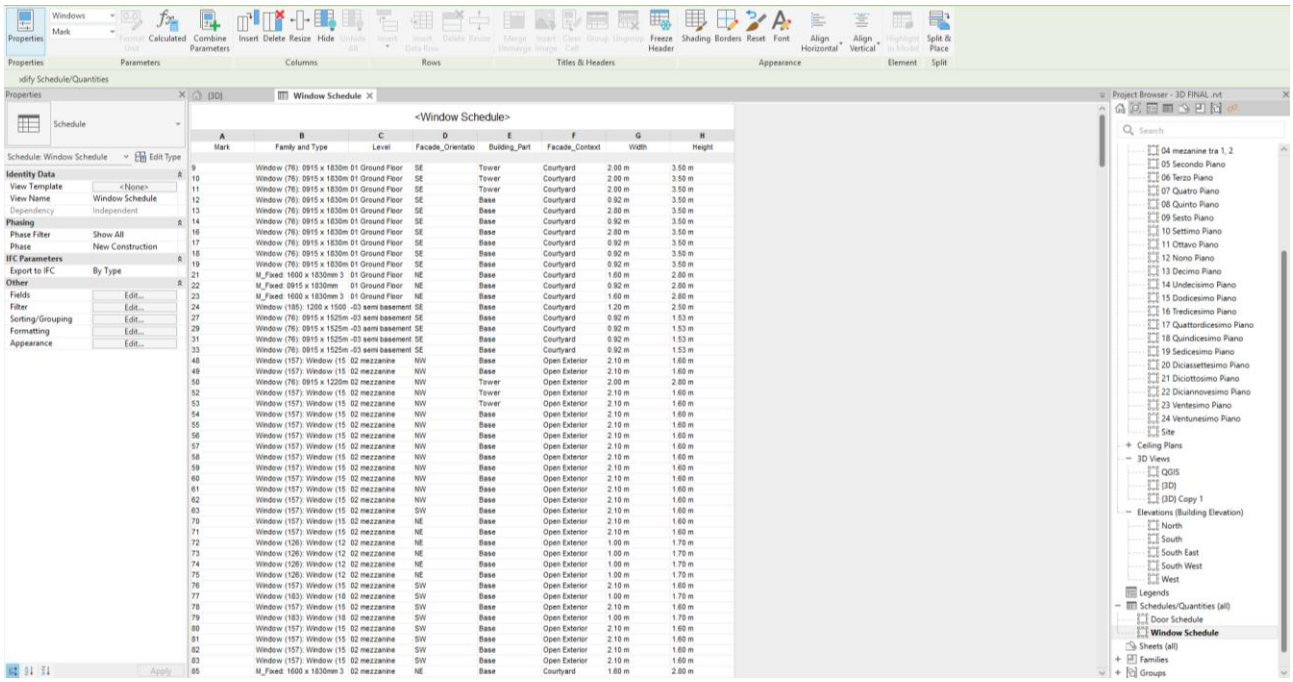


Figure 3.10

Revit schedule used to organize façade openings according to parameters relevant to the solar and electrochromic-glazing analysis. Source: author.

The geographic position and orientation of the building were also established during the BIM modelling process. Autodesk Forma was used as a reference for the site context and for positioning Torre Littoria according to its real location and orientation. The relationship between the Revit model and the surrounding urban context was checked before performing the environmental analyses, since the geographic position and rotation of the building directly influence solar-exposure results.

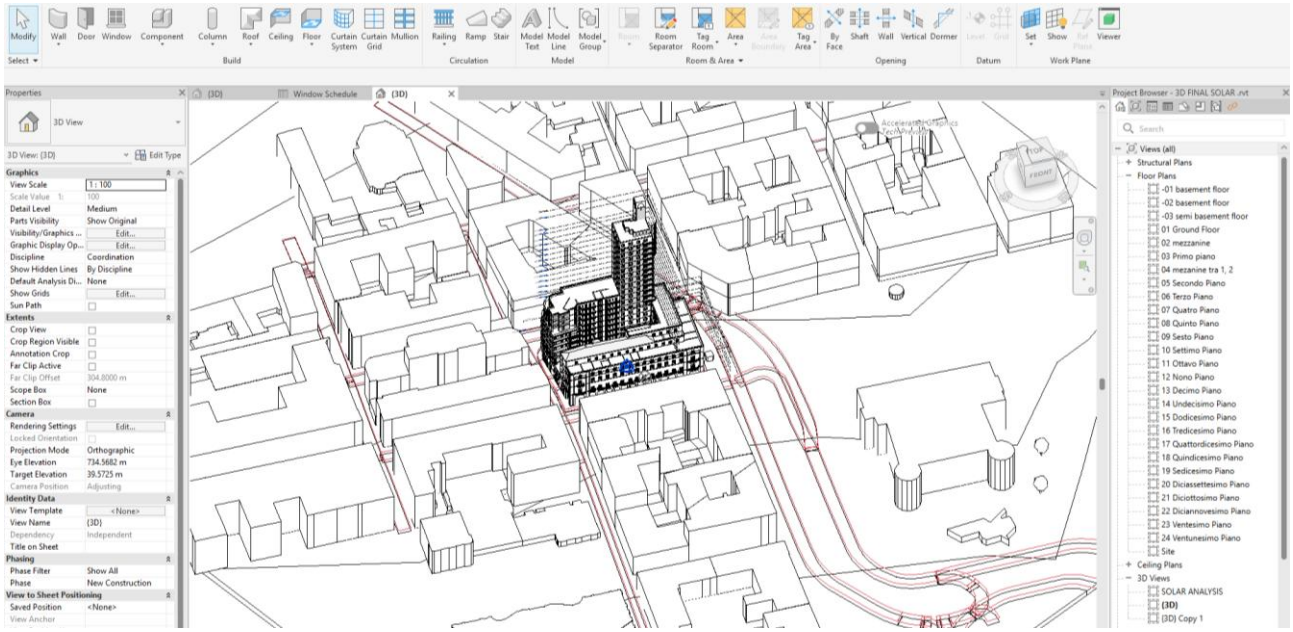


Figure 3.11

Revit BIM model of Torre Littoria positioned within its surrounding urban context for building-scale and environmental analysis. Source: author.

Revit 2026 was retained as the principal building-scale modelling and analysis environment because it supported the Solar Analysis workflow required for the thesis. The completed BIM model therefore served two purposes: it provided the digital representation of Torre Littoria used throughout the research, and it acted as the analytical basis for the building-scale solar investigations. The resulting solar information was exported as numerical data for further calculations, while the Revit model itself was later transferred to ArcGIS Pro as the principal building-scale reference within the final integrated visualization.

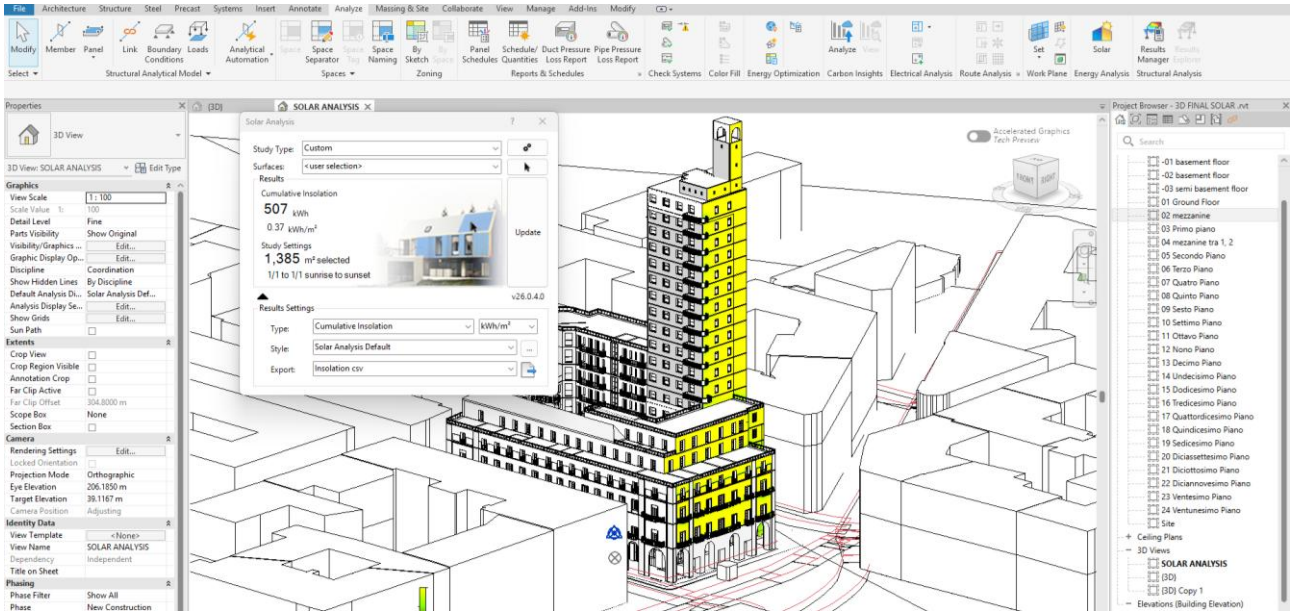


Figure 3.12

Revit Solar Analysis of Torre Littoria, showing the identification of façade openings according to solar exposure. Source: author.

3.5.2 GIS Urban Context Development

The urban-scale digital environment was developed in QGIS in order to represent Torre Littoria within its surrounding urban context and to prepare the spatial dataset required for subsequent environmental analysis. The GIS environment was developed independently from the detailed BIM model, with the objective of representing the wider spatial conditions influencing the building, including neighbouring buildings, streets, pedestrian areas, vegetation, and other relevant land-cover elements.

The required urban and land data were collected from available municipal and geospatial sources, including the datasets provided through the Turin municipal geoportals. These datasets were prepared and organized according to the requirements of the urban environmental workflow, particularly for the subsequent UMEP/SOLWEIG simulations.

Initially, Autodesk Forma was explored as a supporting environment for preparing the building-scale solar analysis workflow. The Revit model was transferred into Forma to verify the spatial positioning of Torre Littoria within its urban surroundings and to support the preparation of the surrounding context used during the solar analysis phase. In this stage, the surrounding building geometry and heights were reviewed and adjusted where necessary to

improve the reliability of the shadow and solar exposure evaluation within the BIM environment.

However, Forma was not adopted as the main environment for the GIS-based urban analysis. The surrounding urban geometry generated through Forma was not sufficiently accurate for the required geospatial analysis workflow. Moreover, although Forma provided integrated urban analysis capabilities, its outputs were mainly intended for visualization and preliminary evaluation and were not directly suitable for further numerical processing, calculation, and integration into the ArcGIS Online web-based visualization environment. Therefore, the final urban context was developed independently in QGIS using more accurate geospatial datasets.



Figure 3.13

Preliminary urban context generation of Torre Littoria in Autodesk Forma during the workflow evaluation phase. Source: Author.

Following this evaluation, the workflow was transferred to QGIS, which provided a more accurate and detailed geospatial representation of the study area. The surrounding urban geometry was prepared using available spatial datasets and refined according to the requirements of the environmental analysis.

The GIS context included the surrounding building footprints, streets, pedestrian areas, vegetation, and other spatial elements required to represent the urban morphology around Torre Littoria. The purpose of this model was not to reproduce the complete architectural complexity of the surrounding buildings, but to provide a consistent spatial framework for analyzing the relationship between the case study building and its urban environment.



Figure 3.14

Urban context of Torre Littoria developed in QGIS, showing the surrounding building footprint and spatial structure of the study area. Source: author.

For the integration of the building geometry into the GIS environment, the geometric representation of Torre Littoria was exported from the Revit BIM model in OBJ format. Although the Revit model had been previously coordinated within the BIM environment, the OBJ export preserved only the geometric information and did not retain the spatial reference information required for direct GIS positioning.

Therefore, the exported geometry was processed in CloudCompare to prepare the model for integration into the GIS workflow. This step was necessary to obtain a suitable geometric representation that could be imported and managed within the GIS environment.

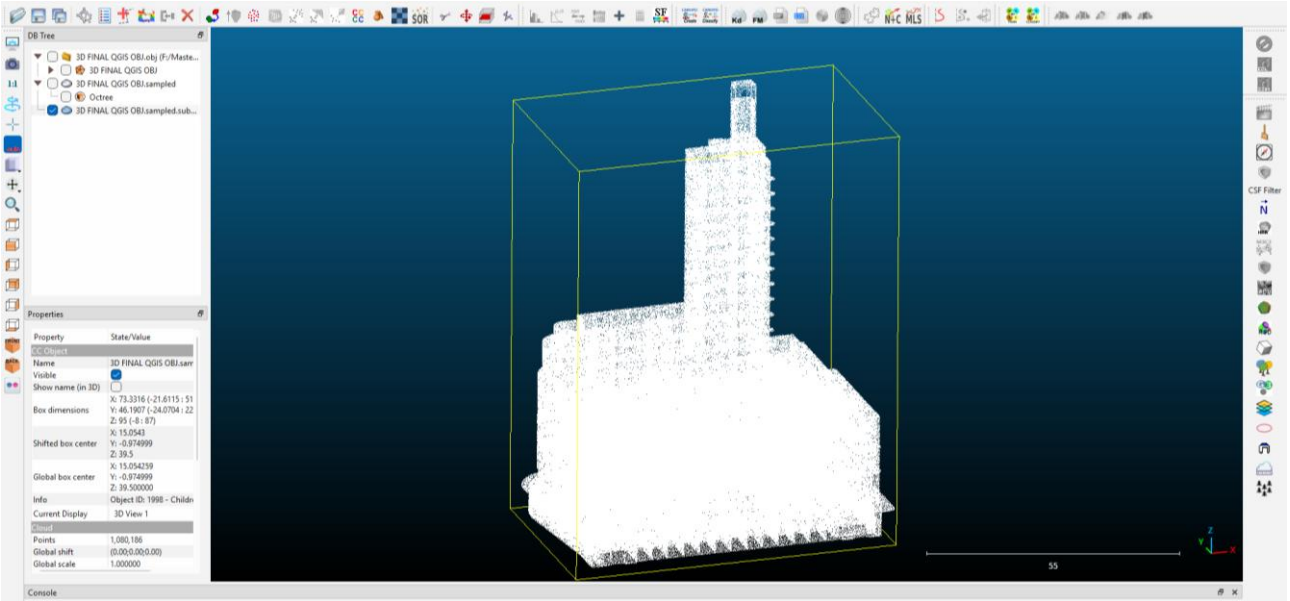


Figure 3.15

Processed 3D representation of Torre Littoria in CloudCompare, used for checking the geometry and height of the building model before integration into the GIS environment. Source: author.

The processed building geometry was subsequently introduced into QGIS and aligned with its real-world position using reference points. This georeferencing step was required because the OBJ exchange format did not preserve the original BIM spatial information. The alignment ensured the correct spatial relationship between Torre Littoria and the surrounding urban dataset.

After this process, the simplified building representation was integrated with the GIS layers describing the surrounding urban context. The resulting model provided a continuous spatial representation of the case study area, combining the building geometry with the urban elements required for environmental analysis.

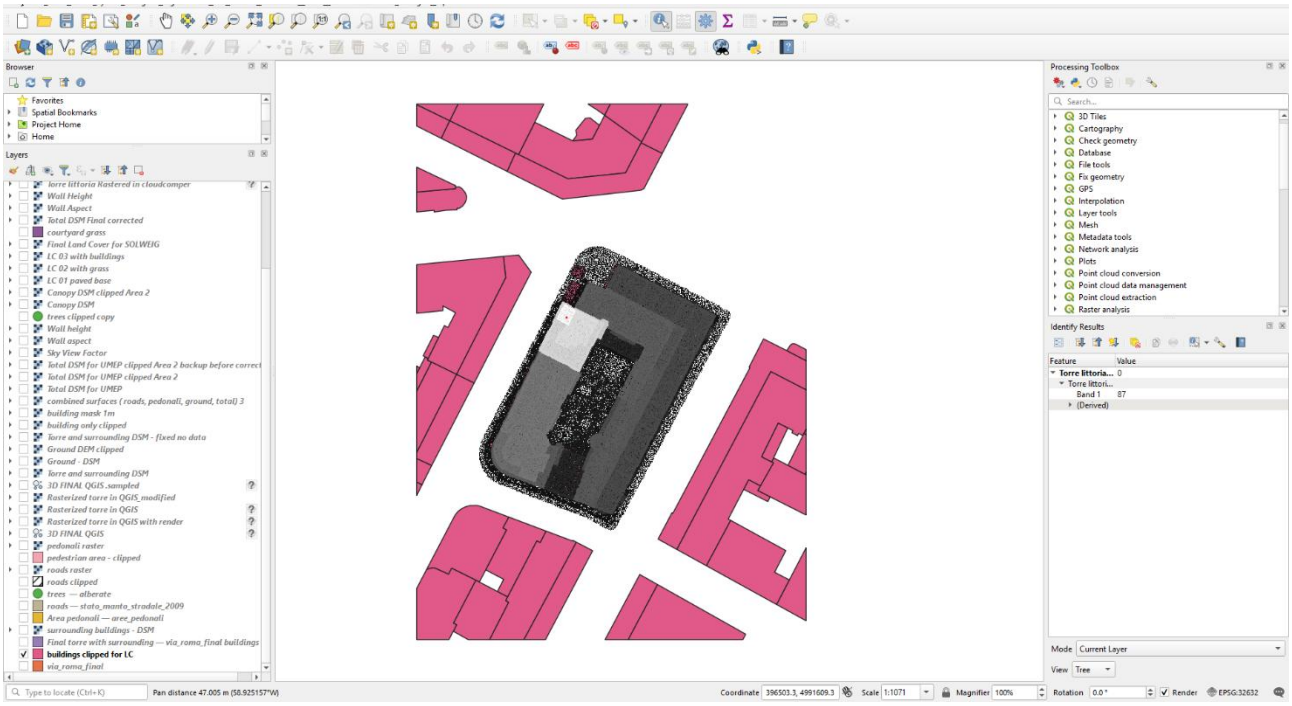


Figure 3.16

Torre Littoria and its surrounding urban context integrated in QGIS as the basis for subsequent urban-scale environmental analysis. Source: author.

The resulting GIS model was intentionally simplified compared with the detailed BIM representation. The objective was not to reproduce architectural components of Torre Littoria within the GIS environment, but to retain the spatial characteristics relevant for urban-scale environmental analysis.

The final GIS representation provided the basis for the subsequent UMEP/SOLWEIG simulations. The generated environmental outputs were later transferred to ArcGIS Pro, where they were integrated with the detailed BIM-based representation of Torre Littoria for the final visualization and decision-support environment.

3.6 BIM-GIS Integration and Data Exchange

The integration between BIM and GIS was developed through a selective data-exchange strategy rather than through a single direct conversion between the two environments. The detailed building model, urban-scale spatial information, and environmental analyses required different representations of the same case study. The workflow therefore preserved the detailed BIM model where building-scale information was required, while simplified geometric representations were generated for the urban environmental analyses. The final integration stage brought these different forms of information together in ArcGIS Pro.

Two principal data-exchange paths were used. The first supported the urban environmental analysis. The geometry of Torre Littoria was exported from Revit in OBJ format and processed in CloudCompare before being introduced into QGIS as a raster-based representation. This transformation provided the geometry required for the urban-scale environmental workflow while reducing the level of BIM information to the elements relevant to spatial and environmental analysis.

This exchange necessarily involved a reduction of BIM information. The OBJ and raster representations preserved the external geometry, position, height, and overall form required for urban analysis, but did not retain the complete semantic structure of the Revit model, such as the distinction between individual BIM categories, element parameters, or relationships between architectural components. This simplification was considered acceptable for the environmental-analysis stage because the required information was primarily related to geometry, urban morphology, surface height, and spatial relationships rather than detailed BIM semantics. Similar interoperability issues between BIM and GIS have also been identified in previous research, particularly in relation to differences in data structures, levels of detail, geometry representation, and information preservation between software environments (Colucci et al., 2022; Barrile et al., 2023).

A second exchange path was therefore maintained for the final integration. Instead of relying only on the simplified representation created for QGIS, the original Revit model was introduced directly into ArcGIS Pro. In this environment, the BIM model remained readable as a structured building dataset, allowing architectural categories such as walls, roofs, floors, and other building elements to remain distinguishable. The purpose of this transfer was not to edit the building model in ArcGIS Pro, but to preserve a more informative building-scale representation while spatially connecting it with the surrounding GIS information.

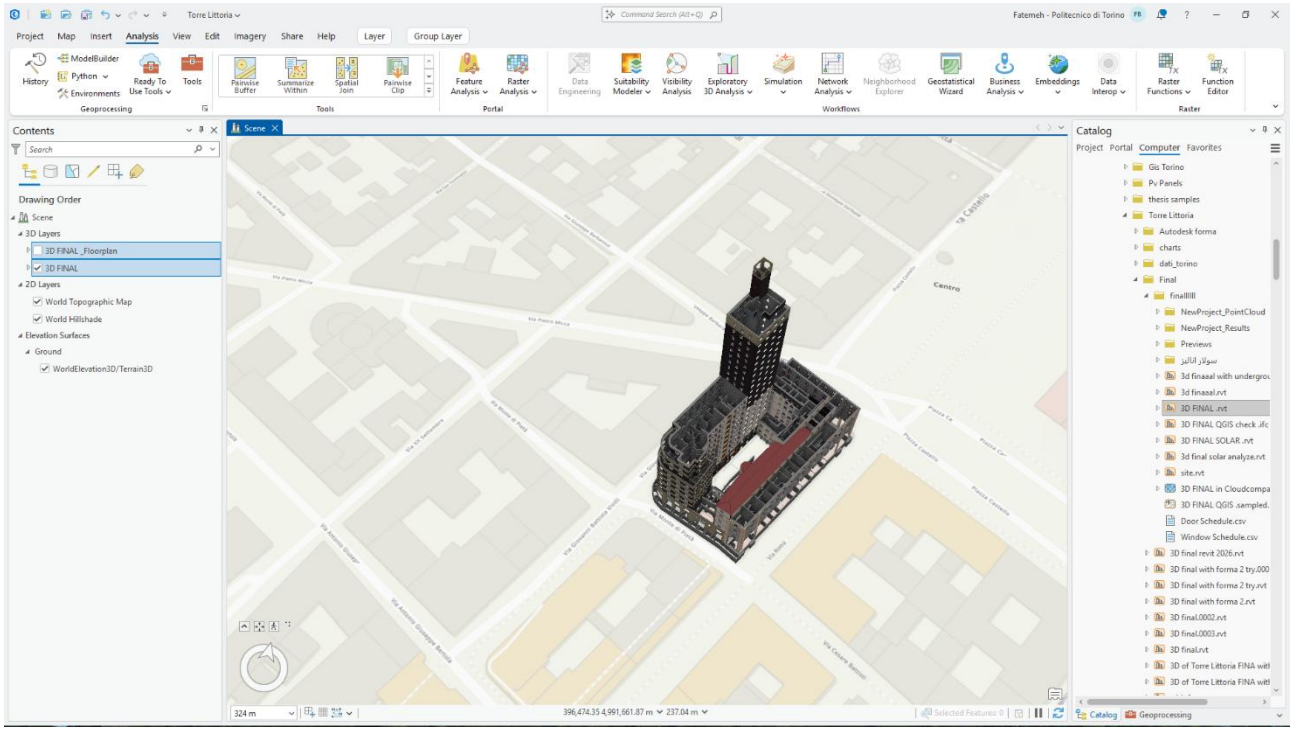


Figure 3.17

Figure 3.13. Revit-based building model integrated with the surrounding GIS context in ArcGIS Pro. Source: author.

The GIS layers and environmental outputs developed in QGIS and UMEP/SOLWEIG were subsequently introduced into the same ArcGIS Pro environment. In this way, the native BIM model could be visualized together with the surrounding urban context and the analytical outputs generated at the urban scale. Building-scale results developed in Revit and through subsequent calculations could also be represented in relation to the corresponding building elements and intervention scenarios.

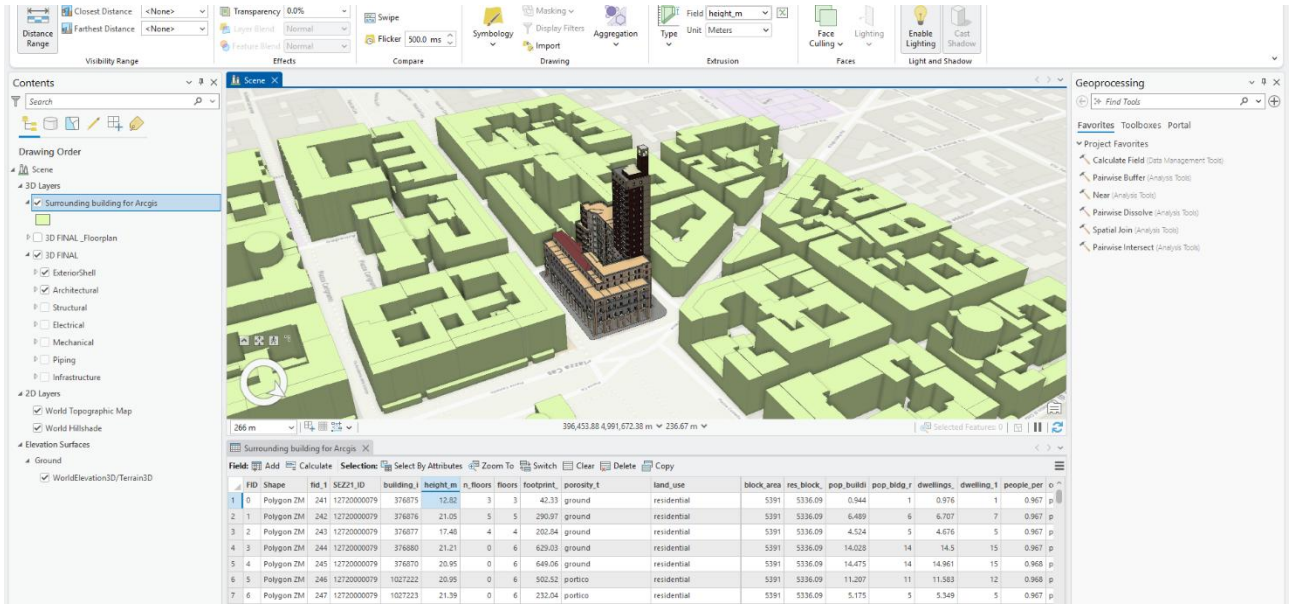


Figure 3.18

BIM-GIS integration in ArcGIS Pro, showing the building model together with spatial context and associated attribute information. Source: author.

The BIM-GIS workflow was therefore based on the coexistence of different representations rather than on the creation of a single universal data model. The detailed BIM model supported building-scale analysis and retained architectural information, while the simplified GIS representation supported urban environmental simulation. ArcGIS Pro was used as the final integration environment in which these different scales and information types could be spatially related and compared.

This approach also provided a basis for evaluating interoperability within the research. Particular attention was given to which information could be transferred directly, which information required transformation or simplification, and which semantic properties were not preserved during the exchange between BIM, three-dimensional processing, raster, and GIS environments. These observations were considered when interpreting the integration results and the limitations of the final digital visualization presented in Chapter 4.

3.7 Environmental Analysis and Sustainable Scenarios

The environmental analysis stage was developed at two complementary spatial scales. At the building scale, the analysis focused on the solar exposure of Torre Littoria and supported the assessment of the electrochromic glazing and photovoltaic intervention scenarios. At the urban scale, the analysis investigated the environmental relationship between the tower and its surrounding morphology, with particular attention to solar access and outdoor thermal conditions. The current post-renovation condition of Torre Littoria was used as the baseline against which the proposed sustainable scenarios were defined and evaluated.

At the building scale, solar analysis was carried out in Revit 2026 using the geolocated BIM model of Torre Littoria. The geographic position and orientation of the building were maintained so that façade orientation, surrounding obstructions, terraces, roof geometry, and the internal courtyard could be reflected in the solar results. The analysis was performed under both annual and warm-season conditions on exterior building surfaces relevant to the proposed interventions. For the electrochromic-glazing scenario, façade openings were evaluated according to their location, façade orientation, and context, while for the photovoltaic scenario, candidate roof-edge surfaces associated with the existing railings were assessed according to their annual solar exposure. The numerical outputs were exported in CSV format and subsequently organized and processed outside the BIM environment.

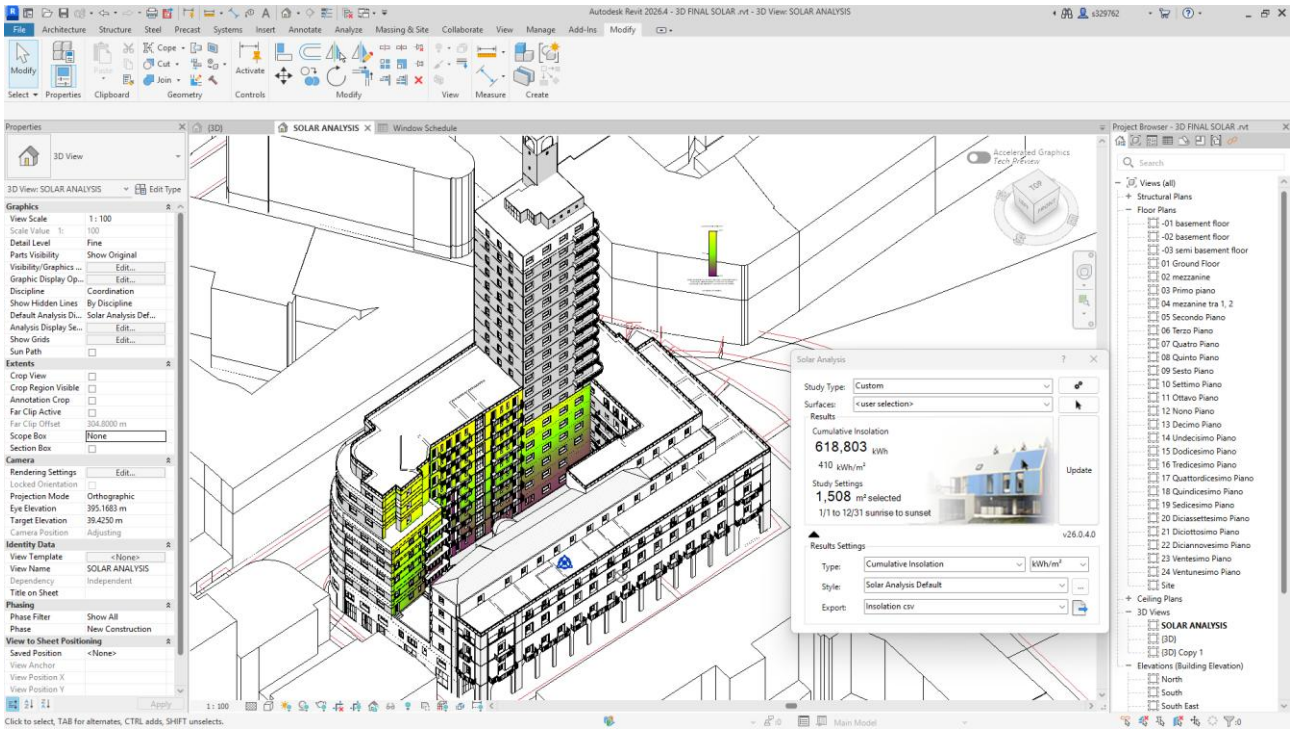


Figure 3.19

Revit Solar Analysis of Torre Littoria, showing the evaluated solar exposure of façade openings and building surfaces. Source: author.

The solar-analysis outputs were subsequently used to support the evaluation of the electrochromic-glazing and photovoltaic intervention scenarios. For the electrochromic-glazing scenario, the annual solar-exposure results were used to identify the façade and context combinations with the highest exposure. The selected groups were then carried forward to the warm-season analysis, and the resulting radiation values were combined with the corresponding transparent opening areas, including windows and glazed doors. The existing and electrochromic glazing states were compared through their solar heat gain coefficients (SHGC) to estimate the potential reduction in transmitted solar gains. The purpose was not to replace all existing glazing, but to identify façade areas where dynamic electrochromic glazing could provide a greater solar-control benefit while maintaining the existing architectural configuration.

The photovoltaic scenario was assessed through a solar-exposure screening of candidate roof-edge surfaces associated with the existing railings. An initial configuration of candidate photovoltaic surfaces was evaluated through an annual cumulative Solar Analysis in Revit, providing the annual insolation and surface-area values for each analysed surface. The exported results were then processed to identify surfaces receiving approximately 500 kWh/m^2/year or more, which was adopted as a project-specific screening criterion for solar suitability. The resulting set of surfaces was further refined by considering the architectural visibility, technical feasibility, and compatibility of the proposed panels with the historic character of Torre Littoria. This process resulted in a selective photovoltaic configuration

rather than assuming that all technically available surfaces were equally suitable for intervention.

At the urban scale, environmental analysis was carried out in QGIS using UMEP and SOLWEIG. The GIS model incorporated Torre Littoria, the surrounding buildings, streets, pedestrian spaces, vegetation, land-cover information, and the internal courtyard. The climatic conditions were defined using the selected Turin EPW weather data, while the spatial model was used to represent the existing urban morphology and environmental conditions around the building. This analysis provided the basis for assessing the outdoor thermal environment and for comparing the baseline condition with the proposed vegetation scenario.

Sky View Factor (SVF) was calculated as a supporting indicator for understanding the existing urban morphology and the degree of openness or enclosure within the study area. It was used primarily to interpret the baseline spatial condition rather than as a performance indicator for comparing intervention scenarios. This was particularly useful in the dense urban fabric surrounding Torre Littoria, where streets, continuous building fronts, courtyards, and differences in building height produce substantially different levels of sky exposure.

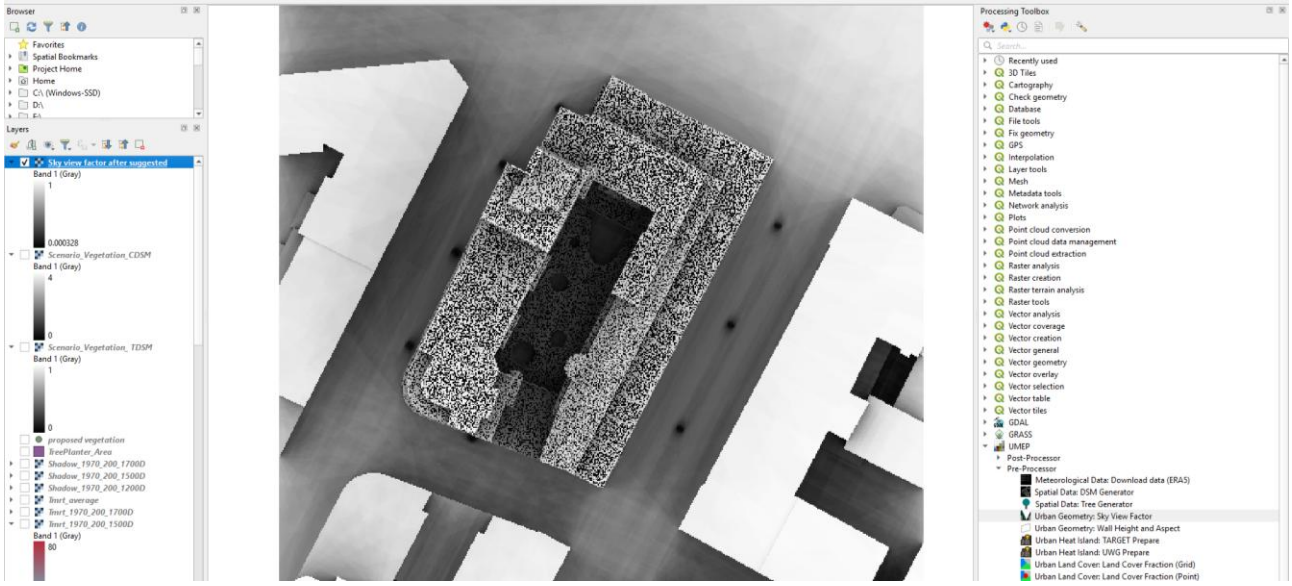


Figure 3.20

Sky View Factor (SVF) analysis of the Torre Littoria block and surrounding urban context in QGIS. Source: author.

The evaluation of outdoor thermal conditions focused on mean radiant temperature (Tmrt), which was used to assess the combined influence of solar radiation, shading, surrounding surfaces, urban geometry, and vegetation on pedestrian-level thermal conditions. SOLWEIG was applied to the baseline condition and to the proposed vegetation scenario using the same spatial and climatic settings, allowing the two conditions to be compared directly. The resulting Tmrt rasters were compared on a cell-by-cell basis to derive the change in mean radiant temperature (ΔTmrt) associated with the vegetation intervention. The ΔTmrt raster was subsequently classified into cooling ranges to identify the spatial distribution and intensity of the cooling effect. The analysis was based on a 0.20 × 0.20 m raster resolution, corresponding

to an area of 0.04 m^2 per valid cell, which also allowed the extent of the different cooling classes to be quantified.



Figure 3.21

Mean radiant temperature (Tmrt) analysis of the Torre Littoria courtyard and surrounding urban environment. Source: author.

The urban-scale analysis subsequently informed the vegetation enhancement scenario. The existing courtyard vegetation and established street trees were maintained as part of the baseline condition and were not modified in the intervention scenario. The proposal instead focused on introducing additional vegetation in locations where pedestrian-level shading and environmental improvement could be provided without altering the existing built fabric. Particular attention was given to the relationship between the vegetated courtyard and the more exposed pedestrian areas surrounding Torre Littoria, with the intervention conceived as a limited and spatially targeted addition rather than a transformation of the existing urban landscape.

The final vegetation scenario therefore focused on selected pedestrian-level areas around Torre Littoria where existing greenery was limited and additional shading could potentially improve outdoor thermal conditions. The intervention was conceived as a lightweight and spatially limited vegetation system, with planting locations selected to provide local shading while maintaining pedestrian circulation and the existing architectural configuration. In this way, the proposal aimed to strengthen the environmental continuity between the vegetated interior of the block and the surrounding pedestrian environment without introducing a substantial modification to the historic built fabric.

Vegetation on the terraces facing the internal courtyard was also considered during the initial development of the intervention strategy. However, these areas generally showed lower solar exposure and different spatial conditions compared with the more exposed pedestrian areas. Considering both their existing environmental conditions and the objective of improving

pedestrian-level thermal comfort, the final vegetation scenario was therefore concentrated primarily on selected outdoor areas surrounding the building.

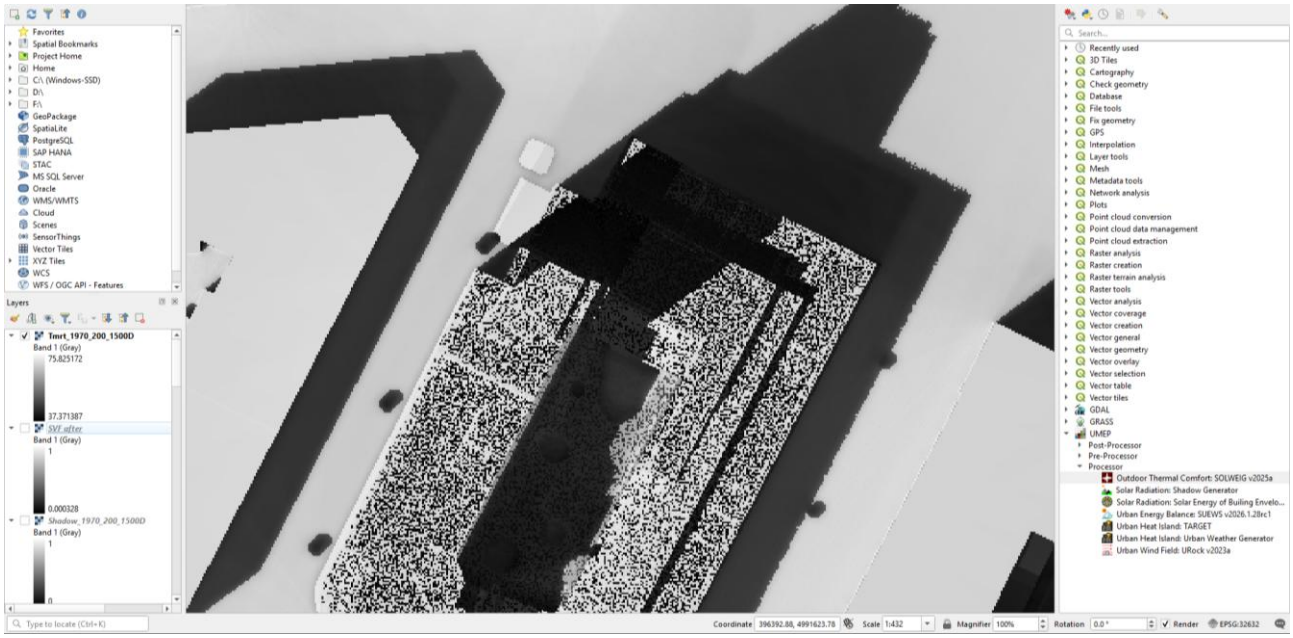


Figure 3.22

Mean Radiant Temperature (Tmrt) analysis of the Torre Littoria courtyard under the analysed vegetation scenario. Source: author.

For the electrochromic glazing scenario, the exported solar-analysis results were combined with the glazing properties assigned to the selected façade groups to estimate the change in solar gains between the existing and electrochromic states. The four façade/context groups selected through the annual solar-exposure screening were subsequently evaluated using warm-season incident solar radiation, since the intervention was primarily intended to address solar gains during the warmer period. For each group, incident solar energy was calculated by multiplying the warm-season average solar radiation by the total glazed area:

$$E_{\{incident\}} = I_{\{warm\}} \times A_{\{glazing\}}$$

The transmitted solar gain was then estimated by applying the corresponding solar heat gain coefficient (SHGC):

$$Q_{\{solar\}} = E_{\{incident\}} \times SHGC$$

For the photovoltaic scenario, the solar-analysis results were used to quantify the incident solar energy available on the candidate PV surfaces and to estimate the corresponding annual electricity production. For each PV layout, the total incident solar energy was calculated from the analysed PV surface area and its average annual solar irradiation:

$$E_{\{incident\}} = A_{\{PV\}} \times I_{\{annual\}}$$

Gross electricity production was subsequently estimated by applying a PV module efficiency of 23%. To account for system-level losses and inverter performance, the gross production

was further multiplied by the remaining system fraction after 14% losses and by an inverter efficiency of 96%:

$$E_{\{net\}} = E_{\{incident\}} \times \backslash eta_{\{PV\}} \times \left(1 - L_{\{system\}}\right) \times \backslash eta_{\{inv\}}$$

This calculation was applied to the initial candidate layout and to the final optimized layout after the solar-exposure screening and spatial filtering of the candidate surfaces. The resulting values were used to compare the available PV area, incident solar energy, and estimated net annual electricity production between the layouts.

For the vegetation scenario, the environmental effect was quantified through a raster-based comparison of the baseline and vegetation conditions. The Tmrt outputs generated by SOLWEIG for the two scenarios were compared on a cell-by-cell basis to derive the change in mean radiant temperature (ΔTmrt):

$$\Delta T_{\{mrt\}} = T_{\{mrt,vegetation\}} - T_{\{mrt,baseline\}}$$

Negative ΔTmrt values therefore represent a reduction in mean radiant temperature associated with the vegetation intervention, whereas positive values indicate a local increase. The resulting ΔTmrt raster was classified into cooling ranges to quantify the spatial extent of the intervention effect. The analysis used a 0.20 × 0.20 m raster resolution, corresponding to 0.04 m^2 per cell. The area represented by each cooling class was therefore calculated by multiplying the number of valid cells within the class by the cell area:

$$A_{\{class\}} = N_{\{cells\}} \backslash times 0.04$$

This procedure allowed the vegetation scenario to be evaluated not only through the magnitude of the local Tmrt change, but also through the total outdoor area affected by different levels of cooling.

The final selection of the three sustainable intervention scenarios—electrochromic glazing, photovoltaic integration, and vegetation enhancement—was based on the combined assessment of environmental performance, the existing condition of the site, architectural significance, heritage and regulatory constraints, visibility from public space, and technical feasibility. The environmental analyses were therefore used to identify the potential of each intervention, while the final selection considered whether the proposed measures could be integrated without compromising the historic and architectural character of Torre Littoria. The objective was not to identify a universally optimal intervention, but to define a set of context-sensitive strategies responding to different environmental conditions and implementation constraints.

Table 3-1

Regulatory feasibility screening of the three final sustainable intervention scenarios for Torre Littoria.

Intervention scenario	Main applicable regulation(s)	Key regulatory condition	Regulatory feasibility	Implication for the thesis
Electrochromic glazing	PRG–NUEA Art. 10 + Allegato A; Regolamento Edilizio n.381, Art. 114(4)	Electrochromic glazing is not explicitly regulated. For existing buildings, isolated window replacement or insertion cannot differ in typology, form or colour from the remaining windows. Under the applicable Allegato A conservation rules, replacement elements may be required to reproduce, or remain coherent with, the original form, colour, material and design.	**Conditional / potentially compatible**	Retain as a selective scenario only where the electrochromic layer or glazing system can be introduced without visibly altering the frames, façade rhythm, geometry and overall appearance. Final admissibility depends on the intervention category and the required approval procedure.
Photovoltaic integration	Regolamento Edilizio n.381, Art. 123; PRG–NUEA Art. 10, Group 4 (Edifici del complesso di Via Roma); general sustainability context: Regolamento Edilizio Arts. 73–75 and PRG Art. 29 (P.EN.CO.)	Art. 123 explicitly states that solar-thermal and photovoltaic panels are not admitted on buildings identified by the PRG as part of the Via Roma complex. General municipal objectives concerning energy efficiency and renewable energy do not, by themselves, override this specific restriction.	**Regulatory conflict — not permitted under Art. 123**	Retain as an analytical scenario to quantify solar-energy potential and to demonstrate the distinction between environmental potential and present regulatory feasibility. Do not present the proposal as an immediately authorizable retrofit; use the result to discuss the possible future role of context-sensitive and visually integrated renewable-energy solutions.
Pedestrian-level vegetation enhancement	PRG–NUEA Art. 25; Regolamento del Verde n.317, Arts. 46, 49 and 61; Regolamento Edilizio n.381, Art. 85. Supporting environmental-design principle: Art. 117(5), limited to retaining walls.	The regulatory framework supports improvement of public space and urban greenery, but new green works must comply with municipal design, planting, maintenance and accessibility requirements and remain compatible with the historic urban context. Art. 117(5) shows that vegetation can be required for environmental protection in retaining-wall design, but it is not a direct authorization for the proposed pedestrian greenery.	**Potentially feasible — subject to detailed design and municipal approval**	Apply the scenario only to selected pedestrian-level areas around Torre Littoria. The design should preserve pedestrian accessibility, portico function, significant views and the historic spatial character. The existing courtyard greenery remains unchanged as the baseline.

The results and scenario outputs produced through these analyses were subsequently prepared for integration in ArcGIS Pro, where building-scale information, urban environmental results, and proposed interventions could be spatially related and compared within the final digital representation.

3.8 Visualization strategies for Decision Support

The final stage of the methodology focused on the visualization and spatial integration of the information produced through the research. ArcGIS Pro was used as the main environment for integrating the building-scale BIM model, the surrounding urban context, environmental-analysis outputs, and the proposed sustainable intervention scenarios within a common spatial framework. The resulting spatial dataset was subsequently prepared for publication in ArcGIS Online and visualization through Experience Builder. The objective was therefore not only to represent the analytical results, but also to establish an integrated visualization environment in which different types of information could be viewed, interpreted, and compared in relation to Torre Littoria and its surrounding urban context.

The Revit model was imported into ArcGIS Pro and represented as a building-scale three-dimensional model alongside the GIS information. Architectural categories and building

components remained distinguishable within the BIM dataset, while the surrounding urban context was represented through the spatial layers developed in QGIS. This integration made it possible to visualize Torre Littoria not only as an individual building, but as part of the wider urban fabric of Via Roma and the Sant'Emanuele block, while maintaining the relationship between architectural elements and their spatial context.

Environmental outputs were organized as separate thematic layers according to their analytical role. Urban-scale results, including the outputs generated through UMEP and SOLWEIG, were spatially related to the surrounding streets, open spaces, pedestrian areas, and courtyard. Supporting layers such as Sky View Factor (SVF) and land-cover information were used to assist the interpretation of the existing urban condition, while the thermal-analysis outputs provided a spatial basis for identifying areas with different levels of outdoor thermal exposure and potential cooling effects associated with the vegetation scenario.

Building-scale information was represented in relation to the architectural elements to which it referred. Solar-analysis results and the subsequent calculations for electrochromic glazing and photovoltaic systems were therefore connected with the relevant façades, glazed elements, roof surfaces, and selected building areas. This relationship between analytical data and physical elements was important for avoiding the separation of numerical results from the architectural context in which intervention decisions would be made.

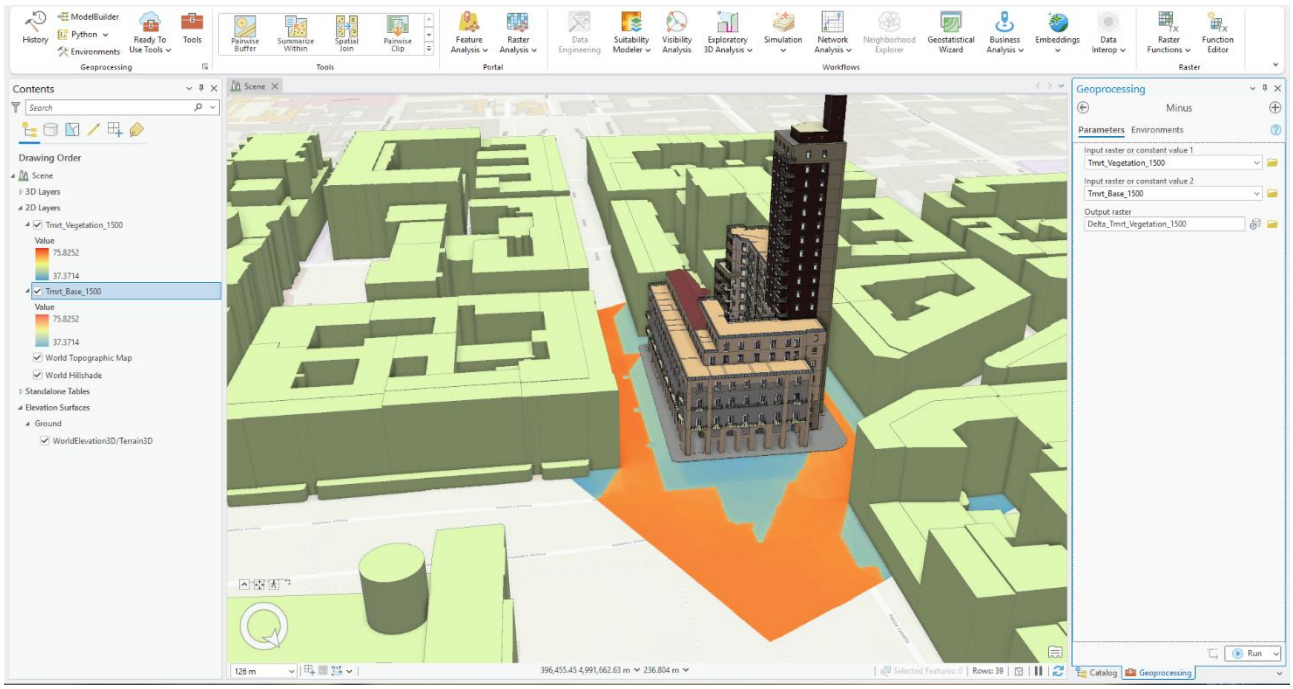


Figure 3.23

Integrated ArcGIS Pro visualization of the Torre Littoria BIM model, surrounding urban context, and baseline mean radiant temperature (Tmrt) raster. Source: author.

The three sustainable intervention scenarios were organized as distinct layers or groups of information so that the existing condition and proposed solutions could be viewed separately and compared within the same spatial environment. The electrochromic glazing scenario was associated with the selected façade openings, the photovoltaic scenario with the identified suitable building surfaces, and the vegetation scenario with the selected pedestrian-level intervention areas. Layer visibility and three-dimensional navigation allowed the scenarios to be examined individually and in relation to the existing building and urban context. The resulting ArcGIS Pro dataset was subsequently prepared for web-based visualization in ArcGIS Online and Experience Builder, allowing the integrated information to be presented through an interactive spatial interface.

The integrated ArcGIS Pro dataset was subsequently prepared for publication in ArcGIS Online and for implementation within ArcGIS Experience Builder. The web-publication stage required an additional data-preparation process because the complete dataset could not initially be published as a single web-ready package. The first publication attempt generated multiple processing and publishing errors, including issues associated with joins, missing attributes, and the complexity of the integrated dataset. The data were therefore progressively checked, simplified, and republished at the layer level. In some cases, unnecessary joins were removed and missing fields were added before the layers were re-analyzed and published. This iterative process was used to preserve the analytical content while adapting the dataset to the requirements of the web environment.

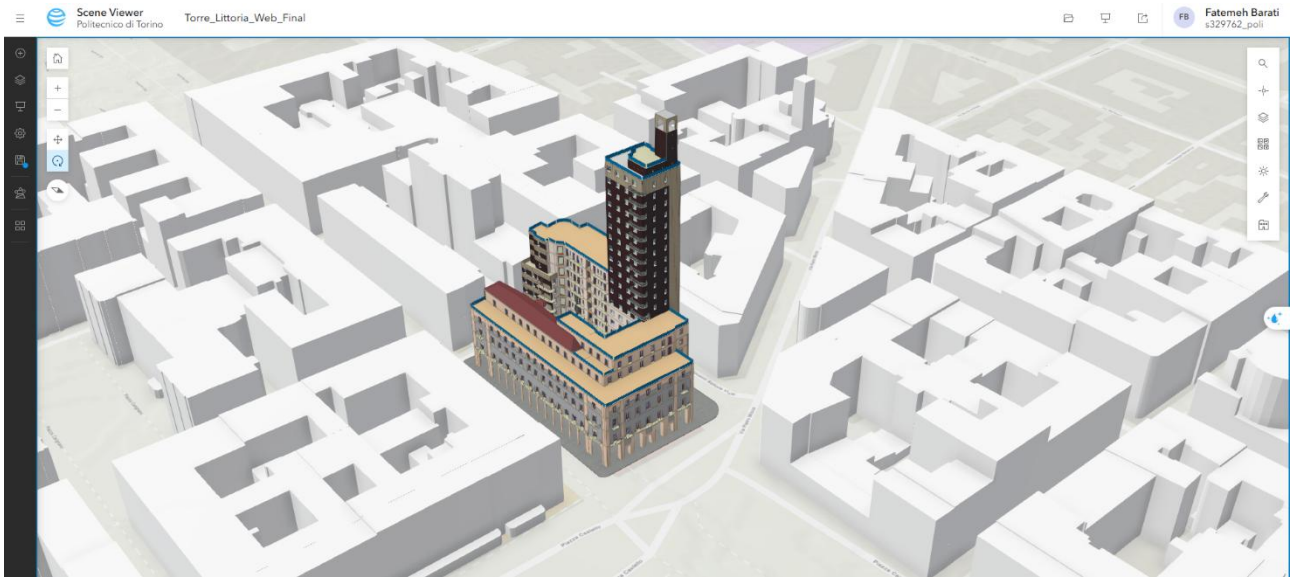


Figure 3.24

ArcGIS Online visualization of the published Torre Littoria model and thematic analytical layers. Source: author.

Additional adjustments were required to obtain an appropriate web representation of the analytical layers. The integrated 3D building model could interfere with the visualization of some thematic outputs when both were displayed simultaneously. This was particularly relevant for the solar-exposure visualization, where the presence of the three-dimensional wall geometry affected the legibility and spatial interpretation of the solar heat-map

representation. Since the required layer visibility configuration could not be reproduced directly within the ArcGIS Online environment, separate web-ready representations were prepared from ArcGIS Pro. In one representation, the complete 3D building model was retained for architectural and contextual visualization, while a second web-ready representation was prepared with the relevant wall layer disabled before export so that the analytical raster could be displayed without being visually obscured or distorted by the building geometry.



Figure 3.25

Alternative ArcGIS Online representation with the relevant wall layer disabled to improve the visibility of the environmental analytical raster. Source: author.

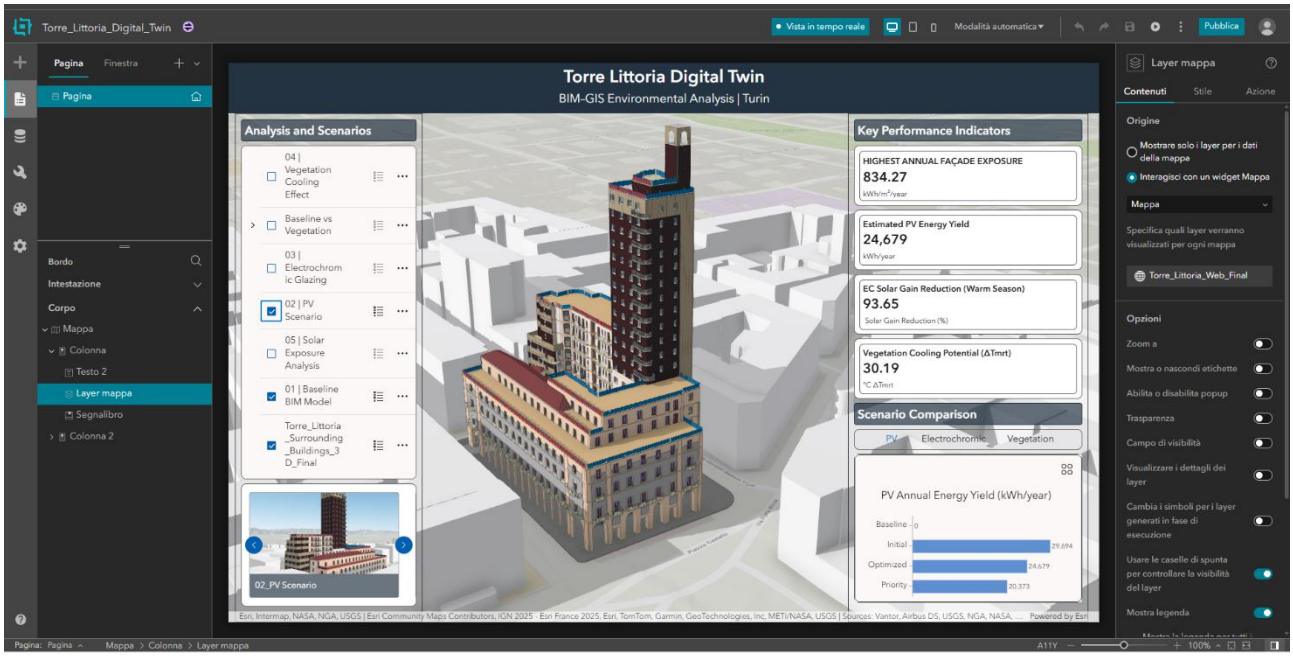


Figure 3.26

ArcGIS Experience Builder interface for interactive visualization of the BIM model, environmental outputs, and sustainable intervention scenarios. Source: author.

The final visualization environment was therefore conceived as a layered digital representation rather than as a single static image. The BIM model, surrounding urban context, environmental-analysis outputs, and intervention scenarios were maintained as distinguishable information components, allowing them to be examined individually or in combination. The resulting ArcGIS Online and Experience Builder environment provided an interactive spatial framework for interpreting the environmental performance, architectural implications, and implementation constraints of the proposed interventions at both building and urban scales.

Rather than presenting a single final image, the visualization environment was conceived as a layered digital representation combining the BIM model, the surrounding urban context, environmental-analysis outputs, and proposed intervention scenarios. Historical documentation and regulatory information were used as supporting interpretative elements rather than as separate analytical layers. The integrated representation therefore provided a common spatial framework for examining Torre Littoria and its surroundings at both building and urban scales, while the web-based implementation in ArcGIS Online and Experience Builder supported interactive exploration of the resulting information.

Chapter 4 Results and Discussion

4.1 BIM-GIS Interoperability and Integration Results

The BIM-GIS integration process resulted in the creation of a coordinated digital representation of Torre Littoria and its surrounding urban context, combining building-scale information with spatial and environmental datasets. The integration aimed to evaluate how information generated at different scales could be connected within a common digital environment to support the analysis of sustainable retrofit scenarios in a heritage-sensitive context.

The final BIM-derived representation preserved the main architectural elements relevant to the environmental analyses, including façades, openings, terraces, porticos, and roof-related surfaces. The model therefore provided a sufficiently detailed building-scale representation for integration with the GIS environment, while avoiding unnecessary geometric complexity that would not contribute to the subsequent analyses.

The BIM-to-GIS transition resulted in a simplified and reorganized dataset in which the building geometry was successfully integrated with the surrounding urban-scale datasets. This allowed the Torre Littoria model to be analysed within the same spatial framework as the surrounding morphology, pedestrian areas, and environmental information.

The interoperability assessment highlighted the limitations of direct model exchange for the requirements of the environmental analysis workflow. Therefore, instead of relying on a direct BIM-to-GIS conversion, the building geometry was exported from Revit in OBJ format and processed in CloudCompare to prepare a simplified geometric representation suitable for integration into the GIS environment. The processed model was subsequently aligned within QGIS using reference points to ensure its correct spatial position relative to the surrounding urban dataset.

The integrated dataset was successfully managed within the ArcGIS environment, where BIM-derived information, urban-context layers, solar-analysis outputs, and environmental scenario results were maintained as separate but spatially related datasets. The resulting structure allowed the different analytical outputs to be visualized and compared in relation to the Torre Littoria model and its surrounding urban context.

The final outcome of the workflow was therefore not limited to a GIS-based representation, but consisted of an integrated, digital-twin-oriented visualization framework combining building information, urban context, environmental analysis, and sustainable retrofit scenarios.

These results answer the first research question by showing that BIM and GIS can be effectively connected through a workflow that combines building-scale and urban-scale information. The process also showed that data must be adapted between different digital environments to support environmental analysis and visualization.

4.2 Environmental Analysis and Scenario Results

The environmental analysis produced results at both building and urban scales, allowing the existing environmental condition of Torre Littoria to be interpreted and the three selected sustainable intervention scenarios to be evaluated. At the building scale, the Revit Solar Analysis identified differences in solar exposure across façades and selected roof-edge surfaces, providing the basis for the electrochromic-glazing and photovoltaic scenarios. At the urban scale, the QGIS-UMEP/SOLWEIG workflow provided spatial information on sky exposure and outdoor thermal conditions, with Mean Radiant Temperature (Tmrt) used as the principal indicator for evaluating the vegetation scenario. The results were subsequently organized in relation to the architectural and urban elements to which they referred, allowing environmental performance to be interpreted together with the spatial and heritage characteristics of the site.

The annual Solar Analysis showed a clear spatial differentiation in the solar exposure of the building envelope. The results reflected the combined influence of façade orientation, surrounding buildings, terraces, roof geometry, and the internal courtyard. More exposed façades and roof-edge surfaces received substantially greater annual solar radiation, while surfaces affected by surrounding obstructions and the geometry of the courtyard showed lower exposure. The results therefore confirmed that the solar behaviour of Torre Littoria cannot be interpreted through orientation alone, as the dense urban morphology and the different building components modify the effective solar exposure of individual surfaces.

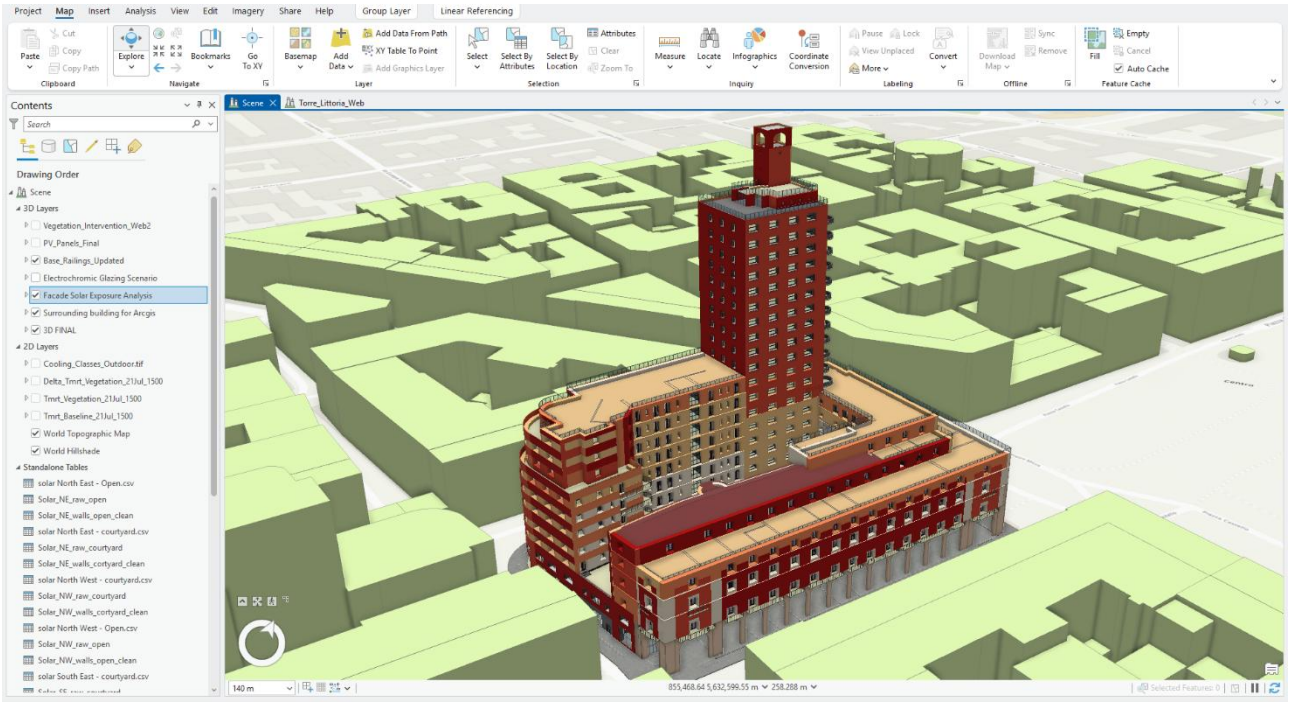


Figure 4.1

Annual solar exposure of Torre Littoria by façade orientation and context.

Table 4-1

Annual and warm-season average solar insolation

Façade	Context	Annual Average Insolation	Warm Season Average Insolation
South East	Open Tower	834.27 kWh/m²/year	440.52 kWh/m²
South West	Open	799.93 kWh/m²/year	393.92 kWh/m²
South East	Open	658.27 kWh/m²/year	354.10 kWh/m²
South East	Courtyard	411.71 kWh/m²/year	236.66 kWh/m²
North West	Open	361.74 kWh/m²/year	N/A
North East	Open	329.38 kWh/m²/year	N/A
South West	Courtyard	320.75 kWh/m²/year	N/A
North East	Courtyard	214.44 kWh/m²/year	N/A
North West	Courtyard	202.28 kWh/m²/year	N/A

Note: N/A indicates that no warm-season value was retained for the corresponding façade/context group.

The results demonstrate that solar exposure varied substantially according to both façade orientation and spatial context. The highest annual value was recorded for the South-East open-tower surface (834.27 kWh/m^2/year), followed by the South-West open façade (799.93 kWh/m^2/year) and the South-East open façade (658.27 kWh/m^2/year). In comparison, the courtyard-facing surfaces generally presented lower annual exposure, with values ranging from 202.28 to 411.71 kWh/m^2/year. The warm-season results showed a similar differentiation, with the highest values occurring on the South-East open-tower and South-West open façades. These differences provided the basis for identifying the façade groups with greater solar exposure and subsequently evaluating their suitability for the electrochromic-glazing scenario.

For the final spatial representation, annual solar exposure was classified using five fixed intervals: 128-300, 300-500, 500-700, 700-900, and 900-1100 kWh/m^2/year. The same classification was maintained across the analysed façade groups to allow visual comparison between different orientations and façade contexts. The resulting map provided a common reference for identifying surfaces with lower, intermediate, and higher solar exposure and was subsequently used to guide the selection of intervention areas.

The solar-exposure results were then used to evaluate the electrochromic-glazing scenario. Rather than considering all windows as equally suitable for intervention, the analysis identified façade groups according to their orientation, building part, and façade context. The warm-season Solar Analysis was used for this scenario because the primary objective of the

intervention was to reduce solar gains during the period in which solar exposure and potential overheating are most relevant. Existing windows and glazed doors were grouped according to their spatial characteristics, and their approximate transparent opening areas were related to the corresponding warm-season solar-radiation values.

The resulting comparison showed that the potential benefit of electrochromic glazing was not uniform across the building. The greatest potential was associated with the façade groups receiving higher levels of warm-season solar radiation, whereas more strongly shaded or lower-exposure groups provided a smaller reduction potential. The calculation therefore supported a selective application of electrochromic glazing rather than a uniform replacement of the existing windows. This result is particularly relevant to the heritage context of Torre Littoria, since limiting the intervention to the most environmentally responsive façade groups reduces unnecessary alteration of the existing envelope while maintaining the established façade rhythm and architectural configuration.

Table 4-2

Electrochromic-glazing calculation results for the selected façade groups.

Façade	Context	Opening Count	Transparent Area (m^2)	Warm-season Insolation (kWh/m^2)	Existing Solar Gain (kWh)	EC Clear Gain (kWh)	EC Tinted Gain (kWh)	Maximum Reduction (%)
South East	Open Tower	53	139.97	834.27	38845.68	23430.73	2466.39	93.65%
South West	Open	84	207.23	799.93	51428.24	31020.21	3265.28	93.65%
South East	Open	75	243.2	658.27	54253.79	32724.51	3444.68	93.65%
South East	Courtyard	158	429.67	411.71	64062.71	38641	4067.47	93.65%
Total	All	370	1020.08		208590.41	125816.44	13243.84	93.65%

The four selected façade groups comprised 370 transparent openings with a combined transparent opening area of approximately 1,020.08 m^2. Under the existing glazing assumptions, the calculated transmitted solar gain was approximately 208,590 kWh. Applying the electrochromic properties reduced the calculated solar gain to approximately 125,816 kWh in the clear-state comparison and to approximately 13,244 kWh under the fully tinted

condition. The corresponding maximum theoretical reduction was approximately 93.65%, while the clear-state comparison indicated a reduction of approximately 39.68%. These results demonstrate that the potential benefit of electrochromic glazing varies primarily with the solar exposure and extent of glazing of each façade group.

The photovoltaic scenario was evaluated by combining the annual solar-exposure results with the geometric and architectural constraints of the roof-edge areas. The initial configuration included the candidate surfaces identified during the modelling stage. The annual Solar Analysis was subsequently used as a screening step to distinguish surfaces with sufficient solar exposure from surfaces affected by strong shading or unfavourable conditions. A project-specific threshold of 500 kWh/m^2/year was applied to remove low-exposure surfaces from the final analytical configuration. This threshold was used as a screening criterion for the case study rather than as a general technical requirement for photovoltaic systems.

The filtering substantially reduced the number of analysed PV surfaces. The initial configuration comprised 428 surfaces corresponding to 214.0 m^2, while the final screened configuration contained 297 surfaces corresponding to 148.5 m^2. The reduction was therefore approximately 30.6% in both surface count and analysed area. The final configuration concentrated the analysis on surfaces with stronger solar exposure and excluded the weaker northern and strongly shaded portions identified during the screening process.

Table 4-3

Initial and final photovoltaic analytical configurations.

Parameter	Initial PV Layout	Final Optimized Layout
Analyzed PV Surface Area (m²)	**214**	**148.5**
Average Annual Insolation (kWh/m²/year)	**730.73**	**875.19**
Total Incident Solar Energy (kWh/year)	**156,376.92**	**129,965.80**
PV Electricity Energy Production – Revit (kWh/year)	**27,133**	**26,513**
PV Surface/Module Count	**428**	**297**
PV Area Reduction (%)	-	**30.61%**
Average Insolation Improvement (%)	-	**19.77%**
Incident Solar Energy Retained (%)	-	**83.11%**

Following the spatial screening, the final PV configuration reached an average annual solar insolation of 875.19 kWh/m^2/year. Based on the analysed area, the corresponding annual incident solar energy was estimated at 129,965.80 kWh/year. A preliminary Revit-based estimate resulted in approximately 26,513 kWh/year of electricity production. An independent calculation was subsequently carried out using the final incident solar energy together with a 23% module efficiency, 14% system losses, and 96% inverter efficiency. This produced an estimated net electricity generation of approximately 24,678.95 kWh/year, or 24.68 MWh/year. The latter value was retained as the final product-based estimate, while the Revit result was maintained as a preliminary cross-check.

The environmental potential identified by the PV analysis should, however, be distinguished from its present regulatory feasibility. The calculated yield represents the energy potential of the screened surfaces under the analytical scenario and does not imply that the installation is currently authorised. The regulatory screening presented in Chapter 3 identified a conflict with the specific restriction applicable to photovoltaic and solar-thermal panels on the Via Roma complex. The PV result is therefore interpreted as a scenario-based analytical potential, while its present implementation remains subject to the applicable regulatory framework.

At the urban scale, the QGIS-UMEP/SOLWEIG workflow incorporated sky-view conditions together with the surrounding urban geometry and land-cover information. The resulting environmental analysis was used to compare outdoor thermal conditions before and after the proposed vegetation intervention, with Mean Radiant Temperature (Tmrt) adopted as the principal indicator.

The outdoor thermal analysis focused on Mean Radiant Temperature (Tmrt), which provided the principal spatial indicator for evaluating the thermal conditions experienced at pedestrian level. The baseline Tmrt raster showed substantial spatial variation within the study area, reflecting differences in solar exposure, shading, surrounding building geometry, surface conditions, and the existing vegetation structure. The internal courtyard presented a distinct thermal environment compared with the more exposed pedestrian areas around the building. The results therefore confirmed the relevance of considering the urban context when evaluating environmental conditions around Torre Littoria.

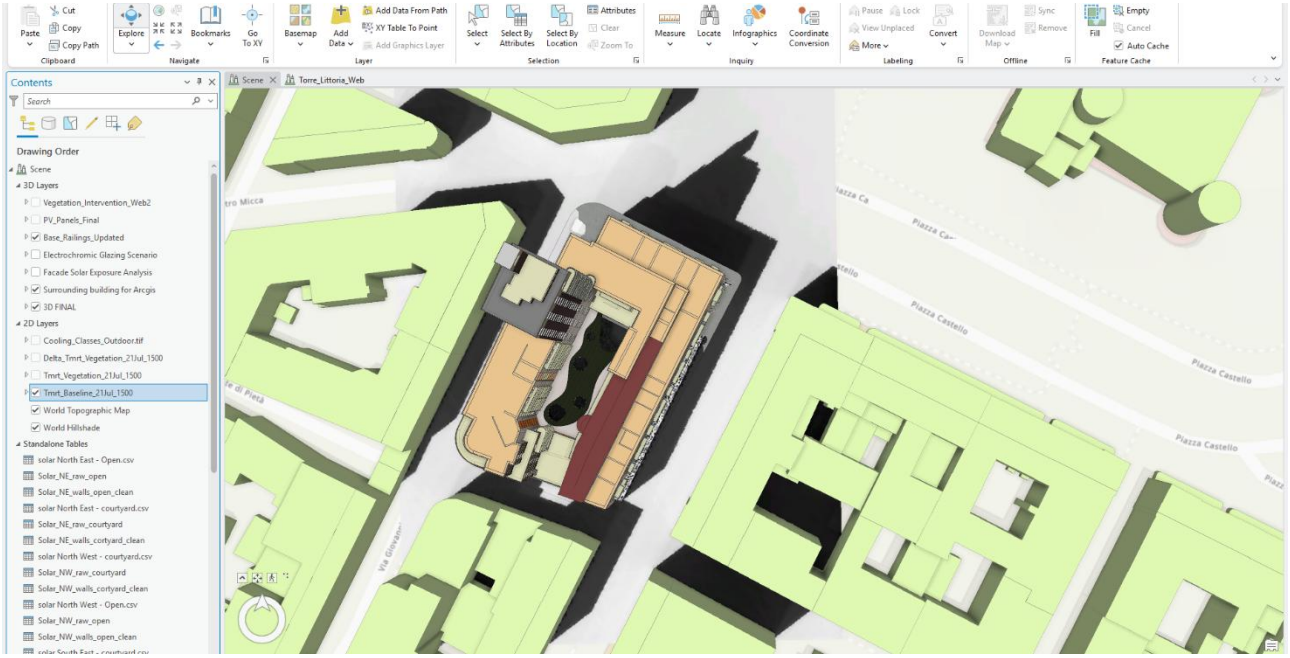


Figure 4.2

Baseline mean radiant temperature (Tmrt) distribution in the Torre Littoria courtyard and surrounding pedestrian environment.

The vegetation scenario was subsequently evaluated by comparing the baseline Tmrt condition with the simulated condition including the proposed vegetation intervention. The intervention was concentrated on selected pedestrian-level areas around Torre Littoria, where additional shading could address relatively exposed portions of the public realm. The existing vegetation of the internal courtyard was maintained as part of the baseline rather than being treated as a new intervention. The comparison therefore focused on the additional vegetation introduced in the selected external pedestrian areas and its effect on the spatial distribution of Tmrt.

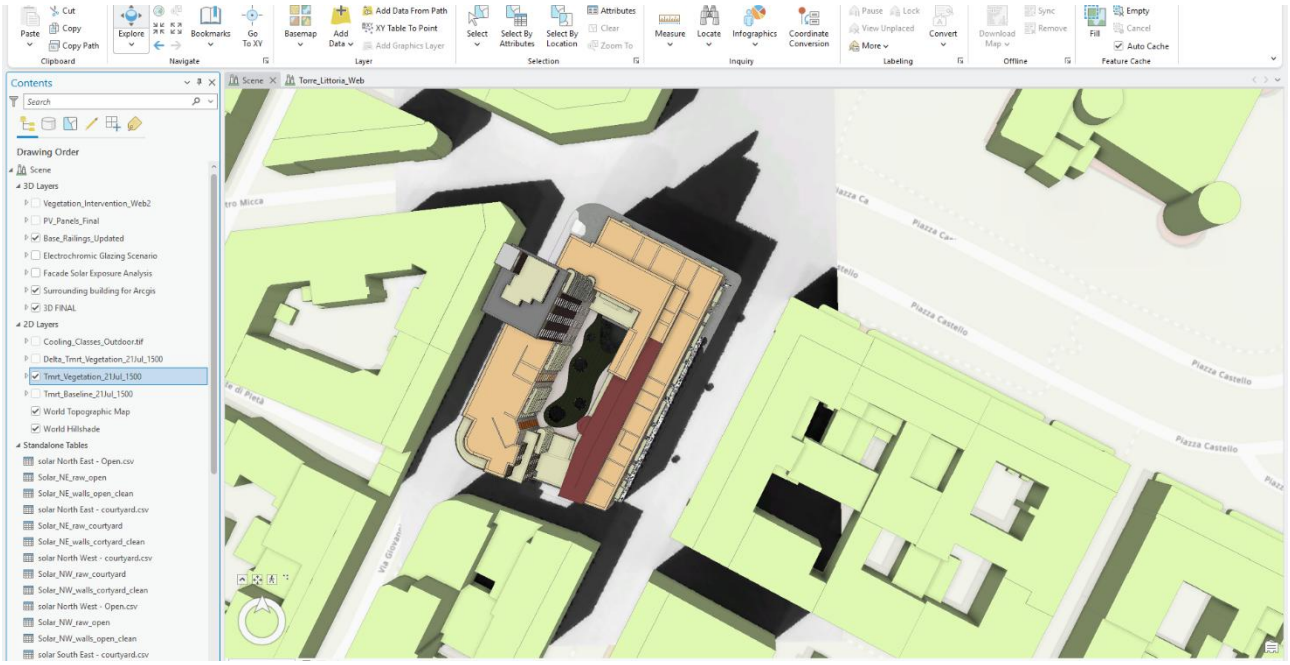


Figure 4.3

Mean radiant temperature (Tmrt) distribution under the analysed vegetation scenario.

The difference between the baseline and vegetation conditions was represented through a ΔTmrt raster, allowing areas of cooling and warming to be distinguished spatially. Negative ΔTmrt values indicate a reduction in mean radiant temperature relative to the baseline, while positive values indicate an increase. For the ArcGIS spatial visualization, the results were classified using five fixed intervals: ≤ −20°C, −20 to −10°C, −10 to −5°C, −5 to 0°C, and > 0°C. For quantitative reporting, these results were additionally grouped into four cooling classes, as presented in Table 4-4, to summarize the extent and intensity of the vegetation-related cooling effect.



Figure 4.4

Spatial distribution of ΔTmrt between the baseline and vegetation scenarios.

Table 4-4

Spatial distribution of ΔTmrt classes under the vegetation scenario

Cooling_Class	Delta_Tmrt_Range_C	Cell_Count	Area_m2	Percent_Outdoor_Area
No cooling / slight warming	0 ≤ ΔTmrt ≤ +0.803	4145	165.80	1.8983
Low cooling	-5 < ΔTmrt < 0	213624	8544.96	97.8329
Moderate cooling	-10 < ΔTmrt ≤ -5	2	0.08	0.0009
Strong cooling	ΔTmrt ≤ -10	585	23.40	0.2679

Taken together, the environmental results demonstrated that the three intervention scenarios responded to different environmental conditions and operated at different spatial scales. The electrochromic-glazing scenario addressed solar gains through the building envelope and showed the value of targeting façade groups according to their warm-season exposure. The photovoltaic scenario demonstrated a substantial reduction of the initially analysed surfaces after solar-exposure screening while retaining a measurable annual energy-generation potential. At the urban scale, the Tmrt analysis demonstrated spatial differences in outdoor thermal conditions and provided a basis for assessing the cooling effect of the proposed vegetation scenario. These results therefore do not identify a single universally optimal intervention; instead, they demonstrate how different strategies can be associated with different environmental problems and spatial conditions within the same historic urban context.

These findings answer the second research question by demonstrating how environmental analysis results can be connected with architectural and urban spatial information to evaluate different sustainable intervention scenarios within their specific context.

4.3 Visualization and Decision-Support Outputs

The results generated through the BIM, GIS, and environmental-analysis workflows were consolidated into an interactive web-based visualization environment using ArcGIS Online and Experience Builder. The resulting interface connects the three-dimensional representation of Torre Littoria with the surrounding urban context, environmental analysis outputs, and sustainable intervention scenarios. Rather than presenting the analytical results as independent maps or tables, the visualization organizes them within a common spatial interface, allowing the relationships between the building, its surroundings, and the evaluated interventions to be explored interactively.

The final interface was structured around the main analytical components of the study. The three-dimensional Web Scene provides the spatial representation of Torre Littoria and its surrounding urban context, while separate thematic layers represent façade solar exposure, electrochromic glazing, photovoltaic intervention, vegetation, and outdoor thermal conditions. Scenario controls and bookmarks allow different views and intervention conditions to be explored without changing the underlying datasets. Pop-up information and layer controls further provide access to selected attributes and analytical information associated with the represented elements.

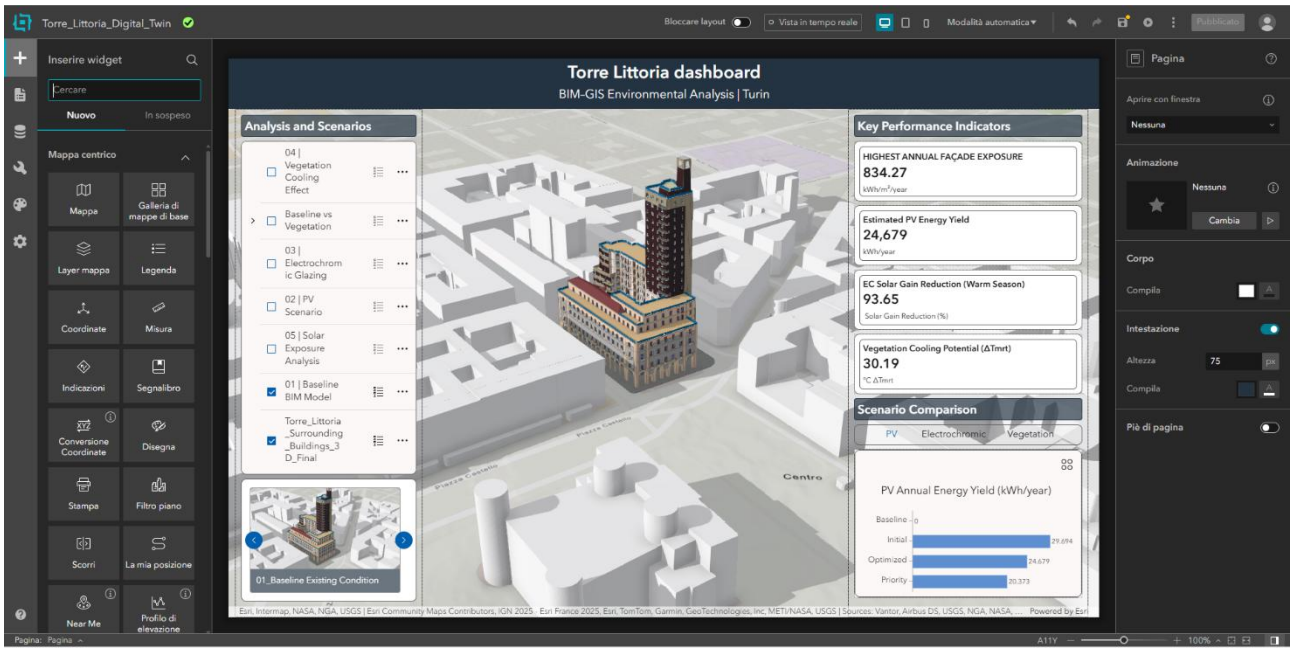


Figure 4.5

Final ArcGIS Experience Builder interface integrating the BIM model, urban context, environmental analysis outputs, and sustainable intervention scenarios.

The visualization was designed not only to communicate the results but also to support comparison between intervention scenarios. The electrochromic glazing scenario can be examined in relation to façade orientation and solar exposure, while the photovoltaic scenario allows the spatial distribution of the proposed PV elements and their associated performance information to be interpreted within the building context. The vegetation scenario is represented together with the outdoor thermal results, allowing the spatial relationship between vegetation placement and changes in mean radiant temperature to be examined. This organization makes the environmental and spatial consequences of the different strategies visible within the same digital environment.

In addition to the spatial representation, selected quantitative indicators were incorporated into the interface to provide a concise summary of scenario performance. These indicators include solar-exposure values, photovoltaic electricity production, electrochromic glazing solar-gain reduction, and vegetation-related thermal effects. The combination of spatial visualization and quantitative information enables the user to move between the location of an intervention and its corresponding analytical results, supporting a more direct comparison of alternatives.

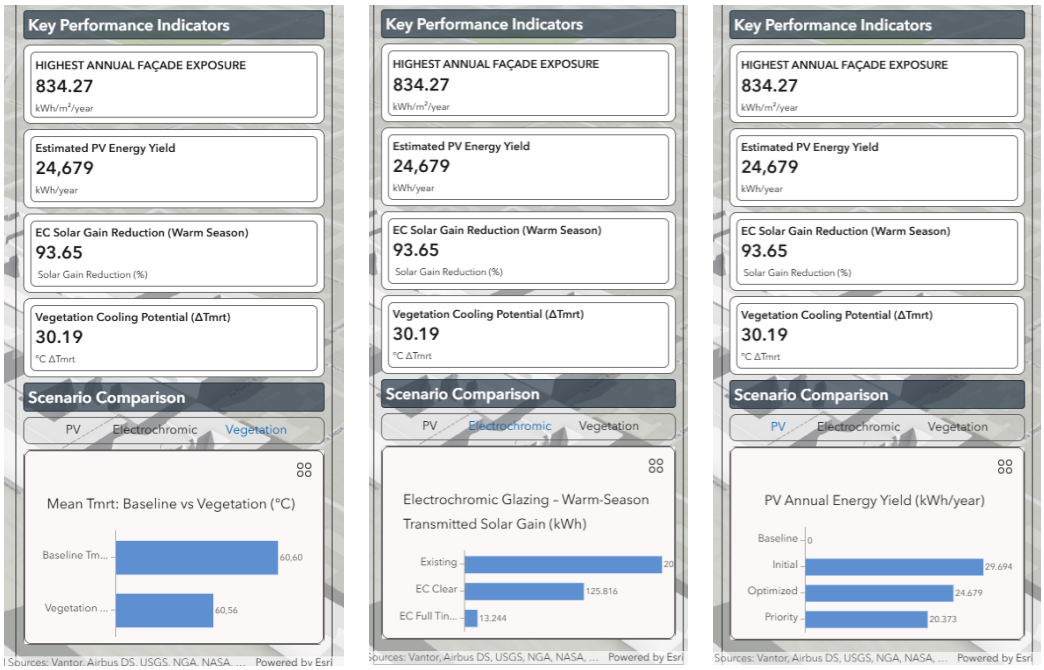


Figure 4.6

Scenario comparison and key performance indicators within the ArcGIS Experience Builder environment.

The final visualization therefore functioned as a decision-support layer connecting the analytical results with their spatial and architectural context. Its main contribution was to transform the outputs of separate modelling and environmental-analysis workflows into an integrated interactive representation. The resulting prototype does not constitute a real-time operational Digital Twin, but provides a Digital Twin-oriented environment in which building information, urban context, environmental performance, and sustainable intervention scenarios can be explored and compared.

This outcome demonstrates the feasibility of integrating heterogeneous datasets into a common visualization environment to support the evaluation and comparison of sustainable retrofit strategies.

4.4 Discussion

The results demonstrate that the assessment of sustainable interventions in a historic urban environment cannot be reduced to a single environmental indicator or to a single spatial scale. The three scenarios investigated in this study responded to different environmental conditions and therefore produced different forms of performance. Rather than identifying one universally preferable intervention, the analysis highlights the importance of matching the intervention strategy to the specific characteristics of the building, its surrounding urban context, and the environmental problem being addressed.

The electrochromic glazing analysis demonstrated that the potential benefit of adaptive glazing is strongly dependent on façade exposure and the extent of transparent openings. The selection of façade groups according to warm-season solar exposure avoided treating all

windows as equally suitable for intervention. This is particularly relevant in the context of Torre Littoria, where the intervention must be considered alongside the architectural and heritage characteristics of the existing envelope. The results therefore support a selective rather than uniform application of electrochromic glazing.

The photovoltaic analysis highlighted a similar relationship between environmental performance and contextual constraints. The initial PV layout provided a larger candidate surface, while the subsequent filtering reduced the intervention area by excluding less suitable locations. The final configuration retained the higher-performing areas and achieved an estimated annual electricity production of approximately 24,679 kWh/year. This demonstrates that optimization does not necessarily require maximizing the installed surface; instead, spatial selection can be used to balance energy generation, solar availability, and the extent of intervention on a historic building.

The vegetation scenario produced a different type of environmental effect. Unlike the building-scale solar interventions, vegetation influenced outdoor thermal conditions at specific locations within the surrounding urban space. The ΔTmrt results showed that the cooling effect was spatially concentrated rather than uniformly distributed. This suggests that vegetation placement should be considered in relation to local outdoor conditions and available urban space rather than as a generalized intervention applied across the entire site.

A key finding across the three scenarios is therefore the value of integrating environmental results with spatial and architectural information. The BIM model provided detailed building information, while the GIS environment allowed these data to be related to the surrounding urban morphology and environmental analysis. The resulting workflow made it possible to evaluate interventions not only according to their calculated performance, but also according to where they occur and how they interact with the existing context.

The Experience Builder implementation further demonstrated the potential of this integration as a decision-support approach. By bringing the BIM-based representation, environmental analysis, intervention scenarios, and quantitative indicators into a common interactive environment, the results could be explored and compared spatially. The platform should nevertheless be understood as a prototype for analysis and decision support rather than as a real-time operational Digital Twin. Its value lies primarily in integrating heterogeneous information and making the relationships between spatial context, environmental performance, and intervention alternatives more accessible.

Finally, the study also revealed several limitations. The environmental analyses were based on selected simulation periods and modelling assumptions, while the intervention scenarios were evaluated primarily through environmental and spatial indicators rather than through a complete life-cycle, economic, or detailed energy-performance assessment. In addition, the heritage feasibility of the proposed interventions depends on regulatory and project-specific evaluation beyond the scope of the digital workflow. These limitations indicate that the

proposed framework should be considered as a supporting tool for early-stage assessment rather than as a substitute for detailed technical and heritage design evaluation.

Overall, the discussion confirms that the research questions were addressed through the integration of BIM, GIS, and environmental analysis workflows. The results demonstrated that building-scale information and urban-scale environmental data can be connected within a common digital environment, while also showing that sustainable retrofit strategies in heritage contexts require a balance between environmental performance, spatial conditions, and regulatory constraints.

Chapter 5 Conclusions

5.1 Conclusions

This thesis investigated the potential of integrating Building Information Modelling (BIM), Geographic Information Systems (GIS), and environmental analysis within a digital framework for the assessment of sustainable interventions in a historic urban context. Torre Littoria in Turin was selected as the case study to examine how building-scale information, urban context, environmental performance, and intervention scenarios could be connected and represented within a common spatial environment.

The developed workflow combined BIM modelling in Revit with GIS-based urban representation and environmental analysis. The BIM model provided the building-scale geometric and semantic information required for the analysis, while the GIS environment extended the representation to the surrounding urban context. Environmental analyses were then used to evaluate solar exposure at the building scale and outdoor thermal conditions at the urban scale. The integration of these outputs into ArcGIS Pro, ArcGIS Online, and Experience Builder demonstrated how information originating from different analytical environments could be brought together within a single interactive representation.

The results showed that the environmental performance of Torre Littoria is strongly influenced by its spatial and architectural context. The solar analysis identified substantial differences between façade groups according to orientation, surrounding buildings, courtyard conditions, and building geometry. These differences provided a basis for the selective assessment of electrochromic glazing rather than treating all transparent openings as equally suitable for intervention. The analysis showed that the selected façade groups had a combined transparent opening area of approximately 1,020 m^2, with the calculated solar-gain reduction under the selected electrochromic assumptions demonstrating the potential of this intervention for high-exposure areas.

The photovoltaic scenario similarly demonstrated the importance of combining environmental performance with spatial and regulatory constraints. Starting from an initial candidate layout, the PV surfaces were progressively filtered according to solar suitability and the selected intervention criteria. The final optimized configuration reduced the PV surface area while retaining a substantial share of the incident solar energy and providing an estimated annual electricity production of approximately 24,679 kWh/year. The comparison between the initial and optimized configurations showed that optimization can improve the performance of the proposed intervention while reducing the extent of the intervention on the historic building.

At the urban scale, the vegetation scenario demonstrated that small-scale vegetation interventions can modify outdoor thermal conditions in specific areas of the site. The comparison between the baseline and vegetation scenarios showed spatially differentiated changes in mean radiant temperature (ΔTmrt), with the strongest cooling effects occurring

only in limited areas. This result indicates that vegetation should be understood as a spatially targeted environmental strategy rather than as a uniform solution across the entire site.

Taken together, the three scenarios demonstrated that different interventions respond to different environmental conditions and operate at different spatial scales. Electrochromic glazing primarily addressed solar gains at the building envelope, photovoltaic systems addressed renewable energy generation while considering the constraints of the historic context, and vegetation addressed outdoor thermal conditions at the urban scale. Their integration within the same digital environment made it possible to compare these different forms of environmental performance while maintaining their relationship with the architectural and urban context.

The final ArcGIS Experience Builder prototype translated the results of these analyses into an interactive decision-support environment. By connecting the BIM-based building representation, urban context, environmental outputs, and intervention scenarios, the platform allowed the results to be explored spatially and compared through selected quantitative indicators. The prototype is not intended to represent a real-time operational Digital Twin; rather, it demonstrates a Digital-Twin-oriented approach for integrating heterogeneous building, urban, and environmental information in support of sustainable intervention assessment.

Overall, the thesis demonstrates that BIM-GIS integration can provide a useful framework for analysing and communicating sustainable interventions in historic urban environments. Its main contribution is not the identification of a single universally optimal intervention, but the development of a workflow through which different interventions can be evaluated according to their environmental performance, spatial conditions, architectural characteristics, and heritage constraints. This approach can support more informed and context-sensitive decision-making for the sustainable transformation of existing historic buildings.

5.2 Future Work

Future development of the proposed workflow could focus on extending the environmental and performance assessment beyond the scenarios investigated in this thesis. The integration of additional building-performance indicators, such as operational energy demand, indoor thermal comfort, and lifecycle-related impacts, could provide a more comprehensive basis for evaluating sustainable interventions in historic buildings.

The environmental analyses could also be extended through simulations covering additional periods of the year and a wider range of climatic conditions. This would allow the seasonal performance of the proposed interventions to be assessed more comprehensively and would reduce the dependence on selected simulation periods.

Another direction concerns the development of the BIM-GIS integration workflow. Future implementations could improve the automated exchange of geometric, semantic, and

analytical information between BIM and GIS environments, reducing manual data preparation and improving the consistency of updates between the different platforms. The integration of more detailed BIM information could also support more advanced building-scale analyses while maintaining the relationship with the surrounding urban context.

The Experience Builder prototype could further be developed into a more dynamic decision-support platform. Future versions could incorporate additional intervention scenarios, user-defined parameters, automated performance comparisons, and updated analytical datasets. Integration with real-time or periodically updated environmental data could also be investigated to move towards a more operational Digital Twin framework.

Finally, future research could test the proposed workflow on additional historic buildings and urban contexts. Applying the methodology to different architectural typologies, heritage constraints, and climatic conditions would help evaluate its transferability and identify which components of the workflow can be generalized. This could contribute to the development of more systematic BIM-GIS-based approaches for supporting sustainable transformation of existing historic buildings.

Chapter 6 References

Amaral, A. R., Rodrigues, E., Gaspar, A. R., & Gomes, Á. (2015). A parametric study of window-to-floor ratio of three window types using dynamic simulation. Energy for Sustainability 2015: Sustainable Cities: Designing for People and the Planet, Coimbra, Portugal.

Attisano, I. (2025). High-rise buildings in Turin between the 20th and 21st centuries: Historical background and structural analysis using the General Algorithm [Master's thesis, Politecnico di Torino].

Barrile, V., Genovese, E., & Favasuli, F. (2023). Development and application of an integrated BIM-GIS system for the energy management of buildings. WSEAS Transactions on Power Systems, 18, 232-240. https://doi.org/10.37394/232016.2023.18.24

Barrile, V., La Foresta, F., Calcagno, S., & Genovese, E. (2024). Innovative system for BIM/GIS integration in the context of urban sustainability. Applied Sciences, 14(19), 8704. https://doi.org/10.3390/app14198704

Bayindir, N. S. (n.d.). Digital Twin of Metro Infrastructure through BIM and IoT Sensor Integration: The Case of Certosa Metro Station, Turin [Master's thesis, Politecnico di Torino].

Benedetto Camerana Studio. (n.d.). Torre Littoria Torino. https://www.camerana.com/portfolio-items/torre-littoria-torino/

Chen, Y., Li, D., He, D., Liu, Y., Taib, N., & Sern, C. H. Y. (2025). Seasonal thermal performance of double and triple glazed windows with effects of window opening area. Scientific Reports, 15, 7890. https://doi.org/10.1038/s41598-025-92600-w

Città di Torino. (2023a). Piano Regolatore Generale di Torino: Norme Urbanistico Edilizie di Attuazione, Volume I. Testo coordinato al 30 giugno 2023. Divisione Urbanistica.

Città di Torino. (2023b). Regolamento Edilizio, n. 381.

Città di Torino. (2026). Regolamento del Verde Pubblico e Privato della Città di Torino, n. 317.

Colucci, E., Iacono, E., Matrone, F., & Ventura, G. M. (2022). A BIM-GIS integrated database to support planned maintenance activities of historical built heritage. In Geomatics and Geospatial Technologies: 24th Italian Conference, ASITA 2021 (pp. 182-194). Springer. https://doi.org/10.1007/978-3-030-94426-1_14

Dehghan Lotfabad, A., Hosseini, S. M., Dabove, P., Heiranipour, M., & Sommese, F. (2025). Impacts of vertical greenery on outdoor thermal comfort and carbon emission reduction at the urban scale in Turin, Italy. Buildings, 15(3), 450. https://doi.org/10.3390/buildings15030450

Del Giudice, M. (2018). Il ruolo delle tecnologie digitali per la rappresentazione progettuale. Disegno, 3, 119-128. https://doi.org/10.26375/disegno.3.2018.12

Faraggiana, G. (2005). In fondo alle vie di Torino: La città e le Alpi. Editris 2000.

Gugliermetti, F., & Bisegna, F. (2003). Visual and energy management of electrochromic windows in Mediterranean climate. Building and Environment, 38(3), 479-492. https://doi.org/10.1016/S0360-1323(02)00124-5

Jung, S. J., Jeon, J. M., & Yoon, S. H. (2026). Data-driven optimization of facade material combinations for enhancing urban microclimates and pedestrian thermal comfort. Urban Climate, 65, 102759. https://doi.org/10.1016/j.uclim.2025.102759

Kritzinger, W., Karner, M., Traar, G., Henjes, J., & Sihn, W. (2018). Digital Twin in manufacturing: A categorical literature review and classification. IFAC-PapersOnLine, 51(11), 1016-1022. https://doi.org/10.1016/j.ifacol.2018.08.474

Kuhn, T. E., Erban, C., Heinrich, M., Eisenlohr, J., Ensslen, F., & Neuhaus, D. H. (2021). Review of technological design options for building integrated photovoltaics (BIPV). Energy and Buildings, 231, 110381. https://doi.org/10.1016/j.enbuild.2020.110381

Lai, C.-C., Sarkar, A., Dinh, P. A., Gaikwad, S., & Hsu, C.-H. (2024). Urban Digital-Twin Planning for Sustainable Smart Cities: System architecture, preliminary experiments, and open challenges. In Proceedings of the 2nd International Workshop on Middleware for Digital Twins (Midd4DT ’24). ACM. https://doi.org/10.1145/3702636.3703443

Lucchi, E., Dall’Orto, I., Peluchetti, A., Toledo, L., Pelle, M., Polo López, C., & Guazzi, G. (2022). Photovoltaic technologies in historic buildings and protected areas: Comprehensive legislative

framework in Italy and Switzerland. Energy Policy, 161, 112772. https://doi.org/10.1016/j.enpol.2021.112772

Martini, A., & Rolfo, D. (2010). Torino, una mappa verticale = Turin: A vertical map. Atti e Rassegna Tecnica della Società degli Ingegneri e degli Architetti in Torino, 64(3), 59-89.

Melis de Villa, A., & Bernocco, G. (1935). Ricostruzione dell'isolato di San Emanuele in Via Roma a Torino. L'Architettura Italiana, 30(12), 405-435.

Moglia, G. (1995). Il risanamento novecentesco del tratto settentrionale di Via Roma. In P. Scarzella (Ed.), Torino nell'Ottocento e nel Novecento: Ampliamenti e trasformazioni entro la cerchia dei corsi napoleonici (pp. 100-121). Celid.

Norberg-Schulz, C. (1980). Genius loci: Towards a phenomenology of architecture. Rizzoli.

Rossi, L., Ziada, H., & Stevens, J. (2025). Beyond the orthographic map: Generative AI and urban morphological analysis. In M. Crapolicchio, R. Gugliotta, & A. Lovisolo (Eds.), Urban Morphology in the Age of Artificial Intelligence: Book of Abstracts (p. 209). Politecnico di Torino.

Sammartano, G., Avena, M., Cappellazzo, M., & Spanò, A. (2021). Hybrid GIS-BIM approach for the Torino Digital-Twin: The implementation of a floor-level 3D city geodatabase. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, XLIII-B4-2021, 423-430. https://doi.org/10.5194/isprs-archives-XLIII-B4-2021-423-2021

Studio Pomero. (2019). Torre Littoria Isolato S. Emanuele / La"piazzetta ritrovata". https://www.studiopomero.com/en/portfolio/torre-littoria-isolato-s-emanuele-the-piazzetta-ritrovata/

Trisciuoglio, M. (2025). Is the city a device? Shaping, mapping, and evolving human settlements towards AI applications in urban forms. In M. Crapolicchio, R. Gugliotta, & A. Lovisolo (Eds.), Urban Morphology in the Age of Artificial Intelligence: Book of Abstracts (pp. 6-7). Politecnico di Torino.

Varlık, A., & Dursun, İ. (2024). Three-dimensional web-based client presentation of integrated BIM and GIS for smart cities. Buildings, 14(9), 3021. https://doi.org/10.3390/buildings14093021

Wang, H., Pan, Y., & Luo, X. (2019). Integration of BIM and GIS in sustainable built environment: A review and bibliometric analysis. Automation in Construction, 103, 41-52. https://doi.org/10.1016/j.autcon.2019.03.005

Yamamura, S., Fan, L., & Suzuki, Y. (2017). Assessment of urban energy performance through integration of BIM and GIS for smart city planning. Procedia Engineering, 180, 1462-1472. https://doi.org/10.1016/j.proeng.2017.04.309

Zhu, J., & Wu, P. (2022). BIM/GIS data integration from the perspective of information flow. Automation in Construction, 136, 104166. https://doi.org/10.1016/j.autcon.2022.104166

Lindberg, F., Grimmond, C. S. B., Gabey, A., Huang, B., Kent, C. W., Sun, T., Theeuwes, N., Järvi, L., Ward, H., Capel-Timms, I., Chang, Y.-Y., Jonsson, P., Krave, N., Liu, D., Meyer, D., Olofson, F., Tan, J. G., Wästberg, D., Xue, L., & Zhang, Z. (2018). Urban Multi-scale Environmental Predictor (UMEP) - An integrated tool for city-based climate services. Environmental Modelling & Software, 99, 70-87. https://doi.org/10.1016/j.envsoft.2017.09.020

Lindberg, F., Holmer, B., & Thorsson, S. (2008). SOLWEIG 1.0 - Modelling spatial variations of 3D radiant fluxes and mean radiant temperature in complex urban settings. International Journal of Biometeorology, 52, 697-713. https://doi.org/10.1007/s00484-008-0162-7