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The Data Pipeline, Passport Generator and Passport Pool

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Publication date
2022

Document Version
Final published version

Published in
The state of circularity

Citation (APA)
Çetin, S., Rukanova, B. D., De Wolf, C., Gruis, V. H., & Tan, Y. (2022). A Conceptual Framework for a Digital Circular Built Environment: The Data Pipeline, Passport Generator and Passport Pool. In S. Shahnoori, & M. Mohammadi (Eds.), *The state of circularity: The content of "the 2nd International Conference on Circular Systems for the Built Environment"* (pp. 97-106). Technische Universiteit Eindhoven.

THE STATE OF CIRCULARITY

The content of the "2nd International conference on

CIRCULAR SYSTEMS FOR THE BUILT ENVIRONMENT"

2nd International Conference of Circular Systems for the Built Environment;
Advanced Technological & Social Solutions for Transitions

ICSBE2

Thursday 09th December 2021

Editors:

Shore Shahnoori &

Masi Mohammadi

The second International Conference of Circular Systems for the Built Environment (ICSBE2- 2021)

Taking place on the 09th December 2021

Eindhoven University of Technology

Department of the Built Environment, Chair of Smart Architectural technologies

Including forewords

by

Professor Michael Braungart

And the closing words

By

Prof. Andy van den Dobbelsteen

Editors:

Shore Shahnoori

Masi Mohammadi

Publisher: **Technische Universiteit Eindhoven**

ISBN: **978-90-386-5486-7**

CHAPTER 5. b)

A Conceptual Framework for a Digital Circular Built Environment: The Data Pipeline, Passport Generator and Passport Pool

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Abstract— **This article proposes a conceptual model to address the structural holes in data sharing between (and beyond) actors in the circular built environment supply chain and monitoring circular economy progress. Current digital innovations such as material passports and Building Information Modelling applications aim at increasing quality and availability of information about materials and their application in buildings to facilitate future reuse or recycling, based on the idea of buildings-as-material-banks. Although these approaches offer great potential to recover value from building materials, they mainly focus on a single building and have a limited capacity to exchange data with other supply chain actors in a timely manner. In this article, we argue that there is a need for an integrated digital infrastructure that expands beyond the industries and countries for enabling a connected global circular economy. Therefore, this article proposes an initial conceptualization of a digital infrastructure towards achieving a circular built environment. The proposed model puts forward three interoperable components: The Data Pipeline, Passport Generator, and Passport Pool, based on emerging technologies such as blockchain technology, the Internet of Things and artificial intelligence.**

Keywords—Circular economy, built environment, construction industry, buildings, digital technology, digital infrastructure, data pipeline, blockchain technology, artificial intelligence

I. Introduction

Our current linear economic system is causing severe ecologic, economic, and societal problems as it highly depends on unsustainable production and consumption of natural resources. Consequently, the concept of Circular Economy (CE) has gained momentum in academic, political, and economic debate and is seen as an alternative economic model by several governments (e.g., Circular Economy Promotion Law by China, European Green Deal). CE is based on a few old schools of thought [1] and aims to create a regenerative system that minimizes resource flows, waste, emissions, and energy leakage [2]. As elucidated in [3, 4], CE follows four distinct resource principles: (1) regenerating resource loops seeks to leave the environment in a better state by, for example, increasing biodiversity and remediating soil; (2) narrowing resource flows is about reducing resource inputs in products; (3) slowing resource loops is keeping them in use by extending their service life through actions like repair and maintenance; and, (4) closing resource loops is about reusing or recycling products when they can no longer be used for the intended purpose.

The application of CE in the built environment (BE) is an emerging research field that has grown in the last couple of years [5]. The BE has tremendous impacts on the natural environment as it is the major contributor to carbon emissions and waste and the largest consumer of raw materials [6, 7]. In the government-wide program for a CE, the Dutch government chose the construction sector as one of the priority areas [8] as CE offers many opportunities for the industry to manage resources effectively with looping actions. These looping strategies range from reducing resource inputs through dematerialization methods in the design stage (narrow) to recovering valuable materials from demolition sites through "urban mining" techniques at the end-of-life stage (close) [9].

Perhaps the most critical issue when implementing looping actions and measuring the progress towards circularity is that making information flows visible between actors in the supply chain across the lifecycle stages of buildings. In this regard, information sharing and collaboration between actors, industries, and countries (across national borders) becomes a critical obstacle to tackle. Wijewickrama et al. [10] argue that "structural holes"- disconnections between actors in the construction supply chain - hinder the successful implementation of circular strategies, as most essential information is lost in certain lifecycle stages of buildings. The continuity of information flow is usually broken due to the change of ownership; for example, some useful information remains with a particular supplier, is not transferred to the next one, and becomes inaccessible to other actors [11]. Also, companies operating in the BE have the obligation to keep building or product documentation for a period, which usually is much shorter than the lifespan of a building. Thus, valuable data, such as floor plans, certificates, material specs, are not passed to the next actor when the building reaches its end of service time.

Several attempts were made to address some of the obstacles described above, particularly for increasing visibility of resources at the end-of-life stage, for reuse or recycling through digital technology (DT), i.e., material passports. These innovations are based on the idea of "*buildings as material depots*" [12] (or *material banks* [13]) that consider building stock as a source of raw materials in the future. The EU-funded project BAMB [14] and Madaster Platform [15] were some of the pioneers in developing the concept of material passports. In addition, scholars also developed BIM-based material passports to evaluate the recycling potential and environmental impact of buildings [16], and BIM plug-ins to estimate the disassembly performance of design variants [17]. Furthermore, the European Commission introduced an EU-wide framework for a digital building logbook to support several policy initiatives such as Circular Economy Action Plan and Renovation Wave [11]. Although these approaches offer great potential to recover value from building materials, they mainly focus on a single building or individual products and have limited interoperability capacity to exchange data with other supply chain actors on time. Also, they fail to give visibility to the resource flows at the international level, as government authorities also need to monitor the resource flows to ensure that measures are properly implemented and not subject to abuse. Such visibility especially is hard to achieve when the flows go beyond the national borders, resulting in the illegal disposal of waste abroad [18] and induce environmental harm elsewhere. Furthermore, as indicated in [19], current CE monitoring efforts are heavily based on statistical data and usually miss the global cross-country dimension. Such approaches therefore remain limited when it comes to controlling and monitoring individual supply chains.

This article, therefore, proposes a conceptual model to address these complex challenges in data sharing among key actors within and beyond the BE supply chain. The proposed model aims to expand our understanding of enabling DTs in the circular BE research and discusses the implications of these DTs in real-life. Our conceptual model is based on literature review and consists of three interoperable components that allow seamless data exchange: The Data Pipeline, Passport Generator, and Passport Pool. The following sections elaborate on the background literature, details of the framework components and research implications.

II. Background literature

DTs are seen as a key enabler for making resource flows visible and processes intelligent through their capabilities in data collection, integration and analysis [20, 21] as well as in transferring information between actors, thus facilitating collaboration. Increased visibility leads to accessing useful data regarding products' location, quality, quantity, material properties and sometimes carbon footprint, which allows capturing value from these products throughout their lifecycle stages. Early research in the intersection between CE and DTs explored enabling functions of some emerging technologies such as cloud manufacturing, the internet of things (IoT) and additive and robotic manufacturing (AM/RM) in sustainable operations [22]. Later on, Kristoffersen et al. [21] introduced a comprehensive smart CE framework for manufacturing companies based on technical mechanisms and business analytics. In addition, several scholars investigated DTs' role in circular business innovation [23], particularly in product-service systems [24, 25].

Although slow, the BE researchers are paying a growing attention to DTs in the field of circularity. A recent study by Çetin et al. [9] identified ten potentially enabling DTs and mapped them onto the regenerate, narrow, slow and close framework along the lifecycle stages of buildings. Authors also explored how DTs facilitate collaboration between supply chain actors in circular projects. A summary of these innovations is given in Figure 1.

Considering the context of this article, some of the technologies included in *close* and *collaborate* principles (see Table 1) demonstrate great potential for filling the structural data holes in circular supply chain collaboration and giving visibility to the resource flows at different scales. These DTs include blockchain technology, material passports, the internet of things (IoT) and digital platforms. Blockchain technology is being explored as a facilitator of the CE because it allows the recording and tracking of data throughout the lifecycle of a building or a component and can help solve issues of mistrust between stakeholders [26]. Material passports are digitally registered data sets used to track material quantities, specifications, location, history, and ownership status, which can help track materials, components, and buildings [9, 27]. Material passports can be created for new and existing buildings. For example, Honic et al. [28] developed a new method for generating material passports for the buildings at their end-of-life stage and demonstrated its relevance on a demolition use case. IoT enables data gathering through tags or sensors on the building elements, for example, to monitor which elements are performing and which ones need to be replaced (e.g., light-as-a-service). Turner et al. [29] proposed an intelligent asset model based on BIM and IoT for sustainable modular construction. Digital platforms are necessary to collaborate, share information, create markets, and deliver circular services [9].

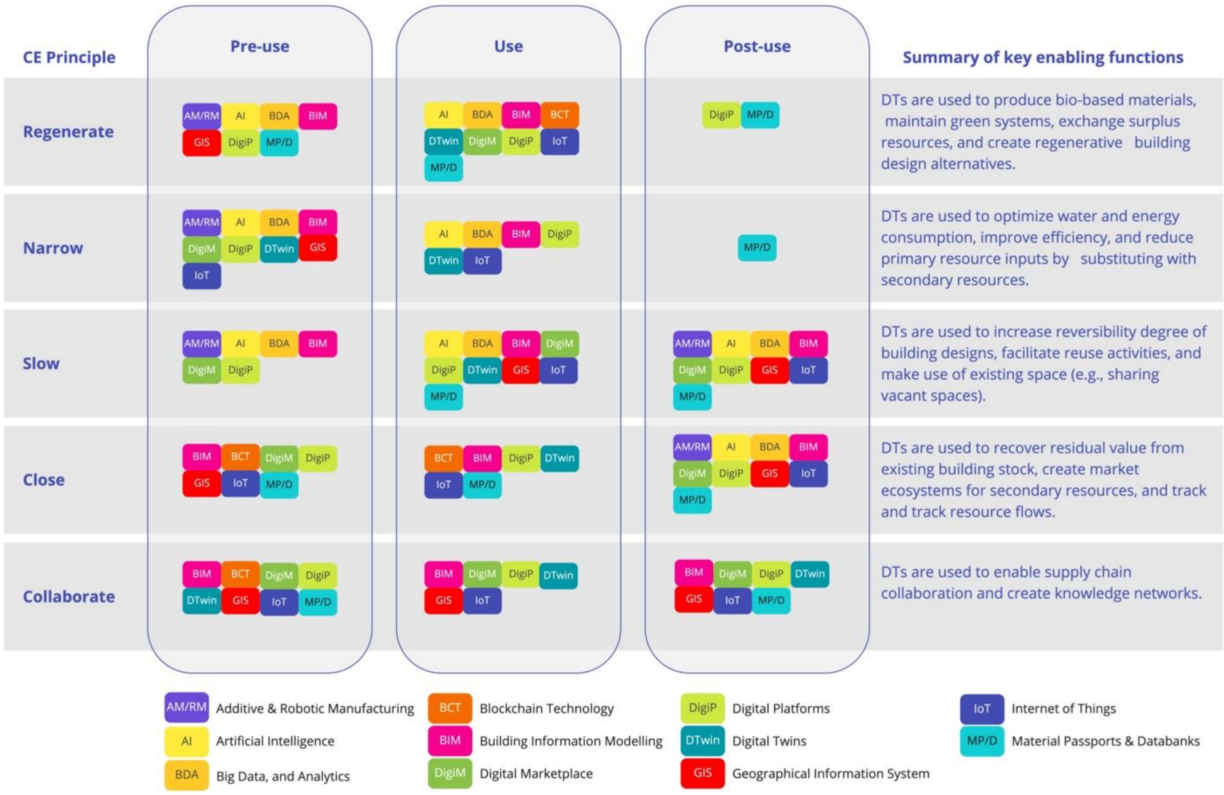

FIGURE I. Summary of potentially enabling digital technologies for a circular built environment, based on [9].

In addition, Rukanova et al. [30] argue that digital trade infrastructures, such as blockchain-enabled data pipelines, could be potential enablers of CE governance as governments worldwide are making commitments and setting targets to stimulate the transition towards a CE. For example, in the Netherlands, the goal is to achieve 50% less use of primary resources by 2030 and be a waste-free economy by 2050 [8]. Such objectives stem from and are aligned with targets at the EU and international levels. Setting targets, however, in itself is not enough; government authorities also need to monitor the CE flows to ensure that measures are properly implemented. In this regard, visibility of resource flows is key to ensuring CE monitoring. To address these issues, Rukanova et al. [30, 31] proposed the concept of an extended data pipeline for CE monitoring and governance. They build on the data pipeline idea developed in the context of international trade and customs [32-34] and piloted on a large scale in a series of innovation projects over a decade (ITAIDE, CASSANDRA, CORE [35], PROFILE [36]). Conceptually, the data pipeline is a solution to overcome fragmentation in information in international supply chains and can be seen as an "internet for logistics". One of the pilots was with what was later commercialized as the TradeLens platform developed by IBM and MAERSK [37], which has become a global, blockchain-enabled platform for the shipping industry. Government authorities can access data related to logistics events throughout the journey of the container (e.g., container loading at the country of export, estimated time of arrival, container pick-up), as well as commercial documents such as invoices, packing lists and Bills-of-Lading containing detailed information about the goods and the value of the goods, and the parties in the transaction. Such information is then used to monitor the international trade flows and cross-validate the customs declarations.

In subsequent research [30, 31], extending the data pipeline for CE monitoring purposes was proposed through three dimensions: (1) extension to capture information to the production processes and the use of raw materials (capturing information such as bills-of-materials); (2) extension to the processes of recycling and reuse; and (3) visibility at the border (e.g., national or EU border) via new technologies (e.g., scans used at border crossing). This extended information visibility will enable tracing what raw materials go into a specific component, how is this component manufactured, where is it subsequently used. At the end of the lifecycle of the product, this information on material composition can be very useful for further reuse or recycling. It is further argued that such extended visibility can be useful for different monitoring actors, including government actors, auditing firms, insurance companies, as well as banks offering green loans.

III. A CONCEPTUAL MODEL: DIGITAL INFRASTRUCTURE FOR A CIRCULAR BUILT ENVIRONMENT

As depicted in Figure 2, this article proposes a conceptual framework for a digital infrastructure that covers the entire lifecycle stages of buildings, resource flows and actors involved in a circular BE ecosystem. This model aims to fill data gaps between supply chain actors and allows CE monitoring within and across the countries. The proposed model consists of three modules, namely, Data Pipeline, Passport Generator, and Passport Pool.

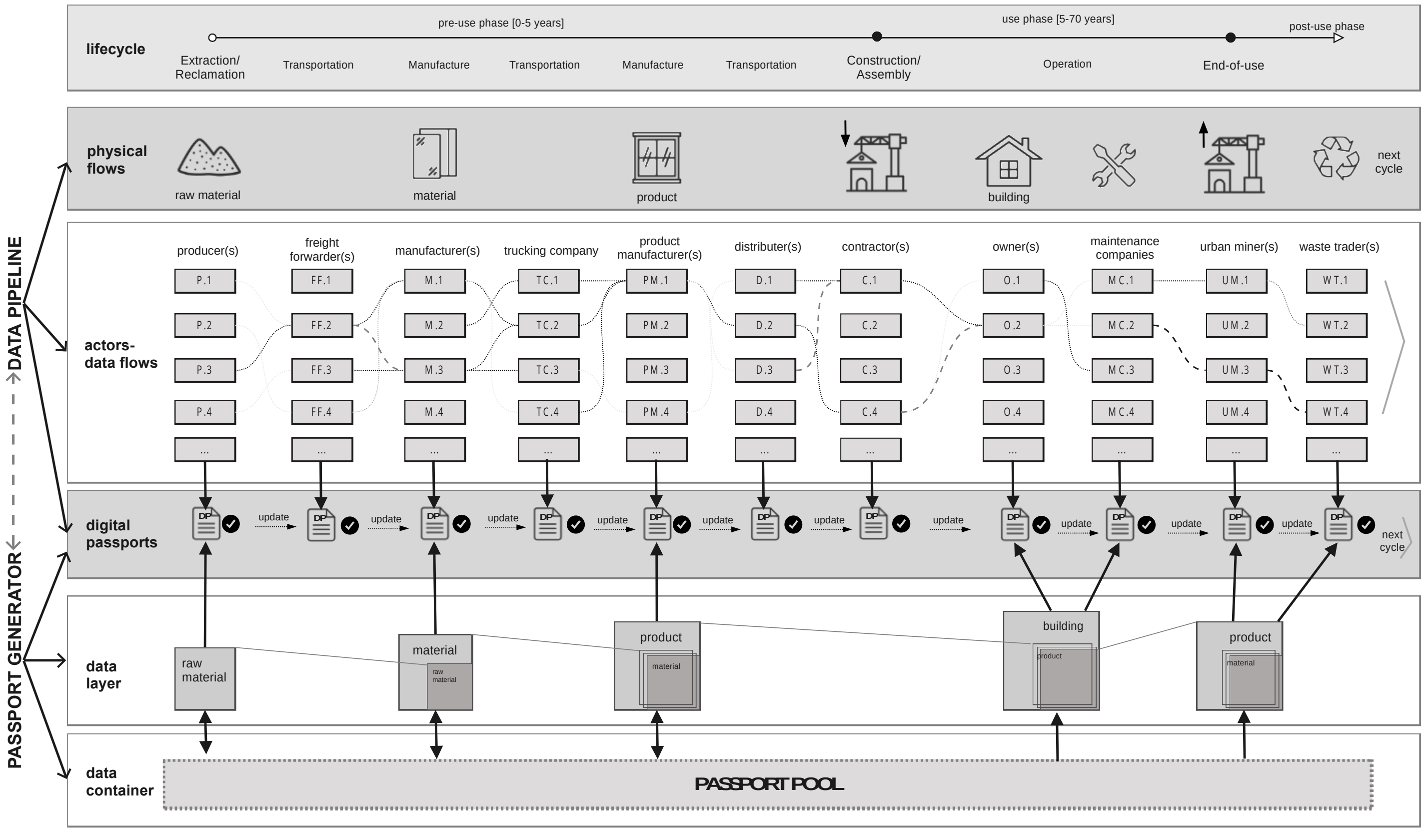

FIGURE II. Conceptual framework for a digital infrastructure towards achieving a digital circular built environment. Built on [9, 27, 30, 34, 38, 39].

The top two layers of Figure 2 capture the physical resource flows, in this case, a window component, along the lifecycle stages. A seamless information flow can be achieved within a data pipeline from the extraction of raw materials until the post-use of secondary products. The data pipeline stores and manages digital passports, which are created for new and reclaimed resources at different aggregation scales: (1) raw material, (2) material, (3) product, and (4) building. It facilitates data sharing between stakeholders as illustrated in Figure 2. Authorized stakeholders are provided with an easy-to-use dashboard to trace their products, update, and monitor digital passports. At each step of the products' journey, the permission system provides authorized actors with secured data while protecting their confidential information, as in the example of Tradelens [37]. Such digital infrastructure can be built with blockchain technology as it enables immutability of data and establishing an audit trail [40]. In using these technologies, however, it is also important to understand the blockchain governance options and the link between the stakeholder requirement and technological design choices [41]. Furthermore, IoT devices can allow to generate additional data and events that can be captured via the data pipeline. For example, smart container seals can capture detailed information about temperature conditions when the goods are transported.

The extended data pipeline aspect in this framework adds a cross-border and the related CE monitoring dimension as additional aspects to be considered when examining circularity in BE. For example, the Carbon Border Adjustment Measure [42], at the EU level legislation, is currently being prepared to impose taxes on a set of products imported in the EU to ensure the level-playing field of EU companies. While this legislation is still in preparation, two key materials, cement, and steel in the construction industry, are considered to fall under this CBAM measure. On the government side, this will also bring new responsibilities of government (e.g., customs that controls cross-border flows of goods) to monitor and control these streams. But beyond carbon emissions, monitoring the origin of raw materials used in construction in the EU and ensuring it reaches the EU targets will be very important. Not only for cement and steel but also other bio-based materials, i.e., wood that will be more and more predominant in the future.

The second component of the framework is the Passport Generator. The primary function of this module is to produce digital passports for materials and products in line with the national and international standards based on producer or user inputs and available data such as CAD drawings and technical specifications of products (See Figure 3). As stressed in the report of the Circular Construction 2023 Platform (a Dutch initiative for construction stakeholders), standardization is crucial for structured and harmonized data sharing [13]. Therefore, the Passport Generator will enable users to standardize their products' information for digital passports.

To automate digital passport generation, AI techniques can be used as current advancements in this area allow identifying and classifying text and forms from extant sources. A real-life example to this is the reMarkable tablet that uses AI methods to recognize handwriting to convert to text [43]. The performance of AI models can be improved by training algorithms when each passport is generated. This automated way of passport generation can free actors from a big burden, save time, also create new business opportunities. Digital passports can be created for new and reclaimed resources based on actors' data needs and could include water, energy, and material properties (potentially carbon calculation) at different aggregation scales.

The passport generator is integrated into both the data pipeline and passport pool as shown with the arrows in Figure 2 and 3. Once a digital passport is generated, actors in the supply chain can update them with their digital signatures and track the journey of their products. These digital passports can then be used to generate digital building logbooks [11] or can be integrated into the current circular building platforms such as Madaster Platform. They can also support monitoring resource flows at the national and international levels.

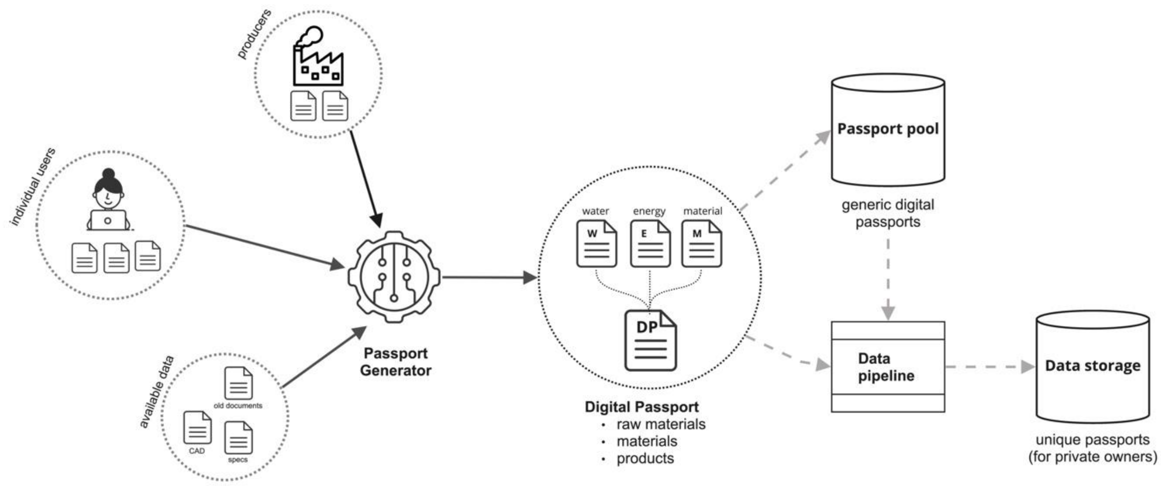

FIGURE III. Schematic illustration of the AI-based passport generation.

The final component of the proposed model is the Passport Pool (the last two layers in Figure 2), where generic digital passports are stored and made ready for reuse. The pool acts as a databank or data repository for all passports generated by the Passport Generator. Considering the massive data generation required for digitizing circular resource flows, this module aims to avoid the data burden in the digital infrastructure and minimize digital waste [44] by allowing actors to reuse generic passports. A distinction should be made between the generic passports stored in the pool and the ones updated by the actors in the pipeline. The former is similar to the unique product identifiers, which are assigned to products by the manufacturers or producers, whereas the latter is built on the generic passports and updated by the actors at each step of the product lifecycle with digital signatures for giving transparency to the supply chain.

IV. Discussion and conclusion

This article presented a conceptual model of an integrated digital backbone for making resource flows visible for achieving a circular BE and enabling CE monitoring. We argue that the current single-focused digital solutions are not sufficient to fill the structural data gaps in the circular supply chains. A shared vision is needed to create a global circular economy, and it could be possible with the enabling digital technologies and collaboration of key actors. We proposed a comprehensive digital infrastructure that connects supply chain stakeholders along the lifecycle stages of buildings. Our model was developed based on state-of-the-art research and consists of three interoperable components: data pipeline, passport generator, and passport pool. These components can be built with emerging technologies such as blockchain technology, AI, and IoT.

This study has a few significant limitations. First of all, we presented a conceptual framework, and we acknowledge the difficulties in achieving such a system in practice as it requires a holistic collaboration between researchers, practitioners, governments, and users. In the current situation, although initial steps have been taken to combine Europe's digital transformation with Green Deal objectives, i.e., Twin Transitions, there is a lack of guiding regulations. Thus, we stress the central role of governments, regulations, and incentives to persuade all actors towards achieving a digital circular economy. Second, although we discussed the main components of the proposed model, we did not cover how such a system could be built in detail. For example, we did not cover data storage, ownership, and governance issues, including legal questions on data privacy as highlighted in [27]. Finally, there is also the issue of costs, as development and implementation of such concepts require investments by multiple parties and articulation of costs and benefits and what part would need to be funded by private and public funding is a major challenge to be overcome.

Based on the discussion so far, we recommend that further research should critically investigate the following issues when developing such a digital infrastructure for the circular flows of resources in the built environment:

- Interoperability at different scales (considering actors and cross-country flows) [38],
- Data governance models: Should it be public, private, or public-private? [11, 27, 30],
- Data requirements of actors: Who needs what data when? And how these data are then delivered?[11, 27],
- Viable business models and emerging roles [27],
- Experimentation with new technologies and associated business models [45],
- Assessments of social, economic, and environmental impacts and rebound effects of implementing these technologies [9].

ACKNOWLEDGMENT

This research was partially funded by the PEN-CP Project (nr. 786773) and by INTERREG NWE CHARM Project. Ideas and opinions expressed by the authors do not necessarily represent those of all partners.

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