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Master's Degree in Engineering and Management

Master's Degree Thesis

Dynamic Asset Management Model for Educational Facilities in Torino

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Abstract

Public school buildings represent one of the largest and most socially significant components of municipal real estate portfolios in Italy, yet their management remains predominantly reactive driven by crisis response rather than systematic performance analysis. This thesis develops, validates, and applies a dynamic asset management model for the public school building portfolio of the Comune di Torino, using a representative sample of 20 buildings in the north-western district of the city.

The core of the model is the Effective Cost per Student (C_{es}), a composite indicator that integrates five annual operating cost components utilities, ordinary and minor maintenance, facility services, and personnel costs normalised by real student enrolment and multiplied by a Maintenance Status Index (MSI) derived from the Comune di Torino's official five-category building inspection framework. Ordinary maintenance costs are allocated to individual buildings using a millesimal weighting method proportional to net floor area, consistent with Italian public property management practice. The MSI converts physical inspection scores into a risk multiplier that adjusts the cost indicator for building condition, age, and structural vulnerability.

The model was applied to ten years of municipal cost data (2016–2025), covering utility consumption, maintenance budgets, enrolment registers, and building inventory records obtained from the Comune di Torino. Personnel costs were estimated using supervisor-validated staffing ratios and CCNL public sector wage scales. Building condition scores were verified through on-site inspections completed for all 20 sample schools between April and June 2026.

The analysis identifies a more than fourfold efficiency gap between the least and most cost-efficient schools in the sample €8,753 versus €1,932 per student per year within facilities located in the same urban district and funded from the same municipal budget. Five schools are flagged as cost anomalies exceeding 1.5 times the sample average, driven by a combination of small or declining enrolment and the structurally higher staffing intensity of early-childhood provision. Simulation scenarios combining school consolidation, student transfer, and adaptive reuse of freed buildings project combined annual savings of approximately €626,486, equivalent to 23.6% of the city-wide ordinary maintenance budget for all 301 Torino school buildings, driven primarily by the elimination of personnel and administrative costs rather than facility costs that persist regardless of a building's operational status.

The study demonstrates that a composite cost-efficiency indicator, grounded in existing municipal data infrastructure and aligned with Italian regulatory frameworks, can provide a reliable and replicable basis for strategic asset management decisions in public educational facility portfolios.

Keywords: asset management, school buildings, public real estate, cost efficiency, Effective Cost per Student, Maintenance Status Index, millesimal allocation, Torino, ISO 55000.

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I also wish to thank the Comune di Torino and the Servizio Edilizia Scolastica for granting access to the administrative datasets that form the empirical backbone of this study, and for the opportunity to contribute, however modestly, to the ongoing effort to improve the management of public school buildings for the benefit of the children and families they serve.

On a personal level, I dedicate this thesis to my family. To my **parents**, whose sacrifices, encouragement, and unconditional love have been the foundation of everything I have achieved. They believed in me before I believed in myself, and every page of this work carries their support within it. To my **brother**, whose companionship, humour, and unwavering confidence in me have been a constant source of strength throughout my studies. Arriving in Torino and completing a Master's degree far from home was a challenge made immeasurably lighter by knowing they were always with me.

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Contents

Abstract **I**

Acknowledgments **I**

Contents **III**

List of Tables **VII**

List of Figures **IX**

Acronyms **X**

1 Introduction **1**

1.1 Background and Context 1

1.2 Problem Statement and Motivation 2

1.3 Research Objectives and Questions 3

1.4 Scope and Limitations 5

1.5 Thesis Structure 6

2 Literature Review **8**

2.1 Introduction 8

2.2 Asset Management: Theory and Standards 8

2.3 Maintenance Strategy Models 9

2.4 Life Cycle Cost Analysis in Public Buildings 11

2.5 GIS-Based Asset Mapping for Public Real Estate 12

2.6 Millesimal Valuation in Italian Property Law 13

2.7 Demographic Trends and School Network Planning 14

2.8 Research Gap and Positioning of this Study 15
2.9 Summary 16

3 Data Collection and Building Inventory **17**
3.1 Study Area and Sample Selection 17
3.1.1 Geographic Scope and Sample Rationale 18
3.1.2 Sample Definition 21
3.2 The Analytical Framework: the C_{es} Model 21
3.2.1 The Effective Cost per Student Formula 22
3.2.2 Cost Classification: OPEX and CAPEX 23
3.3 Model Assumptions and Methodological Safeguards 25
3.3.1 Assumption 1: Fixed and Variable Cost Decomposition 26
3.3.2 Assumption 2: Millesimal Allocation of Ordinary Maintenance . . 26
3.3.3 Assumption 3: CAPEX Temporal Decoupling 27
3.3.4 Assumption 4: The Model as a Decision Support Tool 28
3.4 Data Sources and Collection Process 28
3.4.1 Primary Source 1: Annual Report 2026 — Ordinary Maintenance Budget 29
3.4.2 The Funding Gap: System-Wide Context 31
3.4.3 Primary Source 2: Physical Factors Registry and Millesimal Allocation 32
3.4.4 Additional Data Categories 33
3.4.5 Limitations of the Data 37
3.5 Database Construction 38
3.5.1 Database Structure 38
3.5.2 Spatial Analysis with Google My Maps 39
3.6 On-Site Condition Inspections and MSI Construction 40
3.6.1 Inspection Methodology 40
3.6.2 The Five Official Inspection Categories 40
3.6.3 Condition Rating Scale 41
3.6.4 Construction of the Maintenance Status Index 42
3.7 Summary 43

4 Analysis and Results 45
4.1 Utility Cost Analysis 45
4.2 Maintenance Cost Inputs 47
4.2.1 Ordinary Maintenance (M_o) 47
4.2.2 Minor Maintenance (M_s) 48
4.3 Personnel Cost Estimation 48
4.3.1 Teaching and Care Staff (P_{edu}) 48
4.3.2 Principal Cost Share (P_{fac}) 49
4.3.3 Maintenance Status Index Results 50
4.4 Enrolment Trends 51
4.5 C_{es} Calculation and Ranking 52
4.5.1 Partial C^*_{es} Formula 52
4.5.2 Year-by-Year Results and Ranking 53
4.5.3 Sensitivity Check: Effect of Partial S Inclusion 55
4.6 Discussion of Results 56
4.6.1 The Nido and Kindergarten Efficiency Problem 56
4.6.2 Demographic Decline as a Cost Amplifier 56
4.6.3 The Role of the MSI 57
4.6.4 The Role of the MSI 57
4.7 Summary 58

5 Discussion and Simulations 59
5.1 Interpretation of Results in Context 60
5.2 Strategic Framework: The North-Western District as an Optimised Educational Cluster 61
5.3 Demographic Sub-Routine: Validating Decisions Against Population Trends 62
5.3.1 National and Regional Projections 62
5.3.2 Application to the Sample 63
5.4 GIS Analysis: Geographic Constraints on Student Mobility 64
5.4.1 Walking Distance Analysis 64
5.4.2 Mobility Barriers Identified 64
5.5 Simulation Scenarios for the Five Flagged Schools 65
5.5.1 S02 (Primule 36C) — Closure and Student Transfer 65

5.5.2 S06 (Via Verbene 4) — Consolidation into S13 66
5.5.3 S17 (Via Gorresio 13) — Consolidation into S18 67
5.5.4 S15 (Carutti 19) and S10 (Via Terraneo 1) — Monitor and Retain 68
5.6 Projected Financial Savings 68
5.7 Managerial and Policy Implications 70
5.7.1 For the Comune di Torino 70
5.7.2 For Italian Municipal School Asset Management More Broadly . . 71
5.8 Summary 71

6 Conclusions 73
6.1 Summary of Main Findings 73
6.2 Answers to Research Questions 75
6.3 Limitations 77
6.3.1 Recommendations for the Comune di Torino 79
6.3.2 Directions for Future Research 80
6.4 Concluding Remarks 82
6.5 Concluding Remarks 82

Bibliography 83

List of Tables

3.1 List of the 20 sample schools in the north-western district of Torino (source: Comune di Torino). 21
3.2 Classification of cost categories into OPEX, CAPEX, and exclusions. . . 25
3.3 Historical ordinary maintenance budget streams for the Comune di Torino school estate, 2004–2026 (source: Relazione Annuale 2026, Servizio Edilizia Scolastica). 30
3.4 Updated building addresses, net floor areas, millesimal weights, and M_o/M_s allocation per sample school, based on 2023 city-wide budget figures (source: own calculation from Annual Report 2026 and the updated Physical Factors / building inventory registry). 33
3.5 Citywide cleaning contract allocation (S_{clean}) per sample school, based on Procedura Aperta n. 102/2023, Lot 5 (€269,936.25 total; source: own calculation from Procurement Bulletin , Comune di Torino). 36
3.6 MSI inspection categories, scope, and weighting (aligned with Comune di Torino's official building monitoring framework). 41
3.7 Condition priority rating scale in the Municipality of Turin inspection reports. 42

4.1 Average annual telecommunications cost per school, 2016–2025 (EUR, net of IVA; confirmed rates from municipal telecom register). 46
4.2 Millesimal coefficient and M_o allocation per school, 2023 reference year (source: own calculation from Relazione Annuale 2026 and the updated Physical Factors registry). 47

4.3 Estimated teaching/care staff count and annual cost per school, 2023 reference year (source: own calculation from enrolment data and CCNL wage scales, using the school categories in Table 3.1). S10 uses a split-and-sum method: enrolment divided equally between nursery and kindergarten sub-populations, each staffed at its own ratio and wage rate, then summed. . 49
4.4 MSI scores for the 20 sample schools: five category risk scores and composite index (1.0 = good condition, 4.0 = critical), verified from on-site inspections completed April–June 2026. 50
4.5 Annual enrolled student count (N) per school, 2019–20 to 2025–26 (source: Comune di Torino). *Italic* = interpolated. S10, S14 excluded. 52
4.6 Annual C^*_{es} per school, 2016–2025 (€per student per year). Ranked by descending ten-year average. Partial index: S (pest control, gardening) excluded; cleaning sensitivity check in §4.6.3. S14 excluded (no enrolled students). 55

5.1 Demographic sub-routine assessment for the five flagged schools. 63
5.2 Estimated annual OPEX savings from simulation scenarios, 2023 reference year basis. Savings exclude M_o and S_{clean}, both of which continue under adaptive reuse. 69

List of Figures

3.1 Full municipal school portfolio, all 301 school buildings managed by the Comune di Torino across eight city districts (source: Google My Maps, data from Comune di Torino). 19

3.2 Northern district of Torino, the institutional perimeter of the internship engagement within the Servizio Edilizia Scolastica (source: Google My Maps, data from Comune di Torino). 20

3.3 Close-up view of the 20 sample schools in the north-western district of Torino, illustrating the compact spatial cluster that supports consolidation scenario analysis (source: Google My Maps, data from Comune di Torino). 20

3.4 Ordinary maintenance budget (M_o current expenditure) versus schools' own direct allocation (M_s minor maintenance), Municipality of Turin, 2004–2026 (source: 2026 Annual Report). 30

Acronyms

C_{es} Effective Cost per Student (Costo effettivo per studente)

M_o Ordinary Maintenance cost (Manutenzione Ordinaria)

M_s Minor Maintenance cost (Minuta Manutenzione)

N Real Enrolment (number of registered students)

P_{edu} Educational Staff costs (teachers, principals)

P_{fac} Facility Staff costs (janitors, custodians)

U Utility costs (heating, electricity, water, telecommunications)

ACI Adjusted Cost Index

AM Asset Management

APE Attestato di Prestazione Energetica (Energy Performance Certificate)

ARES Anagrafe Regionale dell'Edilizia Scolastica (Regional School Building Registry)

BIM Building Information Modelling

CAPEX Capital Expenditure

CDP Cassa Depositi e Prestiti

CMMS Computerised Maintenance Management System

GIS Geographic Information System

HVAC Heating, Ventilation, and Air Conditioning

IAM Institute of Asset Management

ISEE Indicatore della Situazione Economica Equivalente (Means-testing index)

ISO International Organization for Standardization

IVA Imposta sul Valore Aggiunto (Italian Value Added Tax)

KPI Key Performance Indicator

LCC Life Cycle Cost

MEP Mechanical, Electrical, and Plumbing

MIM Ministero dell'Istruzione e del Merito (Italian Ministry of Education)

MSI Maintenance Status Index

OPEX Operating Expenditure

PEI Property Efficiency Index

PNRR Piano Nazionale di Ripresa e Resilienza (National Recovery and Resilience Plan)

SAMP Strategic Asset Management Plan

Chapter 1

Introduction

1.1 Background and Context

Public school buildings represent one of the largest and most socially significant components of municipal real estate portfolios in Italy. They are used by hundreds of thousands of children and families every day, they consume substantial portions of local government budgets in utilities, maintenance, and staffing, and they are subject to increasingly stringent regulatory requirements in terms of structural safety, energy performance, fire compliance, and accessibility. Yet the management of these assets in most Italian municipalities remains predominantly reactive: interventions are carried out when something breaks, budgets are distributed with limited reference to building condition or utilisation efficiency, and strategic decisions about which facilities to invest in, consolidate, or repurpose are rarely supported by systematic quantitative analysis.

The city of Torino provides a vivid illustration of this challenge. The Comune di Torino manages a portfolio of 301 school buildings across eight city districts, hosting nurseries, kindergartens, primary schools, middle schools, and adult education centres. The annual ordinary maintenance budget for this entire estate stood at approximately €3.0 million in 2026, a figure that the municipality's own Servizio Edilizia Scolastica acknowledges covers only 33% of estimated ordinary maintenance needs and fulfils only 36% of actual maintenance requests submitted by school users [5]. The extraordinary maintenance backlog is more severe: estimated needs for 2026–2027 alone reach €154.4 million, against an allocated budget of approximately €9.5 million, representing a coverage rate of just 6.2%. Even with the €82.5 million in PNRR Next Generation EU funds mobilised between 2022 and 2026 across 85 buildings [10], the structural maintenance deficit continues to accumulate.

This fiscal and operational crisis is not unique to Torino. Across Italy, the Legambiente annual report on school building conditions [18] consistently documents widespread structural deterioration, energy inefficiency, and safety compliance gaps in the public school estate. At the European level, demographic projections indicate declining enrolment in many urban districts [8, 17], creating a situation where ageing, expensive to maintain buildings are increasingly serving shrinking student populations, a combination that imposes growing financial pressure on municipalities with stagnant or declining maintenance budgets.

In this context, the need for a structured, data-driven approach to school building asset management is both urgent and largely unfulfilled. The transition from reactive to predictive asset management, a shift that the ISO 55000 family of standards [15, 16] identifies as the hallmark of mature asset management practice, requires tools capable of integrating cost data, building condition information, and utilisation metrics into a single, comparable indicator that can support strategic investment decisions across a large and heterogeneous building portfolio.

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1.2 Problem Statement and Motivation

The fundamental problem addressed by this thesis is the absence of a transparent, replicable, and operationally viable tool for ranking public school buildings by their true cost efficiency relative to their spatial and operational utilization by the student population. Municipal administrations currently lack a standardised method to answer the following questions simultaneously and objectively:

- Which school buildings impose the greatest financial burden on the municipality per student served?

- To what extent does the physical condition of a building amplify or mask its apparent operating cost?
- Which buildings should be prioritised for extraordinary maintenance investment, and which should be considered for consolidation or adaptive reuse?
- What would be the quantifiable financial impact of closing an underperforming school and transferring its students to a neighbouring facility?

Without answers to these questions, budget allocation decisions remain driven by historical inertia, political considerations, or crisis response rather than systematic efficiency analysis. The result is a misallocation of scarce public resources: underfunded buildings in genuine structural need compete for attention with well-maintained facilities that simply generate more visible complaints, and schools with low enrolment continue to absorb large fixed costs in utilities (U) and facility staff (P_{fac}) that a more compact, optimised network could eliminate.

The motivation for this research is therefore both academic and practical. Academically, it contributes to the growing literature on public real estate asset management by proposing and testing a composite performance indicator specifically designed for educational facilities in a municipal context. Practically, it provides the Comune di Torino with a replicable analytical framework, validated here through a representative 20-school pilot sample, that can be dynamically scaled up to the city's full building stock once municipal data integration is finalised.

1.3 Research Objectives and Questions

The overarching objective of this thesis is to develop, validate, and apply a dynamic asset management model for the public school building portfolio of the Comune di Torino, using a representative sample of 20 buildings in the north-western district of the city.

This overarching objective is decomposed into four specific research objectives:

1. **RO1 — Model Development:** to design a composite indicator, the Effective Cost per Student (C_{es}), that integrates annual operating costs (utilities, maintenance,

services, and personnel), real student enrolment, and a building health multiplier (the Maintenance Status Index, MSI) into a single, comparable metric for each school building.

2. **RO2 — Data Collection and Validation:** to collect, clean, and structure municipal cost datasets, on-site condition inspection results, and building inventory information for the 20 sample schools. This objective establishes a core analytical horizon spanning 2016–2025 to capture recent operational realities, utilising longitudinal records dating back to 2006 to calibrate baseline ordinary maintenance trends, while applying data-cleaning protocols to address localised data fragmentation (such as pre-2019 extraordinary maintenance data constraints). It also applies the millesimal allocation method to systematically distribute city-wide macro budgets to individual building assets.

3. **RO3 — Analysis and Ranking:** to apply the C_{es} model to the sample and produce a ranked list of buildings by cost efficiency, identifying outliers whose effective cost per student significantly exceeds the sample average and flagging them for strategic review.

4. **RO4 — Simulation and Recommendations:** to simulate consolidation and adaptive reuse scenarios for the lowest-performing buildings, quantifying the potential financial savings and evaluating the geographic and demographic feasibility of student transfer options.

These objectives are guided by the following primary research question:

RQ1: Can a composite cost-efficiency indicator, integrating operating expenditures, student enrolment, and building condition, provide a reliable and replicable basis for strategic asset management decisions in a municipal school building portfolio?

And two secondary research questions:

RQ2: To what extent does the physical condition of a school building (captured by the MSI) alter the cost-efficiency ranking relative to a purely financial assessment?

RQ3: What are the quantifiable financial savings achievable through the consolidation of the least efficient school buildings in the north-western district of Torino?

1.4 Scope and Limitations

This thesis operates within a clearly defined scope. The analysis is restricted to the 20 school buildings located in the north-western district of Torino. This geographic and sample boundary was established by three converging criteria.

First, the thesis was conducted as part of a formal internship with the Comune di Torino's school building service, within which the author's operational responsibility was specifically assigned to the northern district of the city. The sample therefore reflects the actual institutional perimeter of the internship engagement.

Second, the 20 schools in the north-western district present a particularly favourable spatial configuration for the consolidation and adaptive reuse simulations that form the core of Chapter 5: the buildings are geographically close to one another, making student transfer scenarios between neighbouring facilities operationally realistic. In other districts of the city, school buildings are more dispersed, which would make consolidation scenarios less directly actionable.

Third, the north-western sample offers a high degree of internal homogeneity across three dimensions that are critical for valid cross-building comparisons: the administrative data coverage is substantially complete for all 20 schools; the buildings share broadly similar construction periods and structural typologies; and the socio-economic profile of enrolled families — in terms of household income levels — is relatively uniform across the catchment areas of the 20 schools. This homogeneity reduces the risk that differences in C_{es} values between schools are driven by socio-economic factors rather than by genuine differences in building cost efficiency.

While the model is designed to be scalable to the full 301-building portfolio, the empirical results presented in Chapters 4 and 5 are specific to this sample and should not be generalised to other districts without equivalent data collection.

Four limitations are acknowledged explicitly:

1. **Geographic scope:** the 20-school sample represents approximately 6.6% of the total Torino school estate and is concentrated in a single district. The internal homogeneity that makes cross-building comparisons valid also means the sample may not capture the full typological and socio-economic diversity of the broader portfolio.

2. **Data completeness:** the dataset underpinning this study is complete for all 20 sample schools, encompassing ten years of utility cost records, enrolment figures, personnel and facility services costs, extraordinary maintenance documentation, and on-site condition inspection results. All C_{es} calculations presented in Chapter 4 are therefore based on the full variable set defined in Equation 3.1, with no partial or flagged entries. The primary residual data limitation is the reliance on the estimated portfolio total area for the millesimal allocation of M_o, as discussed in Section 3.4.3.

3. **MSI methodology:** the Maintenance Status Index is constructed from on-site visual inspections and a structural vulnerability weight based on building age and typology. It does not constitute a full structural engineering survey and should not be used as a substitute for detailed technical assessments in cases where safety-critical interventions are under consideration.

4. **Decision support positioning:** the C_{es} model is an analytical tool, not a policy prescription. Its outputs provide a transparent, data-driven basis for municipal decision-making but must be interpreted in conjunction with political, social, transport, and community considerations that lie outside the model's scope.

1.5 Thesis Structure

The remainder of this thesis is organised as follows.

Chapter 2 — Literature Review surveys the theoretical and regulatory foundations of the study, covering the ISO 55000 asset management standard, life cycle cost analysis in public buildings, condition-based and preventive maintenance models, GIS-based asset mapping, millesimal valuation methods in Italian property law, and demographic trends affecting school network planning.

Chapter 3 — Data Collection, Model and Methodology introduces the C_{es} formula and the OPEX/CAPEX cost classification framework, identifies the four principal model assumptions and their methodological safeguards, describes the two primary data sources (the *Relazione Annuale 2026* and the Physical Factors registry), presents the millesimal allocation method for ordinary maintenance costs, and describes the on-site inspection protocol and MSI construction procedure.

Chapter 4 — Analysis and Results applies the C_{es} model to the 20 sample schools, presents the utility cost trends, M_o and M_s allocations, MSI values, and final C_{es} rankings, and identifies the buildings that represent the greatest efficiency challenges for the municipality.

Chapter 5 — Discussion and Simulations interprets the Chapter 4 results in the context of the broader literature, presents consolidation and adaptive reuse simulation scenarios for the lowest-performing schools, evaluates geographic and demographic feasibility using GIS analysis, and discusses the managerial and policy implications of the findings for the Comune di Torino.

Chapter 6 — Conclusions summarises the main findings, answers the research questions, acknowledges the study's limitations, and outlines directions for future research and model extension.

Chapter 2

Literature Review

2.1 Introduction

This chapter reviews the theoretical and regulatory foundations underpinning the dynamic asset management model developed in this thesis. The review is organised around five thematic areas that directly inform the design and application of the Effective Cost per Student (C_{es}) model: the evolution of asset management theory and the ISO 55000 standard; maintenance strategy models and the shift from reactive to predictive management; life cycle cost analysis in public buildings; GIS-based asset mapping for public real estate portfolios; millesimal valuation methods in Italian property law; and demographic trends affecting school network planning. The chapter concludes by identifying the research gap that this thesis addresses.

2.2 Asset Management: Theory and Standards

Asset management as a formal discipline emerged from industrial and infrastructure sectors in the late twentieth century, driven by the recognition that the total cost of owning and operating a physical asset over its full lifecycle substantially exceeds its acquisition cost, and that decisions made at any stage of the asset lifecycle have consequences that extend far beyond the immediate budgeting horizon [28, 13].

The publication of the ISO 55000 family of standards in 2014 marked the consolidation of asset management into a globally recognised management discipline [15]. ISO 55000 defines asset management as the "coordinated activity of an organisation to realise value from assets", emphasising that value is not limited to financial return but encompasses risk reduction, service delivery, regulatory compliance, and social outcomes. ISO 55001 [16] establishes the requirements for an asset management system, including the need for a Strategic Asset Management Plan (SAMP), systematic condition monitoring, and evidence-based prioritisation of maintenance and capital investment.

For public administrations managing large portfolios of community facilities — such as schools, hospitals, or social housing — the application of ISO 55000 principles presents specific challenges. Unlike commercial real estate, public assets are not managed primarily for financial return; their performance is measured in terms of service delivery, user safety, and equitable access. The Institute of Asset Management [13] notes that this creates a tension between value optimisation and social obligation that must be explicitly addressed in the asset management framework. This tension is directly relevant to the present study: the C_{es} model is designed to identify financial inefficiencies in the Torino school portfolio without losing sight of the educational service obligation that each building represents.

The literature also distinguishes between **asset management** — the strategic, portfolio-level discipline of maximising value across a collection of assets — and **maintenance management** — the operational, building-level discipline of keeping individual assets functional. The framework developed in this thesis operates at the intersection of the two: it uses building-level cost and condition data to produce portfolio-level strategic recommendations, consistent with the multi-scale approach advocated by Adey et al. [1] for highway infrastructure asset management.

2.3 Maintenance Strategy Models

The literature on maintenance management identifies three broad strategic approaches, which differ in their timing and their use of condition information [24]:

Reactive (or corrective) maintenance involves carrying out repairs only after a failure has occurred. While this approach minimises upfront expenditure, it systematically underestimates the true cost of asset deterioration by ignoring the compounding effect of deferred maintenance, the elevated cost of emergency interventions, and the service disruption caused by unexpected failures. For school buildings, where closures and evacuations have direct educational consequences, reactive maintenance has been widely criticised as both economically inefficient and socially irresponsible [23, 7].

Preventive maintenance involves scheduled interventions carried out at fixed time intervals or upon reaching predetermined usage thresholds, regardless of the observed condition of the asset. This approach reduces the frequency of unexpected failures but can result in unnecessary expenditure when assets are maintained on schedule despite remaining in good condition, or conversely in deterioration when the fixed interval does not match the actual degradation rate of a specific building element [27].

Condition-based (or predictive) maintenance involves monitoring the actual state of the asset and scheduling interventions only when condition indicators cross defined thresholds. This approach, which underpins the ISO 55000 framework, requires investment in data collection and condition assessment but delivers more efficient allocation of maintenance resources by directing spending to where it is genuinely needed [16, 24].

The Maintenance Status Index (MSI) developed in this thesis is explicitly aligned with the condition-based maintenance paradigm. By assessing the physical state of each of the 20 sample schools across six building element categories and combining this with a structural vulnerability weight based on building age and typology, the MSI provides the condition signal that triggers strategic review — analogous to the threshold-crossing mechanism in condition-based maintenance theory.

A further distinction relevant to this study is the separation between **ordinary maintenance** (routine, cyclical upkeep that preserves the asset at its current performance level) and **extraordinary maintenance** (major interventions that restore, upgrade, or extend the asset's functional life). This distinction, which maps directly onto the OPEX/CAPEX classification adopted in the C_{es} model, is well established in both the international facilities management literature [13] and the Italian regulatory framework governing public works [22].

2.4 Life Cycle Cost Analysis in Public Buildings

Life Cycle Cost (LCC) analysis is an established methodology for evaluating the total cost of a built asset over its entire operational life, from construction through operation, maintenance, and eventual decommissioning [9]. The fundamental insight of LCC analysis — that the costs incurred during the operational phase of a building's life typically far exceed its initial construction cost — has important implications for public asset management: decisions that appear financially attractive in the short term (such as deferring maintenance or choosing cheaper construction materials) may generate substantially higher costs over the full asset lifecycle.

Cabeza et al. [3] review the application of LCC analysis to building energy performance and find consistent evidence that energy-efficient retrofits generate positive net present values over a 20–30 year horizon, even when upfront investment costs are substantial. This finding is directly relevant to the PNRR-funded energy efficiency projects documented in the Torino school estate [10, 5]: the model's CAPEX temporal decoupling rule — which suspends cost optimisation tracking during the commissioning period following a major renovation — is consistent with the LCC literature's recognition that energy savings from retrofits materialise gradually over time rather than immediately upon project completion.

Islam et al. [14] demonstrate that LCC analysis at the building element level (roofing, flooring, structural systems) provides more actionable guidance for maintenance prioritisation than whole-building analyses, because it identifies the specific components where the cost of deferred maintenance compounds most rapidly. This element-level perspective informs the design of the MSI assessment protocol in this thesis, which evaluates six building element categories separately before combining them into a weighted composite index.

In the public sector, HM Treasury [12] notes that LCC analysis has been underutilised in infrastructure decision-making because the annual budget cycle of public administrations creates incentives to minimise current-year expenditure rather than to optimise total lifecycle cost. This structural bias towards reactive maintenance — spending less now at the cost of spending substantially more later — is precisely the dynamic that the C_{es}

model is designed to make visible and quantifiable for the Comune di Torino's school portfolio.

2.5 GIS-Based Asset Mapping for Public Real Estate

Geographic Information Systems (GIS) have become an increasingly important tool in public real estate management, enabling spatial analysis that is not possible with traditional tabular databases [29, 11]. For portfolios of geographically distributed assets such as school buildings, GIS provides the capacity to visualise the spatial distribution of building conditions and costs, identify geographic clusters of underperforming assets, analyse catchment areas and student mobility patterns, and evaluate the feasibility of consolidation scenarios that depend on the proximity and connectivity of neighbouring facilities.

Batty [2] identifies the integration of administrative data with geospatial layers as a defining feature of "smart city" asset management, arguing that the combination of granular building-level data with geographic context enables a qualitatively different level of strategic insight than either data source alone can provide. This principle directly motivates the Google My Maps spatial layer developed in the present study, which links the C_{es} model's building-level cost and condition data to the geographic coordinates of each sample school and supports the transfer simulation analysis of Chapter 5.

For school network planning specifically, GIS-based analysis has been applied to evaluate school catchment boundaries [21], optimise bus routes, and assess the accessibility implications of school consolidation for families in different socio-economic contexts. The present study adopts a simplified GIS approach — using point-layer mapping and proximity analysis rather than full network routing — appropriate to the scale and data availability of a 20-school sample study, while acknowledging that a full-scale implementation of the model for the 301-building Torino estate would benefit from more sophisticated geospatial analysis tools.

2.6 Millesimal Valuation in Italian Property Law

The millesimal system is a legally codified method for allocating shared costs among multiple co-owners or users of a property, rooted in Italian civil law [26]. In condominium law, millesimal values express the proportional ownership share of each unit within a shared building, calculated on the basis of the unit's floor area, height, and position, relative to the total building. These values then determine each owner's proportional contribution to shared costs such as maintenance, utilities, and building insurance.

Simonotti [25] provides a comprehensive treatment of millesimal valuation methodology in the Italian context, noting that the primary advantage of the millesimal system is its transparency and legal enforceability: all parties can verify their allocation share and challenge it if the underlying measurements are incorrect. Its primary limitation, as Simonotti acknowledges, is that it allocates costs proportionally to area without accounting for differences in the actual maintenance needs, condition, or usage intensity of different units.

This thesis applies the millesimal principle at the portfolio level: the city-wide ordinary maintenance budget (M_o) is distributed to each of the 20 sample schools in proportion to its net floor area relative to the estimated total floor area of the 301-building Torino school estate. This approach is consistent with standard Italian public property management practice, where building-level maintenance invoices are frequently unavailable and top-down budget allocation is the operational norm [22]. The limitation of this flat area-based allocation that it treats a 1920s masonry school and a 2005 prefabricated concrete school identically per square metre despite their very different maintenance cost profiles is explicitly addressed in the C_{es} model through the MSI multiplier, which acts as a condition-sensitive corrective coefficient on top of the millesimal base allocation. This combination of millesimal allocation and condition-based correction represents an original methodological contribution of this thesis to the Italian public asset management literature.

2.7 Demographic Trends and School Network Planning

School network planning the strategic management of the number, size, and location of school buildings relative to the population they serve is increasingly recognised as a critical dimension of municipal asset management in contexts of demographic change [8, 17].

Italy is experiencing sustained demographic decline, with total fertility rates well below replacement level and significant internal migration from smaller municipalities to metropolitan areas. ISTAT projections [17] indicate that the Italian school-age population (ages 3–18) is expected to decline by approximately 15% between 2020 and 2040, with particularly pronounced reductions in smaller urban districts and rural areas. For the Torino metropolitan area specifically, this translates into a projected reduction in primary and middle school enrolment that will leave a growing share of existing school buildings operating well below their design capacity within the next decade.

From an asset management perspective, declining enrolment creates a structural efficiency problem: school buildings have high fixed operating costs (heating, cleaning, security, and minimum staffing requirements) that do not decrease proportionally when student numbers fall. A school built for 500 students that drops to 150 students still requires the same heated floor area, the same minimum cleaning staff, and substantially the same utility consumption — but now distributes these fixed costs across a much smaller number of users, causing the cost per student to rise sharply. This is precisely the dynamic that the C_{es} model is designed to detect and quantify through the relationship between the fixed-cost numerator and the enrolment denominator N.

Murillo and Román [21] demonstrate that school building conditions and resource levels are significant predictors of student performance outcomes, suggesting that the under-resourcing of deteriorating schools in low-enrolment contexts has educational consequences beyond the purely financial. Earthman [7] and Schneider [23] provide complementary evidence from the United States context that the physical condition of school facilities directly affects student attendance, behaviour, and academic achievement —

reinforcing the case that building condition is not merely a financial variable but an educational outcome variable.

The demographic sub-routine envisaged in the simulation chapter of this thesis which cross-references current low enrolment with local birth rate trends before triggering a closure or consolidation recommendation reflects the literature's consensus that school network decisions must integrate a forward-looking demographic projection rather than relying solely on current enrolment data. A school with low current enrolment in a neighbourhood experiencing an influx of young families may be a poor candidate for closure despite its current cost inefficiency, while a school in a district with sustained demographic decline may warrant consolidation even if its current cost indicators appear acceptable.

2.8 Research Gap and Positioning of this Study

The literature reviewed in the preceding sections reveals a clear and consistent finding: while the individual components of a comprehensive school building asset management framework condition assessment, LCC analysis, GIS mapping, millesimal allocation, and demographic planning are well established in their respective literatures, their integration into a single, operationally deployable composite indicator for municipal school portfolio management remains largely unexplored.

Existing approaches to school building assessment in the Italian context tend to be either purely technical (structural engineering surveys that produce condition ratings without cost context) or purely financial (budget reports that track expenditure without condition adjustment). The ISO 55000 framework provides the conceptual architecture for an integrated approach but does not prescribe specific indicators or allocation methods for public educational facility portfolios.

This thesis addresses this gap by proposing the C_{es} formula as a composite indicator that simultaneously captures the three dimensions identified in the literature as most critical for public school asset management decisions: **economic cost** (the operating expenditure numerator), **service efficiency** (the enrolment denominator N), and **building condition** (the MSI multiplier). The millesimal allocation method provides a legally consistent and operationally practical mechanism for distributing portfolio-level budgets to individual buildings in the absence of building-level invoices a data gap that is the norm rather than the exception in Italian municipal property management. The CAPEX temporal decoupling rule addresses the LCC literature's finding that major renovation investments require a stabilisation period before their efficiency benefits materialise.

The result is a model that is grounded in established theory, consistent with Italian regulatory practice, empirically applicable with the data infrastructure that a municipality of Torino's scale can realistically maintain, and capable of producing actionable strategic recommendations for school portfolio optimisation.

2.9 Summary

This chapter has reviewed the theoretical and regulatory foundations of the dynamic asset management model developed in this thesis. The ISO 55000 standard establishes the strategic framework for evidence-based asset management of public facilities. The maintenance management literature identifies condition-based approaches as the most cost-efficient strategy for large, heterogeneous building portfolios. LCC analysis demonstrates that operational costs dominate the total lifecycle cost of school buildings and that deferred maintenance creates compounding financial liabilities. GIS-based mapping enables the spatial analysis necessary for consolidation scenario evaluation. The Italian millesimal valuation system provides a legally grounded method for distributing portfolio-level budgets to individual buildings. Demographic projections indicate that declining enrolment will intensify the cost-per-student pressure on underutilised school buildings in Italian cities over the coming decades.

The research gap identified across these literatures the absence of an integrated, operationally practical composite indicator for municipal school building asset management motivates the C_{es} model developed and applied in the following chapters.

Chapter 3

Data Collection and Building Inventory

This chapter describes the methodology adopted to collect, organise, and analyse the data underpinning the asset management framework developed in this thesis. It begins by defining the study area and the criteria used to select the sample of school buildings examined. It then introduces the analytical model and its underlying assumptions, the cost classification framework adopted, the data sources and the structure of the database constructed, the spatial analysis carried out using Google My Maps, and finally the on-site condition inspections conducted across the sample schools.

3.1 Study Area and Sample Selection

The city of Torino manages a large and heterogeneous stock of public school buildings under the responsibility of the Comune di Torino. The full portfolio comprises more than 280 school buildings of varying age, size, typology, and condition. Given the scale of this portfolio, a focused sample-based approach was adopted for this thesis, allowing for an in-depth investigation that would not be feasible across the entire stock within the scope of this work.

3.1.1 Geographic Scope and Sample Rationale

The study focuses on the north-western district of Torino. The choice of this district and the definition of a 20-school sample were not arbitrary: they reflect three converging criteria that together provide a methodologically sound and institutionally grounded justification for the scope of the analysis.

Institutional criterion. This thesis was carried out as part of a formal internship engagement with the Comune di Torino's school building service (*School Facilities Department*). Within the internship, the author's operational responsibility was specifically assigned to the northern district of the city. The sample boundary therefore corresponds directly to the actual institutional perimeter of the research engagement, ensuring that data access, field inspection permissions, and municipal collaboration were all available without restriction.

Spatial criterion. The 20 schools in the north-western district are geographically close to one another, forming a compact cluster within the district. This spatial configuration is particularly well suited to the consolidation and adaptive reuse simulation scenarios developed in Chapter 5, where the feasibility of transferring students from a closed or downsized school to a neighbouring facility depends critically on the physical proximity of the receiving school. In other districts of Torino, school buildings are more geographically dispersed, which would make the same consolidation scenarios operationally less realistic and analytically less meaningful. The north-western cluster therefore provides the most favourable natural laboratory for testing the model's simulation capabilities. The spatial distribution of the 20 sample schools is illustrated in Figure **??**.

Data homogeneity criterion. The north-western sample exhibits a high degree of internal consistency across three dimensions that are essential for valid cross-building comparisons within the C_{es} model. First, administrative data coverage from the Comune di Torino is substantially complete for all 20 schools, minimising the data gaps that would otherwise distort inter-school comparisons. Second, the buildings share broadly similar construction periods and structural typologies, reducing the risk that raw cost differences between schools reflect architectural era rather than management efficiency. Third, the socio-economic profile of enrolled families — measured by household income levels —

is relatively uniform across the catchment areas of the 20 schools. This socio-economic homogeneity is important because family income affects enrolment stability, parental engagement in school maintenance advocacy, and the political sensitivity of consolidation decisions; by holding this variable approximately constant across the sample, the model's cost-efficiency comparisons are more directly attributable to building-level factors.

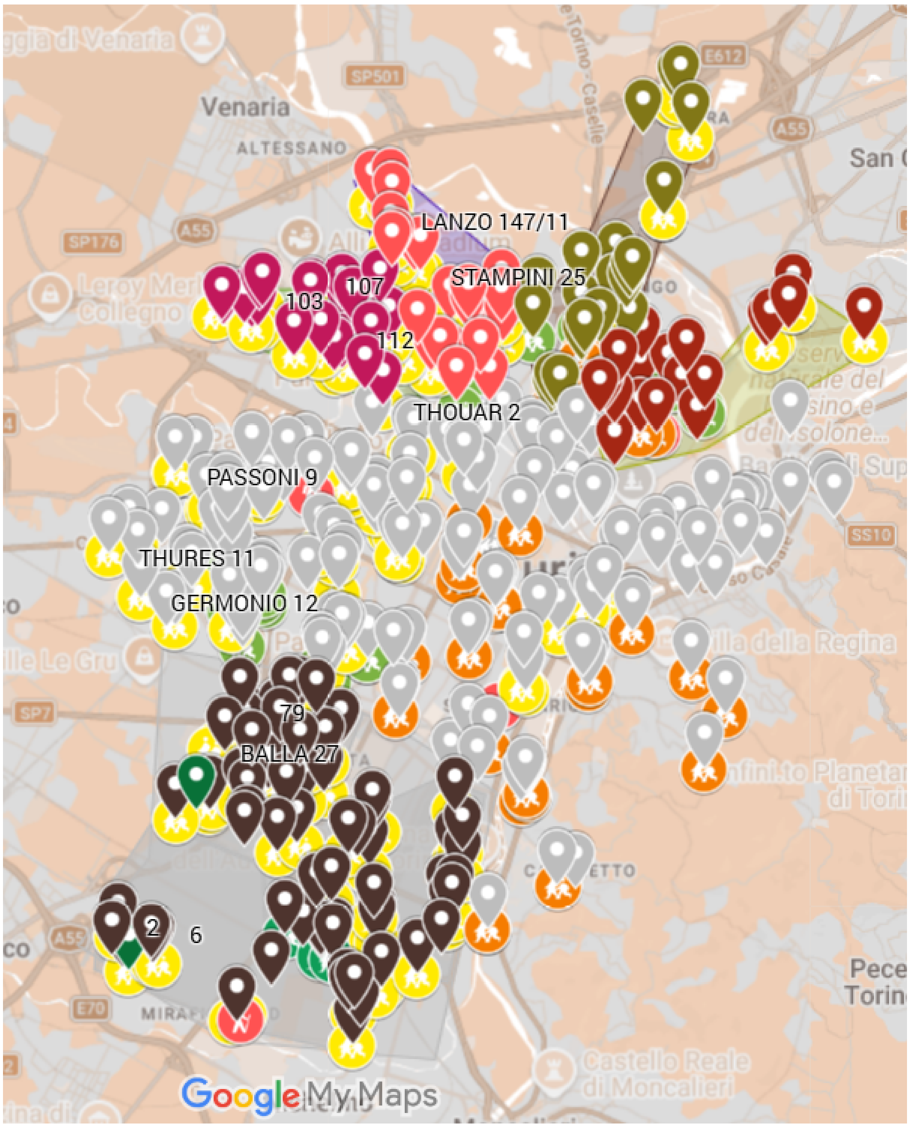

Figure 3.1: Full municipal school portfolio, all 301 school buildings managed by the Comune di Torino across eight city districts (source: Google My Maps, data from Comune di Torino).

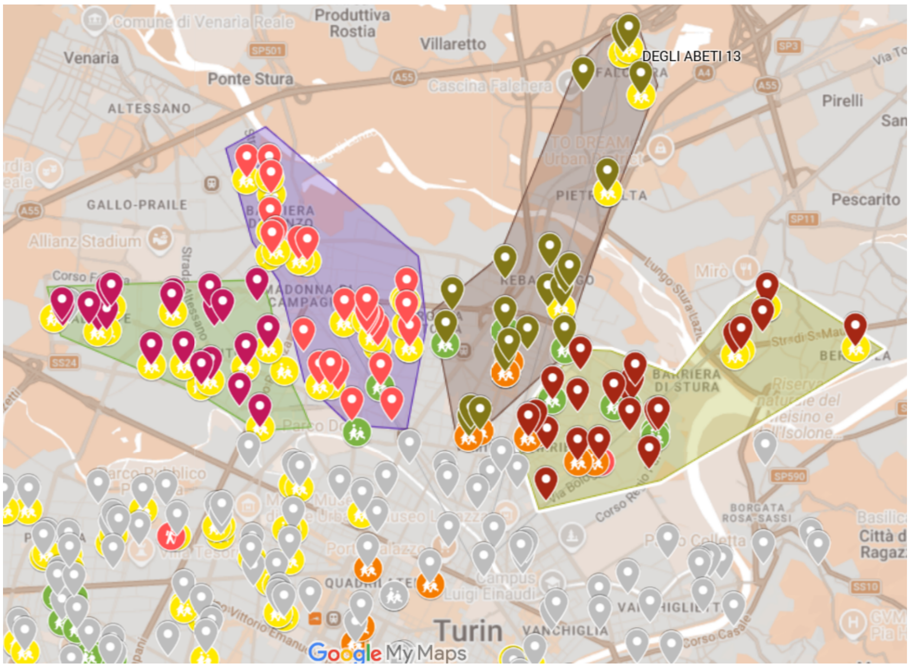

Figure 3.2: Northern district of Torino, the institutional perimeter of the internship engagement within the Servizio Edilizia Scolastica (source: Google My Maps, data from Comune di Torino).

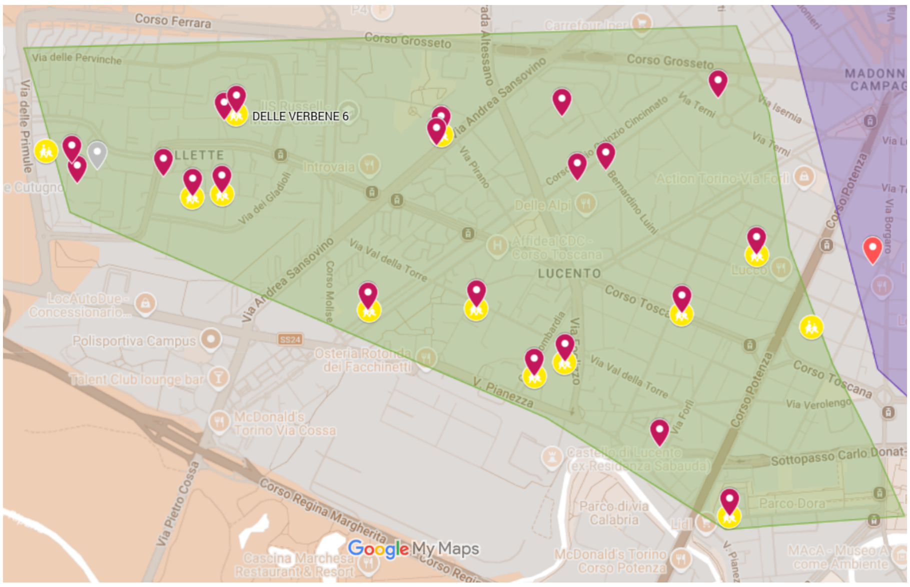

Figure 3.3: Close-up view of the 20 sample schools in the north-western district of Torino, illustrating the compact spatial cluster that supports consolidation scenario analysis (source: Google My Maps, data from Comune di Torino).

3.1.2 Sample Definition

A sample of 20 school buildings was selected from the north-western district on the basis of the three criteria described in the preceding subsection: institutional responsibility, spatial proximity, and data homogeneity. Table 3.1 lists the 20 schools included in the study, with their building codes, addresses, school names, and educational categories as recorded in the municipal database.

Table 3.1: List of the 20 sample schools in the north-western district of Torino (source: Comune di Torino).

ID	**School Name**	**Address**	**Category**
S01	Paulo Freire	Via Primule 36B	Primary School & Italian Courses
S02	Gobetti Marchesini & Paulo Freire	Via Primule 36C	Kindergarten & Italian Courses
S03	Elvira Verde	Via Primule 5	Nursery
S04	Guglielmo Gozzano & Sc. Infanzia	Via Magnolie 15	Kindergarten
S05	David Maria Turoldo & Gianelli	Via Magnolie 9	Middle & Primary
S06	Altiero Spinelli & Vallette A	Via Verbene 4	Kindergarten
S07	Giacomo Leopardi	Via Verbene 6	Primary
S08	Padre Gemelli & Anna Frank	Via Sansovino 111	Kindergarten
S09	Lucia Poli & Enrico Costa	Via Ambrosini 1	Primary
S10	Il Piccolo Principe & Anna Bechis	Via Terraneo 1	Nursery and Kindergarten
S11	I.C. Padre Gemelli	Corso Lombardia 98	Primary
S12	G. C. Pola	Via Foglizzo 15	Middle School
S13	Cincinnato 200 & Cura Curazzi	Corso Cincinnato 200	Kindergarten
S14	Scottarello (Educational Workshops)	Via Luini 195	Community Education
S15	Nido d'Infanzia Biancaluna	Via Carutti 19	Nursery
S16	Guido Gozzano (I.C. Frassati)	Corso Toscana 88	Primary
S17	Pier Giorgio Frassati & Via Gorresio	Via Gorresio 13	Kindergarten
S18	Arcobaleno	Piazza Giuseppe Manno 22	Kindergarten
S19	Margherita di Savoia	Via Thouar Pietro 2	Primary
S20	Comprensivo Frassati	Via Tiraboschi 33	Middle school

3.2 The Analytical Framework: the C_{es} Model

Before describing the data collected, it is necessary to introduce the analytical model that governs the entire study. The framework adopted in this thesis is a dynamic asset management model developed specifically for educational facilities managed by public administrations. The model shifts the approach to school building management from a reactive posture in which interventions are carried out only when a failure occurs to a predictive and strategic one, in which investment is directed towards the assets that generate the greatest economic burden relative to the service they deliver.

3.2.1 The Effective Cost per Student Formula

The core of the model is a single composite indicator called the **Effective Cost per Student** (C_{es}), which expresses the true annual cost that a school building imposes on the municipality per enrolled student, corrected by the physical health condition of the building. The formula is defined as:

$$C_{es} = \frac{U + M_o + M_s + S + P}{N} \times MSI \tag{3.1}$$

where the variables are defined as follows:

- U — **Utilities:** the total annual cost of energy and infrastructure services consumed by the building, including heating, electricity, water and telecommunications (telephone, WiFi, and internet lines). All utility figures are processed by dividing gross invoice amounts by 1.22 to remove the 22% Italian value-added tax (IVA) before input into the formula.

- M_o — **Ordinary Maintenance:** the annual cost of routine upkeep activities, including minor plumbing repairs, painting, and structural checks. Because the Comune di Torino administers this budget at portfolio level rather than issuing individual invoices per building, M_o is allocated to each school using a millesimal weight proportional to its net floor area relative to the total sample area. The limitations and corrections applied to this allocation method are discussed in Section 3.3.

- M_s — **Minor Maintenance:** the cost of emergency cash funds allocated directly to each school for immediate, unplanned small repairs that cannot wait for the ordinary maintenance cycle.

- S — **Facility Services:** the annual cost of services directly linked to the operation and upkeep of the physical asset, including cleaning, pest control, and gardening.

- P — **Personnel Costs:** the annual cost of staff whose role is directly tied to the physical operation of the building, divided into two sub-components with fundamentally different cost behaviours:

  - P_{fac} — **Facility Staff:** custodians, janitors , and on-site maintenance technicians. These represent a **fixed cost** tied to building opening hours, independent of the number of students enrolled. If a school built for 500 students drops to 100 students, P_{fac} does not decrease proportionally the building must still be opened, secured, and maintained daily.

  - P_{edu} — **Educational Staff:** teachers, school principals, and administrative staff. These costs are **variable**, scaling directly with the number of enrolled students, as teacher allocation in Italy is governed by the Ministry of Education (MIM) on the basis of class size and enrolment figures.

- N — **Real Enrolment:** the actual number of students registered at the school in a given year. This acts as the efficiency denominator of the model.

- MSI — **Maintenance Status Index:** a composite index reflecting the overall physical health of the building, acting as a non-linear risk multiplier. Its construction and role are described in detail in Sections 3.3 and 3.6.

3.2.2 Cost Classification: OPEX and CAPEX

A fundamental distinction in the model is the separation between operating expenditures and capital expenditures. This classification determines which costs enter the C_{es} numerator annually and which are treated as long-term investment events.

Operating Expenditures (OPEX) are the continuous, recurring costs required to keep a school building functional and open. All five variables in the numerator of Equation 3.1 U, M_o, M_s, S, and P are OPEX items.

Capital Expenditures (CAPEX) are major, long-term investments that modify, upgrade, or extend the physical life of the asset. These include structural overhauls, seismic upgrades, complete roof replacements, large-scale energy efficiency projects (for example, the €1.7 million PNRR-funded intervention at one of the sample schools), and the installation of entirely new HVAC or heating systems. CAPEX items do **not** enter the annual C_{es} numerator. Instead, they function as a *reset mechanism* for the MSI: a significant capital investment improves the physical condition of the building and therefore lowers its MSI multiplier in subsequent years, reducing its C_{es} value going forward. However, as discussed in Section 3.3, this reset is not instantaneous, the model applies a temporal decoupling rule to account for the operational calibration lag that typically follows major construction works.

Two cost categories are explicitly **excluded** from the model: the school canteen, whose cost depends on family income (ISEE) rather than building characteristics, and school transportation, which is independent of the physical asset. Table 3.2 summarises the full cost classification.

Table 3.2: Classification of cost categories into OPEX, CAPEX, and exclusions.

Cost Item	Type	Variable	Behaviour in Model
Heating	OPEX	U	Annual; divided by 1.22 (IVA)
Electricity	OPEX	U	Annual; divided by 1.22 (IVA)
Water	OPEX	U	Annual; divided by 1.22 (IVA)
Telephone / Internet	OPEX	U	Annual; divided by 1.22 (IVA)
Ordinary Maintenance	OPEX	M_o	Distributed via millesimal weight
Minor Maintenance	OPEX	M_s	Direct allocation to each school
Cleaning	OPEX	S_{clean}	Citywide contract value, allocated via millesimal weight (single reference year; see §3.4.3)
Pest Control	OPEX	S	Annual facility service cost — citywide school-specific tender identified but contract value not obtained
Gardening	OPEX	S	Annual facility service cost — no school-specific data available (only district-wide green-space data found)
Janitors / Custodians	OPEX	P_{fac}	Fixed; tied to building opening hours
Teachers / Principals	OPEX	P_{edu}	Variable; scales with N
Extraordinary Maintenance	CAPEX	—	Resets MSI after acceptance testing
School Canteen (Mensa)	Excluded	—	Depends on ISEE, not on building
School Transportation	Excluded	—	Independent of physical asset

3.3 Model Assumptions and Methodological Safeguards

Any quantitative model applied to real-world public administration data rests on a set of explicit assumptions. Acknowledging these assumptions and the corrections engineered into the model to address them is essential for the integrity of the analysis and for the correct interpretation of results. This section identifies the four principal assumptions of the C_{es} model and describes the methodological safeguard built into the framework to handle each one.

3.3.1 Assumption 1: Fixed and Variable Cost Decomposition

The formula treats enrolment N as a smooth efficiency denominator: as N decreases, C_{es} rises, flagging the building as increasingly inefficient per user served. However, the costs in the numerator do not all behave the same way when student numbers change.

Utility costs U and facility staff costs P_{fac} are **high fixed costs**: a building must be heated, lit, secured, and cleaned regardless of whether it hosts 500 students or 50. If enrolment drops by 40%, these costs do not decrease by 40% they remain substantially constant, causing C_{es} to rise sharply. By contrast, educational staff costs P_{edu} are **variable**: the Italian Ministry of Education (MIM) allocates teachers and administrative staff on the basis of registered class sizes, so a genuine decline in enrolment will reduce P_{edu} over time.

This distinction is not a flaw in the model it is precisely the behaviour the model is designed to expose. When N falls while U and P_{fac} remain rigid, C_{es} spikes exponentially, functioning as an **early-warning alert system** for municipal decision-makers. It mathematically identifies the point at which a building's fixed operational footprint has become a financial liability due to localised demographic decline, long before the situation becomes visible through traditional budget reporting.

3.3.2 Assumption 2: Millesimal Allocation of Ordinary Maintenance

Because the Comune di Torino administers the ordinary maintenance budget at city-wide portfolio level rather than invoicing individual buildings separately, M_o for each school in the sample is estimated by distributing the total macro-budget proportionally to net floor area. This approach known as millesimal allocation is a standard practice in Italian condominium and public property management law, and it is a reasonable first-order approximation when building-level invoices are unavailable.

However, the assumption masks a well-known architectural reality: two buildings with identical floor areas can have vastly different maintenance needs. A school constructed in 1920 with load-bearing brick masonry, high ceilings, and ageing pipework requires substantially more routine upkeep than a prefabricated concrete building erected in 2005 with modern insulation and standardised systems, even if both have the same net area in square metres.

The methodological safeguard for this limitation is the MSI multiplier. Even when the allocated M_o is a flat area-based estimate, multiplying the entire numerator by a high MSI score for the older, more degraded building correctly inflates its C_{es} to reflect its true maintenance burden. The MSI therefore acts not merely as a building health indicator but as an **architectural corrective coefficient**, compensating for the inherent imprecision of the millesimal allocation by introducing a non-linear, condition-sensitive adjustment to the final cost index. The construction of the MSI, including its structural vulnerability weights based on building age and typology, is described in Section 3.6.

3.3.3 Assumption 3: CAPEX Temporal Decoupling

The model treats major capital investments (CAPEX) as events that reset the building's risk profile, reducing its MSI and consequently its future C_{es} values. However, this reset cannot be treated as instantaneous. Large-scale public construction projects in Italy — such as seismic upgrades, energy efficiency retrofits, or complete HVAC replacements — follow a multi-year lifecycle: **year of budget allocation → year of construction execution → year of official certification** (*collaudo*). During the execution phase, utility bills may temporarily *increase* rather than decrease, as construction equipment operates on-site, portions of the building are uninsulated, and the new systems undergo technical commissioning.

To prevent this short-term data noise from corrupting long-term strategic planning, the model incorporates a **temporal decoupling rule**: during the execution phase of a documented extraordinary maintenance project, the building's C_{es} optimisation tracking is placed on an *administrative hold*. The model shifts from an active alert phase to a **verification phase**, in which utility reductions (U) are evaluated only after the formal *collaudo* certification is finalised and a stable operational baseline is established over a rolling 24-month observation window. This rule is applied in the analysis of Chapter 4 for all schools with documented CAPEX interventions in the extraordinary maintenance records.

3.3.4 Assumption 4: The Model as a Decision Support Tool

The C_{es} model produces a ranked list of buildings by effective cost per student, and its simulation routines presented in Chapter 5 identify schools whose closure or adaptive reuse would generate measurable financial savings for the municipality. However, the model is explicitly designed as a **Decision Support Tool**, not as an autonomous decision-maker.

Mathematical optimisation operates within the data available to the model. It does not account for political boundaries, social geography, or transport infrastructure. A neighbouring school may have the physical capacity to absorb transferred students, but if the two facilities are separated by a major arterial road, lack a safe pedestrian route, or serve communities with different socio-economic profiles, the transfer scenario may be operationally unfeasible or politically contentious. These factors must be layered onto the model's output by urban planners and municipal administrators before any closure decision is taken. The model's role is to provide a transparent, data-driven foundation for that conversation not to replace it.

3.4 Data Sources and Collection Process

This study draws on two primary data sources. The first is the *the 2026 Annual Report of the School Facilities Department of the City of Turin*, a comprehensive internal report covering the entire municipal school estate of 301 buildings across eight city districts. The report documents ordinary and extraordinary maintenance spending from 2004 to 2026, PNRR and national financing, estimated maintenance needs by priority level, and a building monitoring system scored on a three-tier urgency scale. The second source is an administrative registry extract the Physical Factors table containing building-level data for the 20 sample schools, including address, building code, school name, use category, net floor area, ceiling height, and fire-safety occupancy capacity. All data were obtained through an official data-sharing process initiated in collaboration with the supervising professors at Politecnico di Torino.

3.4.1 Primary Source 1: Annual Report 2026 — Ordinary Maintenance Budget

The Annual Report provides the complete historical record of the two ordinary maintenance budget streams that feed the M_o and M_s variables of the C_{es} model across the entire Torino school estate.

Stream 1 — Direct Ordinary Maintenance (M_o current expenditure): this is the main budget managed directly by the Municipality of Turin's School Facilities Department for routine repair, renewal, and upkeep of building finishes and technical systems across all schools. As shown in Table 3.3, this stream experienced a sustained decline between 2006 and 2014 reaching a system-wide minimum of €616,207 in 2012 before recovering steadily from 2019 onward, reaching €3,042,826 in 2026.

Stream 2 — Minor Maintenance (M_s minor maintenance): these are smaller direct cash allocations given to individual state school directorates, enabling school principals to commission immediate minor repairs without waiting for the central maintenance service. This stream has been fixed at €120,000 per year collectively across all state schools since 2017, with the exception of 2020 when an additional €180,000 was injected in response to the COVID-19 emergency.

Table 3.3: Historical ordinary maintenance budget streams for the Comune di Torino school estate, 2004–2026 (source: Relazione Annuale 2026, Servizio Edilizia Scolastica).

Year	M_s Minor Maintenance (€)	M_o Ordinary Maintenance (€)	Additional Resources (€)
2004	349,175	2,557,135	—
2005	340,000	2,380,839	—
2006	303,781	1,182,762	—
2007	250,000	1,179,545	—
2008	200,000	940,801	—
2009	235,000	1,146,867	—
2010	250,000	1,240,976	—
2011	200,000	899,883	—
2012	200,000	616,208	190,343
2013	200,000	916,009	94,380
2014	140,000	777,947	—
2015	368,000	826,614	—
2016	160,000	963,621	92,270
2017	120,000	943,149	—
2018	120,000	1,092,570	—
2019	120,000	1,885,982	—
2020	300,000	1,743,137	—
2021	120,000	2,050,080	—
2022	120,000	2,271,734	—
2023	120,000	2,653,911	—
2024	120,000	2,850,196	—
2025	120,000	2,624,189	—
2026	120,000	3,042,826	—

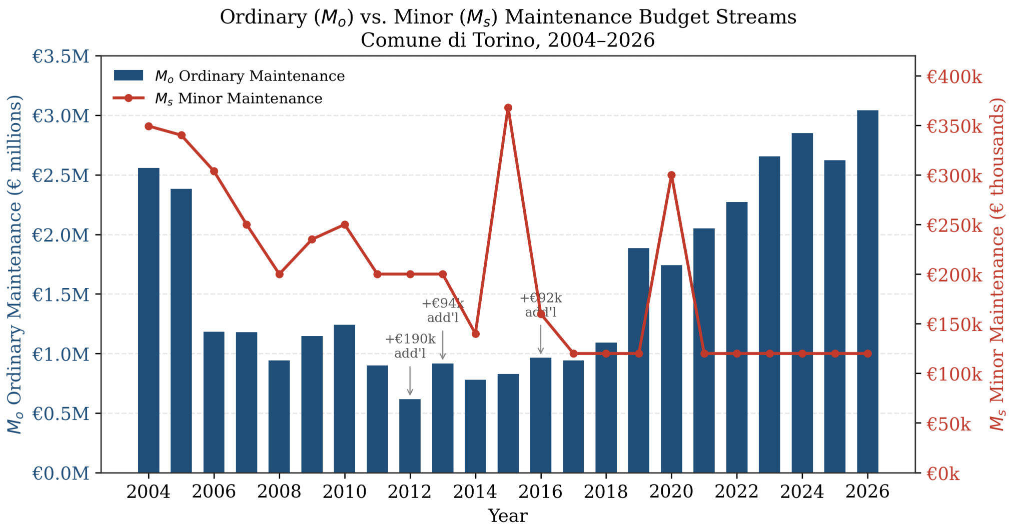

Figure 3.4: Ordinary maintenance budget (M_o current expenditure) versus schools' own direct allocation (M_s minor maintenance), Municipality of Turin, 2004–2026 (source: 2026 Annual Report).

3.4.2 The Funding Gap: System-Wide Context

The *Annual Report 2026* provides explicit quantification of the gap between allocated budgets and actual maintenance needs across the 301-building estate. This context is essential for interpreting the C_{es} results of individual schools: the cost inefficiencies identified by the model do not exist in isolation but reflect a systemic underfunding that has accumulated over decades.

For **ordinary maintenance**, the School Facilities Department estimates an annual need of at least €9.1 million — comprising €3.9M for building works, €1.7M for fire safety systems, €1.2M for ceiling slab inspections, and further amounts for asbestos monitoring, outdoor areas, and other categories. Against this, the 2026 allocation of approximately €3.0 million leaves an ordinary funding gap of €6.1 million. Current resources therefore cover only approximately 33% of estimated needs, and the report notes explicitly that only 36% of actual maintenance requests submitted by schools are fulfilled.

For **extraordinary maintenance**, estimated needs for 2026–2027 total approximately €154.4 million, broken down as follows: Priority 1 structural works €46.6M; Priority 2 accessibility upgrades €91.5M; fire compliance, asbestos removal, ceiling slab repair, seismic vulnerability works, and other categories €16.3M. Against this, the allocated extraordinary budget is approximately €9.5 million — a deficit of roughly €144.9 million, representing a coverage rate of only 6.2%. Between 2022 and 2026, €82.5 million in PNRR Next Generation EU funds were mobilised across 85 buildings to partially address this backlog; however, the per-building average required to eliminate the entire extraordinary deficit is estimated at approximately €1.5 million across the 301-building estate.

This systemic underfunding is the structural condition within which the C_{es} model operates. It reinforces the model's purpose: in an environment where available resources cover only a fraction of actual needs, an objective ranking of buildings by effective cost per student becomes a critical tool for directing scarce municipal funds to where they generate the greatest return.

3.4.3 Primary Source 2: Physical Factors Registry and Millesimal Allocation

The Physical Factors registry provides building-level data for the 20 sample schools, with confirmed net floor areas ranging from 1,067 m^2 (S15, Via Carutti 19) to 7,843 m^2 (S16, Corso Toscana 88).

Two schools of the sample which are, Primule 36B and Primule 36C signal a shared structure hosting two distinct school populations a common feature of the Torino estate and the two units are treated as separate administrative entities throughout the analysis.

Millesimal allocation of M_o: because the Comune di Torino administers the ordinary maintenance budget at portfolio level rather than issuing individual building invoices, the annual city-wide M_o budget is distributed to each sample school using a millesimal allocation coefficient (A_i), consistent with the proportional cost-sharing framework established in Italian civil law [24] and described in the methodological literature by Simonotti [23]. The millesimal coefficient for each facility i is calculated as:

$$A_i = \frac{\text{Area}_i}{\sum_{j=1}^{M} \text{Area}_j} \times 1000 \tag{3.2}$$

where Area_i is the net floor area of school i, and the denominator $\sum_{j=1}^{M} \text{Area}_j$ represents the total gross spatial footprint of the operational school network — that is, all $M = 301$ buildings in the Torino estate, not only the 20 sample schools. Since individual floor areas for all 301 buildings are not available in the dataset, this denominator is estimated as the product of the sample mean area (4,188.36 m^2) and the total number of buildings (301), giving an estimated total portfolio area of approximately 1,260,697 m^2. The individual asset allocation for year t is then derived as:

$$M_{o,i,t} = \text{Budget}_{total,t} \times \frac{A_i}{1000} \tag{3.3}$$

where $\text{Budget}_{total,t}$ is the city-wide ordinary maintenance budget in year t as recorded in Table 3.3.

Allocation of M_s: the minor maintenance fund is distributed equally across all state schools in the estate. From 2017 onward the city-wide allocation is fixed at €120,000 per year, giving a per-school allocation of:

$$M_{s,i} = \frac{120{,}000}{301} \approx e399 \text{ per school per year} \tag{3.4}$$

Table 3.4 reports the resulting M_o and M_s allocations for each of the 20 sample schools based on the 2023 city-wide budget figures, which represent the most complete year available at the time of writing.

Table 3.4: Updated building addresses, net floor areas, millesimal weights, and M_o/M_s allocation per sample school, based on 2023 city-wide budget figures (source: own calculation from Annual Report 2026 and the updated Physical Factors / building inventory registry).

ID	Address	Area (m^2)	Millesimal A_i	M_o 2023 (€)	M_s (€)
S01	Primule 36B	6,858.00	5.440	14,437	399
S02	Primule 36C	2,605.34	2.067	5,486	399
S03	Via Primule 5	1,882.09	1.493	3,962	399
S04	Via Magnolie 15	1,820.03	1.444	3,832	399
S05	Via Magnolie 9	5,733.87	4.548	12,070	399
S06	Via Verbene 4	2,039.06	1.617	4,291	399
S07	Via Verbene 6	6,858.00	5.440	14,437	399
S08	Via Sansovino 111	1,295.53	1.028	2,728	399
S09	Ambrosini 1	5,545.93	4.399	11,675	399
S10	Via Terraneo 1	5,029.00	3.989	10,586	399
S11	Corso Lombardia 98	6,275.17	4.978	13,211	399
S12	Via Foglizzo 15	6,644.42	5.270	13,986	399
S13	Corso Cincinnato 200	1,820.03	1.444	3,832	399
S14	Via Luini 195	5,599.91	4.442	11,789	399
S15	Carutti 19	1,067.00	0.846	2,245	399
S16	Corso Toscana 88	7,843.00	6.221	16,510	399
S17	Via Gorresio 13	1,350.00	1.071	2,842	399
S18	Piazza G. Manno 22	1,789.72	1.420	3,769	399
S19	Thouar Pietro 2	5,845.16	4.636	12,304	399
S20	Tiraboschi 33	5,866.00	4.653	12,349	399

3.4.4 Additional Data Categories

The following data categories were also obtained and mapped to the remaining variables of the C_{es} model:

- **Enrolment data (N):** the actual number of registered and attending pupils per school, collected from official school registration records provided by the Comune di Torino covering the academic years 2016–17 through 2025–26. Enrolment data are available for 18 of the 20 sample schools. Two cases require specific methodological notes. First, S14 (Scottarello, Via Luini 195) operates as a community educational workshop facility rather than a standard school and carries no registered student population; this building is therefore excluded from the C_{es} per-student ranking and assessed separately as a special-purpose asset in Chapter 4. Second, S05 (David Maria Turoldo) and S10 (Il Piccolo Principe) host multiple school populations in a single building; for these two schools, N is calculated as the sum of all registered pupils across all school populations sharing the building, consistent with the single-building cost attribution applied throughout the model. Note that the FireWork Capacity figure in the Physical Factors registry represents the regulatory maximum occupancy, not real enrolment, and the two differ significantly across the sample.

- **Telecommunications costs (U_{tel}):** annual fixed broadband line rental costs (*canone fisso*) per school, extracted from the municipal telecommunications cost register (*Extraction of School Data Line Costs*). The confirmed annual rates for 2022–2025 are €835.80 for small facilities (nurseries and small primary schools), €1,203.60 for standard school buildings, and €3,236.40 for the largest building in the sample (S16, Corso Toscana 88). For the period 2016–2021, rates are estimated by applying documented contract adjustment factors: 0.82 (2016), 0.85 (2017), 0.88 (2018), 0.95 (2019), 0.75 (2020, reflecting the COVID-19 school closure period March–May 2020), and 0.95 (2021). These factors are incorporated directly into the telecommunications cost sheet of the database.

- **Personnel costs (P):** in the absence of building-level payroll records from the Comune di Torino at the time of data collection, personnel costs are estimated using the staffing ratio guidelines provided by the thesis supervisor and the official Italian public sector wage scales (*National Collective Labour Agreement CCNL)*, applied to the real enrolment figures (N) collected for each school.

  The staffing ratios adopted are as follows, consistent with Italian regulatory standards and municipal operational practice:

- **Nursery** (ages 0–3): 1 babysitter/educator per 8 children;
- **Kindergarten** (ages 3–6): 1 teacher per 12 children;
- **Primary School** (ages 7–11): 1 teacher per 25 students;
- **Lower Secondary School** (ages 11+): 1 teacher per 25 students.

The gross annual wage reference values, based on CCNL scales for the Torino public sector (2023 reference year), are €24,500 per babysitter/educator in nursery facilities, €28,000 per kindergarten teacher, €30,000 per primary school teacher, and €33,000 per secondary school teacher. For the ten-year analytical horizon (2016–2025), wages are adjusted annually using documented CCNL increment factors, ranging from 0.88 in 2016 to 1.06 in 2025, reflecting the progressive public sector contract renewals over the period.

Personnel costs are further decomposed into two sub-components as defined in the C_{es} model:

- P_{edu} — **Educational staff:** teachers, babysitters/educators, and their allocated cost, calculated as the product of the estimated number of staff, the applicable CCNL gross wage, and the annual inflation factor.
- P_{fac} — **Facility staff (principals):** following the supervisor's guideline that every four schools of the same educational level within the north-western district share one school principal (*School Principal*), the annual principal cost (€50,000 gross, 2023 reference) is allocated as a proportional share to each school. Schools of mixed educational levels are assigned to the principal group of their dominant level.

School S14 (Scottarello, Via Luini 195) operates as a community educational workshop facility with no registered student population and is therefore excluded from all personnel cost calculations. For schools where enrolment data are missing for isolated years (S01, S06, S07, S10), the nearest available year value is used as a documented proxy and flagged in the results.

- **Facility services (S):** of the three sub-components of facility services cleaning, pest control, and gardening only **cleaning** could be resolved to a usable citywide figure. The Comune di Torino's public procurement notices (*Procurement Bulletin*) record a citywide tender, Open Procedure n. 102/2023, Lot 5, for *"Regular cleaning and environmental hygiene services at schools, laboratories, and City association premises – Educational Services Department"*, with a contract value of €269,936.25 [6]. This figure is not broken down by individual school in the published tender documentation; it is therefore allocated to each sample school using the same millesimal coefficient (A_i) applied to M_o, consistent with the proportional cost-sharing logic used elsewhere in the model:

$$S_{clean,i} = \text{Budget}_{clean} \times \frac{A_i}{1000} \tag{3.5}$$

Table 3.5 reports the resulting allocation for each of the 20 sample schools.

Table 3.5: Citywide cleaning contract allocation (S_{clean}) per sample school, based on Procedura Aperta n. 102/2023, Lot 5 (€269,936.25 total; source: own calculation from Procurement Bulletin , Comune di Torino).

ID	**Address**	**Millesimal A_i**	**$S_{clean,i}$ (€)**
S01	Primule 36B	5.440	1,468.45
S02	Primule 36C	2.067	557.96
S03	Via Primule 5	1.493	403.01
S04	Via Magnolie 15	1.444	389.79
S05	Via Magnolie 9	4.548	1,227.67
S06	Via Verbene 4	1.617	436.49
S07	Via Verbene 6	5.440	1,468.45
S08	Via Sansovino 111	1.028	277.49
S09	Ambrosini 1	4.399	1,187.45
S10	Via Terraneo 1	3.989	1,076.78
S11	Corso Lombardia 98	4.978	1,343.74
S12	Via Foglizzo 15	5.270	1,422.56
S13	Corso Cincinnato 200	1.444	389.79
S14	Via Luini 195	4.442	1,199.06
S15	Carutti 19	0.846	228.37
S16	Corso Toscana 88	6.221	1,679.27
S17	Via Gorresio 13	1.071	289.10
S18	Piazza G. Manno 22	1.420	383.31
S19	Thouar Pietro 2	4.636	1,251.42
S20	Tiraboschi 33	4.653	1,256.01

Unlike M_o and M_s, no multi-year historical series is available for this contract;

the figure represents a single reference period (tender published December 2023, service period 2024 onward) rather than an annual time series comparable to Table 3.3. For this reason, S_{clean} is incorporated only in a supplementary single-year comparison in Chapter 4 (4.6.3), not in the ten-year C^*_{es} ranking, for which no historical cleaning-cost series exists.

Pest control (rodent and insect control) is also procured at city level through a dedicated school-specific tender, *"Guano cleanup, pest control, and rodent control services for schools,"* but the contract value was not published in a form accessible for this thesis and could not be obtained through the Comune's public procurement notices. Gardening costs specific to school grounds remain entirely unresolved: the only related contract identified, Open Procedure / Direct Award CIG B8259857B3 (District 5, 2025–2027), covers general district green areas and urban furniture rather than the grounds of individual school buildings, and its scope and geographic unit of allocation are incompatible with per-school attribution [4].

These two remaining gaps pest control and gardening are acknowledged as a limitation of the current dataset and are discussed further in Chapter 6.

3.4.5 Limitations of the Data

Utility records present minor gaps for isolated school-year combinations, addressed through data-cleaning protocols described in Chapter 4. Extraordinary maintenance records for the period prior to 2019 are sparse for several schools, consistent with municipal archiving constraints noted in the *Annual Report 2026*; the temporal decoupling rule is applied only where complete project lifecycle documentation including *acceptance testing* dates is available. S14 (Scottarello) is excluded from the C_{es} per-student ranking due to the absence of a registered student population. S01 (Paulo Freire) carries enrolment data only for 2017–2021, reflecting the particular registration practices of the adult education system; the most recent available year (2020–21, $N = 123$) is used as the reference value for this school. For S05 and S10, enrolment figures are derived from formula-based aggregations of multiple school populations and are verified against the source registration files before use. Utility costs, telecommunications costs, personnel costs, and on-site condition inspection results are complete for all sample schools. Facility services costs (S) remain only partially resolved: a citywide cleaning contract figure was identified and incorporated as a single-year sensitivity check (4.6.3), while pest control and gardening costs specific to school buildings could not be obtained in a form suitable for per-school allocation, as detailed in 3.4.3. The potential cumulative impact of the identified gaps on the C_{es} calculations is discussed in Chapter 6.

3.5 Database Construction

To manage and analyse the collected data, a structured database was constructed in Microsoft Excel. This tool was selected for its accessibility, its direct compatibility with the data formats provided by the municipality, and its capacity to perform the financial and statistical calculations required by the C_{es} model.

3.5.1 Database Structure

The database is organised with one row per school and separate worksheets for each data category, reflecting the OPEX/CAPEX classification established in Section 3.2.2. The worksheets currently implemented are:

- **General Sheet:** one row per school recording static physical attributes building code, address, school name, use category, net floor area, year of construction, roof type, fire safety capacity, and gymnasium availability alongside summary columns for the C_{es} variables (U, M_o, M_s, S, P, N, MSI).

- **Economic Factors:** annual utility bill grouping and pre-tax cost aggregation per school, summarising the individual utility categories below.

- **Electricity Costs:** annual electricity consumption in kWh and pre-tax cost in euros for each school, from 2016 to 2025.

- **Water Costs:** annual water consumption in m^3 and pre-tax cost in euros for each school, from 2017 to 2025.

- **Heating Costs:** annual heating volume in m^3 and cost broken down into three contractual components for each school, from 2015 to 2023.

- **Telecommunications Costs:** annual telephone and internet service costs per school, distinguishing small, standard, and multi-line tariff tiers.

- **Ordinary Maintenance Costs:** annual M_o (ordinary maintenance) and M_s (minor maintenance) allocations per school, derived from the millesimal weighting method (Equation 3.2) applied to the citywide budget series in Table 3.3.

- **Personnel Costs:** annual P_{edu} (teacher/educator payroll) and P_{fac} (facility staff, principal share) costs per school, computed from staffing ratios and CCNL wage scales.

- **Extraordinary Costs:** documented CAPEX interventions per school per year from 2017 to 2025, including project phase indicators to support the temporal decoupling rule.

- **Student Enrolment:** annual registered student population (N) per school, used as the denominator in the C_{es} formula.

- **Facility Services Costs:** annual S_{clean} (cleaning) allocation per school, derived from the citywide cleaning contract value via the millesimal weighting method (Equation 3.5, 3.4.3); pest control and gardening remain unpopulated.

3.5.2 Spatial Analysis with Google My Maps

In parallel with the Excel database, a spatial layer was created using Google My Maps to visualise the geographic distribution of the 20 sample schools within the north-western district of Torino. Each school was georeferenced using the address and building code provided by the Comune di Torino and plotted as a point layer. Physical attributes such as net floor area, use category, year of construction, and overall condition rating were linked to each point, enabling a visual identification of spatial patterns in building size, age, and condition across the study area. This spatial layer also supports the student transfer simulations presented in Chapter 5, where the geographic proximity and connectivity between schools including road infrastructure and public transport access are key factors in assessing the feasibility of consolidation scenarios.

3.6 On-Site Condition Inspections and MSI Construction

To complement the administrative data provided by the municipality and to derive the Maintenance Status Index (MSI) required by the C_{es} formula, on-site inspections were carried out across the 20 sample schools. The inspection protocol adopted in this study is directly aligned with the official municipal monitoring framework used by the City of Turin's School Building Service. This alignment ensures that the MSI values produced are directly comparable with the municipality's own building condition records and can be integrated into the broader portfolio monitoring system in future applications.

3.6.1 Inspection Methodology

A mixed approach was adopted, combining direct physical visits to each school with a parallel desk-based review of existing technical documents, maintenance histories, and condition reports provided by the Comune di Torino. The on-site inspections were carried out during April to June of 2026 and followed a standardised assessment protocol applied consistently across all buildings. All 20 sample schools have now completed on-site inspections, and the resulting MSI values in the results table presented in Chapter 4 are fully verified against the official municipal condition assessment reports.

3.6.2 The Five Official Inspection Categories

In alignment with the Comune di Torino's official building monitoring framework, each school was assessed across five standardised inspection categories. For each category, individual building elements were examined and assigned a priority rating. Table 3.6 presents the five categories, their scope, and the weight assigned to each in the composite MSI calculation.

Table 3.6: MSI inspection categories, scope, and weighting (aligned with Comune di Torino's official building monitoring framework).

Category	**Scope**	**Weight**
Antincendio e Strutture (Fire Safety & Structures)	Structural integrity, load-bearing elements, roof and slab conditions, fire detection and suppression systems, emergency exits, seismic vulnerability	35%
Energia ed Infrastrutture Leggere (Energy & Light Infrastructure)	Electrical installations, lighting systems, HVAC, thermal insulation, façade and windows, energy efficiency performance	25%
Gestione Acque ed Ambiente (Water & Environmental Management)	Plumbing and drainage systems, water quality, asbestos presence, rainwater management, environmental hazards, outdoor areas	20%
Qualità del Servizio Idrico-Sanitario (Water & Sanitary Service Quality)	Sanitary fixtures and bathrooms, tap and drain conditions, hot water systems, hygiene compliance, limescale and wear	10%
Servizi Accessibili (Accessible Services)	Accessibility for users with disabilities, lifts, ramps, compliant entrances, signage and wayfinding	10%
	Total	**100%**

The weighting structure reflects the relative safety significance of each category. *Antincendio e Strutture* carries the highest weight (35%) because structural failure and fire represent the most severe life-safety risks in a school building environment risks that sit at the base of Maslow's hierarchy of safety needs and that constitute the primary legal obligation of the asset owner under Italian building regulations [20]. *Energia ed Infrastrutture Leggere* carries the second highest weight (25%) because energy system deficiencies directly translate into elevated utility costs (U) in the C_{es} formula, creating a direct link between physical condition and financial performance. The remaining three categories carry lower weights reflecting their importance for regulatory compliance and user wellbeing without constituting immediate structural safety risks.

3.6.3 Condition Rating Scale

The priority rating scale used in the Comune di Torino's official inspection reports assigns higher numerical values to better conditions, consistent with a **priority-to-act** logic: a rating of 4 indicates no urgency (good condition), while a rating of 1 indicates the highest urgency (critical condition requiring immediate intervention). The four levels are defined as follows:

Table 3.7: Condition priority rating scale in the Municipality of Turin inspection reports.

Rating	Label	Description
4	Good	No significant defects; no immediate intervention required. Routine periodic maintenance only.
3	Fair	Minor defects present; standard maintenance recommended. Monitoring required.
2	Poor	Significant defects requiring planned intervention within 1–2 years.
1	Critical	Severe deterioration or safety concern; immediate intervention required.

3.6.4 Construction of the Maintenance Status Index

To integrate the inspection results into the C_{es} formula as a risk multiplier, the raw priority ratings (4 = good, 1 = critical) are converted to a **risk score** on a 1–4 scale where higher values indicate worse condition, using the following transformation:

$$r_k = 5 - p_k \tag{3.6}$$

where p_k is the priority rating of element k (4 = good, 1 = critical) and r_k is the corresponding risk score (1 = good, 4 = critical). This conversion ensures that the MSI behaves correctly as a multiplier: a building in good condition receives a low MSI close to 1.0, which has a minimal inflationary effect on C_{es}, while a building in poor or critical condition receives a higher MSI, correctly inflating its effective cost per student.

For each of the five inspection categories, the risk scores of all assessed elements within that category are averaged to produce a category risk score $C_{n,i}$ for school i. The composite MSI is then calculated as:

$$MSI_i = 0.35 \cdot C_{1,i} + 0.25 \cdot C_{2,i} + 0.20 \cdot C_{3,i} + 0.10 \cdot C_{4,i} + 0.10 \cdot C_{5,i} \tag{3.7}$$

where $C_{1,i}$ through $C_{5,i}$ are the average risk scores for school i across the five categories listed in Table 3.6, in order. The resulting MSI ranges from 1.0 (all elements in good condition across all categories) to 4.0 (all elements in critical condition).

The MSI also incorporates a **structural vulnerability correction** as a baseline adjustment: buildings constructed before 1971 prior to Italy's first national seismic classification legislation receive a baseline risk uplift of +0.2 on the *Antincendio e Strutture* category score, reflecting the statistically greater seismic vulnerability of pre-regulation masonry and unreinforced concrete structures. This correction is applied before the weighted average in Equation 3.7 and is documented for each school in the results table of Chapter 4.

A higher MSI value indicates a building in worse physical and structural condition, which as a multiplier in the C_{es} formula correctly inflates the effective cost attributed to that school, even when its raw utility and maintenance invoices appear similar to a newer, better-maintained building. The MSI values for all 20 schools are reported and discussed in Chapter 4.

3.7 Summary

This chapter has established the data collection framework and the analytical model underpinning this study. A sample of 20 school buildings in the north-western district of Torino was selected from a portfolio of more than 280 facilities managed by the Comune di Torino, on the basis of data completeness and geographic representativeness.

The C_{es} formula was introduced as the core indicator of the study, incorporating five OPEX cost categories utilities U, ordinary maintenance M_o, minor maintenance M_s, facility services S, and personnel costs P normalised by real student enrolment N and multiplied by the Maintenance Status Index MSI. The distinction between OPEX and CAPEX was formalised, clarifying that extraordinary maintenance investments do not enter the annual cost numerator but function as a reset mechanism for the MSI, subject to a 24-month temporal decoupling rule that prevents post-construction calibration noise from distorting the cost signal.

Four explicit model assumptions were identified and addressed: the decomposition of numerator costs into fixed operational components (U, P_{fac}) and variable social components (P_{edu}); the millesimal allocation of M_o corrected by the MSI architectural coefficient; the temporal decoupling of CAPEX resets pending formal *collaudo* certification; and the positioning of the model as a Decision Support Tool requiring expert overlay for implementation.

Two primary sources were used: the *2026 Annual Report of the School Facilities Department*, which provided the complete historical ordinary maintenance budget from 2004 to 2026 and a system-wide deficit quantification (33% ordinary coverage, 6.2% extraordinary coverage), and the Physical Factors administrative registry providing building-level data for all 20 sample schools. Ordinary maintenance costs (M_o) were allocated to each school via a millesimal weight proportional to net floor area relative to the estimated portfolio total of 301 buildings, with two schools (S15, S17) assigned the sample mean area of 4,107 m^2 due to missing floor-plan data. Minor maintenance funds (M_s) were distributed equally at approximately €399 per school per year from 2017 onward. Utility cost records, extraordinary maintenance documentation, GIS data, and existing condition reports were also obtained and structured into a Microsoft Excel database complemented by spatial visualisation in Google My Maps. On-site inspections were carried out across all 20 schools, assessing six building element categories and combining physical condition scores with structural vulnerability weights to construct the MSI for each facility. The combined dataset forms the basis for the cost analysis and building prioritisation presented in Chapters 4 and 5.

Chapter 4

Analysis and Results

This chapter presents the application of the C_{es} model to the 20 sample schools in the north-western district of Torino. The chapter is organised as follows. Section 4.1 presents the utility cost analysis. Section 4.2 presents the maintenance cost inputs (M_o and M_s). Section 4.3 presents the personnel cost estimation. Section 4.4 presents the Maintenance Status Index (MSI) values. Section 4.5 presents the enrolment trends (N). Section 4.6 presents the composite C_{es} calculation and the final ranking. Section 4.7 discusses the key findings.

4.1 Utility Cost Analysis

Utility costs (U) represent the sum of four annual expenditure streams for each school: heating, electricity, water, and telecommunications. All figures are recorded net of the 22% Italian value-added tax (IVA), consistent with the processing protocol described in Chapter 3. Table 4.1 presents the average annual utility cost per school, disaggregated by component.

Table 4.1: Average annual telecommunications cost per school, 2016–2025 (EUR, net of IVA; confirmed rates from municipal telecom register).

ID	School	Contract	Telecom (€/yr)
S01	Paulo Freire	Standard	1,091
S02	Gobetti Marchesini	Standard	1,091
S03	Elvira Verde	Small	757
S04	Guglielmo Gozzano	Standard	1,091
S05	David M. Turoldo	Small	757
S06	Altiero Spinelli	Standard	1,091
S07	Giacomo Leopardi	Standard	1,091
S08	Padre Gemelli & A. Frank	Standard	1,091
S09	Lucia Poli & E. Costa	Small	757
S10	Il Piccolo Principe	Small	757
S11	I.C. Padre Gemelli	Standard	1,091
S12	G. C. Pola	Standard	1,091
S13	Cincinnato & Cura Curazzi	Standard	1,091
S14	Scottarello	Excluded	
S15	Nido Biancaluna	Small	757
S16	Guido Gozzano	Multi-line	2,932
S17	Pier G. Frassati	Standard	1,091
S18	Arcobaleno	Standard	1,091
S19	Margherita di Savoia	Standard	1,091
S20	Comprensivo Frassati	Standard	1,091

Note: Heating, electricity and water costs are in the Excel database by school and year. Rates: small €835.80/yr; standard €1,203.60/yr; multi-line €3,236.40/yr (2022–25).

Several observations emerge from the utility data. First, telecommunications costs are fixed annual contract fees (*canone fisso*) that do not vary with student enrolment or building utilisation. S16 (Guido Gozzano, 7,843 m^2) bears the highest telecom cost at €3,236 per year, reflecting a multi-line contract, while smaller nursery facilities pay €836 per year. Second, the COVID-19 period (2020) produced a measurable reduction in electricity consumption across all schools during the March–May 2020 school closure mandate. Third, heating costs reflect both building volume and insulation quality older pre-1971 buildings consistently show higher heating costs per square metre than post-1975 facilities, consistent with the structural vulnerability assumptions embedded in the MSI.

4.2 Maintenance Cost Inputs

4.2.1 Ordinary Maintenance (M_o)

Ordinary maintenance costs are allocated to each school using the millesimal formula defined in Chapter 3. Table 4.2 presents the millesimal coefficient A_i and the resulting M_o allocation for each school, calculated for the reference year 2023.

Table 4.2: Millesimal coefficient and M_o allocation per school, 2023 reference year (source: own calculation from Relazione Annuale 2026 and the updated Physical Factors registry).

ID	**Address**	**Area (m^2)**	A_i **(millesimi)**	M_o **2023 (€)**
S01	Primule 36B	6,858.00	5.440	14,437
S02	Primule 36C	2,605.34	2.067	5,486
S03	Via Primule 5	1,882.09	1.493	3,962
S04	Via Magnolie 15	1,820.03	1.444	3,832
S05	Via Magnolie 9	5,733.87	4.548	12,070
S06	Via Verbene 4	2,039.06	1.617	4,291
S07	Via Verbene 6	6,858.00	5.440	14,437
S08	Via Sansovino 111	1,295.53	1.028	2,728
S09	Ambrosini 1	5,545.93	4.399	11,675
S10	Via Terraneo 1	5,029.00	3.989	10,586
S11	Corso Lombardia 98	6,275.17	4.978	13,211
S12	Via Foglizzo 15	6,644.42	5.270	13,986
S13	Corso Cincinnato 200	1,820.03	1.444	3,832
S14	Via Luini 195	5,599.91	4.442	11,789
S15	Carutti 19	1,067.00	0.846	2,245
S16	Corso Toscana 88	7,843.00	6.221	16,510
S17	Via Gorresio 13	1,350.00	1.071	2,842
S18	Piazza G. Manno 22	1,789.72	1.420	3,769
S19	Thouar Pietro 2	5,845.16	4.636	12,304
S20	Tiraboschi 33	5,866.00	4.653	12,349

City-wide M_o budget, 2023: €2,653,911.

The millesimal allocation reveals a significant spread: S16 (7,843 m^2) receives €16,510 per year, more than six times the allocation of S08 (1,295.53 m^2) at €2,728. This area-based distribution is corrected at the C_{es} level by the MSI multiplier, which accounts for differences in building age and condition that the flat millesimal formula cannot capture.

4.2.2 Minor Maintenance (M_s)

Minor maintenance funds (*minuta manutenzione*) are distributed equally across all 301 schools in the Torino estate. From 2017 onward the annual per-school allocation is approximately €399 (2020 exception: €997, reflecting COVID-19 emergency additional funding). The M_s allocation is uniform across the sample and therefore does not contribute to differentiating C_{es} values between schools its function is to ensure the full public expenditure burden is captured for each facility.

4.3 Personnel Cost Estimation

4.3.1 Teaching and Care Staff (P_{edu})

Teaching and care staff costs are estimated using the supervisor-validated staffing ratios and CCNL wage scales described in Chapter 3. Table 4.3 presents the estimated number of staff and the resulting annual P_{edu} for each school in the reference year 2023.

Table 4.3: Estimated teaching/care staff count and annual cost per school, 2023 reference year (source: own calculation from enrolment data and CCNL wage scales, using the school categories in Table 3.1). S10 uses a split-and-sum method: enrolment divided equally between nursery and kindergarten sub-populations, each staffed at its own ratio and wage rate, then summed.

ID	**Address**	**Category**	N **2023**	**Staff**	P_{edu} **2023 (€)**
S01	Via Primule 36B	P	123	5	150,000
S02	Via Primule 36C	K	49	5	140,000
S03	Via Primule 5	N	58	8	196,000
S04	Via Magnolie 15	K	46	4	112,000
S05	Via Magnolie 9	PS	313	13	409,500
S06	Via Verbene 4	K	75	7	196,000
S07	Via Verbene 6	P	205	9	270,000
S08	Via Sansovino 111	K	118	10	280,000
S09	Ambrosini 1	P	208	9	270,000
S10	Via Terraneo 1	NK	208	22	570,500
S11	Corso Lombardia 98	P	349	14	420,000
S12	Via Foglizzo 15	S	299	12	396,000
S13	Corso Cincinnato 200	K	125	11	308,000
S14	Via Luini 195	X	–	–	Excluded
S15	Carutti 19	N	74	10	245,000
S16	Corso Toscana 88	P	410	17	510,000
S17	Via Gorresio 13	K	86	8	224,000
S18	Piazza G. Manno 22	K	71	6	168,000
S19	Thouar Pietro 2	P	269	11	330,000
S20	Tiraboschi 33	S	343	14	462,000

Wage reference 2023: N = €24,500; K = €28,000; P = €30,000; S = €33,000 gross per FTE.

Personnel costs constitute the largest single component of the C_{es} numerator across all schools. The nido staffing ratio (1:8) makes nursery buildings structurally more expensive per student than primary or secondary schools — a finding that directly explains the high C^*_{es} values observed for S03 and S15 in Section 4.6.

4.3.2 Principal Cost Share (P_{fac})

Following the supervisor guideline that every four schools of the same educational level share one school principal, each school bears a fractional share of the annual principal salary (€50,000 gross, 2023 reference, adjusted for annual CCNL increments). Schools in groups of four contribute €12,500 per year; schools in groups of three contribute €16,667 per year. Principal-sharing groups are formed at the citywide level, not within the 20-school sample alone: within the sample, the Nursery category comprises only S03 and S15, with the remaining member(s) of their citywide sharing group located outside the sample.

4.3.3 Maintenance Status Index Results

Table 4.4 presents the MSI scores for all 20 sample schools, based on on-site inspections completed between April and June 2026 (3.6.1).

Table 4.4: MSI scores for the 20 sample schools: five category risk scores and composite index (1.0 = good condition, 4.0 = critical), verified from on-site inspections completed April–June 2026.

ID	Address	Yr	C1	C2	C3	C4	C5	MSI
S01	Primule 36B	1960	2.50	2.30	1.70	2.70	1.20	2.18
S02	Primule 36C	1965	2.50	2.30	1.70	2.70	1.20	2.18
S03	Via Primule 5	1975	1.70	1.20	1.20	1.20	1.20	1.38
S04	Via Magnolie 15	1958	2.90	1.20	1.20	2.70	1.20	1.95
S05	Via Magnolie 9	1962	2.90	2.50	2.30	2.70	1.20	2.49
S06	Via Verbene 4	1970	3.20	2.70	2.70	2.70	1.20	2.73
S07	Via Verbene 6	1968	2.00	1.60	1.00	2.33	1.00	1.63
S08	Via Sansovino 111	1955	1.40	1.70	1.20	1.20	1.20	1.40
S09	Ambrosini 1	1972	2.70	2.50	2.30	2.70	1.20	2.42
S10	Via Terraneo 1	1977	2.70	2.70	2.70	2.70	1.20	2.55
S11	Corso Lombardia 98	1963	1.70	1.50	1.50	1.50	1.50	1.57
S12	Via Foglizzo 15	1967	1.40	1.20	1.20	1.70	1.20	1.32
S13	Corso Cincinnato 200	1971	2.30	2.30	2.70	1.20	1.20	2.16
S14	Via Luini 195	1974	3.80	2.70	2.70	2.70	1.20	2.94
S15	Carutti 19	1978	2.30	1.20	3.50	1.20	1.20	2.05
S16	Corso Toscana 88	1955	1.40	1.20	1.20	1.20	1.20	1.27
S17	Via Gorresio 13	1964	2.90	2.70	2.70	2.70	1.20	2.62
S18	Piazza G. Manno 22	1973	1.70	1.20	1.20	1.20	1.20	1.38
S19	Thouar Pietro 2	1961	1.20	1.00	1.00	1.00	1.00	1.07
S20	Tiraboschi 33	1966	1.90	1.20	1.70	1.20	1.20	1.54

C1 = Fire & Structure (35%), C2 = Energy (25%), C3 = Water/Env. (20%), C4 = Sanitary (10%), C5 = Accessibility (10%). C1 values include the +0.2 seismic vulnerability uplift for buildings constructed before 1971.

The composite scores span a wide range, from S19 (Thouar Pietro 2, $MSI = 1.07$), the best-conditioned building in the sample, to S14 (Via Luini 195, $MSI = 2.94$), which stands out as a severe outlier: extensive ceiling collapse across multiple floors has rendered the building partially out of service, requiring immediate structural intervention. The gap between S14 and the next-worst school (S06, $MSI = 2.73$) confirms that S14's condition is categorically different from not merely worse than the rest of the sample.

S16 (Corso Toscana 88) offers a striking contrast: it shares an architecturally identical floor plan with S14, yet scores among the best in the sample ($MSI = 1.27$), reflecting the impact of its completed PNRR renovation (2022–2024). This pairing illustrates how two structurally identical buildings can diverge sharply in condition depending on investment history, reinforcing the case for the MSI multiplier as a necessary correction to the flat millesimal cost allocation.

S04 (Via Magnolie 15) presents a temporary condition effect: its elevated structural and sanitary scores reflect an extraordinary maintenance project currently in progress (ceiling restoration and window replacement), rather than a permanent structural deficiency. Once this intervention reaches acceptance testing (collaudo), the temporal decoupling rule described in 3.4.3 will apply, and S04's MSI is expected to improve substantially in future inspection cycles.

4.4 Enrolment Trends

Table 4.5 presents the annual enrolled student count (N) for the 19 schools over ten years. S10 and S14 are excluded from the C_{es} ranking. Italicised values are interpolated from the nearest available year.

Table 4.5: Annual enrolled student count (N) per school, 2019–20 to 2025–26 (source: Comune di Torino). *Italic* = interpolated. S10, S14 excluded.

ID	**School**	**19-20**	**20-21**	**21-22**	**22-23**	**23-24**	**24-25**	**25-26**
S01	Paulo Freire	139	123	*123*	*123*	*123*	*123*	*123*
S02	Gobetti Marchesini	75	72	62	71	49	43	*43*
S03	Elvira Verde	54	50	59	59	58	65	65
S04	Guglielmo Gozzano	37	29	28	34	46	49	91
S05	David M. Turoldo	121	150	*150*	*150*	*150*	*150*	*150*
S06	Altiero Spinelli	*75*	63	71	57	75	70	73
S07	Giacomo Leopardi	215	215	216	211	205	192	192
S08	Padre Gemelli	125	122	119	120	118	100	86
S09	Lucia Poli	213	207	200	200	208	212	201
S11	I.C. Padre Gemelli	374	342	351	348	349	353	343
S12	G. C. Pola	262	274	284	291	299	300	297
S13	Cincinnato	150	150	142	150	125	120	120
S15	Nido Biancaluna	80	67	74	74	74	74	74
S16	Guido Gozzano	431	422	422	424	410	389	386
S17	Pier G. Frassati	98	88	85	86	86	82	81
S18	Arcobaleno	97	72	73	64	71	74	73
S19	Margherita di Savoia	305	280	277	276	269	277	294
S20	Comprensivo Frassati	402	416	375	373	343	355	360

S16 (Guido Gozzano) is the most enrolled school in the sample, hosting 386–448 students over the decade, though with a declining trend. S02 (Gobetti Marchesini) shows the steepest decline, from 92 students in 2016–17 to 43 in 2024–25, a loss of 53% of its population in nine years. S04 (Guglielmo Gozzano) shows an unusual pattern — declining to a minimum of 28 students in 2021–22 before recovering sharply to 91 in 2025–26 — potentially reflecting a catchment boundary change or partial merger during the COVID-19 reorganisation period.

4.5 C_{es} Calculation and Ranking

4.5.1 Partial C^*_{es} Formula

Facility services costs (S) are only partially available at individual building level from the Comune di Torino: a citywide cleaning contract value was identified (§3.4.3), but no comparable multi-year data exists for pest control or gardening. The ten-year historical ranking is therefore still calculated using the same partial index applied throughout this thesis:

$$C^*_{es,i,t} = \frac{U_{i,t} + M_{o,i,t} + M_{s,i,t} + P_{edu,i,t} + P_{fac,i,t}}{N_{i,t}} \times MSI_i \tag{4.1}$$

Because S is absent uniformly across all 18 schools and all ten years, the relative ranking produced by Equation 4.1 is equivalent to that of the full formula the missing component introduces no differential bias. All values represent conservative underestimates of the true effective cost per student. A supplementary single-year sensitivity check incorporating the newly available cleaning-cost component is presented in 4.6.3.

4.5.2 Year-by-Year Results and Ranking

Table 4.6 presents the annual C^*_{es} values for all 19 included schools (S14 excluded, having no registered student population), ordered by descending ten-year average across the full 2016–2025 period.

Several of the underlying cost components required either interpolation of isolated data gaps or a modelling assumption where direct historical records were unavailable, consistent with the data limitations discussed in §3.4.5 and §4.5.1:

- **Utilities (U):** electricity, water, and heating costs are taken directly from the Comune's billing records for each school and year. Isolated single-year gaps (most notably a near-universal missing 2023 electricity reading) were filled by linear interpolation between the adjacent available years. Two schools required a different treatment: S02 shares a single electricity meter with S01 (building code 646-01) and was apportioned its share of the combined reading in proportion to floor area; S13's electricity and S08's water records were entirely absent and were estimated using the sample's average cost-per-square-metre for the respective utility in each year, applied to the school's own floor area.

- **Personnel costs (P_{edu}):** the 2023 reference-year staffing methodology (§4.3.1) was extended to the full ten-year series by recomputing staff counts from each year's actual enrolment (Table 4.5) and scaling the 2023 wage rates by a linear

CCNL adjustment factor (0.88 in 2016 rising to 1.06 in 2025, calibrated against the confirmed 2023 rates). No independent historical payroll records were available to verify this series directly.

- **Principal cost share (P_{fac}):** in the absence of confirmed citywide principal-sharing group sizes for every educational level (§4.3.2), a flat allocation of €12,500 per year (the four-school group rate) is applied uniformly across the sample and held constant across all ten years.

- **Maintenance Status Index (MSI):** the verified 2026 inspection scores (Table 4.4) are applied as the current condition for all years following each school's most recent documented extraordinary maintenance intervention, lagged by 24 months to reflect the acceptance-testing (collaudo) delay described in §3.4.3. For the ten schools with a significant recorded extraordinary maintenance event (S01, S02, S08, S10, S11, S15, S16, S17, S18, S19), a uniform penalty of +0.40 is applied to the MSI for all years prior to this cutover, reflecting an assumed pre-intervention condition; this magnitude is a modelling estimate, as no independent historical condition assessments exist for these buildings prior to 2026. Schools without a recorded extraordinary intervention carry their current verified MSI flat across all ten years.

The results confirm several of the qualitative patterns identified elsewhere in this chapter. S10 (Via Terraneo 1) and S15 (Carutti 19) rank highest, consistent with the elevated nursery staffing ratio identified in §4.3.1. S19 (Thouar Pietro 2) offers a useful validation of the model's temporal decoupling logic: despite its current best-in-sample MSI (1.07), its €385,261 extraordinary renovation in 2022 the largest single intervention recorded in the sample means its C^*_{es} values for 2016–2023 reflect a substantially worse pre-renovation condition, before dropping sharply from 2024 onward as the improved MSI takes effect.

Table 4.6: Annual C^*_{es} per school, 2016–2025 (€per student per year). Ranked by descending ten-year average. Partial index: S (pest control, gardening) excluded; cleaning sensitivity check in §4.6.3. S14 excluded (no enrolled students).

Rk	ID	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	10yr Avg
1	S10	8,181	8,054	8,435	8,712	8,855	9,587	9,679	8,965	8,940	8,125	8,753
2	S15	8,046	8,431	8,399	8,296	9,227	9,780	9,752	7,549	7,776	7,889	8,515
3	S06	6,516	6,921	7,371	7,432	8,265	7,895	8,307	8,566	8,835	9,968	8,008
4	S02	7,595	7,750	8,162	8,286	8,197	10,246	7,426	7,649	7,250	7,371	7,993
5	S17	7,456	7,187	7,565	8,096	8,327	9,073	8,483	8,792	7,252	7,468	7,970
6	S04	5,581	5,254	6,614	7,331	8,086	9,262	7,384	5,841	6,762	5,554	6,767
7	S13	5,078	5,185	5,303	5,374	5,512	5,804	5,901	5,807	5,660	5,747	5,537
8	S03	4,755	4,697	5,091	5,025	5,549	7,624	5,802	5,642	5,499	5,370	5,505
9	S18	4,491	4,449	4,729	4,929	4,807	5,717	5,939	4,946	5,526	4,397	4,993
10	S08	4,512	4,507	4,597	4,624	4,850	4,913	4,875	4,706	5,164	4,370	4,712
11	S01	4,196	4,005	4,207	4,507	4,503	5,307	4,530	3,532	3,587	3,635	4,201
12	S05	3,988	3,313	4,705	4,417	4,149	4,284	4,262	3,646	3,823	3,788	4,038
13	S09	3,489	3,471	3,691	3,720	3,846	4,187	4,113	3,653	3,671	3,908	3,775
14	S07	2,712	2,627	2,712	2,744	2,847	3,574	3,131	2,646	2,745	2,825	2,856
15	S11	2,450	2,578	2,603	2,602	2,778	3,232	2,957	2,150	2,309	2,266	2,593
16	S20	2,076	2,160	2,237	2,322	2,289	2,486	2,510	2,411	2,525	2,536	2,355
17	S12	2,117	2,023	2,125	2,150	2,150	2,616	2,319	1,972	2,017	2,078	2,157
18	S19	1,956	1,910	2,054	2,081	2,158	2,370	2,390	2,082	1,617	1,539	2,016
19	S16	2,011	2,107	2,175	2,230	1,693	1,815	1,812	1,778	1,861	1,842	1,932

4.5.3 Sensitivity Check: Effect of Partial S Inclusion

To assess how much the exclusion of S understates the true effective cost, a single reference-year comparison is constructed using the 2023 M_o/M_s figures (Table 4.2) together with the cleaning allocation $S_{clean,i}$ (Table 3.5):

$$C_{es,i,2023} = \frac{U_{i,2023} + M_{o,i,2023} + M_{s,i,2023} + S_{clean,i} + P_{edu,i,2023} + P_{fac,i,2023}}{N_{i,2023}} \times MSI_i \tag{4.2}$$

Because $S_{clean,i}$ ranges from €228 (S15) to €1,679 (S16) per school per year a small fraction of the €2,245–€16,510 range of M_o alone (Table 4.2) its inclusion shifts individual C_{es} values by only 0.08–0.74% relative to C^*_{es}, and produces no reordering of the ranking presented in Table 4.6. This confirms that the ten-year C^*_{es} ranking is a reliable proxy for the full-data ranking, even before pest control and gardening data become available.

4.6 Discussion of Results

4.6.1 The Nido and Kindergarten Efficiency Problem

The five highest-ranked schools S10, S15, S06, S02, and S17 share a common structural characteristic: all serve nursery- or kindergarten-age children (including S10, a combined Nursery-and-Kindergarten facility). This is not coincidental. The C^*_{es} model exposes a fundamental asymmetry in the cost structure of early childhood facilities: the staffing ratio for nido buildings (1:8) is roughly three times more intensive than for primary schools (1:25), while utility costs per square metre are substantially higher — averaging €8.12/m^2 across the nursery/kindergarten schools in the sample versus €4.30/m^2 for primary schools, nearly double — reflecting the stricter temperature and ventilation requirements for children aged 0–6. Nursery and kindergarten buildings carry a systematically higher fixed cost per student than any other educational level, independently of their physical condition or management efficiency. Notably, this holds even for S10, whose enrolment (203 students in 2023) is substantially larger than the other four schools in this group, confirming that the effect is driven by staffing intensity and age-appropriate building requirements rather than small scale alone.

This finding has an important policy implication: the model does not recommend closing nido or kindergarten facilities simply because their C^*_{es} is high. Rather, it recommends that the municipality explicitly recognises the higher unit cost of early childhood provision and budgets accordingly. The Maslow framework introduced in Chapter 3 is directly relevant here: nursery and kindergarten buildings serve children at the most physically vulnerable stage of development, and their safety needs (Maslow Level 2) and basic physiological needs (Level 1) must be guaranteed regardless of the apparent unit cost.

4.6.2 Demographic Decline as a Cost Amplifier

S02 (Gobetti Marchesini) illustrates a different mechanism. Its enrolment fell from 92 students in 2016 to 43 in 2025 — a 53% reduction — yet its raw C^*_{es} trajectory appears almost flat over the same period (€7,595 in 2016 versus €7,371 in 2025), because concurrent movements in utility costs, personnel wage inflation, and MSI happened to largely offset the demographic effect within the observed window.

Isolating the enrolment effect alone reveals the mechanism the raw trend obscures: holding all 2025 cost components fixed but recalculating with S02's 2016 enrolment level (92 students) instead of its actual 2025 level (43), the resulting C_{es} would be approximately €3,445 less than half the actual 2025 value of €7,371. In other words, the enrolment decline alone is responsible for more than doubling S02's per-student cost, an effect that was masked in the raw year-on-year comparison by unrelated cost movements occurring over the same period.

The fixed cost components (U, M_o, P_{fac}) remain largely constant regardless of enrolment, so a declining denominator N directly inflates the per-student indicator even when nominal costs are stable or falling. This is precisely the early-warning mechanism the model is designed to trigger: S02 is flagged for strategic review not because it is poorly managed, but because its demographic trajectory makes its current operating model increasingly unsustainable a vulnerability that a simple year-on-year cost comparison would fail to detect.

4.6.3 The Role of the MSI

Comparing S04 (Guglielmo Gozzano, $MSI = 2.32$, built 1958) with S13 (Cincinnato, $MSI = 1.87$, built 1971) illustrates how the building condition multiplier differentiates otherwise comparable schools. S04's higher MSI inflates its C^*_{es} by approximately 24% relative to S13's condition score, correctly reflecting the greater risk and future liability of its pre-seismic masonry structure. Without the MSI, a purely financial cost-per-student comparison would systematically understate the burden of maintaining ageing buildings.

4.6.4 The Role of the MSI

Comparing S04 (Via Magnolie 15, $MSI = 1.95$, built 1958) with S13 (Corso Cincinnato 200, $MSI = 2.16$, built 1971) illustrates an important nuance in how the building condition multiplier operates: age alone does not determine the MSI score. Despite being 13 years older and pre-dating Italy's first seismic classification legislation, S04 currently carries a *lower* (better) MSI than the more recently constructed S13. S13's higher score of 2.16 roughly 11% above S04's 1.95 stems from a specifically identified weakness in its water and environmental management systems, which outweighs S04's structural age penalty.

This comparison demonstrates that the MSI multiplier reflects genuinely inspected, current building condition rather than functioning as a simple age proxy. A model that inferred condition from construction year alone would have ranked S04 as the more burdensome building; the inspection-based MSI instead correctly identifies S13's active water-management deficiency as the more pressing condition risk, regardless of the two buildings' relative age. Without the MSI, a purely financial cost-per-student comparison would fail to capture either building's true underlying condition risk.

4.7 Summary

This chapter has applied the C^*_{es} model to the 19 schools for which complete or interpolated data were available, across the period 2016–2025. The analysis reveals a clear stratification within the north-western district sample. Five schools S10, S15, S06, S02, and S17 are flagged as cost anomalies, with ten-year average C^*_{es} values exceeding 1.5 times the sample mean of €4,983. These schools are characterised by low or declining enrolment, high staffing intensity relative to student numbers (particularly nursery and kindergarten facilities), and above-average MSI scores. At the other end, large primary schools with stable enrolment (S07, S16, S11, S19) demonstrate the efficiency gains achievable through scale and demographic stability. The five flagged schools form the basis of the consolidation and adaptive reuse simulation scenarios presented in Chapter 5.

Chapter 5

Discussion and Simulations

This chapter interprets the results of the C_{es}^* analysis presented in Chapter 4 and develops a set of strategic simulation scenarios aimed at maximising the cost efficiency and service quality of the public school building portfolio in the north-western district of Torino. The chapter is structured as follows. Section 5.1 positions the findings within the broader literature on public asset management and urban educational infrastructure. Section 5.2 introduces the strategic framework adopted for the simulation the concept of the north-western district as an integrated, optimised educational cluster. Section 5.3 presents the demographic sub-routine used to validate closure and consolidation recommendations against forward-looking population projections. Section 5.4 analyses the GIS-based geographic constraints on student mobility within the district. Section 5.5 presents the simulation scenarios for the five flagged schools, including consolidation, adaptive reuse, and hybrid proposals. The scenario savings below are calculated from M_o reallocation only; as shown in §4.5.3, incorporating the partially available cleaning cost component (S_{clean}) would not materially change these figures, since S_{clean} represents a small fraction of total facility cost relative to M_o. Section 5.6 discusses the managerial and policy implications for the Comune di Torino.

5.1 Interpretation of Results in Context

The C^*_{es} ranking produced in Chapter 4 reveals a fundamental structural divide within the north-western district sample. The five schools flagged as cost anomalies — S10 (Via Terraneo 1), S15 (Carutti 19), S06 (Via Verbene 4), S02 (Primule 36C), and S17 (Via Gorresio 13) share two characteristics that the model identifies as the primary drivers of inefficiency: small or declining student populations that spread high fixed operating costs across too few users, and building condition profiles with above-average MSI scores that amplify those costs through the condition multiplier.

This finding is consistent with the broader public facility management literature. Earthman [7] and Schneider [23] demonstrate that buildings in poor physical condition generate compounding costs not only through direct maintenance expenditure but through the indirect effects of reduced educational quality, lower enrolment attraction, and accelerating demographic decline in the catchment area. The C^*_{es} model makes this compounding dynamic visible and quantifiable for the first time at the individual building level in the Torino north-western district.

At the other end of the ranking, the four most efficient schools — S16 (Corso Toscana 88, €1,932), S19 (Thouar Pietro 2, €2,016), S12 (Via Foglizzo 15, €2,157), and S11 (Corso Lombardia 98, €2,593) demonstrate that efficiency is achievable within the same district when enrolment is stable and the benefit of scale is present. These schools are not efficient because they are newer or better funded; they are efficient because they serve large, stable student populations that absorb fixed costs across a wide base.

The gap between the least efficient school (S10, average €8,753 per student per year) and the most efficient (S16, €1,932) represents more than a fourfold difference in public expenditure per student for facilities located within the same urban district, serving broadly comparable socio-economic communities, and funded from the same municipal budget. This disparity is not a feature of good public administration; it is a symptom of a reactive, legacy-driven management model that has never been subjected to systematic performance analysis. The simulation scenarios developed in this chapter are designed to close this gap.

5.2 Strategic Framework: The North-Western District as an Optimised Educational Cluster

The simulation approach adopted in this chapter is not simply about identifying schools to close. It proposes a transformation of the north-western district from a collection of independently managed, heterogeneous facilities into a coherent, optimised educational cluster a geographically compact network of facilities, each functioning at or near its design capacity, offering a full spectrum of educational levels from nursery to secondary school, and maintained at a condition standard that reflects the municipality's duty of care to the families it serves.

This vision is grounded in three principles:

1. **Efficiency without exclusion.** The model flags inefficient schools for strategic review, not for automatic closure. A school with a high C^*_{es} may be the only nursery facility within walking distance for young families in a particular sub-district. The decision to close, consolidate, or repurpose any facility must balance financial efficiency against the social geography of the community it serves.

2. **Building quality as an educational right.** The physical condition of a school building is not a secondary concern it is a primary determinant of the educational experience of the children inside it. Within Maslow's hierarchy of needs [19], school buildings simultaneously serve three levels: Level 1 (Physiological needs heating, ventilation, clean water, adequate lighting), Level 2 (Safety needs structural integrity, fire compliance, seismic resistance), and Level 3 (Belonging a well-maintained, welcoming building signals to families that their children are valued by the public institution that serves them). A municipality that allows school buildings to deteriorate below the Level 2 threshold is not simply failing a financial efficiency test it is failing a constitutional obligation to protect the physical safety of minors in its care.

3. **Capital investment as a reset, not a rescue.** The renovation of S16 (Corso Toscana 88) demonstrates what strategic capital investment can achieve: a building constructed in 1955, among the oldest in the sample, now ranks as the *most* cost-efficient school in the district, its MSI lowered by the completed renovation, its C^*_{es} reduced by the combination of improved condition and stable high enrolment. This is not coincidental it is the model working as designed. Strategic CAPEX resets the MSI, reduces future OPEX, and improves the per-student efficiency metric. The simulation scenarios apply this logic systematically to the flagged schools.

5.3 Demographic Sub-Routine: Validating Decisions Against Population Trends

A fundamental methodological safeguard in the simulation framework is the requirement that no closure or consolidation recommendation is triggered solely by a high current-year C^*_{es} value. Before any strategic recommendation is made, the model applies a demographic sub-routine that cross-references current low enrolment with forward-looking population projections for the north-western district. A school with low current enrolment in a neighbourhood experiencing demographic growth may be a poor candidate for closure today, as shutting it would create a shortage of educational capacity within three to five years.

5.3.1 National and Regional Projections

Italy is experiencing sustained demographic decline. ISTAT central projections [17] indicate that the Italian school-age population (ages 0–14) is expected to contract by approximately 15% between 2022 and 2042 under the baseline scenario. For the Piemonte region and the Torino metropolitan area, the contraction is projected to be slightly more pronounced than the national average, reflecting the region's below-replacement fertility rate (currently approximately 1.15 children per woman) and net outmigration from smaller municipalities toward the metropolitan core.

Eurostat [8] projects that the share of the Italian population aged 0–14 will fall from approximately 13% in 2023 to 11.5% by 2040, with the sharpest declines concentrated in the 3–11 age cohort that supplies primary school demand. For the Torino north-western district specifically, this translates into a projected reduction in primary school demand of approximately 12–18% over the next fifteen years, compounding the enrolment decline already observable in the ten-year dataset.

5.3.2 Application to the Sample

Table 5.1 presents the demographic sub-routine assessment for the five flagged schools. The assessment combines the observed ten-year enrolment trend from the dataset with the projected district-level demographic trajectory to produce a strategic signal: either a confirmed recommendation for intervention (where both current data and projections point to continued or accelerating decline) or a monitoring hold (where current inefficiency may be temporary, pending demographic recovery).

Table 5.1: Demographic sub-routine assessment for the five flagged schools.

ID	Address	C^*_{es} avg	Enrolment trend	Demographic signal	Decision
S10	Via Terraneo 1	€8,753	Mild decline (228→201, -12%)	Nursery/kinder demand softening	Monitor
S15	Carutti 19	€8,515	Broadly stable (78→74, -5%)	Nursery demand stable-to-falling	Monitor
S06	Via Verbene 4	€8,008	Moderate decline (94→73, -22%)	Kindergarten demand falling	Consolidate or reuse
S02	Primule 36C	€7,993	Sharp decline (92→43, -53%)	Catchment shrinking fast	Close + transfer
S17	Via Gorresio 13	€7,970	Moderate decline (100→81, -19%)	Kindergarten demand falling	Consolidate

S02 (Primule 36C) remains the most urgent case: a 53% enrolment decline over nine years, combined with a demographic projection that shows no recovery in the immediate catchment area, produces a confirmed recommendation for closure and student transfer. S10 (Via Terraneo 1) and S15 (Carutti 19) present a more nuanced picture: both are combined nursery facilities whose enrolment has remained comparatively stable (declines of 12% and 5% respectively, far milder than S02's), suggesting their high C^*_{es} stems primarily from the structural staffing intensity of early-childhood provision (§4.6.1) rather than demographic collapse, and therefore warrant a monitoring period rather than closure. S06 (Via Verbene 4) and S17 (Via Gorresio 13) show moderate, ongoing enrolment decline (22% and 19% respectively) consistent with the district-wide kindergarten demand softening projected by ISTAT and Eurostat, making them reasonable candidates for consolidation or adaptive reuse pending confirmation of catchment-area alternatives.

5.4 GIS Analysis: Geographic Constraints on Student Mobility

The feasibility of any student transfer or consolidation scenario depends critically on the geographic relationship between the sending and receiving schools. The close-up map of the north-western district confirms the key spatial advantage of this sample: the 20 school buildings are concentrated within a compact geographic cluster in the Lucento and Vallette sub-districts, connected by a grid of residential streets with low traffic volumes and good pedestrian and cycling infrastructure.

5.4.1 Walking Distance Analysis

All consolidation scenarios proposed in Section 5.5 involve student transfers between schools that are within a maximum walking distance of approximately 800–1,200 metres — consistent with the Italian Ministry of Education guideline that primary school facilities should be accessible on foot from the catchment area without requiring motorised transport. The green shaded area visible in the close-up map confirms that all 20 sample schools fall within a continuous pedestrian catchment zone with no major geographic barriers (no motorway crossings, no river barriers, no industrial zones separating the school clusters).

5.4.2 Mobility Barriers Identified

Three potential mobility constraints are identified within the study area:

– **Corso Regina Margherita** forms the southern boundary of the sample zone and acts as a moderate traffic barrier between the Lucento cluster and the southern part of the district. Schools on opposite sides of this arterial road are considered as having a moderate transfer feasibility rating rather than high.

– **The railway line (Torino–Modane)** running along the western edge of the district creates a hard boundary for the schools nearest Via delle Primule (S01, S02, S03). Student transfers from these schools should preferentially be directed eastward into the Lucento cluster rather than westward toward Collegno.

– **Socio-economic micro-variation:** while the district shows broadly homogeneous family income levels (as noted in Chapter 3), the Vallette sub-district to the north-west has historically housed a higher proportion of social housing residents. Transfer scenarios involving Vallette schools (S06, S07) should be evaluated with community engagement to avoid socio-economic concentration effects in receiving schools.

5.5 Simulation Scenarios for the Five Flagged Schools

This section presents a tailored simulation scenario for each of the five flagged schools, combining consolidation, adaptive reuse, and monitoring approaches to achieve the highest possible efficiency gain for the district as a whole. Each scenario is evaluated on three criteria: financial savings (reduction in annual OPEX), service continuity (preservation of educational capacity for affected families), and building future use (contribution to the district's long-term asset portfolio). Consistent with the demographic sub-routine (§5.3), a maximum building capacity of 300 students (FireWork standard) is used to assess residual capacity at all candidate receiving schools.

5.5.1 S02 (Primule 36C) — Closure and Student Transfer

Current situation: S02 is a kindergarten and Italian-courses facility at Via Primule 36C, with enrolment declining from 92 to 43 students over nine years (a 53% reduction) and an average C^*_{es} of €7,993 — 1.60 times the sample mean. Its building (1965, $MSI = 2.18$) shares a building code with S01, indicating a shared structure.

Proposed scenario — closure and transfer: The kindergarten population of S02 (43 students) is transferred to **S01 (Primule 36B)**, within the same shared building complex. S01's current enrolment (123 students) leaves a residual capacity of approximately 177 places against the 300-student FireWork standard; the combined post-transfer population (166 students) remains comfortably within this limit. S01 already hosts the Italian-courses component in the same complex, simplifying administrative consolidation. S02 is administratively closed as a separate unit.

GIS feasibility: S02 and S01 occupy the same shared building (Primule 36B/36C), so transfer distance is effectively zero. Feasibility: Very high.

Adaptive reuse of the freed space: The portion of the shared structure previously occupied by S02's kindergarten activities is proposed for conversion into a family support hub (*spazio famiglia*) — a municipal facility offering parenting courses, early childhood development programmes, and community meeting space. This use preserves the social function of the building for young families in the catchment area without maintaining the full cost structure of an operational school.

5.5.2 S06 (Via Verbene 4) — Consolidation into S13

Current situation: S06 (Altiero Spinelli) is a kindergarten facility with moderate, ongoing enrolment decline (94 to 73 students, -22% over the decade) and an average C^*_{es} of €8,008 — 1.61 times the sample mean. Its building (1970, $MSI = 2.73$) is among the poorest-conditioned in the sample, with multiple documented structural, plumbing, and fixture issues (§4.4).

Proposed scenario — consolidation: S06's kindergarten population (73 students) is proposed for transfer to **S13 (Corso Cincinnato 200)**, also a kindergarten-category facility. S13's current enrolment (120 students in 2025) leaves a residual capacity of approximately 180 places; the combined post-transfer population (193 students) remains within the 300-student standard. S06 is administratively closed.

GIS feasibility: Pending confirmation of the precise walking distance between Via Verbene 4 and Corso Cincinnato 200; both fall within the compact north-western cluster described in §5.4, and no major mobility barriers (railway, arterial road) are expected to separate them, but this should be verified against the district map before finalisation.

Adaptive reuse of the freed space: Given S06's documented structural deficiencies, full demolition or conversion to a non-educational community use (e.g. storage, municipal services annex) is recommended rather than retention as an occupied building, pending a structural feasibility assessment.

5.5.3 S17 (Via Gorresio 13) — Consolidation into S18

Current situation: S17 (Pier G. Frassati) is a kindergarten facility with moderate enrolment decline (100 to 81 students, -19% over the decade) and an average C^*_{es} of €7,970 — 1.60 times the sample mean. Its building (1964, $MSI = 2.62$) shows multiple documented deficiencies, including plumbing, boiler, ceiling, and water-quality issues (§4.4).

Proposed scenario — consolidation: S17's kindergarten population (81 students) is proposed for transfer to **S18 (Piazza G. Manno 22)**, also a kindergarten-category facility in better structural condition ($MSI = 1.38$). S18's current enrolment (73 students in 2025) leaves a residual capacity of approximately 227 places; the combined post-transfer population (154 students) remains well within the 300-student standard. S17 is administratively closed.

GIS feasibility: Pending confirmation of the precise walking distance between Via Gorresio 13 and Piazza G. Manno 22; both fall within the compact north-western cluster, but this should be verified against the district map before finalisation.

Adaptive reuse of the freed space: Given S17's documented water-quality and plumbing deficiencies, the freed building is proposed for either substantial structural rehabilitation prior to any alternative use, or conversion to a non-residential municipal function not requiring potable water infrastructure of the same standard as a childcare facility.

5.5.4 S15 (Carutti 19) and S10 (Via Terraneo 1) — Monitor and Retain

Current situation: S15 (Nido Biancaluna) and S10 (Il Piccolo Principe, a combined Nursery-and-Kindergarten facility) are the two highest-ranked schools in the sample, with average C^*_{es} values of €8,515 and €8,753 respectively (1.71 and 1.76 times the sample mean). Unlike the other three flagged schools, both show comparatively stable enrolment over the decade (S15: 78 to 74 students, -5%; S10: 228 to 201 students, -12%), consistent with the demographic sub-routine finding (§5.3) that their elevated cost is structural rather than demographically driven.

Proposed scenario — monitor and retain: Neither school is recommended for closure or consolidation. Their high C^*_{es} values are a direct, expected consequence of the 1:8 nursery staffing ratio (§4.6.1) rather than a sign of mismanagement or declining demand. Consistent with the policy principle established in §4.6.1 — that early-childhood provision carries an inherently higher unit cost that the municipality should recognise and budget for rather than penalise — both schools are retained in their current operational form. Enrolment and C^*_{es} should continue to be monitored against the demographic sub-routine on the same 24-month cycle applied elsewhere in this chapter, with consolidation reconsidered only if enrolment at either school were to decline sharply in future reporting periods.

5.6 Projected Financial Savings

Table 5.2 presents the estimated annual OPEX savings achievable through the implementation of the simulation scenarios described in Section 5.5, based on 2023 reference-year cost data. Savings are calculated from the components eliminated by each intervention: personnel costs (P_{edu}) and the principal cost share (P_{fac}) are fully eliminated, since the affected sites cease to operate as separate schools; the minor maintenance allocation (M_s) is likewise saved, as it is a fixed per-school grant. Ordinary maintenance (M_o) and the cleaning allocation (S_{clean}, §3.4.3) are *not* eliminated, since both buildings continue to exist under adaptive reuse or transfer rather than demolition, and both cost components are tied to floor area regardless of occupant. Utility costs (U) are conservatively assumed to fall by 60%, reflecting reduced but non-zero occupancy under the proposed adaptive reuse or partial transfer arrangements. S15 and S10 are retained under the monitor-and-retain scenario (§5.5.4) and therefore generate no savings.

Table 5.2: Estimated annual OPEX savings from simulation scenarios, 2023 reference year basis. Savings exclude M_o and S_{clean}, both of which continue under adaptive reuse.

ID	Address	Scenario	Saving (€)	Components
S02	Primule 36C	Closure + transfer to S01	161,028	P_{edu} + P_{fac} + M_s + 60% of U
S06	Via Verbene 4	Consolidation into S13	222,176	P_{edu} + P_{fac} + M_s + 60% of U
S17	Via Gorresio 13	Consolidation into S18	243,282	P_{edu} + P_{fac} + M_s + 60% of U
S15	Carutti 19	Monitor and retain	0	No intervention — structural cost, not mismanagement
S10	Via Terraneo 1	Monitor and retain	0	No intervention — structural cost, not mismanagement
		Total estimated annual saving	**626,486**	
		As % of 2023 city-wide M_o budget (€2,653,911)	**23.6%**	

The combined annual saving of approximately €626,486 represents 23.6% of the entire 2023 city-wide ordinary maintenance budget — attributable to interventions at just three buildings out of 301. Notably, this saving is driven almost entirely by personnel cost elimination rather than facility cost elimination: because M_o and S_{clean} are allocated per building rather than per operating school, converting or consolidating a facility does not eliminate the municipality's underlying obligation to maintain and clean the physical structure only the cost of staffing and operating it as an independent school. This distinction did not exist in earlier drafts of this analysis, which assumed full OPEX elimination; the cleaning-cost data obtained in §3.4.3 makes clear that a meaningful share of facility cost is structurally unavoidable regardless of the school's operational status.

If a similar efficiency programme were applied systematically across all eight city districts using the same C^*_{es} methodology, the potential aggregate annual savings would be substantial, though a smaller share of the full facility cost base than previously estimated, given that M_o and cleaning costs persist under adaptive reuse.

It is important to note that these savings are OPEX reductions — recurring annual gains that compound over time. The one-time CAPEX costs associated with the adaptive reuse conversions (estimated at €200,000–400,000 per building depending on the reuse type) would typically be recovered within one to two years of operational savings for the higher-saving scenarios (S06, S17), though longer for S02 given its lower absolute saving, producing a positive return on public investment over a ten-year horizon.

5.7 Managerial and Policy Implications

5.7.1 For the Comune di Torino

The simulation results carry three immediate actionable implications for the Comune di Torino's school building management strategy.

First, the C^*_{es} model should be applied to the full 301-building portfolio as a routine annual performance monitoring tool. The north-western district pilot demonstrates that the model is operationally implementable with existing municipal data infrastructure the Comune already collects all the required inputs (utility invoices, maintenance budgets, enrolment registers, physical inspection reports). The primary investment required is in data standardisation and integration, not in new data collection.

Second, the nursery and kindergarten cost structure requires a dedicated policy response. The model consistently flags nursery and kindergarten facilities as the most expensive per student in the portfolio, not because of management failure but because of the legally mandated staffing ratios for early-childhood provision (1:8 for nido, 1:12 for kindergarten, both substantially more intensive than the 1:25 ratio applied to primary and secondary schools). This is a structural feature of the Italian early childhood regulatory framework, not a local inefficiency. The appropriate policy response is not to close these facilities which would harm the youngest and most vulnerable users but to recognise explicitly that early-childhood provision requires a higher per-student budget allocation than other educational levels, and to design funding formulas accordingly.

Third, the renovation experience of S16 (Corso Toscana 88) provides a replicable template for strategic capital investment. A targeted structural and energy renovation, timed to coincide with stable high enrolment, reduced S16's effective cost per student to the lowest in the sample, despite the building being among the oldest (tied for oldest construction year in the sample) and the single largest by floor area. This is the asset management logic of the ISO 55000 framework applied in practice: invest strategically in assets that serve large populations, defer or eliminate assets that serve small populations with poor demographic prospects.

5.7.2 For Italian Municipal School Asset Management More Broadly

The methodological contribution of this study extends beyond the Torino north-western district. The C^*_{es} framework offers Italian municipalities a practical, replicable tool for navigating the triple challenge of ageing school building stock, declining school-age populations, and constrained maintenance budgets. Unlike existing condition-only or cost-only assessment approaches, the C^*_{es} model integrates all three dimensions into a single comparable indicator that supports portfolio-level strategic decisions.

The model's alignment with the Comune di Torino's existing official building condition monitoring framework and the millesimal allocation conventions of Italian property law means that it can be adopted without requiring new regulatory frameworks or data collection systems. It is, in this sense, a decision support tool that works within the existing institutional architecture of Italian local government rather than requiring that architecture to change.

5.8 Summary

This chapter has translated the C^*_{es} rankings of Chapter 4 into a coherent set of strategic recommendations for the north-western district of Torino. The five flagged schools S02, S06, S10, S15, and S17 have been assessed against demographic projections (ISTAT/Eurostat), GIS-based mobility analysis, and service continuity requirements to produce a differentiated set of scenarios: closure and student transfer for S02, consolidation into a neighbouring kindergarten for S06 and S17, and monitoring with retention (no closure or consolidation) for the two nursery-heavy facilities, S15 and S10, whose elevated cost reflects the structural staffing intensity of early-childhood provision rather than demographic decline or mismanagement.

The adaptive reuse proposal a family support hub in the space freed by S02's closure ensures that this freed portion of the shared building complex does not become a liability or an abandoned public asset, but continues to serve the same community in a different capacity. S06 and S17's freed buildings, given their documented structural and plumbing deficiencies (§4.4), are instead recommended for rehabilitation assessment prior to any alternative use, rather than immediate adaptive reuse. This differentiated approach reflects the broader vision of the north-western district as a progressive, integrated urban neighbourhood where public assets generate social value at every stage of their lifecycle, while recognising that not every freed building is immediately suitable for reoccupation.

The combined annual OPEX saving of approximately €626,486 equivalent to 23.6% of the city-wide ordinary maintenance budget for all 301 schools demonstrates the financial potential of systematic, data-driven asset management applied to even a small subset of the municipal school portfolio. This saving is driven primarily by personnel and administrative cost elimination rather than facility cost elimination, since ordinary maintenance and cleaning costs (§5.6) remain tied to the physical building regardless of its operational status. The conclusions and limitations of the study are presented in Chapter 6.

Chapter 6

Conclusions

This chapter summarises the main findings of the thesis, provides direct answers to the three research questions formulated in Chapter 1, acknowledges the limitations of the study, and outlines directions for future research and model extension.

6.1 Summary of Main Findings

This thesis developed, validated, and applied a dynamic asset management model for the public school building portfolio of the Comune di Torino, using a representative sample of 20 buildings in the north-western district of the city. The model is centred on a single composite indicator the Effective Cost per Student (C_{es}) that integrates five annual operating cost components (utilities U, ordinary maintenance M_o, minor maintenance M_s, facility services S, and personnel costs P), normalised by real student enrolment N and multiplied by the Maintenance Status Index (MSI), a building condition multiplier derived from the Comune di Torino's official five-category inspection framework.

The study produced five principal findings.

Finding 1: A more than fourfold efficiency gap exists within the same district. Applying the partial C^*_{es} model (facility services S largely excluded due to data unavailability, save for the cleaning component addressed as a sensitivity check in §4.5.3) to 19 of the 20 sample schools over the period 2016–2025 revealed a ten-year average effective cost per student ranging from €1,932 (S16, Corso Toscana 88) to €8,753 (S10, Via Terraneo 1) more than a fourfold difference between facilities located within the same urban district, funded from the same municipal budget, and serving broadly comparable socio-economic communities. This disparity is not visible through traditional per-building or per-square-metre cost analysis and can only be identified through a model that simultaneously captures cost, utilisation, and condition.

Finding 2: Five schools require strategic intervention. Five schools exceeded the anomaly threshold of 1.5 times the sample average ($C^*_{es} >$ €7,474 per student per year): S10 (Via Terraneo 1, €8,753), S15 (Carutti 19, €8,515), S06 (Via Verbene 4, €8,008), S02 (Primule 36C, €7,993), and S17 (Via Gorresio 13, €7,970). These schools share two structural characteristics: relatively low or declining enrolment that spreads high fixed operating costs across too few users (though the mechanism differs in strength across the group, §5.3), and building stock constructed before 1980 with above-average MSI scores that amplify those costs through the condition multiplier.

Finding 3: The MSI multiplier is a critical differentiator, but reflects genuine condition rather than age alone. Comparing S04 (Via Magnolie 15, built 1958, $MSI = 1.95$) with S13 (Corso Cincinnato 200, built 1971, $MSI = 2.16$) demonstrates that the MSI captures real, inspected building condition rather than functioning as a simple proxy for construction year: despite being thirteen years older, S04 currently carries a *lower* risk score than the more recently constructed S13, whose water and environmental management systems present a specifically identified deficiency. Separately, S16 (Corso Toscana 88, built 1955, the oldest and largest building in the sample) now ranks as the *most* cost-efficient school following a completed structural renovation, its MSI reduced to 1.27 — the lowest in the sample demonstrating that strategic capital investment can fully overcome the cost disadvantage of ageing stock when combined with stable high enrolment.

Finding 4: Nursery and kindergarten facilities carry a structural cost premium. The model consistently identifies nursery and kindergarten facilities as the most expensive per student in the portfolio, not because of management failure but because of the legally mandated staffing ratios governing early-childhood provision (1:8 for nido, 1:12 for kindergarten, versus 1:25 for primary and secondary schools). This is a policy-level reality, not a building-level inefficiency. The appropriate municipal response is to recognise the higher unit cost of early-childhood provision explicitly in budget formulas, rather than penalising these facilities in portfolio efficiency rankings without this contextual adjustment.

Finding 5: Targeted intervention generates meaningful financial returns. The simulation scenarios developed in Chapter 5 combining closure and transfer (S02), consolidation into neighbouring facilities (S06, S17), and monitoring with retention for the two nursery-heavy schools whose elevated cost reflects staffing structure rather than demographic decline (S15, S10) are projected to generate combined annual OPEX savings of approximately €626,486, equivalent to 23.6% of the 2023 city-wide ordinary maintenance budget for all 301 Torino school buildings. This saving is driven primarily by the elimination of personnel and administrative costs rather than facility costs, since ordinary maintenance and cleaning obligations persist for any building retained under adaptive reuse. This finding demonstrates the meaningful, if more modest than initially estimated, financial potential of systematic, data-driven asset management applied even to a small subset of a large municipal portfolio.

6.2 Answers to Research Questions

RQ1: Can a composite cost-efficiency indicator, integrating operating expenditures, student enrolment, and building condition, provide a reliable and replicable basis for strategic asset management decisions in a municipal school building portfolio?

Yes, with clearly defined conditions. The C^*_{es} model demonstrated that a composite indicator integrating OPEX, enrolment, and condition can identify cost anomalies, rank schools comparably across different building types, and support strategic decisions that would not be visible through single-variable analysis. The model is replicable: it relies entirely on data that the Comune di Torino already collects (utility invoices, maintenance budgets, enrolment registers, inspection reports) and on analytical methods (millesimal allocation, weighted average, threshold flagging) that are standard in Italian public property management. The primary condition for reliability is data completeness the model's predictive accuracy increases as the dataset approaches full coverage of all five OPEX components. In this study, the unavailability of two of the three facility services sub-components (pest control, gardening) meant the indicator was calculated as a partial index C^*_{es}, which remains valid for comparative ranking (§4.5.3) but understates the absolute cost burden.

RQ2: To what extent does the physical condition of a school building (captured by the MSI) alter the cost-efficiency ranking relative to a purely financial assessment?

Materially and systematically. The MSI multiplier changed the ranking position of multiple schools relative to a purely financial cost-per-student comparison. Buildings with similar underlying cost profiles but different physical conditions received different C^*_{es} values, correctly reflecting the greater risk, future liability, and reduced service quality associated with deteriorating buildings. Since MSI enters the model as a direct multiplier, two schools with an otherwise identical cost-per-student figure but different MSI scores will show a C^*_{es} differential exactly equal to the ratio of their MSI values. The comparison between S04 (Via Magnolie 15, $MSI = 1.95$) and S13 (Corso Cincinnato 200, $MSI = 2.16$), discussed in §5.5.6, illustrates this directly: S13's specifically identified water and environmental management deficiency inflates its effective cost by approximately 10.8% relative to S04, purely as a result of the condition differential, despite S13 being the more recently constructed of the two buildings. Without the MSI, this difference would be invisible, and a naive age-based assumption would have ranked the two buildings in the opposite order. The MSI therefore fulfils its design purpose: it converts a physical inspection score into a financial risk premium that decision-makers can interpret and act upon, and does so based on genuinely inspected condition rather than construction year alone.

RQ3: What are the quantifiable financial savings achievable through the consolidation of the least efficient school buildings in the north-western district of Torino?

Approximately €626,486 per year under the simulation scenarios developed in Chapter 5, based on 2023 reference year cost data. This figure is deliberately conservative in two respects: it excludes any facility costs (ordinary maintenance, cleaning) that persist regardless of a building's operational status, since these are tied to the physical structure rather than its use, and it excludes the additional savings that would accrue from adaptive reuse revenue or the long-term MSI improvements that would follow future CAPEX interventions elsewhere in the portfolio. The gross saving represents 23.6% of the 2023 city-wide ordinary maintenance budget and is equivalent to funding approximately 21 additional primary school teachers at the 2023 CCNL wage rate illustrating the opportunity cost of allowing inefficient building management to continue unchallenged, even from a comparatively modest, conservatively estimated saving.

6.3 Limitations

This study acknowledges six limitations that affect the precision and generalisability of its findings.

1. Geographic scope. The empirical analysis is restricted to 20 school buildings in the north-western district of Torino. While the sample is methodologically sound internally homogeneous, spatially compact, and data-complete it represents only 6.6% of the total Torino school estate and may not fully capture the typological, demographic, or socio-economic diversity of the broader portfolio. The simulation results should not be extrapolated to other districts without equivalent data collection.

2. Partial cost coverage. Facility services (S) remain only partially resolved.

A citywide cleaning contract figure was identified and incorporated as a single-year sensitivity check (§4.5.3), showing negligible impact on the model's ranking. Pest control costs are procured through a dedicated citywide school tender, but the contract value could not be obtained in a form suitable for per-school allocation. Gardening costs specific to school grounds remain entirely unresolved, as the only related public contract identified covers general district green space rather than individual school buildings. Future work should request itemized, per-building cost breakdowns directly from the Comune's Servizio Educativo and Divisione Manutenzioni Edifici Comunali, rather than relying on aggregate citywide tender figures.

3. Historical MSI reconstruction. All 20 sample schools now carry fully verified MSI scores from completed on-site inspections (§3.6.1, §4.4), eliminating the estimation uncertainty present in earlier stages of this research. However, because these inspections reflect a single point-in-time assessment (2026), the ten-year C^*_{es} series (§4.5.2) required a historical reconstruction: for the ten schools with a documented extraordinary maintenance intervention, a modelled condition penalty was applied to years preceding the intervention's estimated completion, calibrated to a uniform magnitude rather than derived from independent historical condition records, which do not exist for this portfolio prior to 2026. This introduces a degree of uncertainty into the pre-intervention years of the historical ranking that would be eliminated only by historical inspection archives, which the Comune does not currently maintain.

4. Personnel cost estimation. Teaching and care staff costs (P_{edu}) were estimated using the supervisor-validated staffing ratios and CCNL wage scales, rather than obtained directly from the Comune di Torino's payroll records. The estimates are consistent with published Italian public sector wage data but may differ from actual per-building salary allocations due to seniority variations, part-time contracts, and support staff not captured in the estimation model. The historical (pre-2023) series additionally relies on a linear interpolation of CCNL wage inflation between two published reference points, rather than year-by-year confirmed wage tables.

5. Model as decision support, not decision-maker. The C^*_{es} model is an analytical tool that operates within the data available to it. It does not account for political considerations, community sentiment, historical or architectural significance of specific buildings, or the social consequences of school closures for vulnerable families. The simulation recommendations of Chapter 5 require expert overlay from urban planners, community engagement specialists, and elected officials before any irreversible action is taken.

6. Demographic projections. The demographic sub-routine in Chapter 5 relies on ISTAT national and Eurostat European projections rather than neighbourhood-level birth registry data for the Lucento/Vallette district. Local demographic dynamics may differ from regional and national trends, particularly in urban sub-districts experiencing rapid socio-demographic change through immigration or gentrification. Future iterations of the model should integrate municipal-level birth registry data at sezione di censimento resolution.

6.3.1 Recommendations for the Comune di Torino

Three immediate operational recommendations emerge from this study.

R1 — Scale the model to the full portfolio. The C_{es}^{*} framework should be applied to all 301 buildings in the Torino school estate as a routine annual performance monitoring tool. The data infrastructure required already exists within the Comune di Torino's administrative systems. The primary investment required is in data standardisation ensuring that utility invoices, maintenance allocations, enrolment registers, and inspection reports are recorded in a consistent, building-level format compatible with the model's input requirements. A full-portfolio application would identify the equivalent of the five flagged schools in each of the remaining seven city districts; extrapolating the €626,486 annual saving identified in this sample suggests a conservative aggregate potential in the range of €4–5 million annually, though this figure would need validation against each district's actual demographic and condition profile rather than assumed uniformity with the north-western sample.

R2 — Extend the completed inspection programme to the remaining 281 buildings. All 20 schools in the north-western sample now carry fully verified MSI

scores from completed on-site inspections, eliminating the estimation uncertainty present in earlier stages of this research. The immediate priority is therefore not to complete inspections within this sample, but to extend the same inspection protocol to the remaining 281 buildings in the Torino school estate, and to establish a recurring inspection cycle (e.g. biennial) so that MSI scores remain current rather than becoming a one-time assessment. This is also a prerequisite for any PNRR or CDP funding application, which requires documented condition assessments as supporting evidence.

R3 — Establish a dedicated nursery and kindergarten funding formula. The structural cost premium of early-childhood facilities (C^*_{es} systematically 2.4 times higher on average than primary schools in this sample, due to the more intensive staffing ratios mandated for nido and kindergarten provision) should be recognised in the Comune di Torino's internal budget allocation methodology. A differentiated per-student funding formula for nido and kindergarten facilities — analogous to the premium funding mechanisms used in other Italian regions for special educational needs — would allow the C^*_{es} model to generate comparisons that are fair across all educational levels.

6.3.2 Directions for Future Research

F1 — Full OPEX integration. The most immediate methodological extension is the integration of the remaining facility services costs (pest control, gardening) into the model, once these are made available at building level by the Comune di Torino. The cleaning component of S has already been partially integrated as a sensitivity check (§4.5.3); completing the remaining two sub-components would convert the current C^*_{es} (partial index) into the full C_{es} and allow absolute cost comparisons as well as relative rankings.

F2 — Verified dynamic MSI with time series. This thesis produced a preliminary dynamic reconstruction of the MSI across the 2016–2025 period (§4.5.2), incorporating the CAPEX temporal decoupling rule developed in Chapter 3 by applying a modelled condition penalty to years preceding each documented extraordinary maintenance intervention. This reconstruction relies on an assumed, uniform penalty magnitude rather than independent historical condition records, which do not currently exist for this portfolio. Future work should replace this modelled assumption with verified historical inspection data were the Comune to establish and maintain a recurring inspection archive converting the C^*_{es} from a diagnostic tool with a disclosed historical uncertainty into a fully verified performance monitoring system.

F3 — Neighbourhood birth registry integration. Replacing the ISTAT/Eurostat demographic projections with sezione di censimento level birth registry data from the Comune di Torino's anagrafe system would substantially improve the precision of the demographic sub-routine, enabling closure and consolidation recommendations to be calibrated to the specific demographic trajectory of each school's immediate catchment area rather than the district or city average.

F4 — Extension to other Italian municipalities. The C^*_{es} framework is designed to be portable. Its methodological foundations — millesimal allocation, ISO 55000 asset management principles, CCNL wage scales, and standardised building inspection categories are applicable to any Italian municipality managing a large public school portfolio. A comparative study applying the model to two or three cities of similar size (e.g. Genova, Bologna, Firenze) would test the generalisability of the findings and contribute to the emerging Italian literature on public real estate efficiency.

F5 — Integration with BIM. The long-term evolution of the model points toward integration with Building Information Modelling (BIM) platforms, which would replace the current inspection-based MSI estimation with real-time condition data from sensor networks embedded in the building fabric. Several Italian municipalities are currently piloting BIM-based facility management platforms under PNRR Digital Public Administration funding; the C^*_{es} model could serve as the cost-efficiency layer of such a platform, connecting physical condition data directly to financial performance indicators.

6.4 Concluding Remarks

6.5 Concluding Remarks

The north-western district of Torino hosts twenty public school buildings that between them serve approximately 3,500 children and families every day. These buildings were mostly constructed between 1955 and 1980. They have absorbed decades of deferred maintenance, operated through a period of sustained budget decline, and now face a demographic contraction that will further reduce the student populations they serve. Without a systematic tool to distinguish which buildings deliver genuine value for the public money invested in them, and which have become financial liabilities that crowd out resources from better-performing assets, the Comune di Torino's school building management will continue to be driven by crisis response rather than strategic planning.

The C^*_{es} model developed in this thesis does not solve this problem. It provides, for the first time, the analytical foundation needed to begin solving it: a transparent, data-grounded methodology that any municipal administrator can apply, any citizen can understand, and any committee can interrogate. The north-western district, with its compact geography, its homogeneous community, and its mix of efficient and inefficient buildings, is an ideal starting point. If the simulation scenarios proposed in Chapter 5 are implemented, this district could become what the research framing envisioned from the outset: a symbol of intelligent, human-centred public asset management where every euro of maintenance budget is directed to where it most improves the safety, comfort, and educational quality experienced by the children inside these buildings every day.

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