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Digitalisation as an enabler of circular excavated soil management

An evaluation of digital tracking, resource cadaster, and digital twins

Master's thesis in the Master's programme Infrastructure and Environmental Engineering

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MASTER'S THESIS ACEX30

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ABSTRACT

The construction industry faces major challenges in reducing CO_2 emissions and project costs. The management of excavated material typically accounts for approximately 25-40% of the projects' budget. Management of masses affects both economic performance and CO_2 emissions, and significant challenges remain in achieving circular management of excavated soil. The aim is to identify digital tools that can support the circular management of excavated soil. Existing research on digital systems for buildings and the management of excavated soil is examined and compared, with a particular focus on tracking, resource cadaster, and digital twins. The study was conducted as a systematic literature search in which a modified version of the PRISMA method was applied for searches in Scopus. In total, 21 scientific articles on digital systems for the management of material and buildings were analysed and form the basis for the study. The results indicate that digital systems are a prerequisite for achieving a holistic perspective on the management of excavated soil, with real-time monitoring constituting a key functionality. The analysis shows that the existing system used by the Swedish Transport Administration only enables tracking between construction projects and receiving facilities. To achieve comprehensive traceability, the system must also encompass material flows between projects, from projects to private individuals, and movements within the project site. Traceability beyond the project site is considered achievable using IoT-based systems with GPS, enabling real-time monitoring. Within the project site, a combination of multiple technological solutions is required. The primary challenge identified is ensuring the monitoring and verification of material properties and contamination levels during the movement of material within the project site. The study therefore indicates that further research is needed to develop efficient methods for such monitoring. Furthermore, the findings suggest that an effective model for traceability within project sites is a prerequisite for implementing a resource database with a high degree of accuracy and reliability

Keywords: excavated material, management of excavated soil, digital tool, Swedish Transport Administration, tracking, resource cadaster, digital twin

Digitalisering som en möjliggörare för cirkulär masshantering

En utvärdering av digital spårning, resursdatabaser och digital tvilling
Examensarbete inom mastersprogrammett Infrastruktur och miljöteknik
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SAMMANFATTNING

Byggbranschen står inför stora utmaningar att minska CO2-utsläppen och projektkostnaderna. Hantering av jord- och schaktmassor står för ungefär 25–40% av projektets budget. Masshantering påverkar både ekonomi och CO_2-utsläpp. Det finns stora utmaningar med att uppnå cirkulär masshantering. Syftet med denna studie är att kartlägga vilka digitala verktyg som kan användas för att uppnå en cirkulär masshantering. Studien kartlägger och jämför forskning om digitala system för byggnader och masshantering inom spårbarhet, materialdatabaser och digitala tvillingar. Studien genomfördes som en systematisk litteraturstudie där en modifierad version av PRISMA-metoden använts för sökningar i Scopus. Totalt analyserades 21 vetenskapliga artiklar inom digitala system för masshantering och byggnader som ligger till grund för studien. Resultatet visar att digitala system är en förutsättning för att uppnå ett helhetsperspektiv inom masshantering, där realtidsuppföljning utgör en central funktion. Analysen visar att Trafikverkets befintliga system endast möjliggör spårbarhet mellan projekt och mottagningsanläggning. För att uppnå fullständig spårbarhet behöver systemet även omfatta materialflöden mellan projekt, från projekt till privata aktörer samt interna förflyttningar inom projektområdet.
Spårbarhet utanför projektområdet bedöms kunna uppnås genom användning av IoT-baserade system med GPS-utrustade transportfordon, vilket möjliggör uppföljning i realtid. Inom projektområdet krävs däremot en kombination av flera tekniska lösningar. Den främsta identifierade utmaningen är att säkerställa kontroll av materialtekniska egenskaper och föroreningsgrad under materialhanteringen inom projektområdet. Studien visar därför att fortsatt forskning behövs för att utveckla resurseffektiva metoder för sådan kontroll. Vidare indikerar resultaten att en fungerande modell för spårbarhet inom projektområdet är en förutsättning för att en resursdatabas ska kunna implementeras med hög precision och tillförlitlighet.

Nyckelord: schaktmassor, masshantering, digitala verktyg, Trafikverket,

Masshantering, spårbarhet, materialdatabaser, digital tvilling

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Preface

Master's thesis written at Chalmers University of Technology at the Department of Architecture and Civil Engineering in the spring of 2026. The thesis is valued as 30 hp.

I would like to extend my sincere gratitude to my supervisor and examiner, Jenny Norrman at Chalmers University of Technology, for providing valuable input and guidance throughout the process. I would also like to express my sincere thanks to my supervisors at the Swedish Transport Administration, Joakim Cleasson and Carolina Borre, who contributed valuable knowledge regarding the management of excavated soil.

Lastly, I would like to express my thanks to the representatives from the Swedish Transport Administration and the contractors who participated in informal interviews and shared their perspectives on mass management. Their insights regarding digital systems or software development have been highly valuable to this thesis.

Göteborg May 2026
LINNEA BENGTSSON

Acronyms

The acronyms are listed below in alphabetical order:

AMA	General material and work description
	Allmän material och arbetsbeskrivning
BEAst	The Construction Industry Electronic Business Standard
	Byggbranschens Elektroniska Affärsstandard
BIM	Building Information Modeling
CE	Circular economy
CNN	
CO_2	Carbon dioxide
EPA	Environmental Protection Agency
	Naturvårdsverket
GIS	Geographic Information System
IoT	Internet of Things
KM	Sensitive land
	Känslig markanvändning
LoD	Level of Detail
MKM	Less sensitive land
	Mindre känslig markanvändning
MI	Material intensity factor
MRR	Less than slight risk
	Mindre än ringa risk
PHP	Hypertext Preprocessor
PRISMA	Preferred Reporting Items for Systematic reviews and Meta-Analyses
QUOROM	Quality of reporting of meta-analyses
RFID	Radio Frequency Identification,
RISE	Research Institution of Sweden
VTI	Swedish National Road and Transport Research Institute
	Statens väg- och transportforskningsinstitut

Glossary

Artificial intelligence (AI)	Simulation of human cognitive functions by a computer or machines.
Building Information Modelling (BIM)	A visualisation of the built environment in 3D
Convolutional Neural Network (CNN)	Sort of AI in which information about materials is collected using physical hardware such as sensors or cameras. The system can analyse visual information related to structural characteristics, cracks, and colour variations.
Geographic Information System (GIS)	Visualisation of geographic data, where raw data transforms into intelligent maps.
Global Positioning System (GPS)	Navigation of satellites that can provide velocity, location, and time.
Internet of Things (IoT)	A network which is embedded the physical world into the digital world with sensors and software without human interaction.
Radio Frequency Identification, RFID	Movement of building elements, for instance, from factories to construction sites. RFID is a system consisting of three components: an antenna, a reader, and a tag.

1 Introduction

The planning report describes the background to the project, its aim, its limitations, expected results, and how the project is set up in terms of time.

1.1 Background

The handling of excavated materials has a major impact on infrastructure projects, both on the projects' budgets and on the environment. Excavated soil, together with rock and dredging spoils, generated 23% of the total EU waste in 2020 (Cristóbal, et al., 2024). In Stockholm County, the transport of masses by heavy vehicles accounts for 28% of CO_2 emissions (Kinberg Batra, et al., 2022). The cost of soil management varies between projects but can, in many cases, account for up to 30% of total project costs (Kenley & Harfield, 2011). In Sweden, soil management accounts for approximately 25-40% of the total costs of earthworks and civil engineering projects (Swedish Transport Administration, 2024a). Kenley and Harfield emphasize that both project costs and environmental impacts can be reduced through increased reuse of excavated materials, as a result of decreased extraction of virgin natural resources and reduced transportation requirements. Despite the substantial economic and environmental benefits associated with the reuse of excavated soil, the rate of reuse of high-quality material remains low (Magnusson, et al., 2015).

According to the Swedish National Road and Transport Research Institute (VTI), digitalization is an essential component for tracking the movement of material volumes both within and beyond the project boundaries (Eriksson, et al., 2025). Digital systems facilitate the management of information and enable efficient data sharing among relevant stakeholders. Furthermore, the implementation of digital applications demonstrates increased adaptability, improved operational efficiency, and reduced costs (Dongwook, 2024).

Research in resource cadaster for buildings aims to enhance the circular economy by increasing understanding of which materials are stored in buildings (Lanau, et al., 2024). Resource cadaster is a database that contains information regarding building materials, including their type, quantity, and location. Increasing the level of detail in digital databases within the construction industry can be achieved through the application of remote sensing and machine learning. Previous research in this field has focused on the total weight of materials. The objective is to increase the amount of reused material in order to reduce the quantity of construction materials sent to landfill and to decrease the associated carbon dioxide emissions. There are currently several barriers to implementing databases for building materials. Identified challenges include a lack of interest in the circular economy, issues related to the transport and storage of materials, and difficulties in meeting standards when materials may be contaminated. The researchers emphasise that a transition within the industry is required, in which design is adapted to the materials that are available and existing resource cadastres are further developed.

The Swedish Transport Administration (The Swedish Transport Administration) is one of the largest public clients in Sweden, managing approximately 2,500 construction projects annually (Swedish Transport Administration, 2024a). In around 80% of the projects, surplus soil is generated. The management of excavated materials is a complex issue involving multiple areas of expertise and a wide range of stakeholders. Among the aspects identified by the Swedish Transport Administration as critical for achieving more sustainable material management are early-stage knowledge acquisition and planning for material use to reduce the volume of surplus materials and enable their reuse within their own projects. At present, the digital tool, Geokalkyl, is available for use in early project stages to facilitate comparisons of costs and climate impact (Swedish Transport Administration, 2025a).

The Swedish Transport Administration has been initiating efforts to digitise soil management in recent years. The Swedish Transport Administration has developed a system, ELSA, in which digital delivery notes from receiving facilities are managed. A receiving facility is a facility where excavated soil is processed, stored, or deposited. The information is transmitted through the supply chain to the contractor, who in turn delivers the data to the Swedish Transport Administration. The collection of data has been stipulated as a procurement requirement in the Swedish Transport Administration's larger projects since March 2024. But the system currently lacks information on how material is utilized within and between projects. Only material originating from a single project and destined for a receiving facility is currently managed through digital tracking in ELSA. There is ongoing work at the Swedish Transport Administration to visualise the aggregated information submitted to ELSA.

1.2 Aim and objectives

The overall aim of this thesis is to develop recommendations for the design of the Swedish Transport Administration's digital system for mass management to promote sustainable and circular management of excavated soil.

To reach the overall aim, the following objectives were formulated:

- Investigate existing digital systems for tracking of excavated soil used by the Swedish Transport Administration and their functionalities.
- Investigate the current state of research and practical implementation of resource cadastres, digital twins, and tracking within other parts of the construction sector. Evaluate the extent to which such frameworks have been adopted in practice, as well as to assess their potential applicability to mass management processes.
- Formulate recommendations for how the Swedish Transport Administration should further develop its digital systems to enable circular management of excavated soil.
- Based on the reviewed body of research on soil and excavated materials, identify measures that are considered feasible to implement at the Swedish Transport Administration to increase the circularity and traceability of such materials, as well as measures recommended for the long term but not currently feasible under present conditions.

1.3 Limitations

The following limitations are applied to the master’s thesis:

- This report examines only government-funded infrastructure projects for which the Swedish Transport Administration acts as the client. Infrastructure projects commissioned by municipalities are not included.
- The report considers only Swedish regulatory requirements related to infrastructure construction. No consideration is given to laws or conditions of other countries.

- In Sweden, there are several system providers for digital delivery notes; the differences between the companies and the applications offered by the system providers are not examined in this study.
- The proposed measures focus on digital tools for excavated soil and rocks; other materials such as concrete, wood, and brick are not considered.
- Scopus was used as the search engine to identify relevant research for all search strings. Consequently, only articles published in Scopus were included in the search.

2 Practical and regulatory framework

The chapter describes the management of excavated materials in Sweden. Based on applicable legislation and guidelines, classification and categorization of materials, operational work for circular management of materials, barriers to reuse and traceability.

2.1 Guidelines and legislation for excavated soil

The waste hierarchy constitutes the European Union's framework for guiding how member states should manage waste (European Union, n.d). The framework was formally established in 2008. Its primary objective is to prevent harm to human and animal health, as well as to the environment (European Parliament and Council of the European Union, 2008). The first priority within the waste hierarchy is waste prevention, primarily achieved by extending product lifespans. If waste generation cannot be avoided, the next preferred option is preparing for reuse, either for the same purpose or in a modified form. The third stage of the hierarchy involves material recycling through treatment and processing. If recycling is not feasible, the material should be recovered for alternative purposes, such as energy recovery. Landfilling is the final and least preferred option and should be implemented only when no other alternatives are available. Figure 1 illustrates the waste hierarchy and the sequential stages of the pyramid.

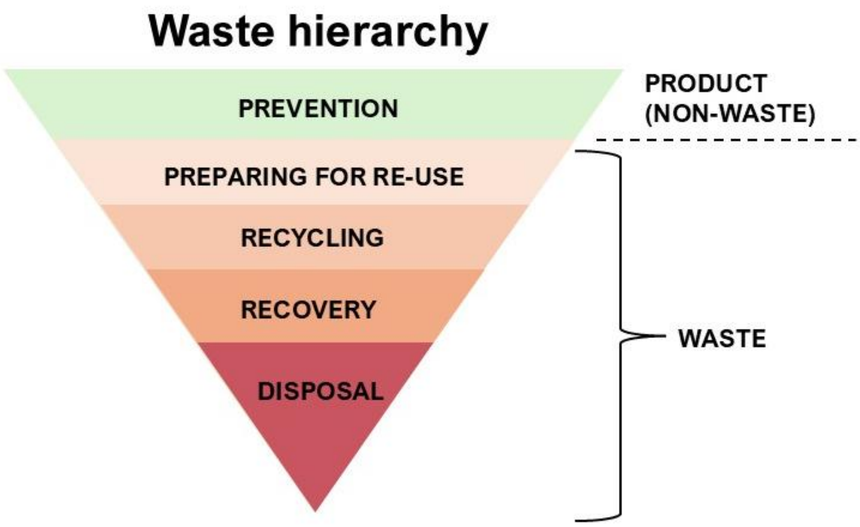

Figure 1. The EU's waste hierarchy describes the priority regarding waste management, with the most beneficial measure at the top (European Union, n.d).

Swedish waste management legislation is governed by the Environmental Code, specifically Chapter 15 (Regeringskansliet, 1998). In Section 1, Paragraph 1, waste is defined as "any substance or object which the holder discards, intends to discard, or is required to discard.". In addition to defining waste, Chapter 15 regulates provisions concerning waste management, reuse, landfilling, producer responsibility, and the waste hierarchy.

In December 2025, the Government submitted a legislative referral to the Council on Legislation proposing amendments to the Environmental Code (Government of Sweden, 2025). The proposed changes include exempting non-contaminated excavated materials from waste legislation, with the aim of facilitating their reuse within the project area. The amendment is proposed to enter into force on 1 July 2026.

2.1.1 Existing guidelines of the Swedish Environmental Protection Agency

The Swedish Environmental Protection Agency (EPA) has pursuant to the applicable provisions of the Swedish Environmental Code, Miljöbalk (SFS 1998:808) and the EU regulatory framework, developed guidelines for the management of excavated materials (Swedish EPA, 2025a). The agency's guidance document, Återvinning av avfall i anläggningsarbeten (2010:1), serves as a reference for supervisory authorities in assessing whether the legal definition of waste is applicable in specific cases (Swedish EPA, 2010). EPA has announced that this guidance is currently under revision; however, the 2010 handbook remains in force at present (Swedish EPA, 2025a).

When excavated materials are encountered, an assessment must be conducted to determine whether they constitute a resource or waste (Swedish EPA, 2023). The determination requires a comprehensive evaluation of the material's potential for reuse and economic perspective. Decision-making support shall be based on previous legal decisions from the Court of Justice of the European Union, Land and Environment Court (Mark- och miljödomstolen), and Supreme Court (Högsta domstolen). The classification of materials as either a resource or waste is decisive for their subsequent management. Figure 2 illustrates the assessment process proposed by the EPA for determining whether excavated materials are to be considered waste.

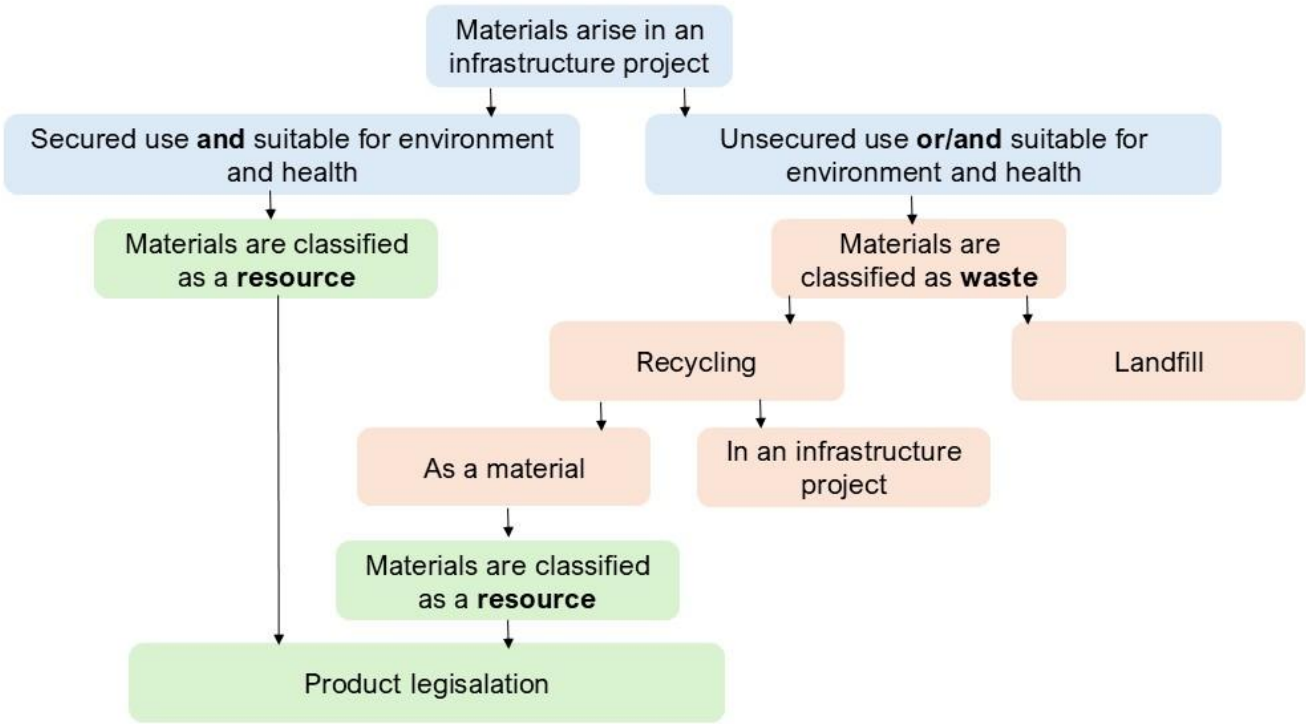

Figure 2. Guidelines from the Swedish EPA on managing excavated materials (Swedish EPA, 2023).

An assessment of the holder's intent to discard must be undertaken in accordance with the statutory definition of waste set out in the Swedish Environmental Code (Swedish EPA, 2023). EPA considers that no intent to discard exists where it can be demonstrated that there is a clear purpose for the use of the materials and that such use is appropriate from a health and environmental protection perspective concerning humans, animals, and the environment. If a specific purpose cannot be substantiated, the materials shall be classified as waste, even if they are environmentally and health-wise suitable. Both criteria must be fulfilled for excavated soil not to be regarded as waste. Written documentation concerning the intended destination of the materials, sampling results, and assessments of environmental and health risks must be specified.

If the materials are classified as waste, the following management options are available: reuse for construction purposes, disposal at a landfill, or material recovery (Swedish EPA, 2023). Reuse in construction applications is not directly regulated under waste legislation. EPA considers construction use to constitute an environmentally hazardous activity in which soil and rock materials serve as the principal construction material. Construction purposes include the development of railways, roads, noise barriers, parking areas, and building foundations. The handbook emphasizes that reuse in construction is preferable to landfill disposal to promote a circular economy. Landfilling of waste should be regarded as a last-resort option when no other feasible alternatives are available. However, materials may cease to be classified as waste after undergoing a recovery operation. Such operations may alter the physical and chemical properties of the material, enabling reuse for the same or a different purpose. This applies provided that the relevant regulatory requirements are fulfilled (Swedish EPA, 2023).

2.1.2 Legislative Council referral of waste legislation

The Government has presented a proposal to amend the legislation stipulating that non-contaminated soil and other naturally occurring materials shall be excluded from waste legislation if they meet the specified criteria (Government of Sweden, 2025). Excavated soil may contain natural background levels of contaminants, such as naturally elevated concentrations of arsenic or sulphides, provided that the material is not classified as hazardous waste. The objective of the proposed amendment is to promote a circular economy by facilitating the use of excavated materials within the project. Surplus soil generated in a project may, without prior notification, be used for noise barriers and landscape construction. The legislative amendment does not apply to concrete, timber, or other construction and demolition materials.

The preparatory document defines four criteria that soil material must satisfy in order not to fall within the scope of the legislation:

- They shall be used in their natural state and must not include processed materials.
- They shall be used for construction or civil engineering purposes.
- They shall be used within the project area.
- Their use shall not pose a risk of harm or nuisance to human health or the environment.

The legislative amendment is proposed to enter into force on 1 July 2026.

2.2 Classification and categorisation of environmental and material engineering properties of excavated soil

In connection with project execution, soil and excavated material samples should be collected. The extent of sampling at different project stages should be planned within a sampling plan (Swedish Transport Administration, 2025c). Samples should be analysed from both environmental and materials engineering perspectives. Sampling is conducted at the project level; at present, there is no overarching statistical database or assessment regarding the types of materials occurring at different locations (Swedish EPA, 2022). Likewise, no comprehensive statistics exist concerning the composition or properties of these materials. Consequently, it is currently difficult to estimate the proportion of generated materials that contain a given level of contamination.

From an environmental engineering perspective, soil and excavated materials are classified according to their degree of contamination (Swedish EPA, 2022). Material below the threshold for less than minor risk, MRR, is considered non-contaminated, whereas material exceeding the guideline value for less sensitive land use, MKM, is considered contaminated. Table 1 illustrates the relationship between contamination levels and the associated terminology. Non-contaminated materials include those where concentration and leaching levels are assessed to pose a low risk, less than minor risk, MRR, when used for construction purposes, or where concentrations are below natural background levels. Information received by the Swedish EPA from other sectors indicates that the proportion of materials with contamination levels below MRR is relatively low. The Agency's general guideline values for contaminated soils are KM (sensitive land use) and MKM. KM represents lightly contaminated materials, whereas MKM refers to contaminated materials. These guideline values are intended to support the assessment of the suitability of soil and excavated materials for different construction and land-use purposes.

Table 1. Contamination levels from the Swedish EPA, the level of contamination is based on identified risk.

Level of contamination	Definition of contamination levels
Uncontaminated materials	Concentration <MRR or below natural background levels.
Slightly contaminated materials	Concentration >MRR and <KM
Contaminated materials	Concentration >KM and <MKM

The technical properties of soil and rock materials are classified in AMA Construction 23, which includes general material and work specifications (Svensk Byggtjänst, 2023). The publication comprises regulations and applications, standard drawings, and dimensional definitions. In chapter C, the management of excavated materials is defined, including those intended for reuse within the project or relocation to external sites. Excavated materials designated for reuse or recycling must be classified in accordance with table AMA CE/1. In Table 2, the application and classification based on CE/1 is outlined.

Table 2. Classification of soil and rock materials intended for use in an infrastructure or construction project (Svensk Byggtjänst, 2023).

Material type	Name of soil and rock material	Content (weight- %) X/Y			Example	Frost class
		Fine 0,063/63 mm	Clay 0,002/ 0,063 mm	Organic soil %/63 mm		
1	Rock type A	<10		≤2	Mica-poor granite or gneiss and other hard and strong rocks such as quartzite, dolerite, porphyry, and leptite	1
	Rock type B	<10		≤2	Mica-rich granite or gneiss, as well as other rock types with moderate strength and low abrasion resistance, for instance, homogeneous limestone.	1
2	Block and boulder soils Coarse-grained soils	≤15		≤2	Boulders, Stone, Gravel, Sand, Sandy gravel, Gravelly sand, Gravelly till, Sandy till	1
3A	Rock type C	≤15		≤2	Rocks with high mica content, clay shale, certain coarse-grained granites, and some porous sedimentary rocks, very strongly metamorphosed rocks	2
3B	Mixed-grained soils	16-30		≤2	Clayey or silty sand Clayey or silty gravel Clayey or silty sandy till Clayey or silty gravelly till Clayey or silty till	2
	Rock type D			≤2	Rocks with high mica content, clay shale, Chalk limestone, Clay-altered rock, Unclassified rock material	3
4A	Mixed-grained soils	31-40		≤2	Clayey or silty sand Clayey or silty gravel Clayey or silty sandy till Clayey or silty gravelly till Clayey or silty till	3
4B	Fine-grained soils	>40	>40	≤2	Clay, Clay till	3
5A	Fine-grained soils	>40	>40	≤2	Silt, Clayey silt, Silty clay, Silty till, Silty till, Silty clay till	4
5B	Mineral soils with organic content			2-6	Muddy clay, Muddy silt	4
6A	Organic, mineral soils			6-20	Clay mud, silty mud, sandy humus soil	3
6B	Organic soils			>20	Mud, peat, hummus soil	1

In projects conducted by the Swedish Transport Administration, AMA Construction 23 applied for material engineering properties and for environmental classification

(Swedish Transport Administration, 2025b), the Swedish EPA general guidelines for contaminated land are applied (Swedish Transport Administration, 2025c). TDOK 2022:0063 contains a step-by-step description of how procedures should be carried out. This is intended to ensure safe handling regarding environmental considerations, improve the efficiency of management of excavated soil, and increase the utilisation rate of excavated materials within projects. The document outlines how the project shall manage excavated soil and the aspects it needs to take into account regarding site conditions, sampling, documentation, and the assessment of soil suitability. TDOK 2022:0063 also describes the Swedish Transport Administration's maximum value for metals in soil applicable to different land-use categories.

The intended workflow for assessing soil in Swedish Transport Administration projects is specified. In addition, it includes a summary table proposing how materials can be categorised by land type, surface condition, duration of exposure, and proposed land use at the site. Based on an analysis of this table, risk assessments for material use can be performed, and it can serve as a basis for determining the types of samples required for chemical analysis.

The level of contamination in soil varies considerably. Although all soil contains some degree of heterogeneity, the extent of heterogeneity differs between sites (Rosén, et al., 2020). Contaminants are primarily associated with finer particle fractions, and the representativeness of the investigated area is influenced by the sampling locations, the degree of site heterogeneity, and the number of samples collected.

2.3 Circular economy, general guidelines and links to mass management

A circular economy is an economic model aimed at reducing environmental impact and the use of natural resources (Swedish EPA, 2025b). Materials should be designed for long service life and high utilisation rates. At the end of their service life, materials should be regarded as resources and reintroduced into the same or an alternative system within society. The use of virgin natural resources should be minimised wherever possible. At present, the linear economy predominates, in which the economic value of materials is lost from the system. Broadly, a linear economy can be described as a sequence of raw material extraction, production, consumption, and waste disposal.

Figure 3 illustrates how EU member states are encouraged to transition towards a circular economy, where each stage of the cycle represents a specific phase in the product life cycle (European Environment Agency, 2024). The EU's framework is primarily designed for products, with buildings identified as one of the product categories where potential is high.

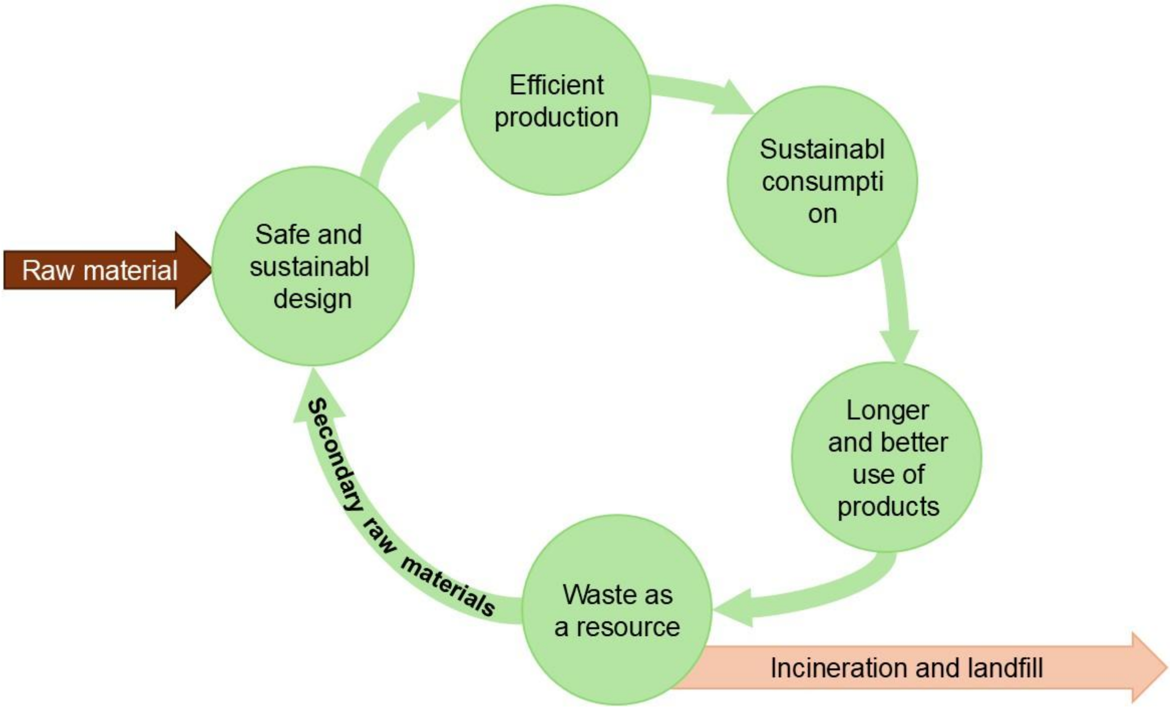

Figure 3. Describes the EEA vision on the circular economy and the working methods that member states should follow to work sustainably. (European Environment Agency, 2024).

The first stage is *safe and sustainable design*, in which strategic decisions are made during the planning and design phase to ensure long-term use and reduced future environmental impact (European Environment Agency, 2024). The next step is *efficient production,* which aims to achieve the highest possible resource efficiency by reducing emissions associated with production and maximising the use of residual materials. The third stage is *sustainable consumption,* which promotes sharing and leasing models as alternatives to ownership. This stage also includes the role of public procurement requirements in driving market transformation. It is more directly relevant to products than to the management of excavated soil. *Longer and better use of products* is the fourth stage, which emphasises that products should be designed for their lifespan. Repair, maintenance, and upgrading should be undertaken to extend product lifespan. At the end of the lifespan, it can be used as *waste as a resource, secondary raw material,* or sent to a *landfill*. Materials should be reused or recovered as secondary resources to achieve a circular economy. When masses go to the landfill, it is only a linear process.

2.3.1 Handling of surplus masses, flows within and outside the project area

In infrastructure projects, excavated materials are generated (Swedish EPA, 2022). The most appropriate management option depends on the properties of the material, the specific conditions of the project, whether it is possible to store soil at the site, or if some other management is suitable. The EPA, in consultation with other stakeholders, has mapped material flows of excavated masses; an illustration of the identified sub-flows is presented in Figure 4. The Government has submitted a bill proposing that non-hazardous waste be exempted from waste legislation (Government of Sweden, 2025). If adopted, the flows in the figure concerning whether a material is classified as waste or not will be altered.

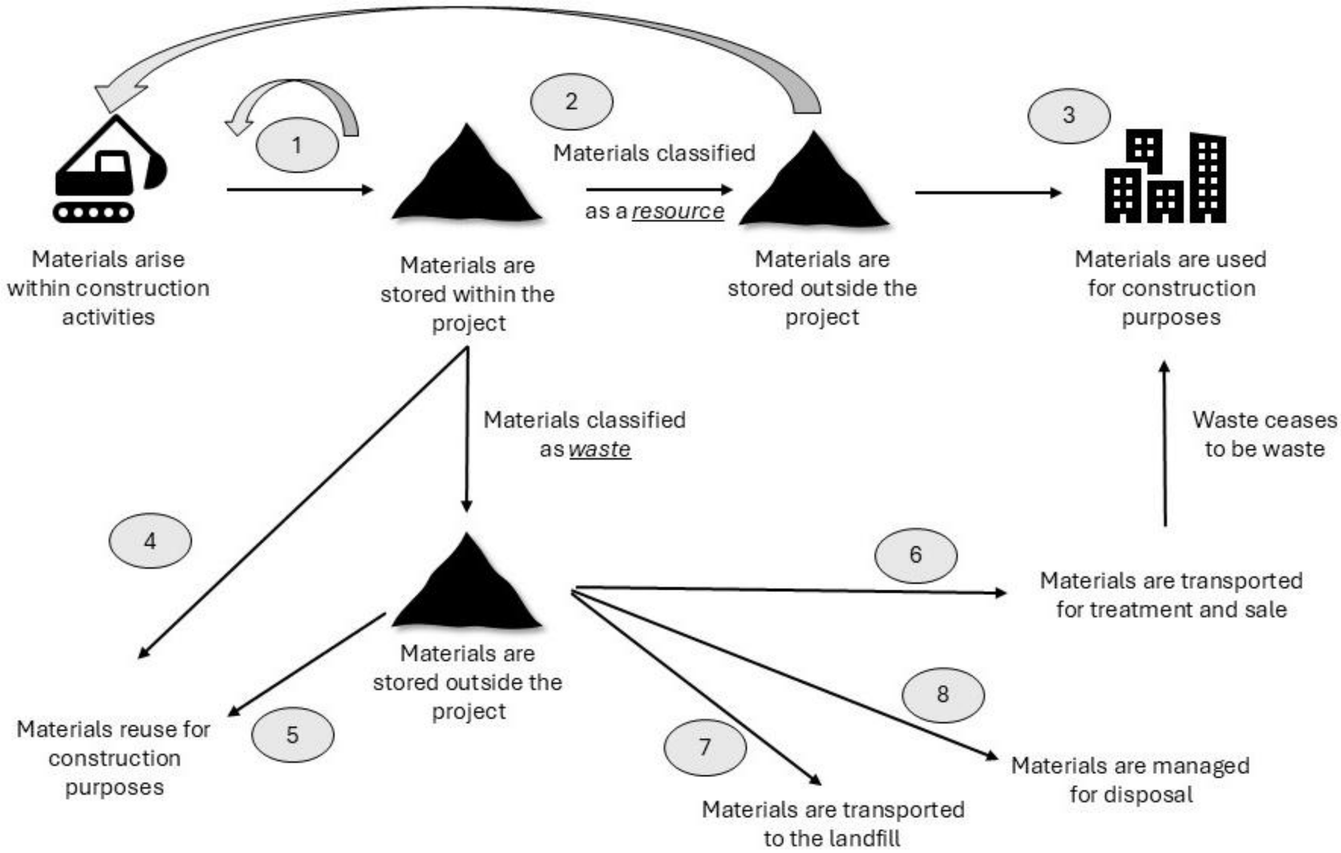

Figure 4. Illustration for potential material flows and use for excavated soil (Swedish EPA, 2022).

In the figure, sub-flow 1 represents materials managed within the project through direct use, storage, or treatment on-site (Swedish EPA, 2022). Limitations may arise due to restricted space for storage within the project area, as well as the requirement that the material properties correspond to the needs of the project. Sub-flow 2 describes the inflow of external materials, including treated excavated materials from receiving facilities and quarries, as well as materials originating from other projects.

Defined sub-flow 3 refers to the processing and sale of materials, including transportation to facilities for handling (Swedish EPA, 2022). In practice, public clients typically transfer responsibility for material management to the contractor. The handling of excavated materials constitutes a major cost driver; consequently, efficient management of soil and excavated materials is a critical factor in enabling contractors to deliver projects at the lowest possible cost.

Instead of storage or processing at another location, materials may be transported directly from the project for construction purposes within or outside the project area, as described in sub-flow 4 (Swedish EPA, 2022). Such construction purposes include recovery uses, for example, as foundation material for buildings or as construction material for noise barriers, railways, or roads. Sub-flow 5 also concerns use for construction purposes, but in this case, the materials are classified as waste. Such use is subject to notification requirements, and its suitability must be assessed by the supervisory authority; the purpose of the use must not be disposal.

Sub-flows 6,7 och 8 refer to materials classified as waste (Swedish EPA, 2022). Sub-flow 6 concerns the treatment of waste, either to enable reuse or for disposal. Following treatment, materials may cease to be classified as waste. Sub-flow 7 relates to landfill engineering or final capping, where materials are used for constructing access roads or as cover material at landfill sites. The final option is disposal, sub-flow 8, where the type of landfill permitted depends on the facility's authorisation; these are typically categorised as inert waste, non-hazardous waste, or hazardous waste. Regulations define requirements for maximum leaching levels, as well as permissible concentrations of metals and other contaminants.

2.3.2 Barriers to the circular economy of excavated soil

The study "Masshantering – indikatorer och nyckeltal för incitament för reducerad klimatpåverkan vid upphandling" investigates systemic barriers to implementation of CE principles for soil and excavated materials in Sweden (Andersson-Sköld, et al., 2022). Interviews were conducted with a range of stakeholders within the sector, including municipalities, the Swedish Transport Administration, County Administrative Boards, and contractors. The study identifies three dimensions of misalignment between actors in the planning process. Firstly, there is often a lack of clear allocation of responsibility both within and between organisations. Project clients frequently consider it the contractor's responsibility to manage materials; however, contractors face difficulties in adopting a strategic approach when the necessary conditions are not in place. Secondly, there is often a temporal gap between sampling and the actual handling of materials, which in some cases affects the conditions for their management.

This dimension of misalignment is organisational in nature, reflecting deficiencies in mutual understanding between actors and, in some cases, also between departments within a municipality (Andersson-Sköld, et al., 2022). Municipalities simultaneously act as regulatory authorities and project clients, which may result in inconsistent decision-making: one department may approve a course of action during the planning phase, while another department, acting as the permitting authority at a later stage, may reject it. The study further demonstrates that the interpretation of environmental legislation (the Environmental Code) varies not only between departments but also between individual case officers within the same department. In a bachelor's thesis conducted in 2024, a survey study targeting municipalities was carried out to examine attitudes towards the reuse of excavated materials (Bengtsson, et al., 2024). The findings similarly indicated that the interpretation of legislation and guidelines varies both between municipalities and individuals within the same municipality.

2.4 Existing systems for digital environmental data reporting in the construction industry in Sweden.

In the chapter, existing systems for digital environmental data reporting are described. First, the connection between BEAst Supply 4.0 and the Peppol network is described, and then the Swedish Transport Administration's own system, ELSA.

2.4.1 The interoperability between BEAst and Peppol

BEAst, Byggbranschens Elektroniska Affärsstandard, aims to develop common standards and working practices for digital communication within the construction industry (BEAst, n.d a). Primarily in relation to procurement, purchasing, logistics, and invoicing. BEAst is a non-profit organisation with approximately 100 members, within which collaboration takes place between Nordic and international organisations. BEAst is an agreement on how information should be reported within standards, rather than a software solution or a specific product. The standard specifies how information is to be processed and read into systems, thereby enabling a higher degree of automation and more resource-efficient communication when information is consistently interpreted across stakeholders.

In practice, a system provider is required for information to be communicated between stakeholders (BEAst, n.d b). Several system providers support the BEAst standard; the systems are suited to different stakeholders. Some systems are designed for material weighing, while others are intended for sellers and/or purchasers. The communication of codes from the standard is carried out via Peppol. The launch of BEAst Supply 4.0 was aligned with the international Peppol network (Carlsson, et al., 2024). Peppol constitutes the network through which electronic messages are transmitted between stakeholders (Agency for Digital Government, 2025). Actors connect to the network via access points, which are typically provided by an operator or system provider. The Peppol-ID is an electronic address, usually consisting of an organization number with a prefix.

2.4.2 ELSA, an environmental reporting system

The Swedish Transport Administration has developed a system for digital environmental data reporting (Swedish Transport Administration, 2024b). The digital reporting includes total fuel consumption for vehicles and masses which leaving the site. Reporting requirements for excavated materials apply to projects exceeding SEK 50 million. The system follows the BEAst standard and is connected to the Peppol network (Swedish Transport Administration, 2026a). Thus, after March 2024, the Swedish Transport Administration requires, in procurement processes, that contracted contractors report to ELSA using digital delivery notes. The contractor is responsible for ensuring that the information reported in ELSA is accurate and traceable, even if subcontractors are engaged in the project. Environmental data reporting shall commence at the start of the project, but an alternative reporting method may be granted during the first six months if the contractor has not worked with ELSA before.

In its specification for digital delivery notes, the Swedish Transport Administration has defined the required content of each submission (Swedish Transport Administration, 2026b). The delivery note shall specify the vehicle, material quantity (in tonnes), machinery, and fuel type. Each category follows a standardised classification based on a standard in the industry. The information contained in the delivery notes is structured into a header and individual line items. The document contains information applicable to all line items, for instance, an individual vehicle. The line items contain specific information relating to a given entry, for instance, a transport from project to landfill. The categories of vehicles included in the requirement for digital reporting are defined in the specification.

2.4.3 PMSv4, Pavement management system

PMSv4 is a tool developed for road maintenance operations (Swedish Transport Administration, 2024c). Its purpose is to facilitate awareness of completed pavement and drainage measures and relevant traffic data. A specific road section may be defined, and characteristics relating to the alignment can be examined within the system. The system includes the national road network surfaced with asphalt. The software is available for internal and external use.

2.4.4 Mass-Portal

Another software application used by the Swedish Transport Administration is Mass-Portal, a platform designed to facilitate the coordination of excavated soil within the Swedish Transport Administration's project (Andersson & Borre, 2024). The tool can be used to identify the locations of other ongoing projects, thereby making it easier to determine which project managers should be contacted when a surplus or demand of materials exists within a project.

Mass-Portal is based on a GIS platform, where project-related data is imported from an Excel sheet (Andersson & Borre, 2024). The Excel file includes information on the project location, construction time, project type and ID, the excavated soil if there is a surplus or demand, quantity, material type according to AMA Construction 23, contamination level according to the Swedish EPA, and any invasive species.

2.5 Incentive models in the construction industry

The EU Directive 2008/98/EC on waste outlines how Member States are to employ incentives as policy instruments to promote sustainable waste management (European Parliament and Council of the European Union, 2008). Incentives may take the form of financial bonuses or charges. Member States are expected to provide waste holders with the necessary conditions to implement waste prevention measures, deliver waste to facilities for the purpose of reuse, and prevent littering.

In AMA Construction 23, general guidelines are provided for the application of bonuses in construction contracts (Svensk Byggtjänst, 2023). Bonuses may be awarded when contractors achieve performance levels exceeding those stipulated in the contract, for instance, through improved functional performance or completion ahead of schedule. Bonuses may also be applicable when the contractor adds value for the client, for instance by reducing energy consumption or fulfilling other specified project objectives. Incentive-based contracts are typically applied in contractual relationships between clients and contractors, particularly in projects carried out on a cost-reimbursable basis. The bonus structure is generally determined in advance and based on defined performance levels. Bonuses can function as a governance mechanism to influence contractor behaviour and promote the overall achievement of project objectives.

The Swedish Transport Administration, as Sweden's largest infrastructure client, may impose requirements on the management of excavated soil during the procurement process. Compliance monitoring is necessary to ensure that these requirements are met (Eriksson et al., 2025; Andersson-Sköld et al., 2022). Interviews with contractors indicated a lack of incentives in the management of material to support the circular economy (Andersson-Sköld, et al., 2022). In contrast, other respondents argued that the contractor's current responsibility for the management of excavated soil created added value by encouraging the reuse of materials. The report includes a compilation of proposed key performance indicators derived from interviews, which could be used in an incentive model for the management of materials.

For road paving, there are established requirement levels for reductions in CO_2e per tonne (Tyréns, 2020). Some municipalities also employ incentive models. The structure of climate bonuses differs between clients, but commonly, the requirement for asphalt mixtures constitutes the baseline, with bonuses granted for percentage improvements in kg CO_2eq/tonne. Table 3 presents examples of bonus models applied in procurement.

Table 3. Examples of asphalt bonus models applied in three municipalities in relation to emission reductions (Tyréns, 2020).

Client	Requirement	Awarded to	Bonus
Linköpings Municipality	Ut=Hb*300+24 or Ut=HPMB*4+24	Asphalt mix producer	B=1.14*(Ut-Ua), SEK 1.14 per tonne of CO2 saved
Project in Uppsala	10 % reduction in climate impact compared to specified baseline levels	Contractor	SEK 100 per tonne of asphalt mix that meets the requirements
Mullsjö Municipality	Total emissions from asphalt production <25 kg CO2e/tonne respectively <20 kg CO2e/tonne over a 4-year period	Asphalt mix producer	SEK 75,000 respectively SEK 100,000

In Table 3, the following abbreviations are used: Ut = baseline level for standard bitumen or polymer-modified bitumen; Hb = quantity of standard bitumen; HPMB = quantity of polymer-modified bitumen; and Ua = emissions associated with the specific production process.

3 Method

This chapter describes the methodology applied in the study and the individual components included in the research process. Figure 5 provides an overview of the overall structure of the study, while each subsection presents detailed methodological information and a thorough description of the applied research procedures.

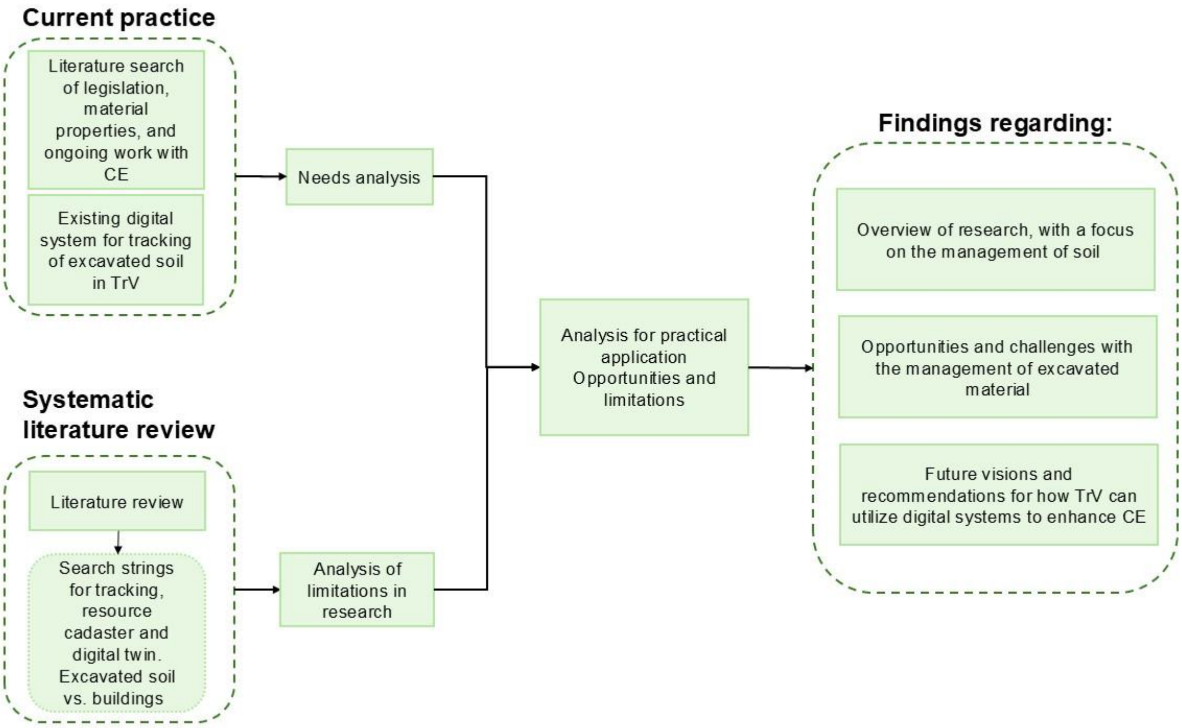

Figure 5. Illustration of the overall methodology.

3.1 Analysis of the current research

First, a literature search was conducted. Chapter 2 describes the management of excavated materials in relation to legislation and guidelines, ongoing efforts toward circular management of masses, and incentive models in infrastructure projects. The purpose of the literature review was to establish a comprehensive understanding and provide background information for a more in-depth analysis of the current state of research within the field. Searches were conducted using Scopus and Google. Scopus was used to identify relevant scientific research, primarily articles concerning the implementation and application of digital systems for mass management. Google was used to retrieve information related to legislation and guidelines, circular mass management, and incentive models in Sweden.

The second part of the current state analysis involved studying existing systems at The Swedish Transport Administration for management of excavated materials, with a particular focus on traceability and resource databases systems. Informal interviews were conducted with specialists in mass management, project managers, and software developers at the Swedish Transport Administration in order to obtain a comprehensive understanding of previous and current working methods, as well as ongoing development projects related to mass management. Two systems for the traceability of excavated material were examined in greater detail: the ELSA and a GIS-based system currently under development. ELSA is used, among other purposes, for the reporting of digital delivery notes for soil and excavated materials, and four projects within the software environment were studied. In addition to the two systems for tracking excavated materials, a system used for pavement and drainage measures, PMSv4, was also examined. Within this system, particular attention was given to how data related to implemented measures are structured and stored.

3.2 Analysis of the research situation in digital system for tracking of excavated soil and resource cadaster

The second part of the methodology consisted of a literature review of ongoing research concerning digital systems for tracking, resource cadastres, and digital twins for buildings and excavated soil. The literature review compares mass management with buildings in order to analyse the volume of research, assess the maturity of the respective research fields and what can be learned from the current research. Search strings were applied in Scopus based on a modified version of the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA). A table with the entire search string is presented in Appendix A.

PRISMA is a framework for the reporting of meta-analyses and systematic literature reviews. The purpose of the metodology is to ensure transparency and clarity in the research process by systematically documenting how the literature search was conducted, which inclusion and exclusion criteria were applied, and how studies were selected or excluded. PRISMA is a development of Quality of reporting of meta-analyses (QUOROM), whose earlier version primarily focuses on the reporting of meta-analyses. With the development of PRISMA, the methodology was expanded to also include systematic literature reviews, while both the flow-chart and checklist were revised to improve transparency. PRISMA includes a standardised flow-chart for the study selection process as well as a checklist consisting of 27 items covering the study title, abstract, introduction, methods, results, discussion, and findings.

In this study, a modified version of PRISMA framework was applied. Excluded components of the PRISMA framework included, for example, sensitivity analysis and analysis of funding sources. Furthermore, the study was conducted by a single researcher rather than by two independent reviewers. The study was limited to an analysis of the 150 most cited articles published between 2020 and 2026, as well as 50 of the most recently published articles for buildings. The rationale for including the most recent publications was to capture the latest research developments and not solely the most widely cited studies. The literature search was carried out in April 2026. Figures 6 and 7 were designed in accordance with the PRISMA recommended flow diagram.

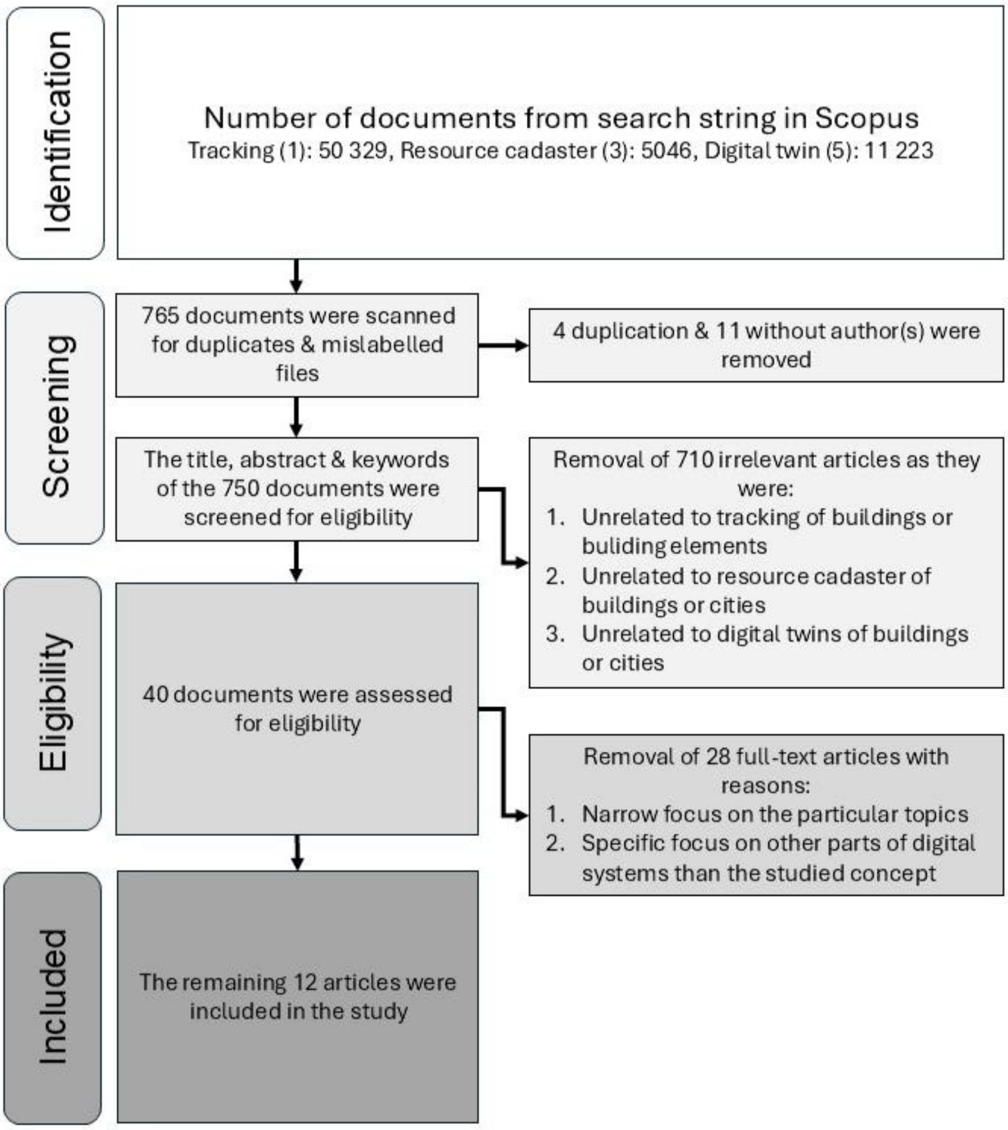

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Figure 6. PRISMA method for buildings, the methodology for the search strings.

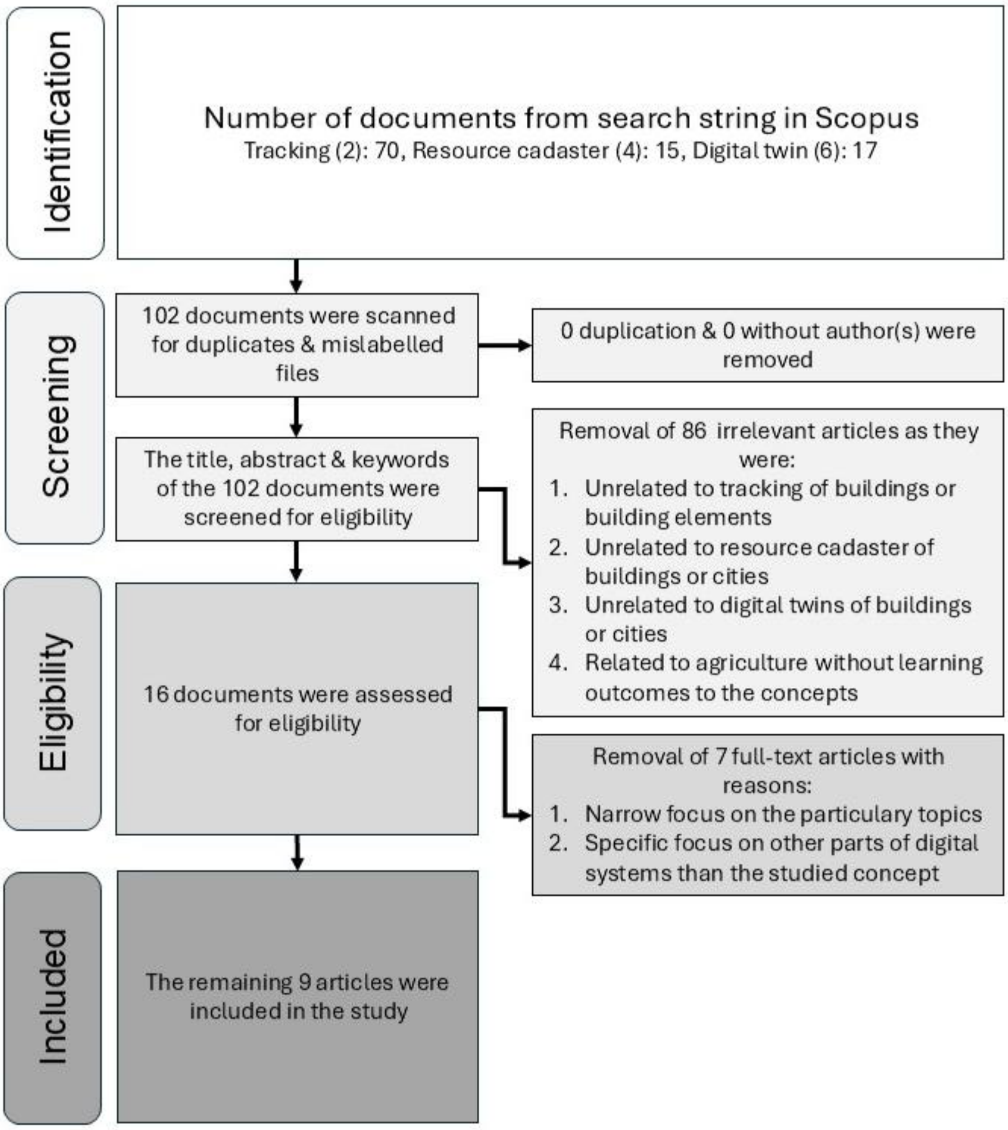

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Figure 7. PRISMA method for excavated soil, the methodology for the search strings.

3.3 Use of AI in this study

In this project, AI is used as a tool to evaluate the relevance of sources and to identify key areas within articles. Primarily, Google NotebookLM is used to assess the relevance of sources. Only open-source material is processed by using AI tools; no documents containing sensitive information is handled by these services. ChatGPT and Grammarly are used as tools to refine wording, grammar, and translation of text. AI is not used to generate or formulate original sentences.

4 Results

The results are divided into four sections. First, the systems currently implemented at the Swedish Transport Administration are presented. This is followed by the results obtained from the search strings, findings related to digital systems for buildings, and findings concerning digital systems for mass management within the fields of tracking, resource cadaster, and digital twins.

4.1 Current situation, digital systems at The Swedish Transport Administration

At the Swedish Transport Administration, two digital systems were identified as being used for the traceability and evaluation of mass management within infrastructure projects. One system is designed to collect digital delivery notes from receiving facilities, while the other is a GIS-based system that enables visual analysis of excavated soil management within projects. Digital delivery notes have been implemented in projects with contracts exceeding SEK 50 million after March 2024. The second system, a visual software platform, has not yet been applied to active projects and was therefore not analysed in greater detail beyond an informal interview with its developer. The long-term intention is for the digital delivery note system to be integrated with the GIS-based system for monitoring and follow-up purposes.

In this study, the software for digital delivery notes was examined through four projects that were under construction during spring 2026. The system facilitates the monitoring of materials transported from project sites to receiving facilities. The contractor is responsible for ensuring that digital delivery notes are submitted and transferred to the Swedish Transport Administration within short lead times. Although the system does not provide real-time updates, information is generally received within approximately one week after the masses have left the project site. The system does not account for the movement of excavated soil within a project or between different projects. Consequently, with the current system, it is only possible to track excavated soil transported from a project to a receiving facility with the wave system.

PMSv4 is used in connection with pavement and drainage measures. All measures related to pavement measures are reported and stored within the system. Consequently, for a selected road section, it is possible to identify both the year and the type of pavement applied at a specific location. In addition to PMSv4, containing pavement maintenance measures, the system also includes data relating to rut depth, annual average daily traffic, and road width. The software is available for both internal and external use. At present, the system is not used to manage unbound material, and no equivalent system currently exists for such applications.

4.2 Research on digital systems of excavated soil and buildings

The search conducted in Scopus resulted in a total of 66,700 search results distributed across six separate searches. Of these, 102 results concerned excavated soil, while 66,598 related to buildings. This corresponds to 99.85% for buildings and 0,15% for excavated soil of the total search results. The majority of the search results were identified within the research area "buildings" and the concept "tracking". Table 4 presents the number of search hits for each respective research area and concept.

Table 4. Results from the literature search with research area, concept, number of results, selected studies through screening, and selected relevant articles.

No.	Research Area	Concept	Number of Results	Screening	Used
1	Building	Tracking	50,329	250	3
2	Excavated soil	Tracking	70	70	5
3	Building	Resource cadaster	5,046	250	6
4	Excavated soil	Resource cadaster	15	15	1
5	Building	Digital twin	11,223	250	5
6	Excavated soil	Digital twin	17	17	3

Within the research area "buildings", a total of 42 studies were identified from abstracts as potentially relevant to each concept. Of these 42 reviewed articles, 12 formed the basis of the presented results. The included studies comprised seven systematic literature reviews and five empirical case studies. The studies primarily focused on technical solutions involving digital systems that can be integrated into the construction process, as well as technical solutions aimed at improving sustainability.

The studies were published between 2020 and 2026, with the majority published in 2020. Geographically, the research was conducted in Europe, China, the United States, Australia, and Canada. In addition to the articles identified through Scopus, three articles within the field of resource cadaster were included based on research conducted by researchers at the institution, Chalmers University of Technology.

Within the research area “excavated soil”, a total of 102 articles were identified through the literature search, followed by screening of titles, abstracts, and keywords; eight were considered relevant. The included studies mainly consisted of empirical case studies and experimental studies. The primary focus of these studies was on technical solutions for increased sustainability. All articles were published between 2020 and 2025, with the majority published in 2022 and 2023. Geographically, the research was concentrated in Europe and China, with only one study conducted outside these regions, in Australia. None of the included studies was carried out in Sweden.

4.3 Findings from research on digital systems for buildings

Research on the digitalisation of the construction industry in relation to traceability, resource cadasters, and digital twins is being conducted from several different perspectives. In many cases, the research also examines how multiple digital systems can be integrated to provide a comprehensive solution, for instance, by using digital twins for tracking purposes.

The article *Digital Twin for Supply Chain Coordination in Modular Construction* describes how digital twins can be used for real-time monitoring (Lee & Lee, 2021). In the proposed system, building information modelling (BIM), Geographic information system (GIS), and Internet of Things (IoT) are used as integrated components to provide information on component properties, the geospatial location, and movement through Global Positioning System (GPS) sensors installed on vehicles or components. One advantage of integrating these components into a digital twin is that the systems can communicate through application layers. Otherwise, data are typically converted into the same format. When converting, there is a risk that information with different formatting will be lost.

4.3.1 Digital tracking systems for buildings

Research is being conducted from several perspectives on how digital systems can be used to increase knowledge regarding the movement of materials from one location to another (Wang, et al., 2020; Jacoby & Usländer, 2020; Lee & Lee, 2021). In several studies, IoT is used to connect and process real-time information from GPS devices and sensors. IoT collects data from the physical environment and generates information about resources being managed. One challenge associated with construction projects is unstable network coverage, as IoT systems require network connectivity to transmit information in real time (Wang, et al., 2020).

In the study *A Systematic Review of Digital Technology Adoption in Off-Site Construction: Current Status and Future Direction towards Industry 4.0*, IoT is used together with Radio Frequency Identification (RFID) and GPS to monitor the movement of building elements from factories to construction sites (Wang, et al., 2020). RFID is a system consisting of three components: an antenna, a reader, and a tag. A tag is attached to the building element, and when it comes within the range of a reader, the location of the object can be identified. If one reader is located at the factory and another at the construction site, the location of the building element can be identified as well as the transportation between the locations. Data from RFID and GPS are processed through IoT in order to provide an overall perspective on the handling of building components.

Some challenges associated with implementing digital systems are examining traceability and digital twins (Wang, et al., 2020; Jacoby & Usländer, 2020). One of the major challenges within the industry is the use of common standards for data formats. Shared standards are required to ensure system compatibility and enable data transfer between stakeholders. The study *Digital Twin and Internet of Things – Current Standards Landscape* also identifies overlaps between standards for digital twins and IoT (Jacoby & Usländer, 2020).

4.3.2 Resource cadaster for buildings

Research on resource cadaster aims to map the resources stored within buildings and infrastructure (Lanau et al., 2024; Bhagya Jayasinghe & Waldmann, 2020; Lanau & Liu, 2020). The objective is to determine how resources stored in buildings can be used as secondary resources instead of primary resources, which constitutes an important aspect of the transition towards a circular economy. Digital systems play a key role in enabling such management practices. GIS and BIM are considered important tools for storing information and visually representing buildings (Lanau, et al., 2024)

A commonly used method within material stock analysis is the “bottom-up” approach, which, in simplified terms, involves multiplying the building size (m^2 of floor area) by the material intensity factor (MI) (Lanau et al., 2024; Marinova et al., 2020). The studies investigate the development of material mapping from different perspectives.

In *Developing an Urban Resource Cadaster for Circular Economy: A Case of Odense, Denmark*, the authors mapped the quantities of 46 different construction materials stored within the built environment (Lanau & Liu, 2020). The materials were located both in buildings and infrastructure. The study analysed the types and quantities of building materials used, as well as differences related to construction periods. The study concluded that significant quantities of products above ground could potentially be reused, as well as underground resources such as pipes and utility networks.

Large-scale studies of material stock mapping have been conducted in Austria and Germany, as well as in the United Kingdom and Ireland (Haberl, et al., 2021; Wiedenhof, et al., 2024). These studies analysed the spatial distribution and quantity of materials with spatial resolution of 10 meters for both buildings and roads. Both studies used satellite data, OpenStreetMap, and material intensity factors to estimate material quantities. The primary difference between the studies concerned the level of detail used for building classifications. The researcher for the study in the United Kingdom and Ireland in 2024 used nine building types instead of five to analyse the built environment (Wiedenhof, et al., 2024). Infrastructure objects were also divided into 32 categories instead of 21 in order to achieve higher precision. A higher level of detail enables improved accuracy when implementing the material intensity factor. In the United Kingdom, many buildings require renovation, and the study contributes broad information regarding the location and quantity of resources within society.

BIM-based tools are used in several studies to analyse material stocks in buildings. An article from 2020 examined how a BIM-based system can be used at the end-of-life stage of a building to quantify reusable resources within buildings (Akbarieh, et al., 2020). The researcher analyses how the level of detail, LoD, affects the level of information provided, where a higher LoD corresponds to greater graphical information and detail regarding building components. The required level of accuracy depends on the intended use of the information. If the information is intended to support dismantling processes, a high LoD is required. In an article from 2020 used BIM together with hypertext Preprocessor (PHP) scripting, HTML, and MySQL database management systems to store information regarding building components and materials (Bhagya Jayasinghe & Waldmann, 2020). The system was implemented as a case study on a building to demonstrate its functionality. The accuracy of the model depended on the precision of the BIM model as well as the quality of the database and data collection process.

Another study focused on developing a database of material intensities (kg/m^2) for six building materials: concrete, timber, steel, aluminum, copper, and glass (Marinova, et al., 2020). MI factors were adapted to four different residential building types: detached houses, terraced houses, apartment buildings, and high-rise buildings. Although the study was based on a limited number of samples, the authors concluded that the results were sufficiently reliable for estimating global average values for building components within each housing category.

In the literature, *Buildings as material mines*, in chapter 3, *Towards digitalization of resource cadaster for circular economy*, the researchers identified which building components stakeholders considered most useful for reuse during the building dismantling process (Lanau, et al., 2024). The role of the stakeholder, such as a type of company or a client, influenced the prioritisation of the reuse of elements. Interest in the reuse of doors and windows was highest. The study further identified three important categories to specify for doors as building elements: descriptive information, condition, and potential challenges that could prevent the reuse.

The studies identified several barriers to implementing resource cadaster on a large scale for existing buildings. First, the lack of detailed information regarding material types, composition, and quantities in existing buildings is problematic (Lanau et al., 2024; Bhagya Jayasinghe & Waldmann, 2020). In some cases, partial information exists, while in others the information is entirely lacking. Second, mapping materials in existing buildings at a detailed level requires considerable resources. Due to limitations in time and building-specific information, estimates based on building age, materials, and quantities are often necessary, resulting in lower reliability. A third challenge is that many older buildings were not designed for dismantling without damaging rebuilding components (Akbarieh et al., 2020; Lanau et al., 2024; Bhagya Jayasinghe & Waldmann, 2020). Further research is also required regarding contaminants and which building elements can be safely reused under current environmental regulations (Akbarieh, et al., 2020).

4.3.3 Digital twins, buildings

A digital twin is a virtual representation of a city or construction site that organizes and manages information (Jacoby & Usländer, 2020). The study *Digital Twin: Benefits, use cases, challenges, and opportunities* maps the application of digital twins across different industries (Attaran & Gokhan Celik, 2023). One of the identified sectors is the construction industry. Four technologies are identified as key enablers: IoT for data collection, AI for analysis and forecasting, Extended Reality for visualisation and interaction, and cloud services for storage.

In the construction industry, BIM is already well established. BIM provides static data, whereas digital twins deliver real-time data (Attaran & Gokhan Celik, 2023; Boje et al., 2020). In a digital twin, an integrated exchange occurs between the physical and virtual environments, resulting in higher precision (Pan & Zhang, 2023). During the construction phase, real-time monitoring enables comparisons between planned and actual outcomes, allowing projects to identify deviations in budget or schedule at an early stage (Attaran & Gokhan Celik, 2023). Bottlenecks within projects can also be identified more easily. If a digital twin has been used during construction, the system can subsequently be transferred to the facility manager upon handover to the operational phase (Boje, et al., 2020). During the operational phase, the digital twin can be used to improve energy efficiency and predict when installations and structural elements require maintenance (Attaran & Gokhan Celik, 2023). It is also possible to evaluate potential refurbishment solutions within the virtual model in order to determine the most economically beneficial alternative.

A literature study conducted in 2022 examined the contribution of GIS and BIM within digital twins for urban design (Xia, et al., 2022). The article describes GIS as contributing to the spatial analysis of the urban environment, while BIM contributes detailed information regarding the lifecycle of buildings. The researchers emphasised how the integration of GIS and BIM within a digital twin creates greater synergy between different disciplines, such as urban transport and urban spaces. The system contributes to improved efficiency, which is also supported by other studies. GIS and BIM are identified as important applications, although the researchers also highlight that integrating additional applications can improve the precision and accuracy of the model.

In another study, a digital twin platform was developed for the real-time monitoring of bridge structures based on design information and real-time data (Rico Thirion, et al., 2026). The platform is based on an identity-semantic-interaction-framework in which data are obtained from BIM, IoT, and semantic modelling protocols. In addition to data acquisition, IFC-based interoperability, parametric modelling, and cloud-enabled digital twin coordination form the basis of the platform structure. For bridge structures, the system is used for real-time monitoring of structural strain, automatically generating cases when structural damage is detected and managing digital inspection reports. The platform was evaluated against specified criteria and demonstrated high reliability and high efficiency, while eliminating the need for manual interventions.

4.4 Research on digital systems for excavated soil within tracking, resource cadaster, and digital twin

Research concerning soil and excavated materials is primarily conducted within the field of agriculture and focuses on optimizing soil quality in relation to food production. The food industry is extensive, and there are significant economic benefits associated with optimising food production processes. It is therefore not surprising that research efforts have mainly focused on this area. In the present study, only articles relevant to the management of soil in construction projects were considered. Studies related to agriculture were included only when the digital systems described were considered potentially applicable to the management of material within infrastructure projects, otherwise, studies were excluded.

Only a limited number of studies indexed in Scopus describe digital systems for mass management within the concepts of tracking, material databases, and digital twins. Within the field of resource cadaster, only one relevant source was identified. There are no comprehensive databases for soil data, and sampling procedures are not always conducted according to the same methodology or at consistent depths (Todd-Brown, et al., 2022). Furthermore, the researcher highlights significant advantages associated with maintaining a database for soil data in order to identify the materials present in the ground, should future interventions be required at the same location.

4.4.1 Digital systems for off-site tracking of excavated soil

The complexity of monitoring the materials leaving a project site depends on the destination of the excavated materials. When materials are transported to a receiving facility for storage, processing, or disposal, weighing systems are available both upon entry and exit from the facility. When materials are transported to private individuals or to other construction sites, it becomes difficult to track which materials and quantities have actually been transported. The following two subsections focus on how materials that are not transported from a project to a receiving facility can be monitored.

4.4.1.1 A BIM-GIS-IoT-Based system for real-time monitoring

In a study conducted in Shenzhen, China, a framework integrating BIM, GIS, and IoT is presented to enable circular management of excavated materials (Huang, et al., 2022). The primary purpose of the system is to facilitate real-time sharing of digital information among stakeholders within the construction supply chain. The system is structured according to a Service-Oriented Architecture (SOA), consisting of five functional layers: the application layer, the service domain layer, the application support layer, the data layer, and the infrastructure layer. This structure enables collaboration between authorities, contractors, transport companies, and receiving facilities through a shared database.

BIM is an established system within the construction industry, but the technology is used only to a limited extent for the management of excavated soil (Huang, et al., 2022). The integration of GIS enables the detailed information contained within the BIM model to be complemented with large-scale contextual information, allowing topography and geology to be considered. IoT technology is used for real-time synchronisation, where GPS enables real-time tracking of transport.

The system can also be used to perform advanced simulations during the planning phases (Huang, et al., 2022). By integrating geological reports directly into the digital model, the system can automate volume calculations and material classification. This provides a decision-making basis for proposing potential applications for excavated materials while also optimising transport routes to minimize costs and environmental impacts. The researcher concluded that substantial cost savings could be achieved when excavated materials were reused within construction and civil engineering projects instead of being transported to landfill.

4.4.1.2 Implementation of digital traceability of excavated soil in France

In France, the legalisation of digital traceability in 2023 marked a significant step towards improving the management of excavated materials in construction projects (Villette & Dumas, 2023). The legal requirements aim to enhance the CE by increasing the use of excavated materials, while also clarifying the developer's legal responsibility for generated waste and ensuring its proper handling. The stricter regulatory framework has driven the development of digital systems for monitoring the lifecycle of excavated materials.

To address these requirements, Altaroad has developed a cloud-based platform that combines IoT technologies with AI to provide automated traceability of excavated materials (Villette & Dumas, 2023). In addition to traceability, the system functions as an operational tool to optimise logistics and environmental performance. Data collection is carried out automatically via IoT sensors, minimising the need for manual data entry. These sensors connect the physical construction site to the digital platform. Instead of a traditional weighing system, a weigh-in-motion system, TopTrack, is used. This is a dynamic weighing system installed directly in the roadway at the exit of the construction sites. As the lorry passes over the sensors, axle load and total weight are measured, which eliminates the need for the vehicle to stop. The weighing system is integrated with a licence plate recognition camera that automatically identifies each vehicle. Based on the weighing system and identified vehicles, digital consignment notes are generated, which can be sent directly to the driver's mobile device and displayed at the receiving facility.

Data processing is carried out in real time using AI-based analysis, enabling project management to gain full visibility of material flows (Villette & Dumas, 2023). In the event of deviation, warning messages are issued in real time, for instance, if a vehicle has an overload or underload. These real-time alerts help ensure safe transport and optimise the number of journeys. Based on defined data and parameters, the system can compile and analyse environmental data. For instance, carbon emissions can be calculated based on transport distance, number of trips, and load weight. The system also identifies the proportion of materials directed towards reuse versus landfill, facilitating the monitoring of environmental targets. Digital monitoring reduces the administrative workload for project managers and increases the traceability of materials leaving the site.

4.4.2 Digital systems for on-site tracking of excavated soil

Tracking of excavated soil on-site is more complex. In the article *Vision-based Explainable Action Recognition Model for Polluted Soil Tracking,* the researcher investigates how sensors and cameras can be used to monitor the movement of materials within a construction site (Viannay, et al., 2023). The research focuses primarily on construction machinery and its movement patterns, which can contribute to improved control over how many materials are relocated within the site area. This represents an initial step towards understanding how excavated materials are moved on-site using machinery. Achieving comprehensive control also requires awareness of material quantities and composition, not solely information regarding movement patterns.

4.4.3 Digital systems for real-time monitoring of road construction

Convolutional Neural Network (CNN) is a form of AI in which information about materials is collected using physical hardware such as sensors or cameras (Fantilli et al., 2023; Zhang et al., 2025). The system can analyse visual information related to structural characteristics, cracks, and colour variations. In the article *ADVANTEX: Research of innovative tools to support the logistics of the use of excavation materials produced by the Lyon-Turin railway line for the best sustainability and circular economy of the process*, CNN technology was used to identify different rock types and estimate grain sizes in excavated materials (Fantillli, et al., 2023). This analysis was limited to individual observations at specific points in time.

To identify changes over time, CNN must be combined with Long Short-Term Memory (LSTM) (Fantillli, et al., 2023). While CNNs extract spatial and visual features, LSTMs enable the analysis of time-series data and the identification of trends. Based on data collected from IoT sensors, an LSTM can model the evolution of physicochemical parameters such as pH, moisture content, and conductivity in soil. Through this combination, both the current condition and patterns of change can be analysed, enabling more advanced monitoring of soil quality. Furthermore, LSTM can be used to generate forecasts of future conditions based on historical data and provide early warnings when threshold values are at risk of being exceeded. In the article *Intelligent Monitoring and Management of Soil Quality based on Deep Learning Algorithm*, IoT sensors were combined with CNN and LSTM technologies to monitor soil quality with the aim of optimizing agricultural production (Zhang, et al., 2025).

The researcher compared the accuracy of sensor- and AI-based methods with traditional sampling approaches and concluded that the systems demonstrated high precision and reliability.

Another method for monitoring land conditions is Digital soil mapping and assessment (DSMA), which encompasses both digital mapping and assessment techniques (Searle, et al., 2021). In the article *Digital soil mapping and assessment for Australia and beyond: A propitious future*, the future development of DSMA is analysed with a focus on the coming 10 to 50 years. The researchers investigated the significance of DSMA under two future scenarios: a slow decline scenario, in which the technology is used to manage crises and degradation in land use, and an outlook vision scenario, where DSMA functions as a strategic enabler for innovation and sustainable land use. The researchers concluded that highly accurate data collection is required in order to create a digital twin of land use capable of supporting information gathering and decision-making. A digital twin should consist of multiple dimensions, including remote sensing technologies in which drones generate high-resolution maps, as well as in-situ sensors that provide real-time data directly from the ground. Machine learning and AI are and are expected to become key components in managing and processing large volumes of data in order to simulate and predict the effects of different forms of land use.

5 Discussion

Management of excavated soil is a complex issue that significantly affects both project economics and environmental impact, depending on how the materials are managed. The complexity arises partly from the fact that material composition and contamination levels influence the possible areas of application, partly from the uncertainty associated with the excavation of material, and partly because projects often operate according to just-in-time principles. Meaning that the right material must be available at the right time. Research is currently being conducted on how infrastructure projects can transition from a linear to a circular economy. Digitalisation within mass management has considerable development potential. Research and development within this field play a crucial role in evaluating and implementing digital systems that contribute to the circular management of excavated soil.

5.1 Analysis of the research landscape for buildings and excavated soil within digital tracking, resource cadaster, and digital twins

The results indicate that substantially more research has been conducted on digital systems for buildings compared with the management of excavated soil. The terms *soil* and *excavated soil* are narrower concepts than buildings, which affects the number of search results obtained. It should also be noted that more exclusion terms were applied in the searches related to buildings compared with excavated soil. This was done to compensate for the broader scope of the primary search term, *buildings*. The delimitations were selected systematically to provide as representative and comparable a picture as possible.

The methodological choice to use PRISMA alongside Scopus searches was based on the intention to examine and evaluate relevant research in the field. It cannot be ruled out that some relevant research was excluded from the study. This is partly due to the extensive body of research on buildings relative to the study's limited timeframe, which allowed screening only 250 articles per concept. In addition, studies published on platforms other than Scopus were excluded from the search. Only two studies included in the review were not retrieved from Scopus, as there was prior knowledge that research on resource cadaster within buildings was being conducted at the Department of Architecture and Civil Engineering at Chalmers University of Technology.

Scopus is a comprehensive database of scientific publications that covers a substantial share of ongoing research. Some research is published exclusively through other platforms. In addition, research and development activities are also conducted by companies and public authorities. In Sweden, organisations such as the Research Institution of Sweden, RISE, VTI, and Ecoloop do research that is more practically applicable to work in the field. Even some contractors are developing their own strategies, but these are not officially published and are handled internally only. Efforts to advance the industry and promote research within the CE are therefore taking place in several sectors, which contribute both to the development of research perspectives and to practical implementation.

5.2 Strategies for the Swedish Transport Administration to achieve circular management of excavated soil

A comprehensive system for managing excavated materials, both within and outside the construction sites, is required to achieve circular management of excavated soil with control throughout the entire process chain. Maintaining control over material flows throughout the chain provides several advantages. It improves traceability and enables the management process to become measurable, while also creating incentives for contractors to adopt circular mass management in practice. The implementation of digital systems can also reduce the administrative burden. One example is the current ELSA system used by the Swedish Transport Administration, in which physical delivery notes have been replaced with digital documentation. Research on digitalisation is ongoing both in relation to the management of excavated soil and, to an even greater extent, within the building sector.

As the largest client for infrastructure projects in Sweden, the Swedish Transport Administration has a crucial role in the transition towards circular management of excavated soil. Through its position as a major client, the organisation can establish standards for how the industry should address these issues and impose technical and environmental requirements to support further development. Collaboration with other authorities, such as the Swedish EPA, is essential to ensure that requirements both achieve their intended effects and are practically feasible to implement. The collaboration surrounding the BEAst industry standard, in which Peppol manages communication between digital system services, represents a concrete example of industry-wide coordination. The Swedish Transport Administration must establish standards and possess the necessary tools to monitor compliance with its requirements. Digital systems for the management of excavated materials provide a resource efficient approach for monitoring compliance with such requirements.

Efforts to achieve circular mass management within projects commissioned by the Swedish Transport Administration should be divided into several sub-areas: tracking, real-time monitoring, and resource database. Tracking to improve knowledge regarding the management of material and enable the measurement of climate impacts. Real-time monitoring to provide an overview of the status of construction sites. Resource cadaster to provide information regarding both bound and unbound material layers within and beneath road structures. The recommendations regarding how the Swedish Transport Administration should proceed towards circular management of excavated soil are based on personal experience, informal interviews, and ongoing research. The proposed measures should be valid though future case studies in order to evaluate their practical feasibility.

5.2.1 Tracking of excavated materials within Swedish Transport Administration projects

Traceability of excavated material must be achieved both within and outside a project's boundaries. Based on current research and available technologies, monitoring how excavated materials are moved within the construction sites remains challenging. Road and railway projects commissioned by the Swedish Transport Administration are conducted over limited time periods and generally extended across large geographical areas. Consequently, the implementation of cameras and sensors installed throughout project sites is difficult to achieve in the short term. However, cameras and sensors may in the future form a part of the data collection systems, most likely through installations on vehicles and within the ground.

In the long term, a combination of soil models, a camera capable of scanning the load volume in the bucket on the excavator, and IoT sensors may provide a potential solution for tracking excavated materials within projects. The ground model would need to contain environmental and material-technical properties and should form the basis for analysis, dividing the project area into zones according to material properties and potential applications. On-site, excavator operators should have access to the soil model through the computer system and be equipped with GPS-enabled machinery fitted with a camera connected to the excavator bucket using CNN functionality to analyse the load. Figure 8 illustrates a flowchart of the described activities.

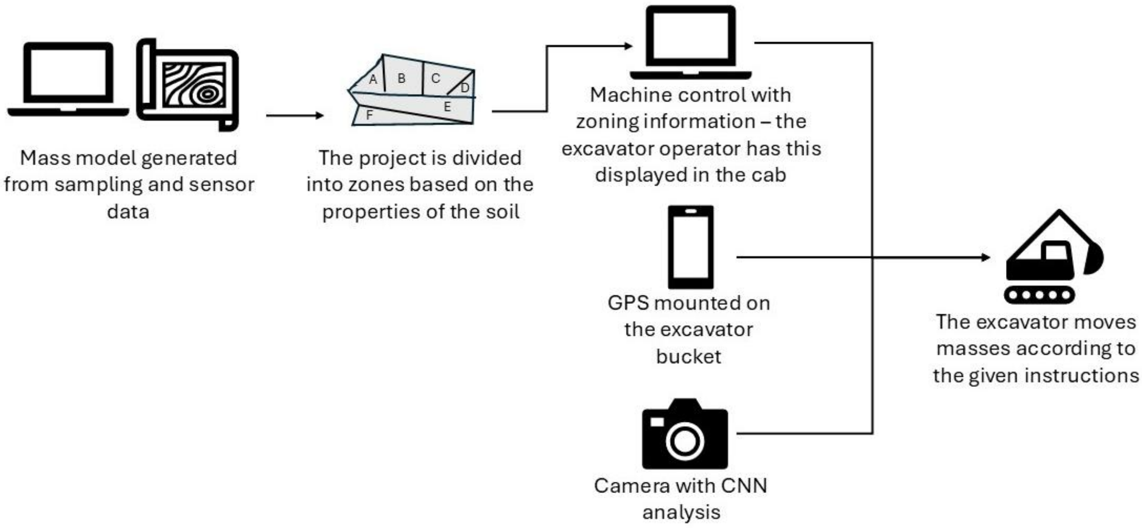

Figure 8. Overview of coordination for the movement of masses within a project.

Once the excavated material has been removed, GPS data can be used to trace how the excavator has moved within the project area and how the excavator bucket has transported materials from one location to another throughout the day. Large quantities of data will need to be processed in order to visualise material movements in an effective manner. For efficient management of data, the potential use of programming scripts or artificial intelligence for data processing should therefore be investigated. Before AI is implemented, its security and reliability should be validated. Infrastructure may constitute assets of importance to Sweden's national security, and system implementation therefore requires careful evaluation before deployment.

5.2.2 Tracking from Swedish Transport Administration projects to receiving facilities

The ELSA system, which is currently used by the Swedish Transport Administration, represents a useful initial step to monitoring the management of excavated material outside project boundaries. The system is not sufficient for monitoring the management of materials within projects. However, it is beneficial that the Swedish Transport Administration can track how excavated soil is transported from a project to a receiving facility. Nevertheless, the objective of circular management of excavated soil is to minimize the proportion of materials transported to landfill. Instead, excavated materials should primarily be reused within the project or in other projects. Consequently, digital monitoring becomes even more important for materials that are reused directly rather than transported to receiving facilities.

At the Swedish Transport Administration, a visual platform in GIS, currently under development, provides a suitable basis for further work related to monitoring excavated material flows. The Swedish Transport Administration should investigate whether it is possible to develop a Service-Oriented Architecture (SOA) system similar to the framework presented in the article *A BIM-GIS-IoT-Based System for Excavated Soil Recycling*, in order to obtain real-time updates regarding how materials transported by lorries are moved between locations. Data regarding transportation movements could subsequently be used to evaluate climate impacts and monitor the number of transports to different destinations. The Swedish Transport Administration should also further investigate how France has worked to improve the traceability of excavated materials, including which aspects have functioned effectively and which implementation challenges have been identified.

5.2.3 Resource database for material within Swedish Transport Administration infrastructure

Research concerning material resources stored within buildings and infrastructure is being conducted at large urban scales and for individual building components. The infrastructure studied includes roads, railways, pipelines, and utility systems. The composition of unbound material layers has received limited attention. Nevertheless, both the level of detail and the precision within the research have increased over the past six years, both regarding individual building elements and the number of defined residential building categories.

A major challenge for further research will be to identify building materials within the existing structures with sufficient reliability for stakeholders to be willing to select secondary materials instead of primary resources. Similar challenges exist within the management of excavated soil, namely the need to establish confidence that contractors will receive the expected quality when using secondary materials. Based on experience from discussions with contractors, the lack of information regarding material composition and material location represents a significant risk when secondary materials are used instead of virgin materials. The implementation of resource databases for unbound material layers within Swedish Transport Administration infrastructure could reduce these risks.

The use of the resource database for unbound materials is currently not implemented. Systems for unbound material layers already exist within the Swedish Transport Administration. PMSV4 is currently used for the documentation of new construction and maintenance of asphalt layers. Since a form of resource database already exists for pavement structures, it would be advantageous to integrate mass management into the same system in order to obtain a comprehensive representation of the road structure. One of the primary challenges associated with intergeneration of mass management into such a system is maintaining control over where the individual loads of excavated materials are placed and ensuring adequate documentation. In most cases, each layer within the bound pavement structure is homogeneous, whereas excavated materials may vary significantly between different loads. Addressing this challenge requires that projects maintain accurate records regarding which materials are transported to the site, establish clear design specifications regarding where different materials should be used, and ensure that contractors follow the same implementation plan. Compared to many building components, excavated materials already have well-defined classifications regarding material technical properties through AMA standards and environmental classifications through the Swedish EPA. Before a standardised system is implemented, both the classification framework and the associated standards should be reviewed. Based on existing research and practical experience, each project area should be classified according to both a material technical parameter and an environmental parameter.

There are several advantages associated with implementing a resource cadaster for excavated materials, particularly in connection with the reconstruction of existing roads. In many projects, limited knowledge regarding the materials located beneath existing roads creates difficulties during the design phase and increases risks during construction. Improved knowledge regarding subsurface materials would create better conditions for effective project planning and increase awareness during construction regarding how excavation adjacent to existing roads should be performed. Furthermore, it would become easier to determine in advance whether existing excavated materials can be reused within the project or should instead be transferred to another project. Improved precision regarding projected material surpluses would also facilitate communication when identifying other projects requiring excavated materials. The implementation of a resource cadaster for excavated materials may therefore contribute both to cost efficiency and to risk reduction.

5.2.4 Incentive models in the construction industry

An incentive model is an effective measure for increasing contractors' motivation to use resources instead of disposal them. However, a holistic perspective is required, where the Swedish Transport Administration is able to trace and monitor how the excavated soil has been managed to ensure that the digital model is capable of achieving its intended purpose. Consequently, a system for digital traceability is required before an incentive model should be implemented.

Based on studies of incentive models for pavement and informal interviews with contractors, it is appropriate to design the model as a tiered model with different levels. If only one level exists, there is a risk that contractors will strive merely to achieve the limit required for the bonus, after which the motivation to continue working circularly may disappear. A tiered incentive model enables contractors to work towards different levels depending on their ambition and level of interest. The bonus should take the form of financial compensation to the contractor.

The challenge in designing an incentive model lies in the fact that the conditions for circular management of masses differ between projects. The material, technical, and environmental properties affect the possibilities for use of the material, as well as whether the material is heterogeneous or homogeneous. Initially, the incentive model should only include masses classified as <MKM and meet the requirements for constructability in accordance with AMA. Excavated soil containing invasive species should not be included.

6 Conclusion and recommendations

This chapter presents the conclusions and recommendations for future research. The conclusion summarises the primary aspects of recent research that may be feasible to implement within projects commissioned by the Swedish Transport Administration in both the short and long term.

6.1 Conclusion

The Swedish Transport Administration has established a digital system for tracking excavated soil from a project to a receiving facility and PMSV4 as a resource database for the asphalt layer, but information regarding the subbase layer and soil is missing. However, ELSA remains fragmented and provides limited opportunities for comprehensive monitoring and traceability of material flows throughout the project lifecycle. The reviewed literature consistently indicates that digital systems that enable traceability are necessary to obtain a comprehensive overview of material flow and to support effective decision-making in mass management. At the same time, the amount of research specifically addressing the management of excavated soil remains limited. Consequently, this study also examined research and practical applications from the wider construction sector to assess the potential applicability of digital tracking systems, digital twins, and resource cadastres within infrastructure projects.

Research from the building sector provided deeper insights into the development and implementation of the resource cadaster. Existing studies examine how resource databases for both existing assets and newly constructed buildings can be documented, as well as the level of detail required for building elements to be meaningfully represented with such registers. For the management of excavated soil, the Swedish Transport Administration has a crucial role to play as Sweden's largest infrastructure client in driving development and promoting the implementation of digital systems that enhance material traceability. However, such implementation will need to be undertaken in stages.

In the short-term perspective, the Swedish Transport Administration should continue the development of ELSA and GIS-based systems for mass management so that they become integrated into a unified platform enabling project monitoring and follow-up within a single system. In addition to existing functionalities, the system should include tracking of excavated material both within a project and, if relevant, between projects, i.e., also for materials that are not transported to receiving facilities. Traceability should be enhanced through the implementation of an IoT-based system in which lorries are tracked using GPS technology. By monitoring vehicles' movements, transport distances can be specified and climate impacts calculated. Information should be available regarding the type of material and its properties in each load, together with the quantity of material (in tonnes) transported.

A major challenge concerns the classification of excavated materials within the project area. As an initial measure to enable classification of all masses, all materials that should be transported outside the project area could be sampled and documented at receiving facilities. Even if they should be used directly in another project or transported to a private individual. However, materials intended for reuse within a project must remain on site, and it must be possible to track not only their movement but also their environmental and material technical properties as they are relocated from one location to another. Consequently, the implementation of a comprehensive digital tracking system within construction sites should be regarded as a long-term objective rather than a measure that can be implemented under current conditions.

In the long-term perspective, the Swedish Transport Administration should investigate how a resource database could be established for the unbound layers within road structures. Before such a database can be developed, traceability of material movements within and between projects must first be established. Improved knowledge regarding the entire road structure would enable more resource-efficient management during reconstruction or demolition projects. During the design phase, greater opportunities would exist to plan how excavated materials should be utilised, while during the production phase, risks could be reduced by selecting measures based on known site conditions.

6.2 Recommendation for the implementation of digital systems for tracking and resource cadaster.

The Swedish Transport Administration, as the largest client in Sweden of infrastructure, has a responsibility to develop the industry. They should implement a digital tracking system that includes not only tracking material flow from a project to a receiving facility, but also movements within a project, and to another project or a private individual. GPS technology should be installed in trucks to enable tracking and processing of transport-related data through an Internet of Things (IoT) system. Table 5 presents the parameters that should be included in a system for how materials are moved between the projects and to provide a holistic perspective on the management of excavated soil in Sweden. The information regarding transportation between projects should be visualized in GIS.

Table 5. Parameters that the digital traceability software should include to provide a holistic overview of the management process.

	Unit	**Comments**
Contract	Only numbers, no unit	Agreement for a project between the contractor and the client.
Number for the delivery note	Only numbers, no unit	
Date and time of loading	20XX-XX-XX, XX: XX	Date and then time, the 24-hour clock shall be used.
Delivery date and time	20XX-XX-XX, XX: XX	Date and then time, the 24-hour clock shall be used.
Date and time of reporting in the system	20XX-XX-XX, XX: XX	Date and then time, the 24-hour clock shall be used.
Vehicle registration number		
Fuel type of the vehicle		The type of fuel used by the vehicle shall be specified (diesel/petrol/hydrogen/electricity/other (please specify)).
Fuel Consumption	gCO_2/km	Number of grams of carbon dioxide emissions that the truck consumes per kilometer
Location of loading, name	Name	
Coordination's of loading	(x,y)	Coordinates shall be specified in SWEREF 99, with the x-coordinate stated first, followed by the y-coordinate.
Location of delivery, name	Name	
Coordination of delivery	(x,y)	Coordinates shall be specified in SWEREF 99, with the x-coordinate stated first, followed by the y-coordinate.
Transport distance	km	Transport distance between loading and delivery
Quantity delivered	tonnes	Each load for a truck must be weighed separately
Material technical classification	AMA-code	The material code defined in AMA shall be used to describe the technical properties of the material.
Environmental classification	<MRR, >MRR<KM, >KM<MKM, >MKM<FA, >FA	The environmental classification defined in the Swedish EPA shall be used.
Material structure	Homogeneous or heterogeneous	

A resource database is required to maintain an overview of the resources present within the road structure, as well as the site-specific conditions. The database constitutes an important asset during reconstruction projects, both identifying potential opportunities and activities. Knowledge of the materials contained within the structure enables excavation works to be carried out in an appropriate manner. Table 6 presents the parameters that a GIS-based resource database should include to ensure reliability.

Table 6. Parameters to be included in a digital resource database system.

	Unit	**Comments**
Road/Railway	Number	The name (number) för the road or railway
County	Name	
Municipality	Nane	
Date	20XX-XX-XX,	Date when the measure is implemented
Coordination's start point	(x,y)	Coordinates shall be specified in SWEREF 99, with the x-coordinate stated first, followed by the y-coordinate.
Coordination's end point	(x,y)	Coordinates shall be specified in SWEREF 99, with the x-coordinate stated first, followed by the y-coordinate.
Distance	m	Distance between start and end points for the measure.
Superficial deposit of layer n	Name	It usually consists of different layers. The layers should be divided based on when properties vary with depth. The number n depends on its properties.
Depth of the layer n	m	The depth for a specific layer
Area, layer n	m^2	The spatial distribution of a material
Material technical classification, layer n	AMA-code	The material code defined in AMA shall be used to describe the technical properties of the material.
Environmental classification, layer n	<MRR, >MRR<KM, >KM<MKM, >MKM<FA, >FA	The environmental classification defined in the Swedish EPA shall be used.
Material structure, layer n	Homogeneous or heterogeneous	
Comments	Text	If there is any notifications that needs to be taken in consideration or something else

6.3 Recommendations for future studies within the digital system

The current volume of research concerning digital systems for the management of excavated materials remains limited. Further research is therefore required to investigate how digital systems can be practically implemented for mass management. Future studies within this field should focus on the following areas:

- Further research should investigate the sampling density required to achieve reliable resource databases, considering factors such as material heterogeneity, type of soil, or whether other parameters need to be taken into consideration.
- Further studies are required to investigate how and when excavated materials should be classified and weighted efficiently before being transported to another project or to a private individual.
- A case study, where the proposed digital system for tracking should be implemented in a real project and evaluated. The case study should validate whether all proposed parameters are necessary and identify any missing parameters. If additional parameters are required, the study should specify which ones and explain why.
- The soil model, which forms the basis for traceability within the project area, needs to be easily modified if it does not correspond to actual site conditions. Further research is needed to investigate how such a system could be designed to allow the excavator operator to revise the soil model manually or automatically during excavation.
- A literature review focusing on countries that have implemented digital traceability systems. What are the key success factors? Which type of system do they use? What software-related challenges exist? How has legislation been adapted to make implementation feasible in practice?

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8 Appendix

8.1 Appendix A

All articles have been studied, while for buildings, the first 10 that were relevant + the first 5 that were relevant of newly written articles have been studied, this is to avoid missing the latest research that has not yet had time to receive any citations.

No.	Research Area	Concept	Search String (Scopus)	Filters	Number of Results	Date	Number of relevant articles
1	Building	Tracking	(TITLE-ABS-KEY (building*) OR TITLE-ABS-KEY (construction) OR TITLE-ABS-KEY (built environment) OR TITLE-ABS-KEY (dwelling*)) AND (TITLE-ABS-KEY (tracking*) OR TITLE-ABS-KEY (IOT) OR TITLE-ABS-KEY (monitoring*) OR TITLE-ABS-KEY (traceability*)) AND NOT (TITLE-ABS-KEY (health) OR TITLE-ABS-KEY (agricultural*) OR TITLE-ABS-KEY (water*) OR TITLE-ABS-KEY (erosion*) OR TITLE-ABS-KEY (carbon*) OR TITLE-ABS-KEY (livestock*) OR TITLE-ABS-KEY (forest*) OR TITLE-ABS-KEY (crop*) OR TITLE-ABS-KEY (battery*) OR TITLE-ABS-KEY (city*) OR TITLE-ABS-KEY (5G*) OR TITLE-ABS-KEY (energy*) OR TITLE-ABS-KEY (Cyber*) OR TITLE-ABS-KEY (medicine*) OR TITLE-ABS-KEY (computer*)) AND PUBYEAR > 2019 AND PUBYEAR < 2027	Cited by (highest), 2020-2026	50.329	4/25/2026	3

2	Excavated soil	Tracking	(TITLE-ABS-KEY ("excavated soil") OR TITLE-ABS-KEY ("surplus soil*") OR TITLE-ABS-KEY ("excavated material*") OR TITLE-ABS-KEY ("sustainable mass management") OR TITLE-ABS-KEY ("circular mass management") OR TITLE-ABS-KEY ("soil management")) AND (TITLE-ABS-KEY (tracking*) OR TITLE-ABS-KEY (IOT) OR TITLE-ABS-KEY (monitoring*) OR TITLE-ABS-KEY (traceability*)) AND NOT (TITLE-ABS-KEY (health) OR TITLE-ABS-KEY (agricultural*) OR TITLE-ABS-KEY (water*) OR TITLE-ABS-KEY (erosion*) OR TITLE-ABS-KEY (carbon*) OR TITLE-ABS-KEY (livestock*) OR TITLE-ABS-KEY (forest*) OR TITLE-ABS-KEY (crop*)) AND PUBYEAR > 2019 AND PUBYEAR < 2027	Cited by (highest), 2020-2026	70	4/22/2026	5

3	Building	Resource cadaster	(TITLE-ABS-KEY (building*) OR TITLE-ABS-KEY (construction) OR TITLE-ABS-KEY (built environment) OR TITLE-ABS-KEY (dwelling*)) AND (TITLE-ABS-KEY (resource cadaster*) OR TITLE-ABS-KEY (resource register*) OR TITLE-ABS-KEY (resource database*) OR TITLE-ABS-KEY (resource inventory*) OR TITLE-ABS-KEY (resource mapping*)) AND NOT (TITLE-ABS-KEY (health) OR TITLE-ABS-KEY (agricultural*) OR TITLE-ABS-KEY (water*) OR TITLE-ABS-KEY (erosion*) OR TITLE-ABS-KEY (carbon*) OR TITLE-ABS-KEY (livestock*) OR TITLE-ABS-KEY (forest*) OR TITLE-ABS-KEY (crop*) OR TITLE-ABS-KEY (battery*) OR TITLE-ABS-KEY (city*) OR TITLE-ABS-KEY (5G*) OR TITLE-ABS-KEY (Cyber*) OR TITLE-ABS-KEY (energy*) OR TITLE-ABS-KEY (medicine*) OR TITLE-ABS-KEY (computer*)) AND PUBYEAR > 2019 AND PUBYEAR < 2027	Cited by (highest), 2020-2026	5.046	4/20/2026	4

4	Excavated soil	Resource cadaster	(TITLE-ABS-KEY ("excavated soil") OR TITLE-ABS-KEY ("surplus soil*") OR TITLE-ABS-KEY ("excavated material*") OR TITLE-ABS-KEY ("sustainable mass management") OR TITLE-ABS-KEY ("circular mass management") OR TITLE-ABS-KEY ("soil management")) AND (TITLE-ABS-KEY (resource cadaster*) OR TITLE-ABS-KEY (resource register*) OR TITLE-ABS-KEY (resource database*) OR TITLE-ABS-KEY (material stock*) OR TITLE-ABS-KEY (resource inventory*) OR TITLE-ABS-KEY (resource mapping*)) AND NOT (TITLE-ABS-KEY (health) OR TITLE-ABS-KEY (agricultural*) OR TITLE-ABS-KEY (water*) OR TITLE-ABS-KEY (erosion*) OR TITLE-ABS-KEY (carbon*) OR TITLE-ABS-KEY (livestock*) OR TITLE-ABS-KEY (forest*) OR TITLE-ABS-KEY (crop*)) AND PUBYEAR > 2019 AND PUBYEAR < 2027	Cited by (highest), 2020-2026	15	4/25/2026	1

5	Building	Digital twin	(TITLE-ABS-KEY (building*) OR TITLE-ABS-KEY (construction) OR TITLE-ABS-KEY (built environment) OR TITLE-ABS-KEY (dwelling*)) AND (TITLE-ABS-KEY (digital twin*) OR TITLE-ABS-KEY (virtual twin*) OR TITLE-ABS-KEY (digital replica*) OR TITLE-ABS-KEY (visual BIM representation*)) AND PUBYEAR > 2019 AND PUBYEAR < 2027	Cited by (highest), 2020-2026	11.223	4/25/2026	5
6	Excavated soil	Digital twin	(TITLE-ABS-KEY ("excavated soil") OR TITLE-ABS-KEY ("surplus soil*") OR TITLE-ABS-KEY ("excavated material*") OR TITLE-ABS-KEY ("sustainable mass management") OR TITLE-ABS-KEY ("circular mass management") OR TITLE-ABS-KEY ("soil-foundation*") OR TITLE-ABS-KEY ("soil management")) AND (TITLE-ABS-KEY (digital twin*) OR TITLE-ABS-KEY (virtual twin*) OR TITLE-ABS-KEY (digital replica*) OR TITLE-ABS-KEY (visual BIM representation*)) AND PUBYEAR > 2019 AND PUBYEAR < 2027	Cited by (highest), 2020-2026	17	4/25/2026	3

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