# Toward a Structural Understanding of Technology Transfer in the Construction Sector in Colombia

Beatriz Liliana Gómez Gómez[1], Johnny Valencia Calvo[2] and Johnny Alexander Tamayo Arias[3]

[1,3] Industrial Engineering Department, Faculty of Engineering, Universidad Nacional de Colombia, Manizales, Colombia.

[2] Department of Natural Sciences and Technology, University of Aysén, Coyhaique 5951369, Chile

**Abstract**

This paper addresses the persistent contraction and low productivity in Colombia's construction sector, despite its access to global technologies (e.g., BIM, Industry 4.0). Addressing technology transfer (TT) failures through System Dynamics (SD) is complex due to the reliance on soft variables like leadership and intercultural communication, which are difficult to quantify. To overcome the subjective bias often found in traditional SD conceptualization, this study introduces a novel methodological framework integrating the CRISP-DM data science standard with structural prospective analysis. This systematic approach allows for the rigorous elicitation, mapping, and operationalization of both soft and hard variables within the socio-technical ecosystem. The application of this framework resulted in a robust dynamic hypothesis and a fully validated Causal Loop Diagram (CLD) mapped in Stella Architect. The model reveals that without adequate absorptive capacity, driven by the structural informality trap, initial technological investments fail to increase sectoral productivity. These findings demonstrate that technology transfer requires more than

just acquiring tools; it demands structural improvements in the ecosystem's absorptive capacity to prevent skill dilution. By overcoming the systemic brake of the informality trap, policymakers and industry leaders can activate a core transfer engine, shifting the system toward a virtuous cycle of sustained productivity and collaborative innovation.

*Keywords:* Technology transfer, CRISP-DM, construction industry, soft variables.

## 1. Introduction

Even though Colombia's construction sector has access to a wide range of technologies worldwide (e.g., Industry 4.0, BIM) and has achieved recent technological advances, why does it remain in a state of contraction (CAMACOL, 2025a; DANE, 2025a) and exhibit low productivity? Could technology transfer (TT) into the sector be failing consistently? Addressing these issues through system dynamics (SD) is challenging because technology transfer relies heavily on "soft variables" (e.g., leadership, intercultural communication, and absorptive capacity), which are difficult to justify and quantify before formal modeling (Sterman, 2000). This paper proposes a novel methodological framework that integrates the CRISP-DM data science standard with prospective analysis. This framework synthesizes and operationalizes soft (qualitative) and hard (quantitative) variables within a socio-technical system.

## 2. Methodology: Adapting the CRISP-DM process for system dynamics conceptualization.

To formalize this methodological contribution, Table 1 presents the systematic mapping between the standard CRISP-DM phases and the system dynamics conceptualization process. Traditional SD conceptualization often relies heavily on the modeler's subjective mental models for boundary selection and variable elicitation, which can introduce bias, especially when dealing with soft variables. Integrating the CRISP-DM framework overcomes this limitation by enforcing a rigorous, data-driven pipeline (incorporating systematic literature review, Delphi, and MIC-MAC algorithms). This structured approach reduces modeler bias, systematically operationalizes qualitative bottlenecks, and ensures that the resulting causal architecture is strictly grounded in empirical and prospective data.

**Table 1**

*Systematic Mapping: CRISP-DM Framework Adapted to System Dynamics Conceptualization*

| CRISP-DM Phase | Research Action | Outcome |
|---|---|---|
| 1. Business Understanding | Sector Analysis: The problem in the Colombian construction sector was identified, and the sector's economic data were analyzed. | It was found that the problem is not a lack of technology, but rather the system's structural inability to absorb it due to a lack of understanding regarding technology transfer dynamics between transfer agents and material manufacturing industries. |
| 2. Data Understanding | Parameter Collection: All characteristics or parameters were gathered through a Systematic Literature Review (SLR), interviews, and the Delphi method. | Gross variable inventory: An extensive preliminary list of heterogeneous (quantitative and qualitative) and unorganized parameters or factors. |

| CRISP-DM Phase | Research Action | Outcome |
|---|---|---|
| 3. Data Preparation | Filtering and Categorization: Structural analysis (MIC-MAC) and methodological triangulation were applied to merge synonyms and clean data. Variables were classified according to their nature within the system. | Refined and categorized variables: Definition of endogenous, exogenous, and excluded variables. Creation of 4 Subsystems: Human Capital, R&D Investment, Technological and Business Subsystem. |
| 4. Modeling | Dynamic Construction: Connection of the refined variables through feedback loops to formulate the dynamic hypothesis. | Causal Loop Diagram (CLD): The conceptual systemic structure that maps the relationships and polarities among the critical variables. |
| 5. Evaluation | Structural Validation: Verification of the causal loops (R1, R2, R3) against the historical Reference Mode and theoretical consistency. | Conceptually validated model: A structural framework that logically explains the historical "Low Adoption Trap" through endogenous feedback. |
| 6. Deployment (Future Work) | Strategic Roadmap & Future Simulation: Use of the CLD to identify initial leverage points and outline the transition toward a formal model. | Strategic roadmap: Initial guidelines for decision-makers and the established baseline architecture for future quantitative policy simulations. |

Following the initial phase of this framework, an analysis of the Colombian construction sector's economic data initially revealed a crucial insight: the core problem is not a scarcity of available technology, but rather the socio-technical system's structural inability to absorb it (business and data understanding). This stems from a lack of understanding regarding the technology transfer dynamics between transfer agents and material manufacturing construction industries. Consequently, the objective of the system dynamics model was defined as analyzing the interactions among actors, resources, and policies that influence the technology transfer process between universities and enterprises as well as within inter-firm contexts, with a focus on the Colombian construction sector.

Within the broader six-phase CRISP-DM lifecycle (Chapman et al., 2000), the critical stage of data preparation was approached through methodological triangulation, performing a successive variable filtering based on three inclusion criteria:

- Theoretical validity criterion: A systematic literature review (SLR) was conducted to extract and identify the main universal factors of technology transfer (TT). Through a Thematic Analysis framework (Braun & Clarke, 2006), these factors were systematically extracted, classified, and coded into a latent modeling architecture, ensuring a conceptual foundation for the system's dynamics model.
- Contextual relevance criterion (qualitative study): Through in-depth interviews with leaders of Technology Transfer Offices (OTRIs) recognized by MinCiencias (Colombian Ministry of Science), theoretical factors were contrasted with real TT bottlenecks in the country. The narratives were then coded and grouped using Atlas.ti.
- Systemic Criticality Criterion (prospective study): Based on the factors extracted from both the literature and the interviews, a prospective study (Godet, 2000) was conducted to assess their future impact on technology transfer in the Colombian construction industry. Initially applying the Delphi method, these preliminary factors were evaluated

by the experts and subsequently grouped into thematic nodes to construct a consolidated structural matrix.

Building on these criteria, a MIC-MAC structural analysis was conducted. Factors that passed the first two filters underwent a cross-impact analysis by a reduced panel of 12 senior experts. This panel was carefully selected from the original Delphi group based on expertise (over 8 years of experience) and balanced sectoral representation (4 academics, 4 industry leaders, and 4 TT managers). Under the CRISP-DM standard, this step is crucial as it acts as a dimensionality reduction algorithm.

The MIC-MAC analysis allowed us to identify which factors possess the highest driving power (motricity) and sensitivity (dependence) within the Colombian industrial structure towards a 2035 horizon. This process successfully distilled the complex system down to 13 critical factors (Table 2) which provide the foundation for the causal loop modeling presented below.

**Table 2.**

The 13 critical socio-technical variables of technology transfer (Horizon 2035), based on the functional logic of the Colombian construction sector.

| ID | Critical Factor | Variable Type | Subsystem (Model Sector) |
|---|---|---|---|
| **V1** | Digitalization of the Ecosystem | Stock | Technological |
| **V2** | R&D Investment | Stock | R&D Investment |
| **V3** | Business Technological Absorption | Auxiliary | Technological |
| **V4** | Technology Transfer | Auxiliary | Technological |

| | | | |
|---|---|---|---|
| **V5** | Specialized Human Capital | Stock | Human Capital |
| **V6** | STI Public Policies | Auxiliary | R&D Investment |
| **V7** | Speed of Adoption | Flow | Technological |
| **V8** | Internationalization | Auxiliary | R&D Investment |
| **V9** | Collaborative Projects Management | Auxiliary | R&D Investment |
| **V10** | Sustainability Indicators | Auxiliary | Business |
| **V11** | Intercultural and multidisciplinary Communication | Auxiliary | Human Capital |
| **V12** | Data Analysis and Metrics | Auxiliary | Technological |
| **V13** | Team Leadership | Auxiliary | Human Capital |

These 13 critical factors were subsequently integrated with key macroeconomic indicators (such as productivity, sales, and informal employment) to construct the formal System Dynamics architecture.

3. The Dynamic Hypothesis

Despite representing 7.4% of the national GDP and generating approximately 1.67 million jobs, the Colombian construction sector remains trapped in a state of low performance, facing global pressures toward digitalization and sustainability. The sector's GDP has contracted for several years, exhibiting persistently low productivity. Figure 1 illustrates the historical volatility and recent contraction of the sectoral GDP, juxtaposed with the persistently stagnant R&D investment levels at approximately 0.38% and Figure 2 shows a severe structural informality rate averaging 68.2%. This trajectories represent the structural stagnation that the model aims to reproduce (CAMACOL, 2025a; DANE, 2021, 2025a, 2025b, 2025c).

**Figure 1**

*Reference Mode (Behavior Over Time) of the Colombian Construction Sector*

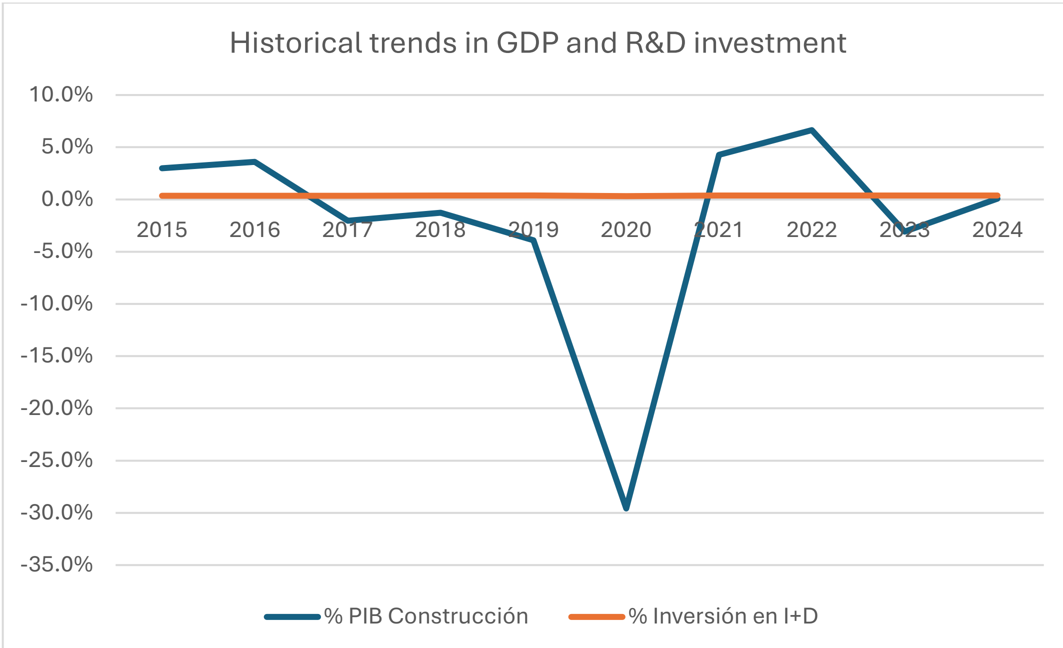
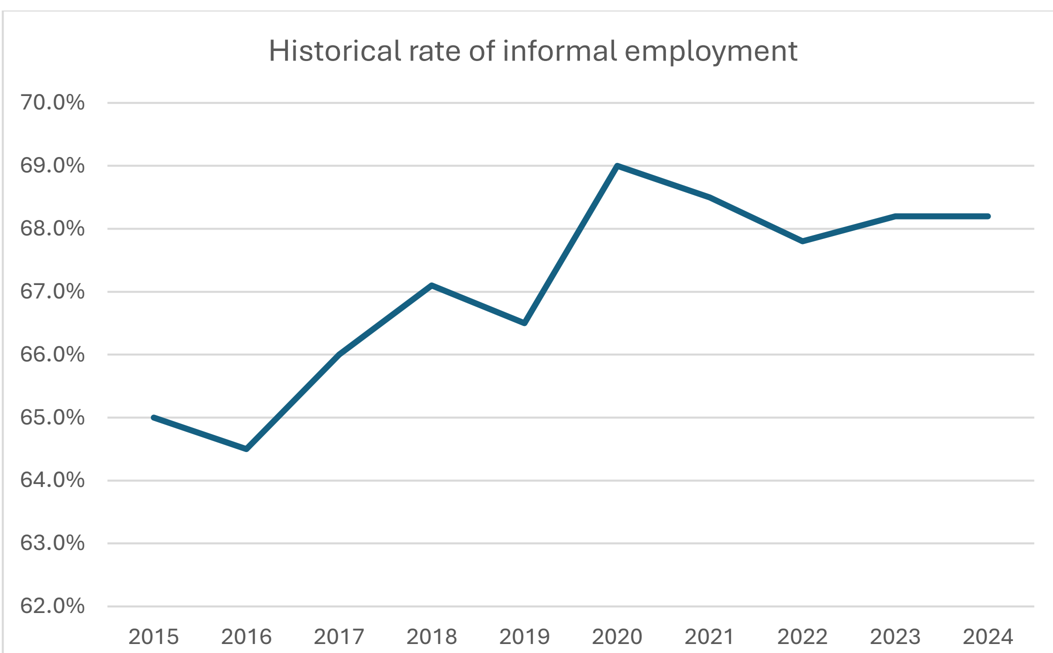



**Figure 1:**

*Reference Mode (Behavior Over Time) of the Colombian Construction Sector*



Based on the refined variables, the following dynamic hypothesis (Figure 3) was formulated to explain this historical reference mode: The stagnation is the result of a system dominated by inefficiencies caused by labor informality. Lacking sufficient specialized human capital (ranging from technical levels to senior postgraduate personnel) capable of understanding and operating the innovations entering the sector, whether through direct transfer or developments from research centers and universities, the system suffers from low absorptive capacity. This neutralizes the impact of acquired technologies, preventing a sustainable improvement in overall sectoral productivity.

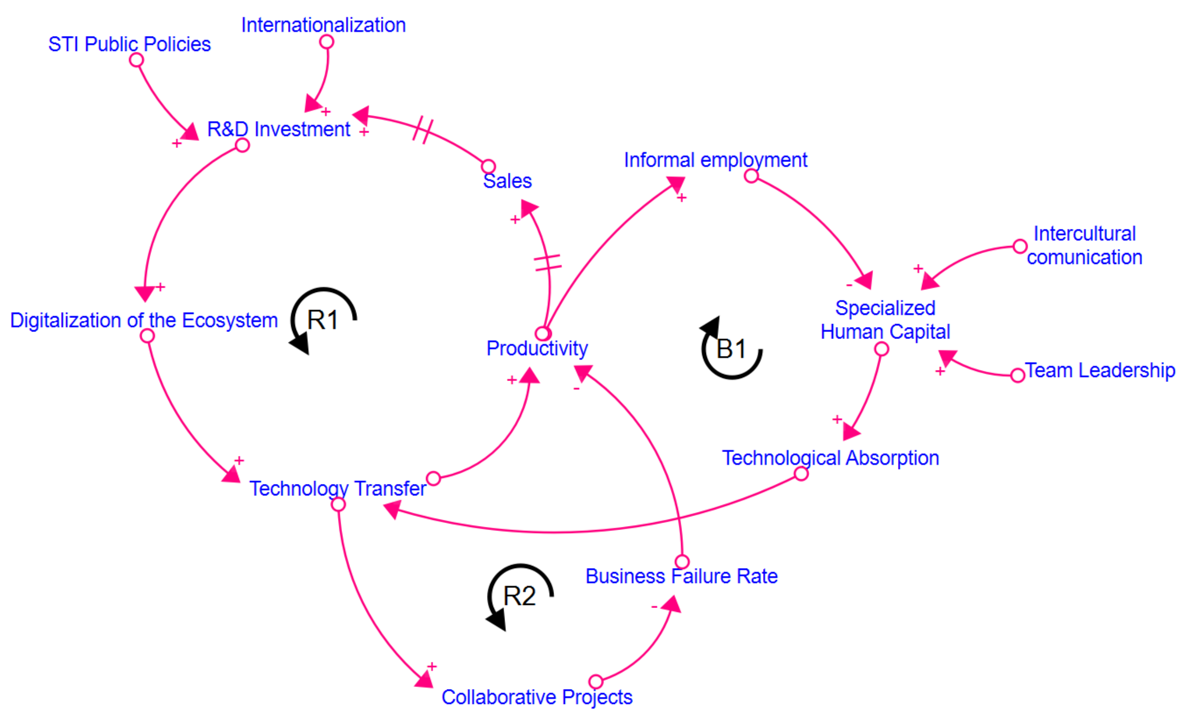
- Reinforcing Loop R1 - The Virtuous Circle of Innovation. This is the core growth engine. It represents how R&D Investment (V2) translates into sales for material manufacturers within the construction sector. Investment (V2) drives Digitalization (V1), facilitating Technology Transfer (V4). If effective transfer is achieved, Labor Productivity rises, increasing material sales and thus providing companies with more resources to reinvest.
- Balancing Loop B1 - The Informality Trap. This is the systemic break that hinders sectoral growth. When labor productivity attempts to increase sales, the pressure to meet demand in a low-tech sector attracts informal labor, which has historically stood at 68.2% (DANE, 2025c). This informality erodes the density of Specialized Human Capital (V5). In terms of the mathematical model, this phenomenon materializes through the massive influx of unskilled personnel via biflows indexed to DANE's employment rates. By inflating the denominator of the total workforce, this flow of informal labor mathematically crashes the specialized talent density, drastically reducing Absorptive Capacity (V3) and, consequently, neutralizing the effect of Technology Transfer (V4).

This dynamic explains why, despite investment efforts, sectoral productivity has contracted in the recent period, forcing the system into a state of low performance.

- Reinforcing Loop R2 - Survival Synergy. This loop demonstrates that technology transfer is not just about ecosystem efficiency, but internal resilience for companies. Technology Transfer (V4) fosters Collaborative Projects (V9), which reduce business mortality. With lower mortality, the business fabric is strengthened, improving productivity, stabilizing sales, and sustaining investment.

**Figure 3**

Causal Loop Diagram of the Technology Transfer structural trap.




4. Expected Outcomes and Contribution

The Causal Loop Diagram demonstrates that true technology transfer requires developing the ecosystem's absorptive capacity. Overcoming the systemic brake imposed by the informality trap (B1) is essential to fully activate the core innovation engine (R1) and leverage survival synergies (R2), shifting the system toward a virtuous cycle of productivity. Figure 3 shows the Causal Loop Diagram (CLD) derived from the defined relationships, which was conceptualized and mapped using Stella Architect (isee systems).

## 5. Acknowledgments

The author(s) would like to acknowledge the financial support provided by the Colombian Ministry of Science, Technology, and Innovation (Minciencias) through the national doctoral scholarship program [Call 785].

Additionally, during the preparation of this work, the author(s) used the Gemini AI tool (Google) to polish the English language, refine the structural formatting, and improve the overall readability of the manuscript. After using this tool, the author(s) reviewed and edited the content and take full responsibility for the final publication.

## 6. References

BlackRock. (2025). *The New Infrastructure Blueprint.* https://www.blackrock.com/uk/professionals/solutions/the-new-infrastructure-blueprint

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. Qualitative Research in Psychology, 3(2), 77-101. https://doi.org/10.1191/1478088706qp063oa

Cámara Colombiana de la Construcción [CAMACOL]. (2025a). *Tendencias de la construcción: Principales tendencias económicas del sector y su prospectiva de aquí a 2026* [Construction trends: Main economic trends of the sector and its foresight up to 2026]. Bogotá, Colombia.

Cámara Colombiana de la Construcción [CAMACOL]. (2025b). *Datos que construyen No. 16: Presupuesto General de la Nación 2026: ajuste fiscal aplazado y recorte en la inversión en vivienda* [Data that builds No. 16: General Budget of the Nation 2026: postponed fiscal adjustment and cut in housing investment]. Bogotá, Colombia. Retrieved from https://camacol.co/descargable/datos-que-construyen-no-16-presupuesto-general-de-la-nacion-2026-ajuste-fiscal-aplazado

Chapman, P., Clinton, J., Kerber, R., Khabaza, T., Reinartz, T., Shearer, C., & Wirth, R. (2000). *CRISP-DM 1.0: Step-by-step data mining guide*. SPSS Inc.

Departamento Administrativo Nacional de Estadística [DANE]. (2021). *Encuesta de Desarrollo e Innovación Tecnológica (EDIT) - Resultados históricos de inversión en I+D* [Technological Innovation and Development Survey (EDIT) - Historical results of R&D investment]. Bogotá, Colombia. Retrieved from https://www.dane.gov.co/index.php/estadisticas-por-tema/tecnologia-e-innovacion/encuesta-de-inversion-en-investigacion-y-desarrollo-i-d

Departamento Administrativo Nacional de Estadística [DANE]. (2025a). *Cuentas Nacionales Trimestrales y Anuales: Anexos estadísticos históricos del Producto Interno Bruto (PIB) a precios constantes por rama de actividad*. [Conjunto de datos]. [Quarterly and Annual National Accounts: Historical statistical annexes of the Gross Domestic Product (GDP) at constant prices by economic activity] [Data set]. Bogotá, Colombia. Retrieved from: https://www.dane.gov.co/index.php/estadisticas-por-tema/cuentas-nacionales

Departamento Administrativo Nacional de Estadística [DANE]. (2025b). *Encuesta de Desarrollo e Innovación Tecnológica (EDIT) - Resultados históricos de inversión en I+D*

[Technological Innovation and Development Survey (EDIT) - Historical results of R&D investment]. Bogotá, Colombia. Retrieved from https://www.dane.gov.co/index.php/estadisticas-por-tema/tecnologia-e-innovacion/encuesta-de-inversion-en-investigacion-y-desarrollo-i-d

Departamento Administrativo Nacional de Estadística [DANE]. (2025c). *Gran Encuesta Integrada de Hogares (GEIH): Anexos de empleo informal y seguridad social por ramas de actividad* [Large Integrated Household Survey (GEIH): Annexes of informal employment and social security by economic activity] [Data set]. Bogotá, Colombia. Retrieved from https://www.dane.gov.co/index.php/estadisticas-por-tema/mercado-laboral/empleo-informal-y-seguridad-social

Godet, M. (2000). The art of scenarios and strategic planning: Tools and pitfalls. Technological Forecasting and Social Change, 65(1), 3–22. https://doi.org/10.1016/S0040-1625(99)00120-1

Sterman, J. D. (2000). Business dynamics: Systems thinking and modeling for a complex world. McGraw-Hill.