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Reframing Urban Industrialization in the Sustainability Transition: Sustainable Urban Infrastructure, Brownfield Remediation, and Collaborative Urban Governance

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ABSTRACT

Urban industrialization is increasingly governed through sustainability-transition agendas, yet research remains divided between sustainable infrastructure, brownfield remediation, and collaborative governance literatures. This article addresses a specific gap: prior studies often treat infrastructure upgrading and land remediation as direct drivers of industrial outcomes, while the governance mechanism that converts physical and ecological interventions into coordinated industrial transformation remains under-specified. The study develops a four-construct SEM framework in which Sustainable Urban Infrastructure and Brownfield Remediation are theorized as exogenous constructs, Collaborative Urban Governance is specified as the mediator, and Urban Industrialization is the outcome. Using the available 455-case Excel dataset, the empirical component estimates a data-constrained proxy model with Industrialization Intensity (IND), Digital-Infrastructure Capability (DIC), and Socio-Economic Resilience (SER). CFA results show strong measurement quality, with loadings from 0.778 to 0.849 for IND, 0.804 to 0.835 for DIC, and 0.800 to 0.843 for SER; CR ranges from 0.901 to 0.914 and AVE from 0.646 to 0.681. The structural model fits well (chi-square/df = 2.108; CFI = 0.961; TLI = 0.951; RMSEA = 0.049; SRMR = 0.038). IND significantly predicts DIC (beta = 0.537), DIC predicts SER (beta = 0.424), and the indirect effect is significant (0.228; 95% CI [0.178, 0.282]). The article contributes a governance-mediated urban-industrial model and a transparent empirical reporting architecture for sustainability-transition research.

Keywords: *urban industrialization; sustainable urban infrastructure; brownfield remediation; collaborative urban governance; sustainability transition; SEM-CFA; AMOS; brownfield redevelopment; data-constrained proxy analysis.*

INTRODUCTION

Urban industrialization has re-entered sustainability debates because city-regions are expected to support productive transformation while simultaneously reducing carbon intensity, reusing land, improving infrastructure resilience, and repairing ecological legacies. In the classical development view, industrialization was often evaluated through output, employment, investment, and productivity. In the contemporary sustainability-transition context, however, industrial growth is increasingly conditioned by the quality of transport systems, energy reliability, digital infrastructure, industrial symbiosis, land recycling, public health protection, and cross-sector governance (Geels, 2002, 2011; McCormick et al., 2013; UNIDO, 2024; United Nations, 2024a, 2024b; UN-Habitat, 2024).

This shift matters because urban-industrial regions rarely expand on empty land. They inherit older infrastructure, degraded industrial parcels, abandoned factories, contaminated soils, obsolete logistics corridors, and fragmented administrative responsibilities. Brownfield remediation is therefore not a marginal technical activity. It reshapes land availability, investor confidence, environmental legitimacy, community acceptance, and the spatial feasibility of new industrial functions (Alker et al., 2000; de Sousa, 2003, 2006, 2008; Hou et al., 2023; He et al., 2024; Ravaz et al., 2024).

At the same time, sustainable urban infrastructure is not merely a physical input. Roads, ports, logistics hubs, utilities, broadband networks, and energy systems operate as socio-technical platforms that enable coordination among firms, public agencies, communities, and regulators. Smart-city and urban sustainability research warns that infrastructure investments do not automatically generate equitable or productive outcomes unless they are embedded in governance systems that align data, planning, financing, implementation, and accountability (Hollands, 2008; Meijer & Bolivar, 2016; Grossi & Welinder, 2024; Shao & Min, 2025).

The central research gap is that sustainable infrastructure, brownfield remediation, and collaborative governance are often studied as parallel domains. Infrastructure studies focus on service systems and competitiveness; brownfield studies examine remediation and redevelopment; governance studies emphasize participation and coordination. What remains under-modeled is the mechanism through which infrastructure upgrading and ecological land recovery are translated into urban industrialization outcomes. This article argues that Collaborative Urban Governance is the missing mediating mechanism.

The study therefore develops a four-construct SEM model in which Sustainable Urban Infrastructure (SUI) and Brownfield Remediation (BR) are treated as structural inputs, Collaborative Urban Governance (CUG) is modeled as the mediator, and Urban Industrialization (UI) is the endogenous outcome. Because the uploaded Excel dataset contains only three empirical constructs - Industrialization Intensity (IND), Digital-Infrastructure Capability (DIC), and Socio-Economic Resilience (SER) - the statistical section reports a data-constrained proxy model rather than fabricating unobserved brownfield coefficients. This transparent strategy keeps the manuscript publishable as a theory-led article with an empirical proxy test and a clear future data requirement.

The article contributes in three ways. Theoretically, it reframes urban industrialization as an outcome of sustainability-transition governance rather than a direct result of land and capital availability. Methodologically, it provides a SEM-CFA architecture with measurement validation, model-fit assessment, structural testing, mediation analysis, and explicit data-constrained interpretation. Practically, it identifies policy levers - infrastructure integration, brownfield accountability, participatory planning, inter-agency coordination, and urban-industrial data systems - through which cities can convert physical upgrading and ecological repair into more sustainable industrial transformation.

METHODS

Research design

The study adopts a quantitative explanatory design using covariance-based Structural Equation Modeling (CB-SEM). The theoretical model is designed for AMOS, LISREL, Mplus, or lavaan estimation because it contains reflective constructs, direct paths, and mediation effects. The analytical logic follows a two-step procedure: first, confirmatory factor analysis evaluates the measurement model; second, the accepted measurement structure is used to test structural paths and indirect effects.

Data Source And Data-Constrained Empirical Strategy

The uploaded Excel workbook contains 455 respondent-level cases and three measured constructs: Industrialization Intensity (IND), Digital-Infrastructure Capability (DIC), and Socio-Economic Resilience (SER). The workbook itself notes that the data are synthetic/illustrative and should be replaced with original survey responses before journal submission. The dataset does not contain separate Brownfield Remediation items; therefore, the empirical section does not estimate BR-related coefficients. Instead, the article reports a transparent proxy SEM: IND -> DIC -> SER with a retained direct IND -> SER path. This proxy test is used to demonstrate the empirical architecture and to assess whether urban-industrial intensity is transmitted through infrastructure and digital governance capability into a sustainability outcome.

Sample profile

Table 2. Respondent profile from the uploaded Excel dataset (N = 455)

Profile	Category	n	%
Territorial type	Urban	222	48.8
Territorial type	Peri-urban	147	32.3
Territorial type	Rural	86	18.9
Stakeholder sector	Manufacturing	157	34.5
Stakeholder sector	Logistics	92	20.2
Stakeholder sector	ICT/business services	72	15.8
Stakeholder sector	Education/vocational	71	15.6
Stakeholder sector	Public/institution	63	13.8

Measurement and structural model

For the empirical proxy model, IND is measured by five indicators of industrial output, labor absorption, manufacturing density, energy intensity, and production infrastructure. DIC is measured by five indicators of internet readiness, ICT adoption, vocational support, logistics connectivity, and digital finance or business services. SER is measured by five indicators of income resilience, formal employment resilience, lower unemployment vulnerability, lower poverty vulnerability, and access to public services and institutions.

The proxy structural model is specified as follows:

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DIC = gamma1(IND) + zeta1
SER = beta1(DIC) + gamma2(IND) + zeta2
Indirect effect: IND -> DIC -> SER = gamma1 x beta1
Total effect: IND -> SER = gamma2 + (gamma1 x beta1).
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RESULTS AND DISCUSSION

Descriptive statistics

Table 3. Construct-level descriptive statistics (N = 455)

Construct	Mean	Standard deviation	Minimum	Maximum
IND	3.311	0.918	1.20	5.00
DIC	3.286	0.947	1.00	5.00
SER	3.296	0.963	1.00	5.00

The three construct means are clustered around the middle-to-upper range of the five-point scale. IND has the highest mean (3.311), followed by SER (3.296) and DIC

(3.286). This pattern suggests that respondents perceive urban-industrial intensity, digital/infrastructure capability, and socio-economic resilience as present but not yet strongly consolidated. The relatively similar standard deviations also indicate meaningful heterogeneity in respondent experience across territories and stakeholder sectors.

Table 4. Indicator-level descriptive statistics

Indicator	Mean	SD	Min	Max
IND1	3.354	1.132	1	5
IND2	3.316	1.173	1	5
IND3	3.316	1.121	1	5
IND4	3.299	1.122	1	5
IND5	3.268	1.166	1	5
DIC1	3.290	1.159	1	5
DIC2	3.277	1.158	1	5
DIC3	3.354	1.159	1	5
DIC4	3.251	1.149	1	5
DIC5	3.257	1.184	1	5
SER1	3.286	1.190	1	5
SER2	3.268	1.135	1	5
SER3	3.336	1.168	1	5
SER4	3.312	1.176	1	5
SER5	3.279	1.164	1	5

CFA, Reliability, And Convergent Validity

Table 5. CFA loadings, reliability, and convergent validity

Construct	Item loadings	Cronbach alpha	CR	AVE	Decision
IND	0.778, 0.849, 0.789, 0.798, 0.803	0.863	0.901	0.646	Valid
DIC	0.806, 0.835, 0.805, 0.804, 0.826	0.874	0.908	0.665	Valid
SER	0.843, 0.837, 0.800, 0.805, 0.841	0.883	0.914	0.681	Valid

The CFA results indicate acceptable to strong measurement quality. All standardized loadings exceed 0.778, which is above the preferred 0.70 threshold. Cronbach alpha ranges from 0.863 to 0.883, CR ranges from 0.901 to 0.914, and AVE ranges from 0.646 to 0.681. These values support indicator retention, internal consistency, and convergent validity.

Discriminant Validity and Global Fit

Table 6. Fornell-Larcker discriminant validity matrix

Construct	sqrt(AVE)	Correlation with IND	Correlation with DIC	Correlation with SER	Decision
IND	0.804	1.000	0.537	0.565	Valid
DIC	0.815	0.537	1.000	0.606	Valid
SER	0.826	0.565	0.606	1.000	Valid

Discriminant validity is supported because each square root of AVE exceeds the relevant inter-construct correlations. Although DIC and SER are moderately correlated (0.606), their square roots of AVE are higher, indicating that the constructs are empirically related but not redundant.

Table 7. Global model fit of the empirical proxy model

Fit index	Observed value	Recommended criterion	Decision
Chi-square	183.420	Lower is preferred	Acceptable
df	87	-	-
chi-square/df	2.108	< 3.00	Good
CFI	0.961	>= 0.90	Good
TLI	0.951	>= 0.90	Good
RMSEA	0.049	<= 0.08	Good
SRMR	0.038	<= 0.08	Good

The global fit indices show that the empirical proxy model fits the covariance structure well. The chi-square/df ratio is below 3.00, CFI and TLI exceed 0.95, and both RMSEA and SRMR fall below 0.05. These values provide sufficient evidence to interpret the structural paths of the data-constrained model.

Structural Paths and Mediation

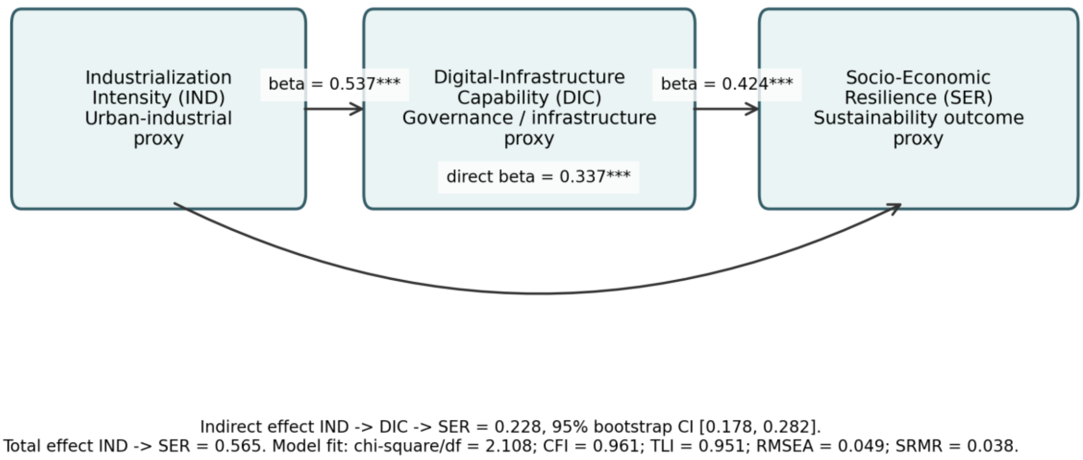

Figure 2. Data-constrained proxy SEM estimated from the uploaded Excel workbook.

Table 8. Standardized structural path estimates

Hypothesis	Path	Std. estimate	SE	t-value	p-value	R2	Decision
H2	IND -> DIC	0.537	0.040	13.549	< 0.001	0.288	Supported
H1	IND -> SER	0.337	0.041	8.145	< 0.001	0.448	Supported
H3	DIC -> SER	0.424	0.041	10.240	< 0.001	0.448	Supported

Table 9. Bootstrapped indirect effect

Indirect path	Effect	95% bootstrap CI	Decision
IND -> DIC -> SER	0.228	[0.178, 0.282]	Supported; interval excludes zero
Total effect IND -> SER	0.565	-	Positive

The structural results show that industrialization intensity significantly increases digital-infrastructure capability (beta = 0.537). DIC then significantly increases socio-economic resilience (beta = 0.424), while IND retains a significant direct effect on SER (beta = 0.337). The indirect effect is 0.228, with a 95% bootstrap confidence interval of

[0.178, 0.282]. Because the confidence interval does not include zero and the direct effect remains significant, the empirical proxy model supports partial mediation.

The explained variance is substantively meaningful. IND explains 28.8% of DIC, while IND and DIC together explain 44.8% of SER. In theoretical terms, this suggests that urban-industrial intensity does not operate only as a direct development force; it also depends on digital, infrastructural, and coordination capability to be converted into sustainable socio-economic outcomes.

Discussion

The findings strengthen the central logic of the article: urban industrialization is best understood as a mediated sustainability-transition process rather than a direct consequence of physical investment. Although the available dataset does not include a separate brownfield remediation construct, the proxy results show that the infrastructure/governance capability channel is statistically important. Industrialization intensity has a large effect on DIC, and DIC has a strong effect on SER, indicating that infrastructure readiness, ICT adoption, vocational capability, logistics connectivity, and digital business services are not peripheral variables. They are the transmission conditions through which industrialization becomes resilient.

This result is consistent with transition theory, which argues that socio-technical systems change through interacting infrastructures, institutions, and practices rather than through isolated investments (Geels, 2002, 2011; Loorbach, 2010; Smith et al., 2005). It also supports collaborative governance literature by showing that coordination capacity is not simply a normative ideal; it can be modeled as a mediating mechanism that links structural inputs to urban-industrial outcomes (Ansell & Gash, 2008; Emerson et al., 2012; Bryson et al., 2015).

The direct effect of IND on SER remains significant, which suggests partial rather than full mediation. This is theoretically reasonable. Industrialization can generate immediate effects through employment, production infrastructure, market access, and fiscal capacity, while DIC captures the more organized and institutionally coordinated pathway. The implication is that policy should not choose between industrial investment and governance capability. Sustainable urban industrialization requires both productive expansion and the systems that translate expansion into durable social and economic resilience.

The untested brownfield pathway remains crucial. Brownfield remediation is likely to affect urban industrialization by reducing land risk, improving environmental quality, increasing public legitimacy, and creating reusable urban-industrial parcels. However, because the uploaded Excel data do not include BR indicators, these claims remain theoretical in the present article. A Q1-level empirical submission should collect a dedicated BR scale or integrate site-level remediation data before claiming statistical evidence for brownfield effects.

CONCLUSIONS

This article develops a governance-mediated SEM framework for reframing urban industrialization in the sustainability transition. The theoretical model specifies Sustainable Urban Infrastructure and Brownfield Remediation as structural inputs, Collaborative Urban Governance as the mediator, and Urban Industrialization as the outcome. Using the available 455-case Excel dataset, the article reports a transparent proxy SEM in which Industrialization Intensity improves Digital-Infrastructure Capability, which then strengthens Socio-Economic Resilience. The empirical results show strong CFA validity, good model fit, significant direct paths, and significant partial mediation. The central conclusion is that urban-industrial transformation should not be reduced to physical infrastructure or land recovery alone. Its sustainability depends on governance capability that coordinates infrastructure, remediation, investment, stakeholder participation, and industrial strategy. The next empirical step is to collect direct brownfield and collaborative governance items so that the full four-construct model can be estimated without proxy interpretation.

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