UF DCP Research Agenda-Setting White Paper

Digital Twin Data Infrastructure for Circular Economy Enhancement

Executive Summary:

The lack of a robust and integrated data infrastructure presents a significant challenge to the widespread adoption of circular economy principles in construction. Without comprehensive systems to track, manage, and analyze material flows and lifecycle data, transparency and traceability are compromised, making implementing sustainability practices difficult. Additionally, existing data infrastructures often fail to capture the complex interactions between building components and their environmental impacts, impeding progress toward sustainability goals.

Building Information Modeling (BIM) and DT technologies offer promising solutions for creating the data infrastructure necessary for circular construction. BIM could support detailed design and material management. By generating a list of components from existing buildings, BIM models serve as an inventory for new projects. Digital Twins potentially support decision-making by tracking lifecycle material and space tracking, monitoring material conditions in real-time and synchronizing them with waste management, space repurposing, and providing insights into design, construction procurement, maintenance, aging, and recycling.

This proposal aims to develop a *DT* data infrastructure that integrates *Circular Economy* principles in typical scenarios, such as post-disaster rebuilding and everyday construction practices. By leveraging digital technologies, the research seeks to reduce waste, enhance material traceability for reuse and repurposing, and improve the economic and environmental sustainability of construction and development. The research team will explore the foundational systems, tools, technologies, and frameworks supporting data collection, processing, networking, governance, integration, and analytics. The research

team, comprising experts from construction management, information systems, operations management, and economics, is well-positioned to develop this research.

WG Members:

Name/ Title	Affiliation	Academia/ Industry/ Government
Lead: Rui Liu	Rinker School of Construction Management	Academia
Co-lead: Lijian Ma	Department of Civil and Architectural Engineering, Tennessee State University	Academia
Members: Raymond Issa	Rinker School of Construction Management	Academia
Members: Amy Pan	Department of Information Systems and Operations Management, Warrington College of Business, UF	Academia
Members: Patricia Kio	Sustainability in the Built Environment + School of Architecture	Academia

Description of the Problem, Key Research Areas / Priorities

Traditional construction methods often result in significant material waste and environmental damage, which is increasingly untenable in a world facing urgent environmental challenges. By adopting adaptive reuse and *Circular Economy (CE)* principles, the construction industry is discovering new ways to minimize waste, extend the lifecycle of materials, and optimize the use of existing spaces. Integrating CE principles into construction is essential for sustainable development. The Ellen MacArthur Foundation's ReSOLVE framework provides six key strategies - Regenerate, Share, Optimize, Loop, Virtualize, and Exchange - guiding the transition toward a circular economy in the built environment. These strategies apply to various assets, including buildings, infrastructure, and cities.

However, the lack of a robust and integrated data infrastructure remains a significant challenge in the widespread adoption of circular economy principles. Without comprehensive systems to track, manage, and analyze material flows and lifecycle data, transparency, and traceability are compromised, making implementing efficient reuse and recycling practices difficult. The absence of centralized data platforms also hinders the synchronization between stakeholders involved in construction, waste management, and material sourcing, slowing the transition to circular models. Moreover, existing data infrastructures often fail to capture the complex interactions between building elements and environmental impacts, leading to inefficiencies in resource use and impeding progress toward decarbonization goals. Innovative business models and integration of emerging technologies into construction practices are needed to enhance the sustainability and resilience principles of the built environment in the face of ongoing resource constraints and construction time constraints.

Primary Research Question

1. How can innovative technologies such as Digital Twin support the integration of Circular Economy (CE) principles in construction?
2. What are the primary challenges in implementing a robust data infrastructure for tracking material lifecycle and flows in the construction industry?
3. What are the economic and environmental benefits of integrating BIM and DT technologies in material management and waste reduction?
4. What emerging business models and technologies are most effective for enhancing sustainability and resilience in construction?

Solutions and Methodological Considerations

Building Information Modeling (BIM) and DT technologies offer promising solutions for creating the data infrastructure necessary for circular construction. BIM models could support detailed design and material management. BIM models can support material management by generating a list of components from existing buildings, which serves as an inventory for new projects. Associating BIM data with each component streamlines reuse in future designs. Starting with a building like Rinker, designed for deconstruction, the inventory grows as more buildings are added, creating a large, adaptable materials collection. With a growing inventory of adaptable materials, businesses can minimize reliance on new resources, promoting sustainability while lowering operational costs. Digital Twins can potentially support decision-making by tracking lifecycle material and space tracking, monitoring material conditions in real-time and synchronizing them with waste management, space repurposing, and providing insights into design, construction procurement, maintenance, aging, and recycling. This allows businesses to reduce waste and optimize material reuse in future projects, cutting costs on procurement. Integrating BIM and DT in circular construction aligns with sustainability goals and can help businesses meet regulatory compliance for waste reduction and environmental impact.

Description of the Research Approach

The research methodology integrates BIM, DT, and LCA technologies through a systematic five-task approach to establish a comprehensive data infrastructure for circular construction practices.

Task 1 focuses on system analysis and requirements definition, establishing key performance indicators for material reuse, waste reduction, and embodied carbon assessment. This phase includes developing data collection protocols, and a material classification system aligned with Environmental Protection Agency (EPA) guidelines and CE principles.

Task 2 comprises developing BIM-DT-LCA integration architecture creating a unified platform that incorporates BIM modeling, LCA calculations, and DT monitoring capabilities. The system architecture will establish interoperability protocols using the Industry Foundation Classes (IFC) format and develop a comprehensive database schema for material properties, environmental data, and performance metrics.

Task 3 implements the framework through sensor network deployment for real-time monitoring of environmental parameters and material tracking. This phase includes developing machine learning algorithms for material deterioration prediction, reuse optimization, and environmental impact forecasting, with environmental data collection and material tracking.

Task 4 is to validate the framework and system with three case studies: a new academic facility construction, a major renovation of a residential building, and an industrial facility demolition recovery project. Each case study examines different aspects of material reuse, environmental impact monitoring, and circular economy implementation by comparing predicted versus actual performance metrics and producing comprehensive technical documentation. The framework will integrate with existing facility management systems through standardized Application Programming Interfaces (APIs), with regular validation against physical inventories to ensure accuracy and reliability.

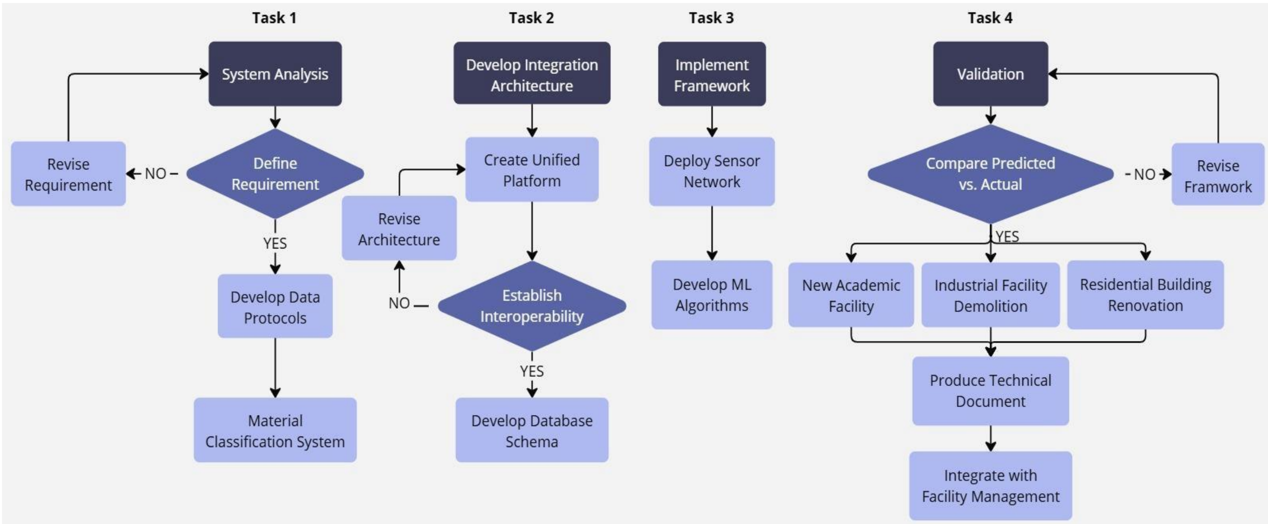

Figure 1. The workflow of this project.

WG's Strengths, Weaknesses, Opportunities, and Challenges:

Strengths	Weakness
• **Innovative Approach:** The integration of Digital Twin (DT) technologies and Building Information Modeling (BIM) provides a cutting-edge solution for addressing current inefficiencies in material tracking, lifecycle analysis, and space optimization. • **Alignment with Circular Economy (CE) Principles:** The research adopts Circular Economy (CE) principles, which are essential for sustainable development. • **Comprehensive Framework:** The proposal outlines a robust framework that includes data collection, processing, networking,	• **Complex Data Integration:** The challenge of integrating diverse data sources, such as building information, economic data, condition monitoring data, and environmental impacts, is significant. • **Resource Intensive:** Implementing BIM and Digital Twin technologies can be expensive and resource-intensive, which may limit the scalability and adoption of the proposed solutions.

	and governance, making the project well- rounded and capable of addressing multiple dimensions of sustainability. • **Multidisciplinary Team:** The involvement of experts from construction management, information systems, operations management, and economics strengthens the proposal's ability to address the problem from multiple perspectives.		
Opportunities	• **Global Sustainability Goals:** Aligning the project with global decarbonization goals presents opportunities to attract funding and partnerships with organizations focused on sustainability and climate action. • **Expansion to Urban Planning:** The approach could be expanded beyond individual buildings to entire cities and infrastructure, allowing for large-scale sustainability efforts and urban resilience planning. • **Emerging Markets:** The increasing importance of CE principles and sustainability in construction markets provides an opportunity for this research to contribute to future policy frameworks and business models. • **Post-Disaster Applications:** The proposal highlights the application of Digital Twin infrastructure in post-disaster rebuilding, opening avenues for faster and more sustainable recovery processes.	• **Data Governance and Privacy:** Handling vast amounts of sensitive data related to material sourcing, cost, and environmental impacts requires stringent data governance and privacy measures. • **Stakeholder Collaboration:** Ensuring synchronization between stakeholders from diverse sectors (construction, waste management, material sourcing) is challenging. • **Regulatory and Legal Barriers:** Adoption of circular economy principles and Digital Twin infrastructures may face regulatory challenges in different regions.	**Challenges**