Towards Circular Predictive Maintenance in Building Supply Networks: A Multi-Agent and Data-Driven Approach

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1 MOTIVATIONS & RESEARCH QUESTION(S)

MOTIVATIONS

During the operational phase of buildings, the increasing deployment of **sensors, Building Management Systems (BMS), Building Automation Systems (BAS), Digital Twins (DT), and Internet of Things (IoT)** platforms has substantially increased the availability of operational data. However, the systematic use of these data for maintenance decision-making remains limited. **Predictive Maintenance (PdM)** provides an opportunity to exploit this information for early fault detection, intervention planning and resource optimisation.

RESEARCH GAPS & HIGHLIGHTS

- Limited integration between PdM and building-operation supply-chain processes. → Bridges PdM analytics with circular supply-chain decision-making.
- Fragmented coordination among maintenance, procurement, inventory and component-recovery actors. → Uses MAS to support collaborative decision-making across these actors.
- Insufficient integration of data- and knowledge-based approaches for circular maintenance decisions. → Combines hybrid-data- and knowledge-based models to support PdM and circular decisions.

Main Research Question

How can building-generated data, intelligent models, and multi-agent systems support PdM decision-making and coordinate circular maintenance processes across hybrid collaborative building networks?

SPECIFIC RQs

RQ1 — **What is the state of the art in BIM, BMS and IoT data integration for building PdM, and how does it connect with sustainable supply-chain management?**

RQ2 — **How can a conceptual model integrate heterogeneous data with knowledge- and data-based algorithms to support PdM decisions and circular processes?**

RQ3 — **How can a MAS coordinate PdM decisions with building operators, maintenance services, suppliers, inventory functions and component-recovery actors?**

2 METHODOLOGY

The methodology combines quantitative and qualitative approaches to investigate the factors influencing PdM decision-making in buildings and its coordination with supply-chain processes. The research is structured using the CIMO framework (Context, Intervention, Mechanism, and Outcome), whose practical orientation supports the systematic definition of the main dimensions of the research problem.

CIMO framing

C	I	M	O
Context	**Intervention**	**Mechanism**	**Outcome**
Building operational environments	Circular PdM integrated with supply-chain processes	MAS + hybrid data- and knowledge-based models	Coordinated collaborative maintenance decisions

WORKFLOW

1. **Tertiary systematic review**
   Map PdM approaches, building data sources, integration technologies and links with circular supply-chain processes.
2. **Conceptual model development**
   Define the relationships among PdM, circular maintenance processes, building information and collaborative networks actors.
3. **Algorithmic proof of concept:**
   Develop and evaluate survival-analysis models and maintenance scheduling to connect failure-risk prediction with intervention planning.
4. **Multi-agent integration**
   Implement MAS-based coordination to connect maintenance decisions with procurement, inventory, repair, reuse and component-recovery actors.

METHODS / TOOLS

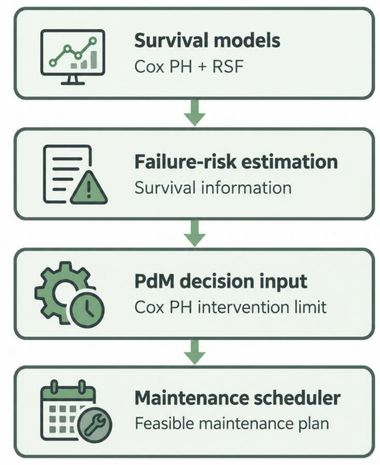
- ✓ **CIMO framework**
- ✓ **Tertiary systematic review**
- ✓ **Survival analysis**
- ✓ **Maintenance scheduling**
- ✓ **Multi-Agent Systems (MAS)**

3 PRELIMINARY RESULTS

Proof of concept

Survival-based PdM outputs are translated into maintenance scheduling decisions through intervention limits.

Decision chain tested so far



KEY FINDINGS

- **Cox PH outperformed RSF** in the current PoC.
- **20 maintenance actions** were scheduled in the controlled instance.
- **Zero tardiness** was achieved in the reported scheduling run.

Scientific caution

Current evidence demonstrates methodological feasibility not field-level effectiveness.

NEXT STEP

- ✓ **Embed prediction and scheduling within a MAS coordination architecture.**
- ✓ **Assess collaborative decisions on repair, reuse, recovery, procurement, and inventory.**

4 KEY CONCLUSIONS AND PERSPECTIVES

MAIN CONCLUSIONS

This research positions predictive maintenance as a bridge between building analytics and coordinated circular actions across hybrid collaborative building networks

1. FROM PREDICTION TO COLLABORATION

PdM in buildings should be understood not only as a prediction problem, but also as a collaborative decision-making problem involving multiple technical and organisational actors.



2. COORDINATION LAYER

MAS provide the coordination mechanism needed to transform PdM outputs into coordinated actions across the building-operation network, aligning maintenance planning with procurement, inventory management, repair, reuse and component recovery decisions.



3. PERSPECTIVE

Future work will focus on validating the MAS-based coordination layer in more realistic building-operation scenarios, assessing the quality, feasibility, and robustness of collaborative decisions across maintenance and supply-chain actors.



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