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THE SYSTEM OF SUSTAINABLE MANAGEMENT OF DEMOLITION WASTE: PRINCIPLES, METHODS AND PROSPECTS FOR DEVELOPMENT

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The full-scale war in Ukraine caused large-scale destruction of residential, industrial, transport and engineering infrastructure, which led to the formation of unprecedented volumes of destruction waste. Existing waste management systems formed to function in peacetime conditions have proven insufficiently adapted to the treatment of such waste streams. As of September 2025, about 17.2 million tons of waste have accumulated in the Ukrainian Government-controlled area alone, of which approximately 11.7 million tons need to be cleared, sorted and recycled. The considerable heterogeneity of waste composition, the presence of potentially hazardous components, limited resources and damage to infrastructure make it difficult to manage and reuse it safely.

The purpose of the study is to substantiate the theoretical foundations and develop a conceptual model of the system of sustainable management of destruction waste in the conditions of the post-war recovery of Ukraine. The methodological basis of the work is a systematic approach, content analysis of international and national regulatory documents, comparative analysis of modern practices of construction waste management and generalization of the results of scientific research in the field of circular economy.

As a result of the study, a system of interrelated principles of sustainable waste management of destruction was formed, which includes the principles of waste management hierarchy, material life cycle, circularity, extended responsibility, proximity, digital transparency and institutional coordination. A classification of management methods covering mechanical, thermochemical, biological, digital and organizational and economic methods is proposed. Conceptual and structural models of the management system have been developed, which integrate regulatory, technological, digital, economic, institutional and environmental components into a single management decision support system.

It is shown that up to 70% of the residual volume of waste from military destruction, which is about 8.2 million tons, can potentially be involved in reuse or processing as secondary material resources, provided that the relevant infrastructure is developed, digital systems for the traceability of material flows are implemented and economic incentives are created for the use of secondary raw materials. The proposed approach contributes to the implementation of the principles of the circular economy, reducing the volume of waste disposal, increasing resource efficiency and forming scientifically based mechanisms for the post-war recovery of Ukraine.
Key words: sustainable development, demolition waste, circular economy, waste management system, waste hierarchy, digitalisation, post-war reconstruction, CDW.

Система сталого управління відходами руйнації: принципи, методи та перспективи розвитку. Сорочинська О.Л., Хрутьба В.О., Іщенко В.А., Коломієць С.В.

Повномасштабна війна в Україні спричинила масштабні руйнування житлової, промислової, транспортної та інженерної інфраструктури, що призвело до утворення безпрецедентних обсягів відходів руйнації. Існуючі системи управління відходами, сформовані для функціонування в умовах мирного часу, виявилися недостатньо пристосованими до оброблення таких потоків відходів. Станом на вересень 2025 року лише внаслідок пошкодження та знищення житлового фонду на підконтрольній Уряду України території накопичилося близько 17,2 млн т відходів, з яких приблизно 11,7 млн т потребують розчищення, сортування та перероблення. Значна неоднорідність складу відходів, наявність потенційно небезпечних компонентів, обмеженість ресурсів та пошкодження інфраструктури ускладнюють їх безпечне управління та повторне використання.

Метою дослідження є обґрунтування теоретичних засад та розроблення концептуальної моделі системи сталого управління відходами руйнації в умовах післявоєнного відновлення України. Методологічною основою роботи є системний підхід, контент-аналіз міжнародних і національних нормативно-правових документів, порівняльний аналіз сучасних практик управління будівельними відходами та узагальнення результатів наукових досліджень у сфері циркулярної економіки.

У результаті дослідження сформовано систему взаємопов'язаних принципів сталого управління відходами руйнації, яка включає принципи ієрархії управління відходами, життєвого циклу матеріалів, циркулярності, розширеної відповідальності, наближеності, цифрової прозорості та інституційної координації. Запропоновано класифікацію методів управління, що охоплює механічні, термохімічні, біологічні, цифрові та організаційно-економічні методи. Розроблено концептуальну та струк-

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турну моделі системи управління, які інтегрують нормативно-правову, технологічну, цифрову, економічну, інституційну та екологічну складові в єдину систему підтримки управлінських рішень.

Показано, що до 70 % залишкового обсягу відходів воєнної руйнації, що становить близько 8,2 млн т, потенційно можуть бути залучені до повторного використання або перероблення як вторинні матеріальні ресурси за умови розвитку відповідної інфраструктури, впровадження цифрових систем простежуваності матеріальних потоків та створення економічних стимулів для використання вторинної сировини. Запропонований підхід сприяє реалізації принципів циркулярної економіки, зменшенню обсягів захоронення відходів, підвищенню ресурсоефективності та формуванню науково обґрунтованих механізмів післявоєнного відновлення України. *Ключові слова:* сталий розвиток, відходи руйнації, циркулярна економіка, система управління відходами, ієрархія управління відходами, цифровізація, післявоєнна відбудова, CDW.

Statement of the problem. Full-scale armed aggression against Ukraine caused large-scale destruction of residential, industrial, transport and engineering infrastructure. An international RDNA3 study conducted with the participation of the World Bank, the European Commission and the United Nations estimates that the volume of destruction waste in Ukraine is measured in millions of tons [1]. According to more recent data from the United Nations Development Programme, as of September 2025, approximately 17.2 million tons of waste had accumulated within the damaged and destroyed housing stock in the controlled area alone, of which about 11.7 million tons still need to be cleared, sorted and recycled [6; 7].

Existing waste management systems in Ukraine were formed for peacetime conditions and are not designed for such extraordinary loads. Much of the sorting, recycling and safe storage infrastructure is damaged or destroyed, and the regulatory framework did not, until recently, contain systematic mechanisms to control the preparation of destruction waste for reuse [8]. This leads to chaotic accumulation and placement of waste at landfills, increases the risks of soil, water bodies and air pollution.

At the same time, destruction waste, subject to the application of the principles of the circular economy, can be considered not only as an environmental problem, but also as an important resource for reconstruction. Therefore, it is not a separate technological or economic measure that is relevant, but the formation of a holistic system of sustainable management of destruction waste – with clearly defined principles, classified methods and a coherent institutional model.

Relevance of the study. Reconstruction of Ukraine requires significant volumes of building materials and energy resources, access to which is limited in the war and post-war periods. An important step in the formation of state policy in this area was the approval of the Action Plan for the implementation of the National Waste Management Plan for 2025–2033, which provides for the improvement of the waste management system from destruction, the conduct of analytical studies and the development of economic models for the management of such waste, as well as the creation of the necessary infrastructure, in particular, the formation of a network of local and regional mobile installations for the treatment of waste from destruction. A further step was the approval by the Cabinet of Ministers of Ukraine in February 2026 of the procedure for implementing the target indicators for the preparation of construction waste and destruction waste for reuse, processing and other material recovery, which imposes on enterprises that generate such waste the obligation to submit relevant declarations and annual monitoring of processing indicators [9; 10].

At the same time, the approximation of the Ukrainian regulatory framework to the requirements of the EU Framework Directive on Waste (2008/98/EC), which defines the hierarchy of waste management as the main methodological reference point, continues [2; 3]. In this context, the study of the principles and methods of building a system of sustainable management of destruction waste is relevant not only from an ecological, but also from an integration point of view, as it corresponds to Ukraine's course towards European integration and the formation of a transparent market for secondary building materials.

The connection of the work with important scientific and practical tasks. The study of the system of sustainable management of destruction waste corresponds to the strategic priorities of the restoration of Ukraine, the requirements of the legislation of the European Union in the field of waste management and the circular economy, as well as modern methodological approaches to the post-conflict restoration of territories. The work has a practical direction, as its results can be used by state authorities, local self-government bodies and enterprises of the construction industry during the development of regional and sectoral programs for the management of destruction waste.

Analysis of recent research and publications. The issues of construction and destruction waste (CDW) management are actively researched in the world scientific literature at the intersection of environmental, technological and socio-economic aspects.

In review I. Papamichael with co-authors [2] systematized the principles of circular economy in the management of the CDW and emphasized the defining role of the waste management hierarchy enshrined in the EU Waste Framework Directive. C. Zhang and co-authors [3], based on the analysis of the practice of EU countries, showed that the consistent application of the waste management hierarchy makes it possible to significantly increase the level of circularity of the construction sector and outlined the technological barriers of concrete processing.

T. G. Weerakoon with co-authors [4] proposed a multi-criteria decision-making (AHP) technique to select a construction waste management strategy, proving that environmental criteria carry the greatest weight among

economic, technical and social factors. S. Kaewunruen with co-authors [5] explored the possibilities of integrating BIM modeling and digital doubles to plan dismantling and account for material flows, which makes it possible to increase the transparency and cost-effectiveness of recycling processes.

The specifics of the management of destruction waste in the conditions of war in Ukraine are highlighted in the World Bank report on municipal management of destruction waste [8], which identified institutional and financial gaps, including the lack of mechanisms to compensate for the costs of dismantling and removing waste from private households. A study commissioned by the United Nations Development Program quantified the potential of waste processing in Ukraine and identified priority steps for 2026–2028 regarding the development of the secondary raw material market [6; 7]. Technological aspects of concrete debris recycling within the S3RoU (Safe, Sustainable and Swift Reconstruction of Ukraine) project, implemented with the participation of the University of Leeds, are considered in work [11], while examples of public initiatives for separate dismantling and reuse of building materials are given in the Yale Environment 360 material [12]. The conducted analysis shows that modern research mainly focuses on individual technological solutions or economic aspects of waste management. At the same time, the issues of integrating the principles of circular economy, digitalization and institutional management into a single system remain insufficiently developed, which determines the direction of this study.

Highlighting previously unresolved parts of the general problem, to which this article is devoted. Despite the presence of a significant body of research, most of them focus either on individual technological solutions (concrete processing, BIM accounting) or on economic or institutional evaluation separately, without forming a coherent system model that would combine principles, methods and organizational mechanisms into a single structure adapted to the conditions of post-war reconstruction. Approaches to the classification of destruction waste management methods according to their functional purpose within a single system also remain insufficiently developed.

This article is devoted to the elimination of the specified gap by developing a generalized system of principles and methods of sustainable management of destruction waste and substantiating the prospects for its development in the context of the reconstruction of Ukraine.

The novelty. The scientific novelty of the study consists in the development of a complex conceptual model of sustainable management of destruction waste, which combines seven interrelated principles and five groups of methods into a single system covering regulatory, organizational, technological, digital, economic, institutional and environmental components. Unlike the available research, which mainly focuses on certain technological or economic aspects of construction and destruction waste management, the proposed approach ensures their comprehensive coordination within a single concept focused on the implementation of the principles of the circular economy in the process of post-war recovery. The practical significance of the obtained results lies in the formation of a structural model suitable for use during the development of state and regional programs for the management of destruction waste, as well as to support management decision-making regarding the reuse of secondary material resources.

To specify the declared novelty, Table 1 shows the juxtaposition of the proposed approach with the key works analyzed in the previous section.

As can be seen from Table 1, the available studies mostly focus on individual aspects of CDW management, while the proposed model integrates these aspects into a single management decision support system.

Research methodology. The methodological basis of the research is a systematic approach to the management of destruction waste, which involves considering the processes of formation, sorting, processing and reuse of materials as interconnected elements of a single system. The work uses a complex of general scientific and special research methods. The method of system analysis was used to form the structure of the system of sustainable management of destruction waste and to determine the relationships between its regulatory, technological, digital, economic, institutional and environmental components. Benchmarking has been applied to collate traditional linear and circular waste management models. Content analysis of international and national regulatory documents, scientific publications and analytical reports of international organizations was used to determine modern principles and methods of destruction waste management. The generalization and systematization of the results made it possible to form a classification of the principles and methods of sustainable management and to develop a structural model of the system.

To ensure the logical sequence of the research, the methodical procedure was built in the form of six interrelated stages.

At the first stage, an analysis of international scientific publications, regulatory and legal documents and analytical reports of international organizations on the management of construction waste and destruction waste, the principles of the circular economy and the post-war restoration of territories was carried out in order to determine modern trends, problems and best practices.

At the second stage, the principles of sustainable management of destruction waste were systematized in accordance with the concepts of waste management hierarchy, material life cycle assessment, circular economy, digitalization and institutional management.

The third stage provided for the classification of destruction waste management methods according to their functional purpose, with the selection of five groups: mechanical, thermochemical, biological, digital and organizational and economic methods.

Table 1

Comparison of the proposed approach with the available research

Source/approach	Focus	What is missing compared to the proposed model
Papamichael I. et al. [2]	Principles of Circular Economics in CDW Management	Does not integrate technological methods and the digital component into a single decision support system
Zhang C. et al. [3]	Hierarchy of waste management in EU practice	Not adapted to the conditions of large-scale military destruction
Weerakoon T. G. et al. [4]	Multi-criteria decision making (AHP) to choose a waste management strategy	Focus only on the decision-making procedure, without a structural model of the system
Kaewunruen S. et al. [5]	BIM modeling and digital doubles for disassembly planning	Considers only the digital component, without regulatory and institutional components
World Bank [8]	Institutional and financial gaps in the management of destruction waste in Ukraine	Diagnosis of the problem without proposing a holistic conceptual model
Proposed model (this study)	Integration of seven principles, five groups of methods and six functional constituents	It integrates the regulatory, technological, digital, economic, institutional and environmental components into a single management decision support system

Table 2

Principles of the system of sustainable management of destruction waste

Principle	Essence and role in the system
Hierarchies of waste management	Priority of waste prevention, hereinafter – reuse, recycling, recovery and only last landfill (according to the logic of the Waste Framework Directive 2008/98/EC) [2; 3].
Life cycle of materials	Taking into account the impact of building materials on the environment at all stages – from extraction of raw materials to dismantling and re-engagement in circulation.
Circularity	Replacing the linear model «mining – production – waste» with a closed cycle of material circulation, which minimizes the attraction of primary resources [2–4].
Extended responsibility	Assigning responsibility for waste management to all participants in the life cycle of the – developer, contractor, owner, local self-government body.
Proximity and priority of local processing	Placement of sorting and processing facilities as close as possible to waste generation sites to reduce transport costs and emissions.
Digital transparency and traceability	Mandatory digital accounting of material flows (BIM models, registers, «material passports») to control the volume and quality of secondary raw materials [4; 5].
Institutional coordination	Concerted interaction of state authorities, local self-government bodies, business and public initiatives within a single regulatory framework [8; 9].

At the fourth stage, using system analysis, the relationships between the principles, methods and functional components of the management system were determined, which made it possible to form its hierarchical structure.

At the fifth stage, the author's conceptual model of the system of sustainable management of destruction waste was developed, which integrates regulatory, technological, digital, economic, institutional and environmental components into a single system of support for management decisions.

At the final, sixth stage, the proposed conceptual model was compared with modern international approaches presented in the scientific literature and documents of international organizations, which made it possible to assess its conceptual coherence and potential suitability for use in the conditions of the post-war reconstruction of Ukraine.

Presentation of the main material. As stated above, the volumes of accumulated destruction waste already exceed the capabilities of the traditional construction waste management system formed for peacetime conditions. According to estimates by international organizations, up to 70% of this volume could potentially be used as secondary material resources, provided that an effective system of their management is established [6; 7].

The obtained results indicate that the solution to the specified problem cannot be limited to the introduction of individual processing technologies or the improvement of regulatory and legal regulation. Significant volumes of waste, their heterogeneous composition, spatial dispersion of places of formation and the need to ensure environmental safety require a comprehensive systematic approach that combines all stages of destruction waste management within a single functional structure.

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The work proposes to consider the system of sustainable management of destruction waste as a set of interconnected organizational, technological, informational, economic and environmental processes aimed at maximum preservation of material resources and minimization of negative impact on the environment. Compared to the traditional approach, which is focused mainly on waste disposal, the proposed system is based on the principles of a circular economy and provides for the return of the maximum possible share of materials into economic circulation.

The basis of the developed system is a set of interrelated principles that determine the logic of management decision-making at all stages of destruction waste management – from the assessment of damaged objects to the reuse of secondary raw materials in the reconstruction process. It is substantiated that the effectiveness of the system is determined not by individual principles, but by the level of their integration into a single management mechanism.

To systematize the conceptual foundations of sustainable management of destruction waste, a complex of seven interrelated principles was formed, which are given in the table. 2. Their choice was carried out taking into account the modern requirements of the circular economy, international practice of construction waste management and the peculiarities of the post-war recovery of Ukraine.

After analyzing the proposed principles, it was established that the system-forming role is performed by the principle of the waste management hierarchy, which determines the sequence of priorities during management decision-making. At the same time, the principles of life cycle assessment, circularity, digital transparency, extended responsibility, proximity and institutional coordination ensure the functioning of the system as a single interconnected complex.

It is rational to consider digital transparency not as a separate technological tool, but as an integrating element of the system, which ensures information interaction between all its functional components. This creates prerequisites for controlling material flows, increasing the reliability of accounting for secondary raw materials, and making informed management decisions at the state, regional, and local levels.

The analysis of the given principles shows that they are not isolated elements, but form an interdependent management system. Central to the principle of the waste management hierarchy, while digital transparency provides information support for all other principles. Institutional coordination creates organizational conditions for the practical implementation of the proposed system.

Central to the proposed principles is the principle of the waste management hierarchy, which determines the logic of management decision-making at all stages of the system's functioning (Fig. 1). It is shown that it is the consistent observance of the priority of waste prevention, reuse, processing, material recovery and only in the extreme case of burial that ensures the maximum preservation of the resource potential of destruction waste.

Instead of the traditional linear approach, the proposed system considers destruction waste as a secondary material resource suitable for reuse in the post-war reconstruction process. This approach makes it possible to simultaneously reduce the volume of waste disposal, reduce the consumption of primary raw materials and minimize the negative impact of construction activities on the natural environment.

Methods of managing destruction waste. The implementation of the proposed principles requires the application of an interconnected complex of technological, digital and organizational solutions. The work forms a classification of methods of sustainable management of destruction waste, which unites five functional groups: mechanical, thermochemical, biological, digital and organizational and economic methods (table. 3).

Compared to the existing classifications, which mainly consider processing technologies separately



Fig. 1. The hierarchy of destruction waste management as the basis of the system of sustainable development

Table 3

Classification of methods of handling destruction waste

A group of methods	Examples of methods	Main purpose
Mechanical	concrete crushing, magnetic and air separation, screening, mobile crushing and sorting complexes	obtaining secondary crushed stone, scrap metal, fractionated raw materials
Thermal and chemical	neutralization of chemical residues, heat treatment of dangerous fractions, stabilization of asbestos-containing waste	disposal of dangerous and toxic components
Biological	composting the organic fraction using wood waste as a structural additive; using the organic fraction as a biofuel or substrate	utilization of wooden and organic fractions
Digital	BIM modeling, digital material registers, «material passports», IoT flow monitoring [4; 5]	accounting, dismantling planning, traceability of materials
Organizational and economic	quality standards for secondary materials, «green» public procurement, market incentives, permitting procedures [8; 9]	formation of the market of secondary raw materials, stimulation of processing

from management mechanisms, the proposed approach integrates all methods into a single process of material flow management. This ensures the coordinated functioning of technological operations, information support and economic incentives at all stages of the life cycle of materials.

The conducted analysis showed that each group of methods performs an independent function, but the greatest efficiency of the system is achieved only with their complex application.

It was found that mechanical methods ensure the preparation of secondary mineral raw materials for further use in construction, thermochemical – safe management of dangerous components, biological – disposal of organic fractions, digital – information support of material flows, and organizational and economic – creation of regulatory and economic conditions of system functioning.

This classification allows methods to be considered not as isolated technological operations, but as complementary elements of a single management system. This approach provides the possibility of comprehensive planning of the processes of sorting, transportation, processing, reuse and environmental control of destruction waste.

A feature of the proposed system is the integration of digital methods with technological and organizational and economic mechanisms. It is advisable to use digital tools as a basis for informational support for management decision-making, which ensures the traceability of material flows, control of compliance with regulatory requirements and the formation of a reliable database on the generation, processing and reuse of destruction waste.

The obtained results show that the proposed classification forms the conceptual basis for building an integrated system of sustainable management of destruction waste and substantiates the need to develop the author's conceptual model of its functioning (Fig. 2).

The proposed conceptual model reflects the interrelationship of the key elements of the system of sustainable management of destruction waste and the sequence of the main processes – from the generation of waste, its inventory, sorting and processing to the reuse of secondary materials in the process of post-war reconstruction. The model integrates regulatory, organizational, technological, environmental, economic and digital components, providing a comprehensive approach to the implementation of the principles of the circular economy.

Unlike traditional approaches, which focus mainly on individual technological operations, the proposed model combines all stages of material flow management into a single integrated system. It covers the assessment of damage to objects, inventory of materials, their classification, sorting, selection of optimal processing technologies, production of secondary raw materials and their further use during infrastructure reconstruction.

The efficiency of the system's functioning is ensured by the interaction of technological processes with digital management tools (BIM, electronic registers, monitoring systems), regulatory and legal regulation, environmental control and economic mechanisms for stimulating the reuse of materials. Such integration creates conditions for continuous management of material flows, increasing resource efficiency and minimizing resource losses at all stages of the life cycle.

The proposed model demonstrates that the management of destruction waste is not limited to its recycling. The final result of the functioning of the system is the return of secondary materials to economic circulation, which contributes to the reduction of the use of primary raw materials, the reduction of waste disposal volumes, the reduction of the ecological burden and ensures the implementation of the principles of the circular economy in the process of post-war reconstruction.

A feature of the developed model is the integration of environmental control and digital support processes at all stages of management, which creates conditions for making timely and well-founded management decisions.

The next result of the research was the development of the author's structural model of the system of sustain-

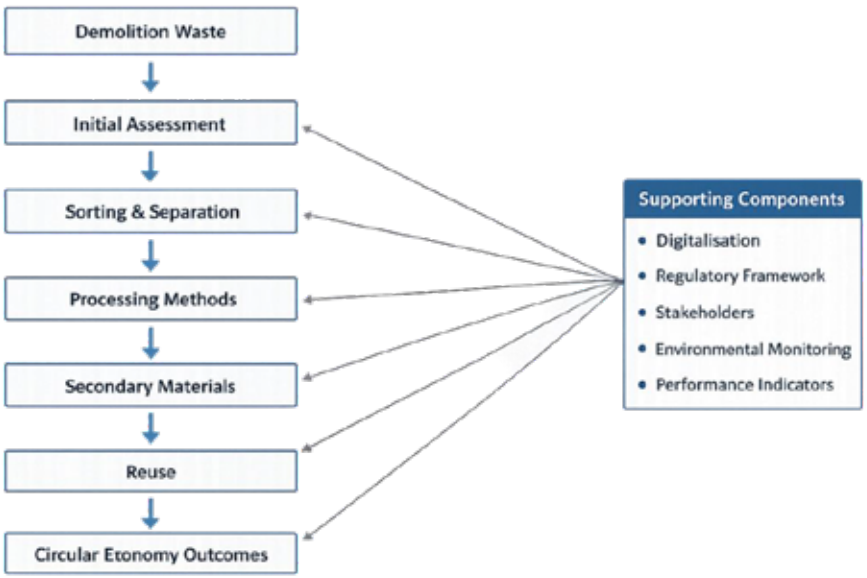


Fig. 2 Conceptual framework for sustainable demolition waste management based on circular economy principles (developed by the authors)

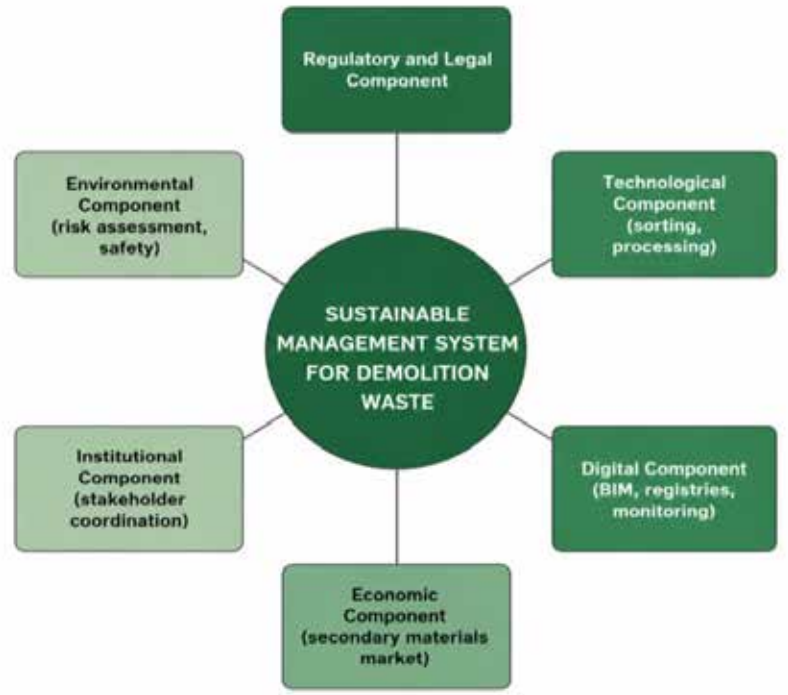


Fig. 3 Structural model of the system of sustainable management of destruction waste (developed by the author).

able management of destruction waste, which reflects the relationships between the main functional components of the system (Fig. 3).

Unlike existing conceptual approaches, the proposed model combines regulatory, technological, digital, economic, institutional and environmental components into a single management decision support system.

It is worth using the digital component as an integrating element of the system, which ensures informational interaction between all participants in the destruction waste management process. This makes it possible to carry out operational accounting of material flows, monitor the fulfillment of regulatory requirements, evaluate the efficiency of processing and ensure the transparency of management decision-making processes.

Each functional component of the system performs certain tasks, but only their complex interaction ensures the achievement of sustainable management goals. The

regulatory and legal component forms the regulatory environment, the technological component ensures sorting and processing processes, the economic component creates incentives for the development of the secondary raw material market, the institutional component coordinates the interaction of all interested parties, and the environmental component ensures monitoring of the impact of the system on the environment.

It is argued that it is the digital integration of all functional components that allows to ensure their coordinated work, increase the efficiency of management decision-making and improve the efficiency of using the resource potential of destruction waste.

On the basis of the conducted systematic analysis, it was established that the proposed model can be used as a methodological basis for the formation of state and regional programs for the management of destruction waste. Its application ensures the integration of the principles of circular economy, modern processing technologies, digital management tools and economic mechanisms for stimulating the reuse of materials within a single system.

The proposed concept is consistent with modern international trends in the development of construction waste management systems, however, unlike existing research, it integrates regulatory, technological, digital, economic and institutional mechanisms into a single management decision support system.

It is advisable to use a digital control loop that ensures continuous exchange of information between all participants in the – process bodies of state power, local self-government, waste management operators, project organizations and enterprises of the construction industry. This makes it possible to increase the transparency of material flows, simplify the control of the fulfillment of regulatory requirements and ensure the support of management decisions in real time.

A feature of the proposed system is the integration of the principles of the circular economy with organizational and economic mechanisms, which ensures not only the technological processing of waste, but also the formation of a sustainable market of secondary construction raw materials. This approach creates the prerequisites for scaling the system at the regional and national levels.

The practical implementation of the proposed system is already partially taking place in Ukraine. Thus, the Cabinet of Ministers of Ukraine, by a resolution dated February 5, 2026, approved the procedure for the implementation of target indicators for the preparation of construction waste for reuse, processing and other material recovery, which establishes uniform requirements for enterprises – generators of such waste, regardless of the form of ownership [9]. As part of international technical assistance, the S3RoU project is being implemented with the participation of the University of Leeds, aimed at developing technologies for processing concrete fragments into low-carbon building materials suitable for reuse in reconstruction facilities [11]. In parallel, a number of community initiatives are developing, including mobile dismantling and sorting facilities implemented by voluntary organizations in de-occupied areas and combining manual sorting with training of local residents [12].

The digital component of the system is becoming increasingly important thanks to the development of BIM modeling and digital twin technologies, which make it possible to model the dismantling process in advance, forecast the volume and quality of secondary raw materials, as well as evaluate the economic effect of various waste management scenarios [4; 5]. The integration of such tools into the destruction waste management system increases the transparency of material flows and facilitates the control of the implementation of established recycling targets.

For a generalized comparison of linear (preferred disposal) and circular (system) models of destruction waste management, Table 4 shows the main differences according to key indicators.

As the comparison shows, the transition from a linear model to a system circular model does not require fundamentally new technologies – the vast majority of the necessary methods have already been tested in global practice [2–5]. The main challenge remains the coordinated integration of regulatory, technological, digital,

Table 4

Comparative characteristics of linear and circular models of destruction waste management

Indicator	Linear model (preferred burial)	Circular (system) model
Volume of destruction waste as of September 2025.	17.2 million tonnes formed; 11.7 million tonnes need to be cleared [6; 7]	same, but seen as a resource base
Reuse potential	not used or used fragmentarily	up to 70 % (≈ 8.2 million t) are recyclable and reusable [6; 7]
Regulatory framework	no recycling targets	target indicators of preparation for reuse and processing, established by the resolution of the CMU dated February 5, 2026. [9]
Technological base	isolated examples of mobile recycling	network of mobile and fixed sorting and processing complexes [10]
Digital support	practically absent	BIM modeling, digital registers and tangible passports [4; 5]

Table 5

Key performance indicators for evaluating the proposed sustainable demolition waste management system

Indicator	Unit	Target	Data source
Recycling rate	%	>70	Regional waste management reports
Landfilled waste	%	<20	Municipal waste registry
CO_2 emissions	kg CO_2/t	Decrease	LCA calculations
Secondary materials	t	Increase	Material flow database

Table 6

Illustrative application of the proposed framework for reconstruction of a damaged road bridge

Stage	Main actions	Expected result
1. Damage assessment	Bridge inspection, digital fixation	Determination of waste volumes
2. Inventory	Identification of materials	Database formation
3. Sorting	Separation of concrete, metal, asphalt concrete	Preparation for processing
4. Recycling	Crushing of concrete, melting of metal	Secondary raw materials
5. Reuse	Use of materials during reconstruction	Reducing the use of natural resources
6. Monitoring	KPI assessment	System performance control

economic and institutional components within a single national system, which is the main task of the research presented in this article.

Evaluating the effectiveness of the functioning of the proposed system requires the use of quantitative indicators that reflect the degree of achievement of the goals of the circular economy and sustainable management of destruction waste. For this purpose, a system of key performance indicators is proposed, given in the table. 5.

The proposed system of indicators provides a comprehensive assessment of the effectiveness of sustainable management of destruction waste. The use of quantitative indicators makes it possible to monitor the effectiveness of the system's functioning, assess progress in achieving the goals of the circular economy, and support management decision-making at the state, regional, and local levels.

Demonstration of the application of the conceptual model. To demonstrate the capabilities of the proposed conceptual model, a conditional example of the restoration of a damaged road bridge after its destruction as a result of hostilities was considered. The example is not the result of a real project, but is used to illustrate the sequence of functioning of the developed system.

At the initial stage, the degree of damage to structures is assessed and material resources are inventoried. Debris is classified by types of materials (concrete, reinforcing steel, asphalt concrete, wood and other materials), after which it is sorted in accordance with the requirements of safe management and the possibilities of further processing.

Concrete waste after crushing has significant potential for use as a secondary aggregate in the installation of road surface foundations and the preparation of construction sites. Metal elements are sent for remelting, and suitable asphalt concrete can be reused during highway repairs. At the same time, the widespread introduction of secondary materials in road and civil construction requires further development of the regulatory and technical framework, harmonization of national standards with European requirements, and introduction of procedures for assessing the quality and safety of such materials. Materials that cannot be reused or recycled are transferred to controlled disposal in accordance with current environmental requirements.

At the same time, digital tools (BIM models, geoinformation systems and electronic registers of materials) ensure the traceability of material flows, documentation of processing processes and evaluation of the effectiveness of decisions made. The effectiveness of the system's functioning is evaluated according to the proposed key performance indicators (table. 5).

The conditional example demonstrates that the application of the proposed conceptual model ensures the return of a significant part of material resources to the production cycle, reduces the volume of waste disposal, reduces the consumption of primary raw materials, and contributes to the implementation of the principles of the circular economy during the post-war restoration of transport infrastructure.

The application of these indicators makes it possible to evaluate the effectiveness of the implementation of the principles of the circular economy, determine directions for improving the management system and monitor the achievement of the strategic goals of the post-war recovery.

The example proposed in Fig. 3 demonstrates the possibility of practical application of the developed conceptual model during the restoration of a damaged road bridge. The sequence of stages covers damage assessment, inventory of material resources, selective dismantling, sorting, waste processing, production of

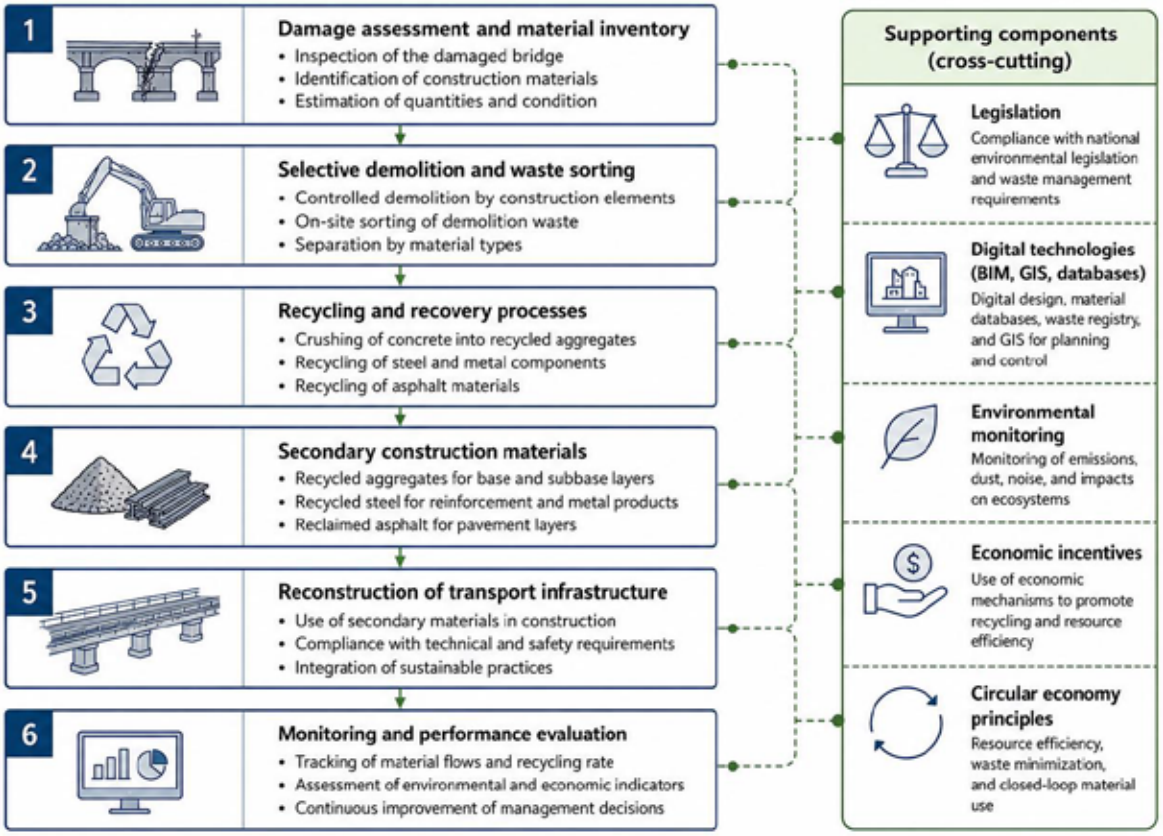


Fig. 4 Illustrative application of the proposed conceptual framework for sustainable demolition waste management during the reconstruction of a damaged road bridge (developed by the author)

secondary raw materials and their reuse in the process of reconstruction of transport infrastructure. This approach ensures the implementation of the principles of the circular economy throughout the life cycle of material flows.

An important component of the proposed model is the integration of digital technologies, in particular BIM, Geographic Information Systems (GIS), electronic waste registers and digital material passports. Their use ensures the traceability of material flows, increases the transparency of management processes, simplifies the monitoring of key performance indicators and supports the adoption of well-founded management decisions during the implementation of post-war recovery projects.

Although the given example is illustrative in nature, it demonstrates the logic of the functioning of the proposed system and confirms the possibility of its practical application during the restoration of transport infrastructure facilities. It is advisable to direct further research to the approbation of the model on real infrastructure facilities using actual data on the generation, processing and reuse of destruction waste.

Main conclusions. The work developed a conceptual model of sustainable management of destruction waste, based on the principles of a circular economy and covering all the main stages of management with material flows – from damage assessment and waste sorting to the production of secondary raw materials and their reuse in the process of post-war reconstruction.

The proposed model integrates the regulatory, organizational, technological, environmental, economic and digital components of management, which provides a comprehensive approach to the functioning of the system and creates prerequisites for increasing resource efficiency and reducing the negative impact on the environment.

The scientific novelty of the study consists in the development of an integrated conceptual model of sustainable management of destruction waste and a system of key performance indicators that can be used to evaluate the effectiveness of the implementation of the principles of the circular economy in the processes of post-war restoration of transport infrastructure.

The practical significance of the work lies in the possibility of using the proposed model by state authorities, local self-government bodies, project organizations and enterprises of the construction industry during the planning, monitoring and implementation of measures for sustainable management of destruction waste.

It is advisable to direct further research to the approbation of the proposed model at real transport infrastructure facilities, the development of a system for quantitative assessment of the effectiveness of its functioning, and the integration of digital technologies (BIM, GIS,

digital material passports) into the processes of destruction waste management.

Research limitations. The study is conceptual in nature and is based on systematic analysis, generalization of modern scientific publications, international regulatory documents and analytical reports. The proposed system did not undergo large-scale practical testing in the conditions of real post-war reconstruction, and its effectiveness needs further quantitative assessment. In addition, the dynamic nature of military destruction and the constant increase in the volume of destruction waste may require periodic clarification of the structure of the system and the target indicators of its functioning.

Management implications. The developed conceptual model can be used by state authorities, local self-government bodies, construction industry enterprises and waste management operators during the development of state and regional destruction waste management strategies. Its application will contribute to the planning of the development of sorting and processing infrastructure, the implementation of digital systems for the traceability of material flows, the formation of quality standards for secondary raw materials and the integration of the principles of the circular economy into the processes of post-war reconstruction in accordance with the requirements of the European Union.

Prospects for using the research results. It is advisable to direct further research to the practical approbation of the proposed system in certain regions of Ukraine and the evaluation of its effectiveness using quantitative indicators. Prospective directions are the development of a system of performance indicators, management decision support models, the application of life cycle assessment (LCA) methods, material flow analysis (MFA), as well as the use of digital doubles and artificial intelligence technologies to predict the generation, sorting and reuse of destruction waste. Such research will contribute to the formation of scientifically based mechanisms for the implementation of the principles of the circular economy in the process of long-term recovery of Ukraine.

References

1. Ukraine Third Rapid Damage and Needs Assessment (RDNA3): February 2022 – December 2023. Washington, DC ; Brussels ; New York : World Bank, European Commission, United Nations, 2024. URL: https://www.worldbank.org/en/news/press-release/2024/02/15/updated-ukraine-recovery-and-reconstruction-needs-assessment-released (дата звернення: 20.07.2026).
2. Papamichael I., Voukkali I., Loizia P., Zorpas A. A. Construction and demolition waste framework of circular economy: a mini review. Waste Management & Research. 2023. URL: https://doi.org/10.1177/0734242X231190804
3. Zhang C., Hu M., Di Maio F., Sprecher B., Yang X., Tukker A. An overview of the waste hierarchy framework for analyzing the circularity in construction and demolition waste management in Europe. Science of the Total Environment. 2022. Vol. 803. Art. 149892. URL: https://doi.org/10.1016/j.scitotenv.2021.149892
4. Weerakoon T. G., Zvirgzdins J., Lapuke S., Wimalasena S., Drukis P. Integrating Circular Economy (CE) Principles into Construction Waste Management (CWM) Through Multiple Criteria Decision-Making (MCDM). Sustainability. 2025. Vol. 17, No. 17. Art. 7770. URL: https://doi.org/10.3390/su17177770
5. Kaewunruen S., Lin Y.-H., Guo Y. BIM-driven digital twin for demolition waste management of existing residential buildings. Scientific Reports. 2025. Vol. 15. Art. 28989. URL: https://doi.org/10.1038/s41598-025-13938-9
6. Implementation of the Debris Recycling and Reuse System in Ukraine: Summary Report on the Findings and Recommendations of the Feasibility Study. Kyiv : United Nations Development Programme, 2026. URL: https://www.undp.org/ukraine/publications/study-debris-recycling-and-reuse-in-ukraine (дата звернення: 20.07.2026).
7. Ukraine could recover up to 8.2 million tonnes of secondary raw materials from war-generated debris, UNDP study reveals : press release, 9 June 2026. *United Nations Development Programme*. URL: https://www.undp.org/ukraine/press-releases/ukraine-could-recover-82-million-tonnes-secondary-raw-materials-war-generated-debris-undp-study-reveals (дата звернення: 10.07.2026).
8. Recommendations Toward a Policy Note: Municipal Debris Management in Ukraine. Washington, DC : World Bank, January 2025. URL: https://documents1.worldbank.org/curated/en/099053025113533353/pdf/P180174-29bcff8a-ddba-4d1c-9692-ae99e929a796.pdf (дата звернення: 20.07.2026).
9. Про затвердження Порядку реалізації цільових показників підготовки будівельних відходів та відходів руйнації до повторного використання, переробки та іншого матеріального відновлення : Постанова Кабінету Міністрів України від 05.02.2026. За повідомленням: *Ukraine approves rules to boost recycling of construction and demolition waste*. *Global Cement*. 2026. URL: https://www.cemnet.com/News/story/180781/ukraine-approves-rules-to-boost-recycling-of-construction-and-demolition-waste.html (дата звернення: 20.07.2026).
10. Кабінет Міністрів України. План заходів з реалізації Національного плану управління відходами на 2025–2033 роки. Київ, 2025. URL: https://zakon.rada.gov.ua/laws/show/1353-2024-%D1%80#Text (дата звернення: 20.07.2026).
11. Rubble recycling could be key to rebuilding Ukraine [S3RoU project, University of Leeds]. *Build in Digital*. 2025. URL: https://buildindigital.com/rubble-recycling-could-be-key-to-rebuilding-ukraine/ (дата звернення: 20.07.2026).
12. From Ruins to Reuse: How Ukrainians Are Repurposing War Waste. *Yale Environment 360*. 2025. URL: https://e360.yale.edu/features/ukraine-war-debris-recycling (дата звернення: 20.07.2026).

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