A SOCIO-TECHNICAL PERSPECTIVE ON THE ADOPTION OF DIGITAL TRACKING TECHNOLOGIES FOR CIRCULAR ECONOMY IN THE SWEDISH PREFABRICATED CONCRETE SECTOR

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ABSTRACT

Background and gap: The construction sector is globally a major consumer of natural resources and a significant contributor of extensive resource exploitation and waste generation (Bonoli et al, 2021; Fei et al., 2021). In Sweden, the construction and demolition sector alone generate approximately 10 million tonnes of waste annually (Byggföretagen 2019). This waste generation process aligns with the linear economy. Therefore, transitioning from a linear to a circular economy (CE) in the construction sector is crucial for advancing several United Nations Sustainable Development Goals (SDGs). This transition promotes sustainable resource use through improved waste management practices and reduces environmental impact through climate mitigation actions (Eurostat, 2023).

Digital Tracking Technologies (DTT) offer a promising solution to enhance sustainability and material circularity, particularly in the concrete industry (Camodeca & Almici, 2021; Del Rio et al, 2021). DTTs are pivotal in advancing construction circularity by enhancing material traceability and transparency, ensuring compliance, enabling effective lifecycle management, and facilitating data-driven decision-making (Davari et al. 2023). Notwithstanding such benefits, the construction industry is slow to adopt Digital Technologies (DT) in general (Davari et al. 2023; Dervishaj et al, 2023; Giovanardi et al., 2022; Wuni, 2022). Currently, several concrete manufacturing companies use DTT, such as QR codes, mainly for project planning rather than for CE purposes. These companies face barriers to adopting DTT for CE, including high start-up costs, complex supply chains, and lack of technical skills, which hinder the full implementation of DTT in promoting circular practices (AlJaber et al., 2023; Lobo et al., 2021). Thus, it is crucial to focus on how these companies can effectively leverage DTT for CE practices.

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Current studies in the construction sector often focus on individual technologies such as Building Information Modeling (BIM), the Internet of Things (IoT), Radio Frequency Identification (RFID), and blockchain, emphasising their technical aspects (Vahidi et al., 2024; Dervishaj et al, 2023; Teisserenc & Sepasgozar, 2021). This narrow focus overlooks the socio-technical dynamics in the concrete sector, including the interplay between technological advancements, regulatory frameworks, industry practices, and societal trends. Consequently, there is a gap in understanding how these technologies collectively impact and transform the sector within the context of a CE.

Aim: This study aims to analyse the multi-level dynamics that lead to the barriers and opportunities in adopting DTT for CE in the Swedish prefabricated concrete sector.

Theoretical framework: The study employed the Multi-Level Perspective (MLP) framework to analyse the socio-technical transitions required for DTT adoption. MLP provides a structured approach to understanding the interactions between three levels: niches, regimes, and landscapes. The niche is a protected arena (from the existing system) arena at the micro level where radical innovations emerge. The regimes, at the meso-level, encompass the established practices and rules that stabilize existing systems. At the macro-level, landscapes include broader societal influences such as economic systems, cultural norms, and regulatory frameworks (Geels, 2002; 2011). The regime level involves actors whose actions are influenced by various contextual factors, including their attitudes, behaviours, and perceptions (Geels 2002). Understanding the interactions and influences of these actors are central components of the MLP framework, which is the central part of this study.

Methods: The study utilised a mixed-method approach, combining quantitative text analytics and qualitative semi-structured interviews following Creswell's (2014) methodology. Text analytics was used to identify prevailing themes and sentiments from academic literature and social media discussions related to DT (various technologies that digitise processes and enhance efficiency) generally for circularity in the construction industry. This was achieved through techniques such as word cloud visualisations, topic modelling, and sentiment analysis. Simultaneously, semi-structured interviews with 10 key Swedish construction stakeholders were conducted to get their in-depth perceptions and the contextual factors influencing the adoption of DTT (technologies for tracking and monitoring materials, resources, and processes). Furthermore, a triangulation strategy was adopted to cross-reference the sentiment analysis results with insights from the interviews. Through this, the study captured both broad societal attitudes and specific industry viewpoints. This multi-layered approach enabled the identification of patterns across niche innovations, regime behaviours, and landscape-level influences, providing a deeper understanding of the socio-technical dynamics shaping the adoption of DTT in the concrete industry.

Key Findings: Thematic analysis of the interview data revealed 22 driving factors, 24 barriers, and 15 opportunities associated with DTT adoption in the sector. Key drivers identified for DTT adoption include regulatory support, technological advancements, and increased stakeholder collaboration. However, significant barriers persist, such as technical limitations, financial constraints, and resistance to change within the industry. The opportunities identified revolve around the potential at the *niche* level for creating standardized protocols for DTT implementation for improvement at the *niche* level include developing standardized protocols and enhancing training programs for industry professionals. Corroborating these findings, text analytics reveal that the most frequent terms in academic literature and social media posts regarding the adoption of DT for CE include 'sustainability,' 'circularity,' and 'digitalisation'. These *landscape* factors are interpreted as drivers for the adoption of DTT. Topic modelling identified themes such as the benefits of DT for material traceability, while the sentiment analysis indicated a generally positive attitude at the *regime* level towards DT, recognizing its potential to enhance CE practices. Together, insights from both text analytics and interviews provide a comprehensive understanding of DTT adoption, mapped to the MLP framework. At the niche level, findings suggest innovation potential, with actors pushing for DTT adoption to improve resource efficiency and circularity. At the regime level, while there is recognition of DTT's importance, established practices, resistance, and financial concerns continue to hinder large-scale adoption. Positive societal attitudes toward sustainability at the landscape level exert pressure on both niche innovations and regime shifts, creating favourable conditions for progress in the sector.

Conclusion and Recommendation: To encourage DTT adoption, introducing *incentives and subsidies* for industry stakeholders is recommended to stimulate investment. Additionally, *training programs* should be developed to address skill gaps, equipping professionals to adopt DTT more effectively. *Improving technology solutions* to ensure seamless integration into existing workflows will reduce disruption and build confidence in the transition to digital solutions

Future Works: Future research should prioritise expanding stakeholder engagement and ensuring inclusion in data collection across various regions. This approach will provide a more diverse and representative understanding of the challenges and opportunities related to DTT adoption, enabling more comprehensive and inclusive solutions for the construction industry.

Keywords: Digital Tracking Technologies (DTT), Adoption, Circular Economy (CE), Prefabricated Concrete, Socio-Technical Transition (STT), Multi-Level Perspectives (MLP)

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