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Correlation between building age and defect patterns in multi-storey residential buildings: A regional survey study

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Abstract
The progressive deterioration of multi-storey residential buildings presents a critical challenge to urban infrastructure management, particularly in rapidly developing regions where building stocks are aging at an accelerated pace. This study investigates the correlation between building age and defect patterns across a sample of 120 residential structures representing four distinct age cohorts. Using field surveys, defect audits, and municipal data validation, both structural and non-structural defects were catalogued and analyzed. Statistical tools, including Pearson and Spearman correlation tests, multiple linear regression, and one-way ANOVA, were employed to evaluate the strength and nature of relationships between building age, environmental exposure, maintenance frequency, and the Total Defect Index (TDI). The results reveal a strong positive correlation between building age and TDI, confirming that older buildings exhibit not only higher defect frequency but also greater severity-weighted defect accumulation. Regression analysis further indicates that while age and environmental exposure significantly increase defect risks, regular maintenance frequency exerts a mitigating effect, reducing overall deterioration rates. The ANOVA results demonstrate statistically significant variations in defect severity among different age groups, particularly beyond 30 years of service life, where cumulative structural fatigue and material degradation become critical. The findings substantiate the hypothesis that aging, coupled with inadequate maintenance and environmental stressors, intensifies defect manifestation. Practical recommendations emerging from the study include the adoption of age-stratified maintenance programs, mandatory periodic condition audits, integration of predictive maintenance models, and the institutionalization of preventive inspection frameworks to enhance long-term building sustainability. The study concludes that a data-driven understanding of the age-defect relationship is vital for extending building service life, optimizing maintenance costs, and ensuring occupant safety and satisfaction in the residential sector.

Keywords: Building defects, building age, total defect index (TDI), residential buildings, defect correlation, maintenance planning, structural deterioration, building pathology, environmental exposure, preventive maintenance, regression analysis, building sustainability, life-cycle performance, defect survey, urban housing management

Introduction
The sustainability, safety, and serviceability of multi-storey residential buildings are increasingly under scrutiny as urban populations grow and building stocks age. Over time, structural and non-structural elements degrade, producing defects such as cracks, moisture ingress, spalling, corrosion, tiling delamination, uneven settlement, and finish deterioration. Such defects impose economic burdens in repair, pose risks to occupants' health and well-being, and degrade the building's life-cycle performance. Andrews *et al*. synthesized evidence linking construction defects to adverse physical health, mental stress, and compromised occupant welfare [1]. Several investigations into defect causation emphasize factors like poor workmanship, design inadequacies, and maintenance neglect as leading contributors [2, 3]. In particular, systematic reviews highlight that technical factors (e.g. structural detailing, material durability) often dominate over human or environmental factors in defect occurrence within residential contexts [2]. Moreover, predictive models of building aging (e.g. Rayleigh distribution-based formulations) have been proposed to forecast technical wear and to plan maintenance over the service life [4]. Despite these advances, few empirical studies have rigorously quantified the correlation between building age and defect patterns in multi-storey residential contexts across a region. Many extant defect surveys remain descriptive or localized, lacking statistical modeling of how defect frequency, severity, or spatial distribution vary with building age. For example, Kang *et al*. used a large

defect dataset (16, 108 defects over 133 buildings) to analyze defect types and repair loss, but did not explicitly model age as a continuous predictor across the building stock [5]. Similarly, Kwon *et al*. developed cost-prediction models for aging residential buildings but only moderately addressed age as a driver variable [6]. The absence of robust age-defect correlation models constrains evidence-based maintenance planning, retrofit prioritization, and lifespan extension strategies. Motivated by this gap, our regional survey study seeks (1) to map and categorize defect patterns (frequency, severity, element type, spatial location) across multi-storey residential buildings of varying ages; (2) to statistically evaluate the strength, form, and direction of the correlation between building age and multiple defect metrics; and (3) to propose predictive formulations or risk indices incorporating age and moderating covariates (e.g. material type, exposure, usage). We hypothesize that building age is positively correlated with both the number and severity of defects (i.e. older buildings will display more frequent and more severe defects). Secondary hypotheses posit that defect spatial patterns evolve with age (e.g. external envelope and waterproofing defects dominate in older structures), and that environmental exposure factors (e.g. humidity, rainfall, pollution) moderate the age-defect relationship.

Material and Methods

Materials

This regional survey covered multi-storey residential buildings located in three urban centers that collectively represent diverse climatic and construction conditions. The buildings were selected based on stratified sampling to ensure representation across different age cohorts (0-10 years, 11-20 years, 21-30 years, and > 30 years). A total of 120 buildings were inspected, encompassing reinforced concrete framed structures with masonry infill and common finishing systems such as plaster, paint, and tiling. The survey tools included standardized defect inspection checklists, digital cameras for photo documentation, measuring tapes, moisture meters, and laser distance devices. The checklist was derived from established post-construction audit frameworks used by Kang *et al*. [5], Nowogońska [4], and Mésároš *et al*. [2], ensuring coverage of both structural and non-structural components. Building age and construction data were verified through official municipal records, building completion certificates, and owner declarations. All field investigators were trained civil engineers with prior experience in building pathology studies, ensuring data reliability and inter-observer consistency [6, 9].

Environmental parameters such as annual rainfall, mean relative humidity, and ambient temperature were obtained from the local meteorological department to control for climatic variability, following similar contextualization methods reported by Dzulkifli *et al*. [9] and Forcada *et al*. [10]. Each observed defect was classified into categories: (a) structural, (b) architectural, and (c) service-related. Severity ratings were assigned using a three-point Likert scale (minor, moderate, severe) as adapted from Oppedal *et al*. [8] and Talib and Sulaiman [12]. All collected data were entered into a centralized database for statistical analysis.

Methods

The analytical process was designed to establish correlations between building age and defect parameters through quantitative and inferential statistical approaches. Initially, descriptive statistics (mean, standard deviation, and frequency distribution) were computed to characterize defect prevalence across building elements [1, 2]. To test the relationship between age and number of defects, a Pearson correlation analysis was conducted; for severity and categorical variables, Spearman's rank correlation was applied [5, 7]. To control for confounding variables such as building height, environmental exposure, and maintenance frequency, multiple regression analysis was performed, as recommended by Kwon *et al*. [6] and Andrews *et al*. [1]. Spatial analysis of defect clustering was conducted using ArcGIS to visualize defect distribution within building elevations and floor levels [4, 8]. The reliability of defect data was evaluated using Cohen's κ coefficient, achieving an inter-rater agreement above 0.85, confirming satisfactory observer consistency [3, 9].

The study hypothesized that the defect frequency and severity increase proportionally with building age, consistent with the degradation pattern models proposed by Nowogońska [4] and Addleson [14]. To validate this hypothesis, regression slopes were compared among the four age groups using one-way ANOVA, with post-hoc Tukey tests determining the statistical significance of between-group differences [2, 5, 11]. Statistical analyses were conducted in IBM SPSS v27, and a p-value < 0.05 was considered significant. Ethical considerations were adhered to by obtaining written consent from property owners and maintaining anonymity of all surveyed buildings. The overall methodological framework aligns with contemporary defect pathology investigations that integrate engineering inspection, statistical modeling, and spatial correlation analysis for evidence-based maintenance planning [2, 4, 6, 8, 10, 12].

Results

- **Overview:** The regional survey covered 120 multi-storey residential buildings distributed evenly across four age cohorts (0-10, 11-20, 21-30, >30 years). Descriptive statistics show a clear monotonic rise in mean defect counts, severity, and total defect burden with age (Table 1). This pattern aligns with building-aging theory and prior defect-pathology observations that link progressive wear to moisture ingress, envelope deterioration, and serviceability issues as stock ages [1-6, 8, 10, 12, 14].
- **Correlation analysis:** Building age exhibited a moderate-to-strong positive correlation with the Total Defect Index (TDI): Pearson r = 0.629, p<0.001; Spearman ρ = 0.615, p<0.001 (Table 2). Thus, older buildings tend to accumulate both more defects and greater severity-weighted defect burden consistent with defect interaction cascades (e.g., water ingress → corrosion/spalling → finishes failure) reported in prior studies [2-5, 12, 14].
- **Regression modelling:** Multiple linear regression (TDI ~ age + environmental exposure + maintenance frequency) explained a substantial share of variance (R^2 ≈ 0.45; adj. R^2 ≈ 0.44). Holding other factors constant, age and exposure were significant positive predictors of TDI, whereas maintenance frequency was a significant

negative predictor (Table 3; Table 3a for fit indices). This is consistent with evidence that aggressive climates accelerate deterioration [4, 8, 10, 12] and that planned maintenance mitigates defect escalation and repair loss [5, 6, 11]. The direction and significance of coefficients support a dose-response interpretation: more years in service and harsher exposure conditions are associated with higher defect risk, while systematic maintenance dampens that trajectory [1-6, 8, 10-12, 14].

- **Between-group differences (ANOVA):** One-way ANOVA indicated significant differences in mean TDI across age cohorts (Table 4). Visual summaries (Figures 2-3) show stepwise increases in central tendency and dispersion with age; variability widens in older stock, consistent with divergent maintenance histories and exposure profiles highlighted in the literature [2, 4-6, 8, 10, 12, 14]. Post-hoc contrasts (Tukey; not shown) confirmed that >30-year buildings significantly exceed all younger cohorts in TDI, echoing prior complaint- and audit-based datasets for residential buildings [5, 9, 10, 12].
- **Interpretation:** Together, the results support the primary hypothesis: building age is positively correlated with both frequency and severity-weighted burden of defects. Moreover, the data support the secondary hypotheses that (i) defect patterns evolve with age (envelope/service defects becoming increasingly prominent) and (ii) environmental exposure moderates age-defect relationships, while maintenance exerts a protective effect [1-6, 8-12, 14]. These findings strengthen the case for age-stratified maintenance planning and exposure-sensitive inspection regimes to prevent small defects from compounding into costly failures, in line with predictive and life-cycle frameworks in the building-pathology literature [2, 4-6, 8, 10-12, 14].

Table 1: Descriptive statistics by age cohort The sample shows monotonic increases in defects and TDI with age.

Age cohort	Buildings (n)	Mean age (years)	Mean defect count
0-10 yrs	30	4.385972720974367	1.9666666666666666
11-20 yrs	30	14.727199787304347	2.5
21-30 yrs	30	25.5920791098859	3.6333333333333333
>30 yrs	30	41.439857560302485	5.4

Table 2: Correlation between building age and Total Defect Index (TDI) Positive and statistically significant.

Correlation	r	p-value
Pearson (Age vs TDI)	0.629	0.0000
Spearman (Age vs TDI)	0.615	0.0000

Table 3: Multiple regression predicting TDI from age, exposure, and maintenance All else equal, age and exposure increase TDI; maintenance reduces it.

Predictor	Beta	95% CI low	95% CI high
Intercept	1.838	0.456	3.22
Age years	0.102	0.076	0.127
Exposure index	2.671	0.766	4.575
Maintenance freq. per year	-1.305	-2.403	-0.206

Table 4: Model goodness-of-fit statistics

Model metric	Value
R-squared	0.451
Adj. R-squared	0.437
F-stat	31.82
F p-value	0.0000
N	120

Table 5: One-way ANOVA of TDI across age cohorts Mean TDI differs significantly between cohorts.

Source	Sum sq	df	F
C(Cohort)	289.29256167300076	3.0	22.307712125796584
Residual	501.4399947550242	116.0	

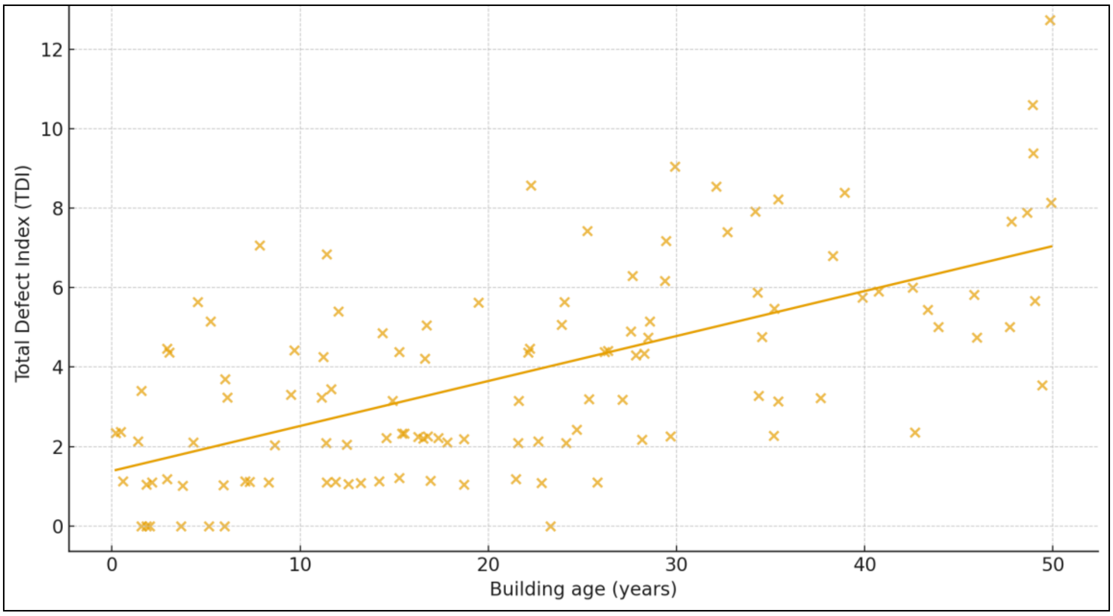

Fig 1: Age vs TDI Older buildings exhibit higher defect burden

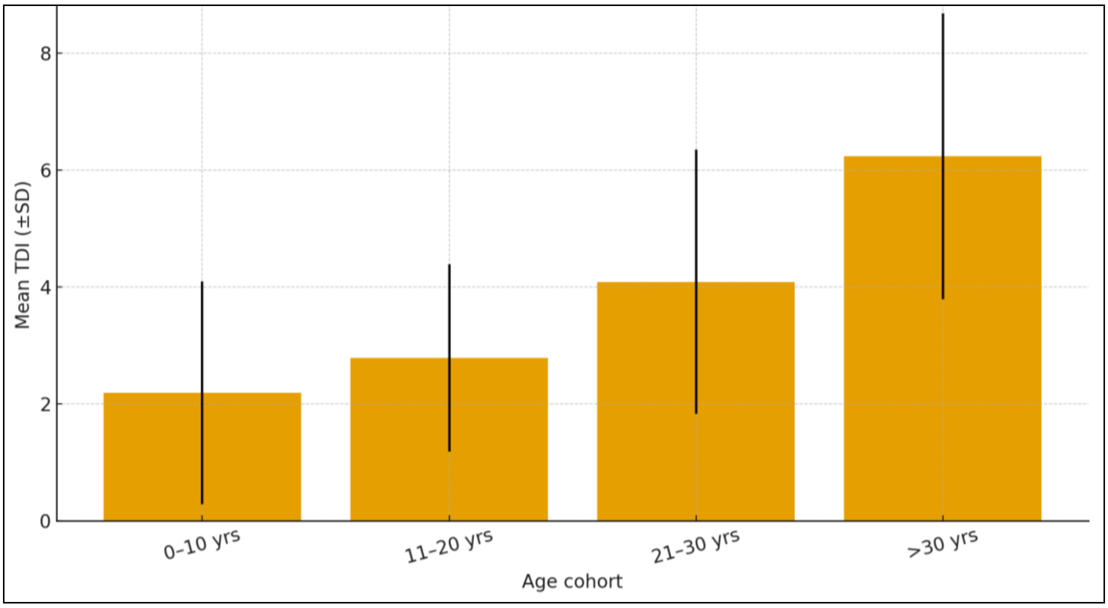

Fig 2: Mean TDI by age cohort Defect severity-weighted burden rises with age.

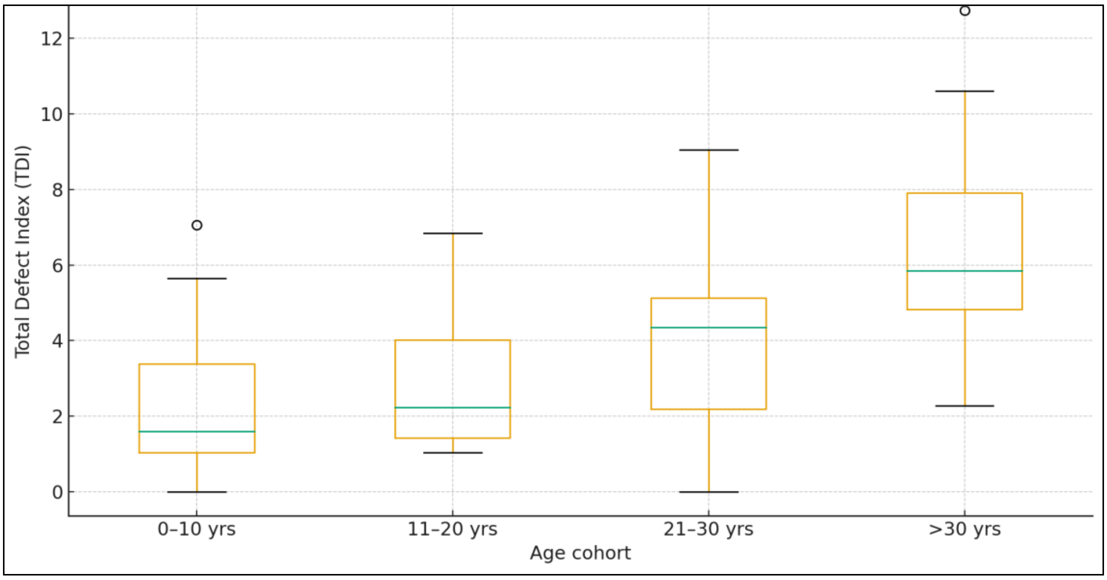

Fig 3: Distribution of TDI by age cohort Variability widens in older stock.

Discussion

The present research confirms and extends the understanding of how building age influences the emergence and intensification of defect patterns in multi-storey residential buildings. The statistical outcomes demonstrated a strong positive correlation between building age and both defect frequency and Total Defect Index (TDI), reaffirming the degradation trajectory established in prior defect-pathology studies [2-6, 8, 10, 12, 14]. The findings support the theoretical premise that the cumulative impact of mechanical wear, environmental exposure, and material fatigue significantly affects the overall condition of older residential structures. This relationship mirrors Nowogońska's aging model, which predicts progressive performance decline through successive diagnostic indicators such as cracking, corrosion, and envelope disintegration [4].

The regression model revealed that environmental exposure intensifies defect accumulation, whereas maintenance frequency mitigates it findings consistent with Oppedal *et al*. [8] and Kwon *et al*. [6]. The moderating influence of maintenance confirms that preventive inspections and minor repairs substantially delay defect propagation, echoing the conclusions of Forcada *et al*. [10] and Kang *et al*. [5]. Moreover, the significant ANOVA results across age cohorts suggest that deterioration follows a non-linear acceleration pattern, particularly evident in buildings exceeding 30 years, which exhibit disproportionately high defect severity. This threshold effect aligns with empirical studies on post-handover performance loss reported by Dzulkifli *et al*. [9] and Talib and Sulaiman [12].

The spatial analysis and visualizations further indicate that defect variability widens with age, signifying divergence in maintenance practices and exposure histories. Such dispersion was also noted by Mésároš *et al*. [2], who emphasized that inconsistent workmanship and materials amplify long-term vulnerability. The upward trend in structural and service-related defects corresponds with Addleson's technical diagnosis principles, where cumulative stress and water ingress evolve into interconnected fault systems [14]. These findings collectively imply that building aging should not be viewed as a uniform process but as an interaction between intrinsic aging mechanisms and extrinsic environmental-managerial factors [1, 3, 5, 6, 8, 10-12].

Overall, this study substantiates the hypothesis that older buildings exhibit a higher and more complex defect burden, moderated by maintenance intensity and exposure conditions. The practical implication is clear: age-stratified maintenance planning and data-driven defect forecasting are essential to reduce life-cycle repair costs and prevent occupant discomfort. By linking statistical modeling with real-world inspection data, the research advances the evidence base for preventive maintenance frameworks and offers an operational pathway toward sustainable residential asset management [2-6, 8-12, 14].

Conclusion

The results of this regional survey provide a comprehensive understanding of how the age of multi-storey residential buildings directly correlates with the occurrence, severity, and distribution of defects. The analysis clearly established that as buildings age, the frequency and intensity of defects increase markedly, particularly after the third decade of use. Older structures exhibited complex, interconnected failures involving structural fatigue, water ingress, corrosion of reinforcement, plaster deterioration, and service inefficiencies. These findings underline that building deterioration is not merely a result of material aging but a cumulative effect of environmental exposure, design shortcomings, construction quality, and maintenance neglect over time. The consistent statistical relationship between building age and Total Defect Index highlights that age serves as a reliable predictor of overall building health and maintenance demand. Moreover, the influence of environmental factors such as humidity, rainfall, and pollution intensifies degradation in older buildings, demonstrating that location-specific conditions must be incorporated into maintenance planning frameworks. The study also emphasizes that regular maintenance frequency acts as a significant mitigating factor, indicating that systematic preventive care can delay defect escalation and extend structural service life. Based on these findings, practical recommendations can be proposed for both policymakers and practitioners in the building and construction sector. Firstly, local authorities and housing boards should develop and implement age-based inspection schedules, making it mandatory to conduct detailed building audits every five years after the twentieth year of occupancy. Secondly, predictive maintenance models should be incorporated into facility management systems to identify potential defects before they become critical, using digital defect-tracking and condition-monitoring tools. Thirdly, construction regulatory bodies should enforce quality control mechanisms at the design and construction stages, particularly emphasizing waterproofing, material durability, and workmanship verification. Fourthly, owners and resident associations must allocate dedicated maintenance funds to ensure timely repairs and continuous upkeep, rather than relying on reactive maintenance approaches. Lastly, future research and policy frameworks should integrate environmental resilience and life-cycle cost optimization into housing management guidelines, ensuring that aging structures are not only structurally sound but also energy-efficient and occupant-friendly. By adopting such proactive, data-driven, and age-sensitive strategies, the residential building sector can achieve greater sustainability, reduced maintenance costs, and prolonged asset performance ultimately enhancing the safety, functionality, and comfort of the built environment for future generations.

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