DIGITAL PRODUCT AND MATERIAL PASSPORTS FOR BETTER MANAGEMENT OF MATERIAL FLOWS IN ROAD CONSTRUCTION AND MAINTENANCE

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Abstract: *One of the main challenges in road construction and maintenance is ensuring traceability and transparency in managing large quantities of excavated soil and stone. In Slovenia, around 7 million tons of such materials are produced annually. They are often reused on-site or backfilled, yet still treated as waste, without considering their chemical and geotechnical properties or potential value. The new EU Construction Products Regulation (EC 3110/2024) introduces digital product passports to improve transparency and traceability of material properties. Although excavated soil and stone are not clearly defined as construction products under this regulation, applying its principles is increasingly important due to the large volumes involved. This research addresses digital product passport requirements and presents the development of digital material passport platforms for excavated soil and stone within the LIFE IP RESTART project. It explores pathways based on material status, such as waste, by-product, or construction product, supporting more efficient resource use in line with circular economy principles*.

Keywords: *Circular economy, digital product passport, excavated soil and stone, construction and demolition waste management.*

DIGITALNI PASOŠI ZA PROIZVODE I MATERIJALE ZA BOLJE UPRAVLJANJE MATERIJALNIM TOKOVIMA U IZGRADNJI I ODRŽAVANJU CESTA

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Rezime: *Jedan od glavnih izazova u izgradnji i održavanju puteva je obezbeđivanje sledljivosti i transparentnosti u upravljanju velikim količinama iskopanog zemljišta i kamena. U Sloveniji se godišnje proizvede oko 7 miliona tona takvih materijala. Često se ponovo koriste na istoj lokaciji ili za izgradnju nasipa, ali se i dalje tretiraju kao otpad, bez razmatranja njihovih hemijskih i geotehničkih svojstava ili potencijalne vrednosti. Nova Uredba EU o građevinskim proizvodima (EC 3110/2024) uvodi digitalne pasoše proizvoda kako bi se poboljšala transparentnost i sledljivost svojstava materijala. Iako iskopano zemljište i kamen nisu jasno definisani kao građevinski proizvodi prema ovoj Uredbi, primena njenih principa je sve važnija zbog velikih količina koje se generišu. Ovo istraživanje se bavi zahtevima za digitalne pasoše proizvoda i predstavlja razvoj platformi za digitalne pasoše materijala za iskopano zemljište i kamen u okviru projekta LIFE IP RESTART. Istražuje puteve zasnovane na statusu materijala kao što su otpad, nusproizvod ili građevinski proizvod, podržavajući efikasnije korišćenje resursa u skladu sa principima cirkularne ekonomije.*

Ključne reči: *cirkularna ekonomija, digitalni pasoš proizvoda, iskopana zemlja i kamen, upravljanje otpadom od gradnje i rušenja.*

1. INTRODUCTION

The construction sector is one of the most resource-intensive industries worldwide. In the European Union, nearly half of all extracted raw materials are used for buildings and infrastructure. At the same time, construction and demolition activities generate more than 30% of total waste [9], with excavated soil and stones (European Waste Classification code 17 05 04) [5] representing the largest share. These figures clearly demonstrate the importance of improving transparency, traceability, and sustainable management of material flows at national, regional, and local levels, particularly in the context of circular economy and climate neutrality objectives [20]. The absence of structured and standardised digital documentation frequently limits valuable reclamation of resources, complicates quality verification, and increases administrative burdens related to environmental compliance. Digital product and material passports offer great potential to improve traceability, facilitate reuse planning, and support more sustainable construction projects. Scientific literature highlights digitalisation as a critical enabler of circular construction, addressing a fundamental barrier to sustainability: the limited availability of structured lifecycle data on materials and

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components. Atta et al. [14] demonstrate that digital material passports can provide both qualitative technical information and quantitative sustainability indicators, enabling more informed decisions throughout the building/infrastructure lifecycle. Byers and De Wolf [15] further highlight that material passports linked to digital traceability tools (e.g., QR codes) preserve knowledge about components across lifecycle stages, thereby facilitating reuse and reducing information loss between construction and end-of-life phases.
At the European level, a coherent legislative framework has been progressively established, positioning digital product passports (DPPs) as a central instrument for improving product sustainability and supply chain transparency. This development is closely aligned with the objectives of the European Green Deal and the Circular Economy Action Plan, which emphasise improved resource efficiency and increased use of secondary raw materials [16][17]. The main horizontal legislative act in this field is the Ecodesign for Sustainable Products Regulation (ESPR) [12]. The regulation establishes the Digital Product Passport as a structured digital dataset containing essential information on a product throughout its lifecycle, including data on composition, durability, reparability, reuse potential, recyclability, and environmental performance. Importantly, the ESPR introduces DPP requirements progressively for specific product groups rather than through a single universal passport model. For the construction sector, the new harmonised rules for the marketing of construction products (i.e. “new construction product regulation) EU 2024/3110 strengthens requirements regarding digital availability and accessibility of product information [6]. Although DPPs for construction products are not yet fully operationally defined, the regulation clearly signals that construction product data will need to be standardised, digitalised, and linked to environmental and circular performance indicators. Recent literature identifies DPPs as a key bond between digitalisation and sustainability transitions. A systematic review by Zhang et al. [18] highlights that DPP systems combine structured product information to improve transparency, traceability, and circular value retention, with their development strongly influenced by evolving European regulatory frameworks. In addition, Koppelaar et al. [19] demonstrate that DPPs can contribute to improved recovery of critical raw materials by enabling unique product identification and enhanced access to material composition data, thereby supporting the development of secondary material markets.

Based on this regulatory and scientific background, this article presents the initial development of the Slovenian National Digital Product Passport of Construction Products and Materials SLO-DPLGP (Slovenski digitalni potni list gradbenih proizvodov). A practical implementation case focuses on excavated soil and stone (17 05 04 according to European Waste Code List) flows and related value chains at the Dogoše demonstration site in Maribor, operated by NIGRAD. The development of SLO-DPLGP was initiated within the LIFE IP RESTART project, where the foundational digital architecture was established, while the SLO-DPLGP was upscaled on the previous basic DPP system in the Interreg Central Europe ReBuilt project.

2. METHODOLOGY

This study applies an integrated methodological framework combining normative legal analysis, quantitative mass flow assessment, case-based empirical validation, and digital data model prototyping. The objective was not only to interpret national legal requirements governing excavated soil and stone, but to systematically translate these requirements into a functional DPP architecture and validate its feasibility under real operational conditions.

2.1. Legislative framework and status pathways of excavated soil and stone

The first methodological step consisted of a systematic review of Slovenian environmental and construction legislation regulating the management of excavated soil and stone. The analysis covered the Environmental Protection Act [1], the Waste Regulation [2], the Decree on management of waste arising from construction work [3], and the Decree on burdening of soil with waste spreading [4].

The Environmental Protection Act establishes general principles of environmental liability and waste management [1]. The Waste Regulation defines waste classification, hazardous properties, and recovery and disposal operations in line with Commission Decision 2000/532/EC [2][5]. Decree on management of waste arising from construction work specifies obligations related to construction site waste management plans, reporting requirements, and preparation for reuse [3]. Decree on burdening of soil with waste spreading defines the conditions under which excavated materials may be introduced into soil, including inertness criteria and mandatory chemical analysis requirements [4]. In addition, the broader legal framework also includes rules governing waste treatment in mobile treatment plants, under which treated material may still retain waste status unless further legal and technical conditions are fulfilled.

Based on this broader legislative framework, several possible regulatory pathways were identified. In the first pathway, excavated material remains classified as waste under code 17 05 04 (only waste without hazardous properties was considered in the study) and is managed under applicable waste legislation,

including recovery operations such as R5 or R10, while retaining waste status unless conditions for another legal status are fulfilled [2][5]. In the second pathway, excavated material may be considered for by-product status if the relevant legal conditions are fulfilled, including certainty of further use and compliance with environmental standards [1][2]. In the third pathway, the material may be placed on the market as a construction product only where the relevant legal and technical conditions are met, including compliance with construction product legislation and performance declaration requirements under Regulation (EU) 2024/3110 or Regulation (EU) No 305/2011, as well as national construction product legislation [6][7].

For each pathway, procedural obligations, reporting requirements, and data generation points were systematically mapped in accordance with the applicable national legislative framework [2][3][4]. This mapping formed the regulatory basis for structuring digital passport architecture.

2.2. National mass flow analysis of construction and excavated materials

To quantify the systemic relevance of excavated soil and construction waste, a quantitative assessment of national waste generation and treatment flows was conducted. The analysis relied on official datasets from the Slovenian Ministry of the Environment (IS-odpadki database) [8], the Statistical Office of the Republic of Slovenia (SURS) [10], and Eurostat material flow accounts [11].

The assessment examined total annual waste generation in Slovenia, total quantities of construction and demolition waste (EWC chapter 17), specific quantities of excavated soil and stone (EWC 17 05 04 and 17 05 03*), distribution of treatment operations (R5, R10, other recovery, disposal) and multi-year trends and structural characteristics of recovery pathways.

This quantitative layer enables the identification of structural imbalances between material volumes and traceability mechanisms. It provides empirical justification for introducing batch digital traceability systems in high-volume waste streams such as excavated soil and stone.

2.3. Case-based assessment: Dogoše site

The third methodological step consisted of an empirical assessment conducted at the Dogoše site in Maribor, Slovenia, which operates as a regional centre for recycling and reuse of construction waste and materials. The assessment was performed in alignment with procedural requirements for waste holders, transporters, and recovery operators as defined in national waste legislation [2][3].

The analysis identified the main actors involved in material handling, including waste holders, transport operators, treatment facilities, laboratory services, and potential construction product manufacturers [1][2][6]. In parallel, data generation points were mapped throughout the material lifecycle, from excavation and sampling to laboratory analysis, transport documentation, recovery operations, and potential product conformity documentation [2][4].

Attention was given to chemical and geotechnical parameters required for determining contamination status and technical suitability for reuse in accordance with regulatory annexes and technical specifications [2][4]. The case study enabled verification of how regulatory obligations translate into operational documentation practices under real site conditions [3].

2.4. Development of the SLO-DPLGP base

The final methodological step consisted of the conceptual and technical development of the Slovenian National Digital Product Passport for Construction Products (SLO-DPLGP), designed to reflect national regulatory requirements and the emerging DPP framework under the new EU Construction Products Regulation [6].

The SLO-DPLGP base was structured around defined material batches as primary digital units to ensure traceability consistent with waste holder responsibilities and product conformity requirements [2][6]. For each batch, structured data categories were defined, including origin and identification data, quantitative parameters, chemical and geotechnical characteristics, regulatory status, type of recovery operation, and performance-related attributes where applicable [2][4][6].

Decision logic for status determination was modelled in accordance with legal pathways for waste, by-product, and construction product classification [1][2][6]. Data field definitions were aligned with laboratory testing requirements and national reporting obligations [2][4]. The resulting architecture enables regulatory compliance while supporting digital interoperability and structured material traceability in line with the evolving EU digital product passport framework [6].

3. RESULTS AND EXPERT ANALYSIS

3.1. Quantitative context of excavated soil and construction waste in Slovenia

The national waste management context in Slovenia confirms that construction and demolition mineral flows represent a highly relevant material stream from the perspective of circular economy implementation, environmental compliance, and digital traceability. This is consistent with the wider European context, where construction and demolition waste accounts for more than one third of all waste generated in the EU and is recognised as one of the most important waste streams for improving resource efficiency and secondary material use [9].

In the Slovenian case, the national mass flow assessment described in Chapter 2 was used to identify the relative weight of construction and demolition waste within total waste generation, with particular attention given to waste falling under Chapter 17 of the European Waste Classification and especially to excavated soil and stone under code 17 05 04.

From the perspective of digital passport development, the key finding is not only the absolute quantity of these materials, but also their systemic characteristics. Excavated soil and stone are generated in large volumes across dispersed infrastructure, utility, slope stabilisation, and maintenance activities. At the same time, these materials frequently move through different legal and operational pathways, including temporary storage, transport, recovery, backfilling, on-site reuse, or, where relevant conditions are met, transition toward by-product or construction product status [1][2][3][4][6].

This creates a documentation environment in which the same material flow may simultaneously require geospatial identification, quantity tracking, laboratory verification, legal status determination, and evidence of further use. Such conditions expose a structural mismatch between material volume and information structure. While quantities are often recorded for reporting and compliance purposes, the underlying data needed for consistent traceability, technical verification, and future reuse are typically fragmented across multiple actors and documents. In practice, this limits transparent decisions and makes it more difficult to support valuable recovery pathways [8][9][10].

For this reason, the national mass flow analysis is not treated merely as a statistical background, but as an empirical justification for introducing batch-based digital traceability for excavation materials and related mineral waste streams. In regulatory terms, this need for structured traceability is increasingly aligned with broader EU digitalisation policy. The new Construction Products Regulation introduces a construction digital product passport system for relevant construction product information and explicitly aligns it, to the extent possible, with the digital product passport approach established under the Ecodesign for Sustainable Products Regulation [6][12]. Even though excavated soil and stone are not automatically construction products, the direction of regulation clearly supports the development of interoperable digital information models for material flows with circular reuse potential.

3.2. Operational characteristics of the Dogoše case

The Dogoše case provides an operational illustration of how excavated soil and stone flows emerge in practice across a heterogeneous set of municipal infrastructure interventions. In methodological terms, the case is relevant because it allows the transition from a general regulatory and statistical perspective to a site-based examination of how material quantities, locations, and intervention types can be linked to traceability requirements identified in the legal framework [2][3][4]. The role of the Dogoše site within the present study is therefore not to provide a fully comprehensive material characterisation dataset, but rather to support a cautious and practical assessment of the types of information that are already available at the operational level and those that would still need to be systematically integrated into a digital passport model.

Based on the data currently available for the Dogoše demonstration context, the recorded material flow amounts to 4.510.810 kg, across eight identified locations and several types of interventions [13]. The largest recorded share is associated with regular maintenance of municipal roads, sewage systems, and green areas, amounting to 2.176.250 kg. This is followed by sewerage network with 939.480 kg, slope remediation activities with 722.200 kg in total, hot water pipeline construction with 432.840 kg, municipal road construction with 140.640 kg, and bus stop construction with 99.400 kg [13]. Even at this limited observational scale, the case demonstrates that excavation material streams do not originate from a single homogeneous activity, but from multiple intervention types with different technical contexts, locations, and probable future use pathways.

This heterogeneity is important from the perspective of traceability. Although the currently available case data already include basic information, these parameters alone do not provide a complete basis for regulatory or technical decisions. Under Slovenian waste and construction legislation, additional information may be required depending on the intended pathway of the material, including waste classification, sampling and laboratory results, recovery route, evidence of further use, and, where applicable, conformity data for market placement as a construction product [1][2][4][6][7]. The Dogoše case, therefore, illustrates a common

practical situation in which operationally relevant information exists but remains only partially structured for consistent lifecycle traceability.

From an expert perspective, the value of the Dogoše case lies precisely in this intermediate level of information maturity. The available data are sufficient to identify discrete material events and to define batch candidates based on origin, mass, and intervention context. At the same time, the dataset also shows why digitalisation cannot rely solely on quantity reporting. A meaningful digital passport for excavated soil and stone must be able to connect basic operational records with legal status determination, geotechnical and environmental testing, logistics, and eventual reuse or recovery outcomes. In this sense, the Dogoše case supports the argument that the initial digital unit should not be defined only as “waste generated”, but rather as a traceable material batch linked to a clearly identified source event and progressively enriched with additional technical and regulatory attributes [2][6].

For the purposes of this article, the Dogoše case is therefore interpreted as a realistic but intentionally limited implementation example. It does not claim to represent the full complexity of all excavation material flows in Slovenia. However, it provides a sufficiently robust empirical basis to demonstrate that even relatively simple operational datasets already reveal the need for better structured digital traceability if circular reuse pathways are to be supported in a legally transparent and technically credible way [2][3][6].

3.3. Identification of traceability gaps in current practice

The combined review of the regulatory framework, national mass flow context, and the Dogoše case indicates that the current management of excavated soil and stone is characterised by a persistent gap between material handling practice and information continuity. Material flows are physically present, operationally managed, and at least partially recorded, yet the associated information is often not organised in a way that enables consistent traceability across the lifecycle of a material batch [2][3][4][6].

A first gap relates to record fragmentation. Information relevant to excavated material is generated by different actors for different purposes, including site management, waste reporting, transport documentation, laboratory testing, recovery planning, and, where applicable, construction product compliance. Although these records may fulfil their immediate administrative or technical purpose, they do not necessarily form a single structured information chain linked to one identifiable material unit. This makes it difficult to reconstruct the full pathway of a material stream from generation to final recovery or reuse [1][2][3][6].

A second gap concerns the relationship between quantity and technical evidence. In operational settings such as the Dogoše case, basic data on mass, location, and intervention type can already be identified [13]. However, these data alone are not sufficient for decisions on reuse potential, environmental suitability, or transition toward by-product or construction product status. Such decisions require additional evidence, including classification, laboratory results, and intended use conditions, which are often stored separately or generated only when a specific administrative need arises [2][4][6][7].

A third gap is linked to legal status determination and data usability. Excavated soil and stone may follow different legal pathways depending on their origin, characteristics, and intended use, including classification as waste, possible qualification as by-product, or, under certain conditions, placement on the market as a construction product [1][2][6][7]. In practice, these transitions are rarely supported by a clearly structured digital logic showing what evidence was used, how the status was assigned, and which actor carried responsibility at each stage. Even where relevant information exists, it is often recorded in formats designed for isolated reporting obligations rather than for continuous reuse decisions. From the perspective of circular construction, the key challenge is therefore not the absence of data, but the absence of integration [6][7].

From an expert point of view, these traceability gaps do not necessarily indicate the absence of control, but rather insufficient integration of already existing data sources and documentation steps. The practical challenge is therefore not to create an entirely new information universe, but to define a structured digital framework capable of linking the data that are already generated under current legal and operational conditions. This is precisely the point at which a batch digital passport model becomes relevant. Its function is not merely descriptive, but integrative: to connect origin, quantity, status, testing, movement, and information on reuse into one traceable material identity that can support both compliance and circular value creation [2][6].

3.4. Proposed digital passport logic for excavated soil and stone

The traceability gaps identified in current practice indicate that a meaningful digital solution for excavated soil and stone cannot be based solely on static reporting or isolated document storage. Instead, it must rely on a structured digital logic capable of linking material origin, batch identity, regulatory status, technical evidence, and subsequent handling steps into one coherent information record [2][6]. In this study,

this logic is conceptualised through the Slovenian Digital Product and Geomaterial Passport base (SLO-DPLGP), developed as a batch digital traceability model aligned with both national legal requirements and the broader direction of EU construction product digitalisation [6].

The central design principle is that the primary digital unit should be a traceable material batch rather than a generic waste category or an aggregated annual quantity. A batch-based approach makes it possible to connect a specific source event with a defined material quantity, spatial origin, intervention type, and subsequent analytical and administrative evidence. This is particularly important in the case of excavated soil and stone, where materials that may appear similar at the aggregate level can differ significantly in origin, environmental suitability, technical characteristics, and legal treatment pathway [1][2][4]. The batch, therefore, functions as the minimum meaningful unit for lifecycle traceability.

Within such a model, the digital passport must integrate several interrelated data layers. The first layer includes origin and identification data, such as source location, intervention type, date of generation, responsible actor, and batch identifier. The second layer contains quantitative and logistical data, including mass, temporary storage, transport events, and receiving location. The third layer consists of technical and environmental evidence, especially chemical and material properties where these are required for determining the suitability of further use or compliance with construction requirements [2][4]. The fourth layer captures regulatory status and procedural pathway, indicating whether the material remains waste, is being considered under by-product conditions, is used under recovery operations such as R5 or R10, or is being prepared for a construction product pathway [1][2][6][7]. A fifth layer may include performance and conformity attributes where the material enters a product use scenario [6].

From a system design perspective, the digital passport should not merely store data but also reflect decision logic. The proposed model, therefore, assumes that status determination is supported by structured decision points linked to predefined legal and technical conditions. For example, the system should be able to distinguish whether a batch is being managed entirely under waste legislation, whether further evidence is being assembled to support a by-product interpretation, or whether the batch is moving toward a construction product context requiring additional information [1][2][6][7]. This does not mean that the digital tool replaces legal decisions. Rather, it provides a transparent framework in which the relevant evidence and procedural steps can be documented in a coherent and auditable manner.

A further important feature of the proposed logic is progressive data enrichment. In practice, all information about a material batch is rarely available at the point of generation. A workable passport system must therefore allow the record to evolve across the lifecycle of the batch. Initial information may consist only of origin, quantity, and intervention type, as illustrated in the Dogoše case [13]. Additional data, such as laboratory results, classification outcomes, transport documentation, recovery operation details, and evidence of final use, may then be added as the material progresses through successive operational and regulatory stages. This progressive structure is essential if the system is to reflect real practice without requiring unrealistic levels of upfront data completeness.

The proposed passport logic also has an interoperability function. By structuring data around standardised attributes and clearly identified batches, the model improves the possibility of connecting environmental, technical, and administrative datasets that are otherwise recorded separately. This is particularly relevant in the context of emerging EU requirements for more standardised and digitally accessible product information in construction [6]. Although excavated soil and stone do not automatically fall under the same regulatory category as harmonised construction products, the application of similar digital principles can substantially improve traceability, comparability, and confidence in circular use pathways.

In this article, the SLO-DPLGP concept is therefore understood as a regulatory and operational interface rather than as a purely technical database. Its added value lies in the fact that it translates fragmented compliance, testing, and material flow information into a unified traceability structure. In doing so, it supports more transparent status assessment, better documentation of recovery and reuse pathways, and a stronger information basis for circular material management in road construction and maintenance [2][6].

3.5. Implications for circular road construction and maintenance

The proposed batch digital passport logic has broader implications for circular road construction and maintenance beyond the immediate question of documentation. Its main contribution lies in improving the conditions under which excavated soil and stone can be assessed, managed, and, where appropriate, redirected from administrative waste handling toward more transparent and technically justified recovery or reuse pathways [2][3][6].

In the context of road construction and maintenance, material flows are often generated through repeated small and medium scale interventions distributed across a wide spatial network, as also illustrated by the Dogoše case [13]. Under such conditions, circular use does not depend only on the physical existence of reusable material, but also on the ability to identify its origin, verify its characteristics, document

its legal status, and communicate this information across actors involved in excavation, transport, testing, recovery, and reuse. A digital passport model supports this by establishing a structured traceability framework at the level where practical decisions are made, namely at the level of identifiable material batches [2][6].

This has several practical implications. First, it can strengthen confidence in secondary material use by improving the availability and continuity of supporting information. Second, it can reduce administrative uncertainty in cases where material pathways depend on technical evidence and legal interpretation. Third, it can improve the transparency of recovery and reuse practices, which is particularly relevant for high-volume mineral materials that are often managed under time and logistics pressures. In this sense, digital traceability not only serve control functions but also acts as an enabling condition for more credible circular material management [1][2][4][6].

From a system perspective, the relevance of such an approach is likely to increase as construction sector documentation becomes more digital, structured, and interoperable under the evolving EU framework [6][12]. Even where excavated soil and stone remain outside the strict scope of harmonised construction product rules, the application of digital passport principles can still provide significant value by aligning waste management practice with the logic of lifecycle information continuity, material transparency, and circularity.

For these reasons, the approach presented in this article should be understood not merely as a technical proposal for one project case, but as a transferable model for improving the management of mineral material flows in infrastructure practice. Its relevance is especially strong in contexts where large quantities of excavation material are generated, while decisions on reuse, recovery, or further treatment depend on fragmented technical, regulatory, and operational information.

4. CONCLUSION

This article addressed the problem of insufficient traceability in the management of excavated soil and stone generated in road construction and maintenance. Although such materials arise in large quantities and often have potential for recovery, reuse, or further valorisation, their management remains strongly influenced by fragmented documentation, dispersed responsibilities, and limited continuity of information across the material lifecycle (Environmental Protection Act, 2022; Waste Regulation, 2022; Decree on management of waste arising from construction work, 2008; Decree on burdening of soil with waste spreading, 2008). The challenge is therefore not only technical or regulatory, but also informational.

To address this issue, the study applied an integrated methodological framework combining legal analysis, national mass flow assessment, case validation, and digital data model development. On this basis, three key regulatory pathways for excavated soil and stone were identified, namely management as waste, possible qualification as by-product, and transition toward construction product use where relevant legal and technical conditions are met [1][2][6][7]. The analysis further showed that the practical difficulty lies not only in determining the appropriate status of a material, but in ensuring that the relevant evidence can be documented and communicated in a structured and credible way across actors and process stages.

The Dogoše case illustrated that even where operational data on material quantities, source locations, and intervention types are available, this information alone is not sufficient to support full technical, legal, and circular decisions [13]. At the same time, it demonstrated that these existing records already provide a realistic starting point for defining traceable material batches and for progressively enriching them with additional analytical, regulatory, and logistical data. In this respect, the study confirmed that the key opportunity does not lie in replacing current practice, but in integrating already existing data into a more coherent digital traceability structure.

The proposed SLO-DPLGP model was therefore developed as a batch digital passport concept that connects origin, quantity, status, testing, handling, and reuse information within a unified material identity [2][6]. Its relevance lies in the fact that it translates legal and operational complexity into a traceable digital logic that can support both compliance and circular value creation. Although the model was developed in the context of the LIFE IP RESTART project, its conceptual basis is broader and may be transferable to other mineral waste and secondary material streams in infrastructure and construction practice.

In conclusion, the study shows that digital passport principles can provide a meaningful framework for improving transparency, traceability, and circular management of excavated soil and stone, even in cases where these materials do not fall straightforwardly within conventional product regulatory categories. Their value is greatest where large material volumes, multiple actors, and fragmented documentation practices create barriers to recovery and reuse. In such contexts, structured digital traceability can become an important enabling condition for more credible and operationally effective circular construction.

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