



Baština Akademije nauka i umjetnosti Bosne i Hercegovine

SMART MANUFACTURING ON THE HORIZON: A Conceptual Shift from Industry 4.0 to Industry 5.0: Industrija

Karabegović, Isak

2026

Academy of Sciences and Arts of Bosnia and Herzegovina

<https://bastina.anubih.ba/handle/123456789/875>

Preuzeto s Baštine Akademije nauka i umjetnosti Bosne i Hercegovine

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Digitalization and the Circular Economy in Bosnia and Herzegovina: Challenges of the Twin Transition in a Transitional Economy

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Abstract: *The transition from a linear economic model to a circular economy (CE) is vital for sustainable development, climate mitigation, and resource resilience. Industry 4.0 digital technologies (DTs), as the Internet of Things (IoT), Artificial Intelligence (AI), Big Data analytics, and block-chain are increasingly recognized as structural enablers of this transformation. They facilitate real-time monitoring, resource tracking, and data-driven decision-making across product lifecycles. However, while developed nations rapidly advance toward "intelligent circular systems," transitional economies like Bosnia and Herzegovina undoubtedly face distinct socio-economic, institutional, and technological barriers. This paper evaluates the intersection of entrepreneurship and digital transitions in operationalizing circular business models within Bosnia and Herzegovina. Through a qualitative literature synthesis and contextual analysis, this short study maps the applications of digital tools in resource optimization, identifies systemic issues - including regulatory fragmentation and digital literacy deficits and proposes a strategic pathway for accelerating the twin digital and green transition. The findings indicate that localized entrepreneurial initiatives, supported by targeted institutional incentives, can effectively bridge existing governance gaps and catalyze sustainable economic restructuring.*

Keywords: *Circular Economy, Digitalization, Bosnia and Herzegovina, Transitional Economies, Industry 5.0, Sustainable Entrepreneurship.*

1. Introduction

Today's global economy is facing unprecedented environmental degradation and resource depletion, driven by an unsustainable linear development paradigm [1, 2]. As a response, the concept of the Circular Economy (CE) has emerged as a regenerative alternative aiming at decoupling economic growth from finite resource consumption. CE principles focus on designing out waste, extending product lifecycles, and regenerating natural systems through narrow, slow, and closed resource loops [2, 3].

In international policy frameworks, such as the European Green Deal, the ecological transition is increasingly intertwined with digital transformation and it is conceptually formalized as the "Twin Transition" [3, 4]. Digital technologies

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(DTs) serve as the underlying infrastructure and primary catalyst for scaling circular business models. Technologies such as IoT sensors, cloud computing, and big data enable companies to monitor material flows in real time, predict maintenance needs, optimize reverse logistics, and transition toward advanced Product-Service Systems (PSS) [1, 5].

However, the operationalization of this twin transition is heavily contingent upon institutional maturity, domestic infrastructure, and macroeconomic stability. Consequently, the transition dynamic varies widely across geographical and political boundaries. While advanced economies are establishing comprehensive legislative mandates, such as the EU's Digital Product Passport (DPP), transitional post-conflict economies in the Western Balkan and specifically Bosnia and Herzegovina significantly lag behind in both: digital adoption and ecological compliance [6, 7, 8].

Bosnia and Herzegovina face a complex institutional frame characterized by a highly fragmented administrative structure, an export-dependent yet resource-intensive manufacturing base, low recycling rates, and a dominant linear business mindset. Although the country is bound by the Sofia Declaration on the Green Agenda for the Western Balkans, the integration of Industry 5.0 solutions into environmental management is still on its embryonic level.

This paper explores the synergetic potential between digitalization and the circular economy within the specific transitional context of Bosnia and Herzegovina. The primary objective is to analyze how digital tools can enable circular business models, evaluate the profound systemic barriers hindering this integration, and offer base for strategic recommendations for policymakers and entrepreneurial ecosystem in the future [9].

2. Paradigm Shift

The European Commission has defined three core objectives pursued by Industry 5.0: human-centricity, sustainability, and resilience [10]. These three objectives are not isolated; rather, each conditions and reinforces the remaining two, and it is only through their mutual interaction that the full potential of the paradigm is realized.

Human-centricity shifts the focal point of industrial development, whereby the question "what can a human do with new technology?" is transformed into "what can technology do for the human?" [10]. On business perspective, this implies that employees do not adapt to technology - instead, technology is adapted to the employee. In daily activities, this translates to the deployment of collaborative

robots that assume physically demanding, repetitive, and hazardous tasks, while humans remain focused on creative, analytical, and relational work [11]. Employees are actively involved in the design and implementation of new technological solutions to enable technology to fulfill its transformative role. Consequently, humans are placed at the center of all strategic business decisions, while the benefits of Industry 5.0 are manifested through organizational resilience, longevity, and sustainability [12].

Sustainability, as the second objective, focuses on transitioning away from the linear economic model towards a circular economy based on reuse, remanufacturing, and recycling [11]. Organizations leverage digital technologies to monitor energy consumption and optimize resources, thereby aligning their business strategies with the demands of environmental responsibility [13]. This requirement places society as a whole at a turning point, necessitating a shift in both attitudes and behaviors within the workplace, the enterprise, and ultimately, wider society [13].

Industry 5.0 offers a direct response to the lessons learned from previous global crises by building resilience founded on supply chain diversification, modular and adaptable capacities, and reinforced cyber-security - thus, through the processes and practices of crisis-induced learning, organizational routines are established and adaptive capacities are built [14].

3. Digitalization: A Core Circular Enabler

The interplay of Industry 5.0 and circular business practices recently has generated substantial academic attention, and it is moving beyond viewing digital tools merely as functional IT assets – instead, it is conceptualizing them as structural mechanisms for "intelligent circular systems" that actively drive sustainable development goals [5].

According to the Global Alliance on Circular Economy and Resource Efficiency (GACERE), digitalization fundamentally reshapes resource efficiency across macro, mezo, and micro levels [3]. For instance, comprehensive ICT deployments within smart urban ecosystems have the potential to reduce municipal solid waste generation by up to 20% and optimize industrial resource throughput [1].

The literature categorizes the deployment of digital technologies based on their specific roles across the product and material life cycle phases [1, 5]:

1. Internet of Things (IoT) and Remote Sensing: IoT solutions serve as the sensory layer of the circular economy. By embedding sensors into

physical components, enterprises can track the location, health, and status of assets in real time [1]. This forms the operational baseline for reverse logistics - enabling optimized municipal waste collection routes and accurate asset-tracking in construction and heavy manufacturing [15, 16].

2. Artificial Intelligence (AI) and Machine Learning (ML): AI algorithms are critical for processing the massive datasets generated by IoT infrastructure. In circular frameworks, AI is deployed to forecast waste generation patterns, automate the high-speed sorting of recyclable materials, and predict machine component failures, thereby drastically slowing resource loops through preventative maintenance [1, 5].
3. Blockchain and Distributed Ledger Technology (DLT): Block-chain ensures immutable data transparency and cryptographic traceability across fragmented global supply chains [1]. It provides verifiable proof of material provenance, which is an absolute prerequisite for authenticating recycled content and enforcing Extended Producer Responsibility (EPR) mandates [2, 3].
4. Digital Twins and Product Life-Cycle Software: Digital twins create virtual replicas of physical assets or systems. This allows engineers to simulate so called “wear-and-tear” option, to optimize component disassembly, and to design products with eco-design parameters that facilitate straightforward future remanufacturing [1, 16].
5. Digital Matching Platforms and Marketplaces: Online platforms can dramatically lower transaction costs and eliminate information asymmetry by linking waste-generators directly with material recovery facilities - thereby facilitating industrial symbiosis and peer-to-peer (P2P) asset sharing [1, 2].

A vital interest of the theoretical domain is the evaluation of how national macro-environments influence sustainable commercial activities. Authors Fernandes, Veiga, and Ramadani [4] demonstrate that a country's performance in the circular economy is fundamentally moderated by its National System of Entrepreneurship (NSE) [2].

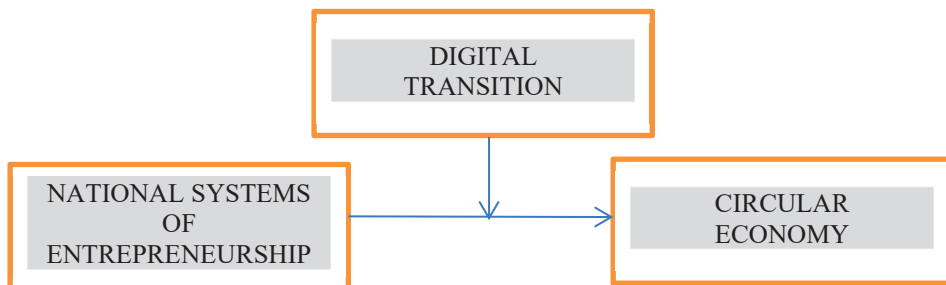


Figure 1. National System of Entrepreneurship [4]

Countries possessing robust entrepreneurial ecosystems, characterized by high-quality institutional setups, deep capital markets, and solid knowledge spillover mechanisms, exhibit significantly higher rates of circular business model innovation. Crucially, their empirical model reveals that the digital transition acts as a powerful moderator that amplifies the positive effects of entrepreneurship on circular outcomes [4].

If digital transition metrics are in advance, entrepreneurial proxies can bypass rigid or inefficient physical institutional infrastructure - utilizing digital platforms to establish agile, resource-efficient supply chains and transition from traditional product-oriented models to use-oriented or result-oriented Product-Service Systems (PSS) [2, 4].

4. Contextual Analysis for Twin Transition: Bosnia and Herzegovina

The paper utilizes an exploratory, qualitative research methodology appropriate for evaluating emerging socio-economic phenomena within constrained data environments. Given the pronounced deficit of localized quantitative metrics regarding digital circularity indexes in the Western Balkans, a multi-step contextual analysis was executed:

1. A review of the literature (2022–2025) - focusing on foundational frameworks regarding intelligent circularity [5], digitalized business typologies [2], and the institutional dynamics of entrepreneurship-led transitions [4].
2. Analysis of institutional reports - strategic development frameworks (including the Federation of BiH and RS environmental and waste management strategies), and commitments under the Western Balkans Green Agenda were analyzed to contrast theoretical digital-circular paradigms against the contemporary socio-economic reality of Bosnia and Herzegovina.

3. Thematic mapping for identify constraints - they were categorized utilizing a modified institutional economics framework to highlight the specific structural friction points inherent in transitional economic systems.

Bosnia and Herzegovina operates within a highly specific socio-economic reality. As a country undergoing protracted economic transition, it simultaneously faces the pressure of harmonizing its legal framework with the EU legislative while managing deep-seated structural inefficiencies.

The application of the "Twin Transition" concept in Bosnia and Herzegovina reveals a significant implementation gap. While the domestic Information and Communications Technology sector (ICT) can be recognizes as highly dynamic, technologically sophisticated, and strongly export-oriented, still it remains fundamentally decoupled from the traditional manufacturing, agricultural, and municipal infrastructure sectors [6, 7, 8, 9, 17].

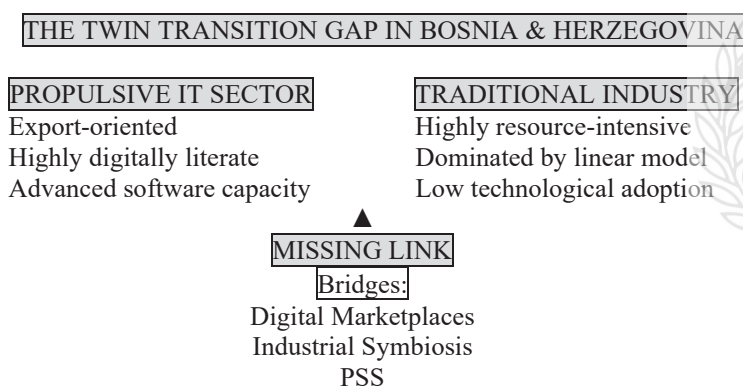


Figure 2. Twin transition gap [6, 7, 8, 9, 17].

The barriers preventing the deployment of digital technologies for circular economy advancement in Bosnia and Herzegovina can be synthesized into four core systemic directions [6, 7, 8, 9, 17]:

A. Institutional and Regulatory Fragmentation

The highly decentralized political governance of Bosnia and Herzegovina (state, entity, cantonal, and district levels) results in an extraordinarily fragmented regulatory environment. Waste management laws and environmental standards are inconsistent across jurisdictions. Crucially, Bosnia and Herzegovina lacks the

penalty economic instruments that make linear business models unviable in European Union, such as high landfill tipping fees, strict enforcement of Extended Producer Responsibility (EPR), and carbon taxes. Furthermore, while digital legislation may exist, operational frameworks for widespread electronic signatures, digital contracting, and cross-institutional open data sharing are either fragmented or under-implemented, stalling the legal deployment of digital material tracking and supply chain transparency.

B. Infrastructure Deficits and Low Industrial Tech Levels

The baseline industrial landscape in Bosnia and Herzegovina is dominated by small and medium businesses (SMBs) engaged in primary or low-value-added secondary processing (e.g., wood processing, metal fabrication, textiles). The vast majority of these firms operate with basic automation profiles. Digital tools are confined to standard administrative or accounting software, with virtually zero penetration of IoT, predictive data analytics, or AI-driven quality control. On a macro-structural level, the delayed rollout of advanced telecommunications infrastructure, such as commercial 5G networks, directly restricts the deployment of distributed sensor networks required for smart utility grids and intelligent municipal waste collection systems.

C. Financial Constraints and Distorted Investment Incentives

Transitioning to circular business models supported by digital infrastructure asks for significant primary capital expenditure. Domestic SMBs in Bosnia and Herzegovina operate within narrow liquidity margins and face high borrowing costs. Local commercial banks possess limited expertise in evaluating "green" or "circular" investments, often classifying digital-circular transformations as high-risk ventures. Furthermore, state-level or entity-level subsidies and grant mechanisms are highly constrained, and they are lacking the scale and strategic continuity needed to de-risk corporate investments in advanced resource-recovery technologies or custom software development.

D. The Interdisciplinary Skills Deficit

The educational architecture in Bosnia and Herzegovina remains partial in its segments. Universities produce technical specialists within isolated domains (e.g., traditional engineering, computer science, or business management), but fail to offer interdisciplinary curricula that merge environmental science with digital systems engineering and entrepreneurship. Consequently, there is an "acute" domestic shortage of industrial data analysts, circular supply chain managers, and

eco-design specialists. This deficit of technical competency is compounded by a modest level of digital awareness among executives, who frequently view sustainability initiatives as regulatory burdens or peripheral public-relations costs rather than core drivers of long-term operational efficiency and global competitiveness.

5. Discussion for Strategic Framework

The intersection of the constraints of digital transition and the circular economy within Bosnia and Herzegovina reveals that while institutional architectures on the macro level stagnate, entrepreneurial activity on the micro-level can catalyze "blastoff" – simply because they have to [3, 4]. By aligning the domestic software engineering capacity with traditional manufacturing, Bosnia and Herzegovina can systematically "bypass" physical institutional gaps through targeted digital interventions.

I - Digital Industrial Symbiosis Platforms

A primary strategic mechanism for Bosnia and Herzegovina may involve the development of automated, localized resource-matching platforms [2, 4]. In key national industrial sectors, such as wood processing and metal fabrication, immense volumes of manufacturing byproducts (e.g., sawdust, timber offcuts, metal scraps) are currently discarded as municipal waste or burned inefficiently for heat.

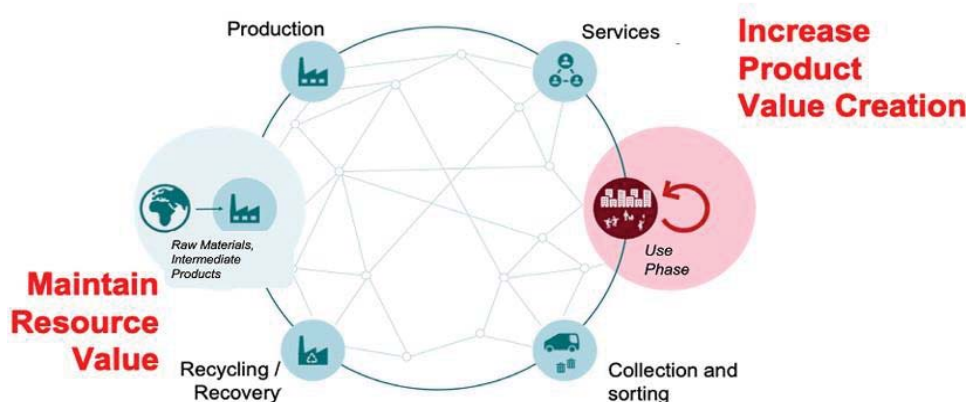


Figure 3. The Circular Economy as a Networked System [2]

By deploying decentralized web-based marketplaces, local software firms can connect these disparate small and medium enterprises (SMEs). This could eliminate localized information asymmetries, also structurally optimizes supply routes, and allows industrial byproducts from one factory to become secondary raw inputs for another, effectively operationalizing industrial symbiosis at a minimal operational cost [1, 5].

II - Product-Service Systems (PSS) and Asset Lifecycle Management

Furthermore, the domestic economy can benefit significantly from transitioning toward use-oriented and result-orientation in Product-Service Systems (PSS) powered by basic digital tracking layers [2]. Rather than engaging in the outright capital-intensive sale of physical machinery, industrial equipment, or eco-efficient lighting installations, domestic manufacturers and distributors can pivot toward leasing and functional performance models [1].

Embedding low-cost microcontrollers and IoT diagnostic sensors into distributed machinery enables manufacturers to maintain ownership and remotely monitor real-time operational efficiency [15, 16]. This operational data-stream facilitates predictive and preventative maintenance protocols, directly extending the functional lifecycle of national industrial assets, reducing localized environmental friction, and aligning commercial incentives with resource conservation rather than raw consumption volume [4, 5].

6. Policy Recommendations

To operationalize the twin transition within Bosnia and Herzegovina, a synchronized multi-tiered policy mix could be implemented across entity and cantonal structures:

1. Regulatory standardization and Open Data frameworks: Align national environmental data frameworks with the EU's Digital Product Passport (DPP) paradigms [3]. Municipalities could standardize electronic waste tracking registries and open up environmental monitoring APIs, enabling external technology entrepreneurs to build commercial solutions as public utility infrastructure [2].
2. Targeted financial risk mitigation: Establish dedicated state-backed and donor-funded green innovation credit lines [4]. Commercial banking institutions require technical assistance to evaluate digital-circular business models, reducing collateral requirements for SMBs that invest explicitly in Industry 5.0 resource-tracking infrastructure [3, 15].

3. Interdisciplinary curriculum integration: Transformation of traditional university silos by establishing structural interdisciplinary education and professional training programs that merge computer science, organization design, environmental engineering, and sustainable entrepreneurship [4, 16].

7. Conclusion

The transition toward a circular economy in Bosnia and Herzegovina cannot be achieved using analog methodologies or isolated ecological mandates [17]. Digital technologies provide the analytical substrate, connectivity, and data transparency required to transform highly fragmented, linear supply systems into resilient, intelligent circular structures [1, 5].

While institutional and infrastructure deficits present ongoing systemic friction in Bosnia and Herzegovina, the national entrepreneurial ecosystem moderated by targeted digital deployment has the strong capacity to spearhead economic “restructuring” [4]. By actively linking its thriving digital sector with legacy manufacturing industries, Bosnia and Herzegovina can forge an autonomous path toward its green future and long-term integration into competitive European value chains [6, 7, 8].

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