REINCARNATE: SHAPING A SUSTAINABLE FUTURE IN CONSTRUCTION THROUGH DIGITAL INNOVATION

Preprint · March 2024

DOI: 10.13140/RG.2.2.28985.79206

5 authors, including:

Sabine Kruschwitz
Bundesanstalt für Materialforschung und -prüfung

Christoph Völker
Bundesanstalt für Materialforschung und -prüfung

Benjamí Moreno Torres
Bundesanstalt für Materialforschung und -prüfung

Ghezal Ahmad Zia
Bundesanstalt für Materialforschung und -prüfung

Spring Convention & conference on
advanced construction materials and processes for a carbon neutral society
10-12 April 2024, Milan, Italy

REINCARNATE: SHAPING A SUSTAINABLE FUTURE IN CONSTRUCTION THROUGH DIGITAL INNOVATION

Sabine Kruschwitz[1,2], Christoph Völker[2], Ghezal Ahmad Jan Zia[3] and Benjami Moreno Torres[4], Timo Hartmann[5]*

[1] Prof. Dr., Bundesanstalt für Materialforschung und -prüfung and Technische Universität Berlin, sabine.kruschwitz@bam.de
[2] Dr, Bundesanstalt für Materialforschung und -prüfung, christoph.voelker@bam.de
[3] Dr., Bundesanstalt für Materialforschung und -prüfung, ghezal-ahmad.zia@bam.de
[4] MSc, Technische Universität Berlin, benjamin.moreno.torres@tu-berlin.de
[5] Prof. Dr., Technische Universität Berlin, timo.hartmann@tu-berlin.de

ABSTRACT

We introduce the REINCARNATE project, funded by the European Union's Horizon Europe program, to boost circularity by merging digital innovations with practical applications and a focus on material reuse. The heart of REINCARNATE is the Circular Potential Information Model (CP-IM), a digital platform designed to assess and enhance the recyclability of construction materials, construction products, and buildings. The CP-IM integrates advanced technologies such as digital twins, AI, and robotics to revolutionize the handling of construction waste, turning it into valuable resources and cutting the environmental footprint of the sector. Among its features are digital tracing, material durability predictions, and CO_2 reduction materials design. These are showcased in eleven European demonstration projects, highlighting the practical benefits of these technologies in reducing construction waste and CO_2 emissions by up to 80% and 70% respectively. REINCARNATE aims to marry innovation with real-world application, providing the construction industry with strategies for sustainable and circular practices.

Keywords: construction sustainability, European project, life cycle, recycled materials, digital construction.

Corresponding Author Name, PhD, PEng, etc.

Address Lines, City, State/Province, Country, Postal/Zip Code

Email: abcd123@example.com | **Tel:** +1 123-456-8900 | **Web:** www.example.com

1. INTRODUCTION

The concept of circular economy has gained significant attention in recent years as a sustainable approach to resource management and waste reduction. Within the European Union, initiatives such as the Horizon Europe-funded project REINCARNATE have been at the forefront of advancing circular economy practices in the construction and demolition sector. This paper provides an overview of the four-year REINCARNATE project launched in 2022, highlighting its objectives, methods, and (as yet) key outcomes in promoting the reuse and recycling of construction and demolition waste materials.

The construction sector is a major user of natural resources and produces a large volume of waste, including materials such as concrete, bricks, asphalt, and wood. The industry's traditional 'take, make, dispose' model contributes to environmental harm, resource waste, and economic losses (Fig. 1). Construction and demolition waste (CDW) is the predominant waste category, forming about 25-30% of the EU's total waste. Furthermore, the EU faces an issue with the short lifespan of its buildings, typically between 25 to 30 years, and sometimes only 39 years according to certain studies. Buildings are often demolished earlier than necessary due to outdated functionality rather than structural problems, leading to unnecessary waste [1]. There is also a notable deficiency in the construction industry's use of recycled materials. Despite the possibility of repurposing building materials, their application in high-value or new settings is minimal. This lack of reuse is part of a larger problem in the industry's linear economic approach, which undervalues recycled materials and overlooks the benefits of sustainable material management [2].

Construction and demolition waste (CDW) is the largest waste stream in the EU	Limited average lifespan	Low percentage use of secondary materials by the construction sector
Current CDW accounts for approximately 25-30% of all waste, which consists of numerous materials that often cannot be separated meaningfully. The embodied energy and embodied eq. CO2 emissions in the CDW are significant (8.5 MT eq. CO2 for construction in Sweden in 2015).	The average lifespan of buildings is only 39.1 years. According to 3L, one of our team members,it is even shorter in the EU (in Germany, an estimated 25-30 years). The main reason for demolishing buildings is that they are functionally obsolete.	It is not possible to reuse entire buildings, building products, or building materials of high product quality within a different setting or for a different purpose. The building sector hardly uses any secondary materials.

Figure 1: Motivational aspects for the initiation of the REINCARNATE project.

In this paper, we present an overview of the REINCARNATE project, including its objectives, consortium partners, and research activities. We look at the methods used, such as the general approach and the technological innovations envisaged, and how we demonstrate them in the real-estate management and construction practice (all described in Chapter 2). Special emphasis is placed on our current largest scientific contribution to the REINCARNATE project, namely the idea of extending the service life of components based on information from non-destructive testing methods (described in Chapter 3) and recycling materials using artificial intelligence (described in Chapter 4).

2. GENERAL APPROACH AND INNOVATIONS

2.1. Approach

Recognizing the challenges described above, the REINCARNATE project was started with the aim of transforming the construction and demolition sector into a more circular and sustainable system. The overall objectives are to develop innovative techniques and technologies for the efficient reuse and recycling of construction and demolition waste materials, thereby reducing the environmental impacts and promoting the circular economy principles. Through collaboration between industry partners, research institutions, and policy makers across Europe, the project seeks to address key challenges and barriers hindering the widespread adoption of circular practices in the sector.

The project pursues the ambitious goal of transforming the real-estate management and construction industry. This shall be achieved by introducing innovative technical and social methods to recycle buildings, components, and materials so that they can be used again in the sense of a "rebirth". The focus here is on extending the useful life on several levels: that of the entire building, individual components and the materials used. A key aspect of this is the creation of complete and transparent documentation of all the positive characteristics and value of these elements. This documentation serves as a basis for the trust and reliability of the components and materials, which should ensure their reuse in subsequent high-quality construction projects.

The project stands on three fundamental pillars (Fig. 2): Firstly, the creation of a Circular Information Management Platform (CP-IM); secondly, the practical implementation of 10 digital innovations aimed at enhancing the recycling process; and thirdly, the application of these developed strategies to 11 specific demonstration projects, bringing theory into practice.

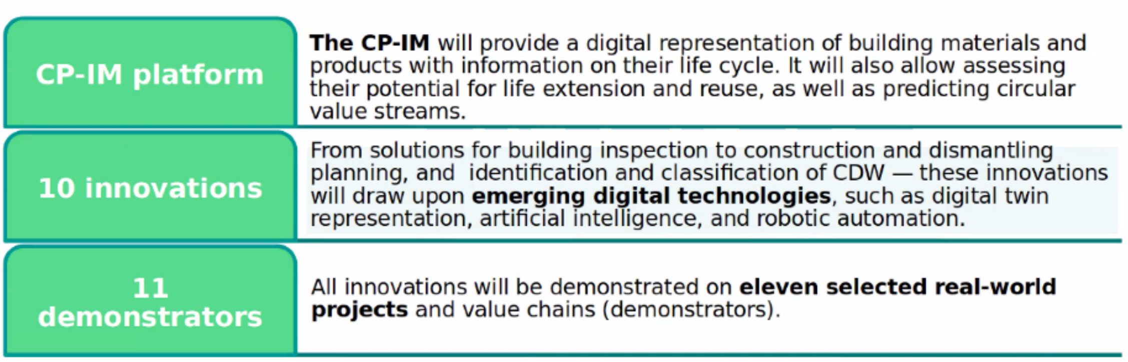

Figure 2. The REINCARNATE project is founded on three core elements: the development of the CP-IM platform, the introduction of 10 digital innovations, and their practical application across 11 real-world demonstration projects.

The REINCARNATE consortium brings together 16 organizations from seven EU countries and Serbia. The consortium includes players from all major industries that are required to transform the industry: Experts in Systems Engineering and Material Science, experts from the real-estate industry, as well as, architects, civil engineers and construction professionals. Additionally, the consortium includes digital experts in computer vision, robotics, internet of things applications, and building information modeling. Moreover, the consortium also includes a waste management organizations and social science, as well as business experts.

2.2. Innovations

A key innovation of the Reincarnate project is the so called CP-IM platform, a digital platform for transparently tracking lifecycle information about a building, building components, and building materials (Fig. 3). The platform is designed around the latest in tech, like digital twins that create virtual models of materials, artificial intelligence that can make smart recommendations, and provides interfaces to robots that can help in data collection, construction, demolition, and building upgrade. These tools will help us inspect buildings better, plan more efficient construction and dismantling, and keep track of construction debris, but also to support the design of buildings around reusable materials and components.

The CP-IM platform is designed around a common ontology that formalizes and maps the required knowledge all major stakeholders within the real-estate management, construction, and reuse sector requires. The core of the platform is provided by BIM technologies that provide a representation of a building and its important components. Another key-element of the platform is its internet-of-things interfaces that makes it possible to connect the platform to sensors to seamlessly, routinely, and consistently collect information about the life-cycle qualities of building materials and products.

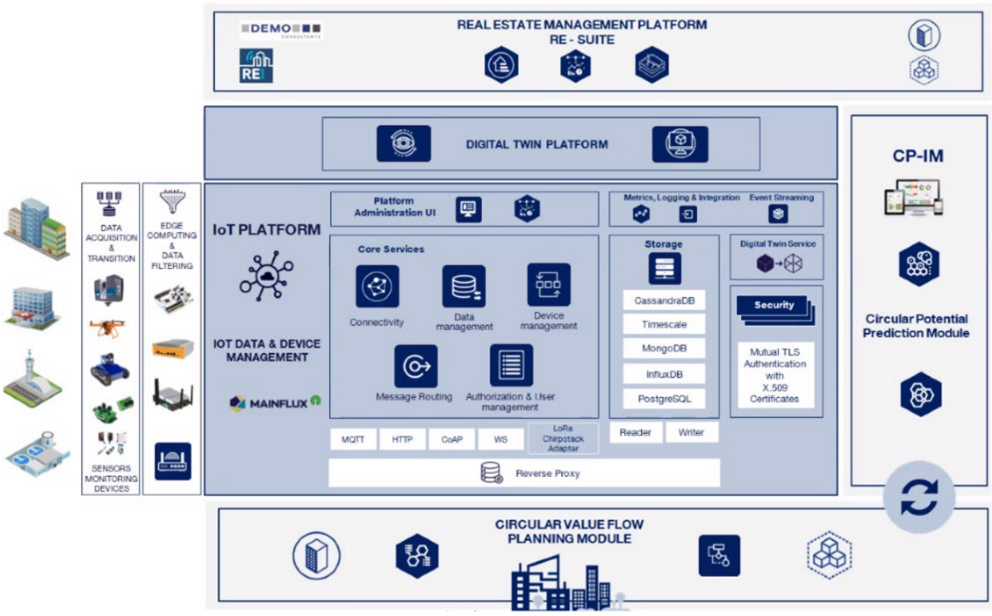

Figure 3. Sketch of the CP-IM and its functions.

REINCARNATE will use the CP-IM database to create and showcase ten technological advances ranging from building inspection to construction and demolition planning, and from automated categorization and sorting of construction and demolition waste (CDW) to sophisticated support systems for architects and property managers. These advances will harness the power of new digital technologies including digital twins, artificial intelligence, and robotic automation. In addition to these technological developments, REINCARNATE will explore the social dynamics within the construction industry to gain a deeper understanding of how to foster the widespread adoption of practices that support the high-quality remanufacturing and reuse of building materials at a high quality. This will include an examination of the industry's current behaviors and attitudes towards material reuse.

In Chapters 3 and 4 of this paper, we describe our specific contributions to the project in the areas of lifetime extension through NDT (WP 2) and material recycling through AI (WP 3) and illustrate how we are contributing to the innovations 1, 2, 5 and 10 (Fig. 4).

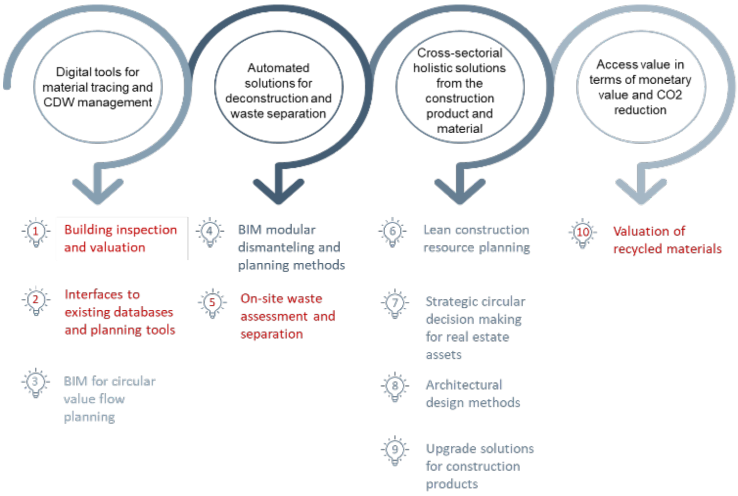

Figure 4. Process innovations for CDW management and reduction.

2.3. Demonstrators

The REINCARNATE project will showcase its innovations through at least six selected demonstrators, developing business process guidelines, an online learning platform with training materials, and standard proposals to enhance the dissemination and use of its findings. A key goal is to share project results with society, dedicating efforts to implement these innovations in different buildings. This text briefly presents several demonstration cases (Fig. 5) to highlight the applied innovations and their scope.

1. **Technical Museum Entrance, Berlin, Germany:** Utilizing image analysis to evaluate the historical significance of pre-existing brick structures on a railway station platform.
2. **Water Treatment Plant, Albacete, Spain**: Proposes reusing concrete elements from an old plant in a new wastewater treatment facility, assessing their condition with non-destructive techniques and exploring SLAMD for developing new, corrosion-resistant concrete formulations.
3. **Dutch Demolition Company, Amsterdam, Netherlands**: Integrates a data-driven decision-making tool and practices from the REINCARNATE project into its demolition, dismantling, and circular economy resource management.
4. **Wooden Structure Renovation, Werdau, Germany**: Advises on the condition of aged wooden structures for potential partial or total replacement using Non-Destructive Testing (NDT) and data analysis.
5. **Public Real Estate Management, Berlin, Germany:** Incorporates REINCARNATE innovations into circular economy management of construction resources across its building portfolio, starting with digital twins for two fire stations and a refugee center.

6. **Modular Housing Solution, project:** A project partner's development that incorporates REINCARNATE's innovations across planning, design, material management, construction, and monitoring, focusing on material and space reuse for urban sustainability.

These cases demonstrate various applications of REINCARNATE project innovations in assessing, maintaining, and enhancing infrastructure and buildings through sustainable and non-destructive methods.

Figure 5. Selected demonstration objects for the projct innovations, first row left to right: Technical Museum Entrance, Berlin, Water Treatment Plant, Albacete, Dutch Demolition Company Amsterdam. Second row, left to right: Wooden Structure Renovation, Werdau, Public Real Estate Management, Berlin, Modular Housing Solution Project.

3. LIFECYCLE EXTENSION THROUGH NDT

In Work Package 2 (WP2) "Solutions for Life Cycle Extensions" of the REINCARNATE project, our focus is on extending the durability of construction materials. We leverage the CP-IM database to merge non-destructive field data with advanced material models. This fusion enables the real-time evaluation of material properties, offering precise longevity predictions. We develop methods to integrate non-destructive test data with established civil engineering material models, improving sustainability in material management. Additionally, we embed non-destructive testing techniques into a digital workflow for building inspections bridging information barriers amongst stakeholders.

To evaluate the durability or condition of a building component, it is imperative to understand the deterioration phenomena impacting its longevity. Typically, the progression of these phenomena is intricately linked to both the component's function (e.g., the load on a beam or column, sun exposure on a roof) and its material composition (e.g., wood beams exhibit different deterioration mechanisms compared to steel or reinforced concrete beams).

Consequently, the initial step involves compiling a detailed inventory of deterioration phenomena, categorized by prevalent construction materials such as concrete, mortar, steel, wood, brick, and stone.

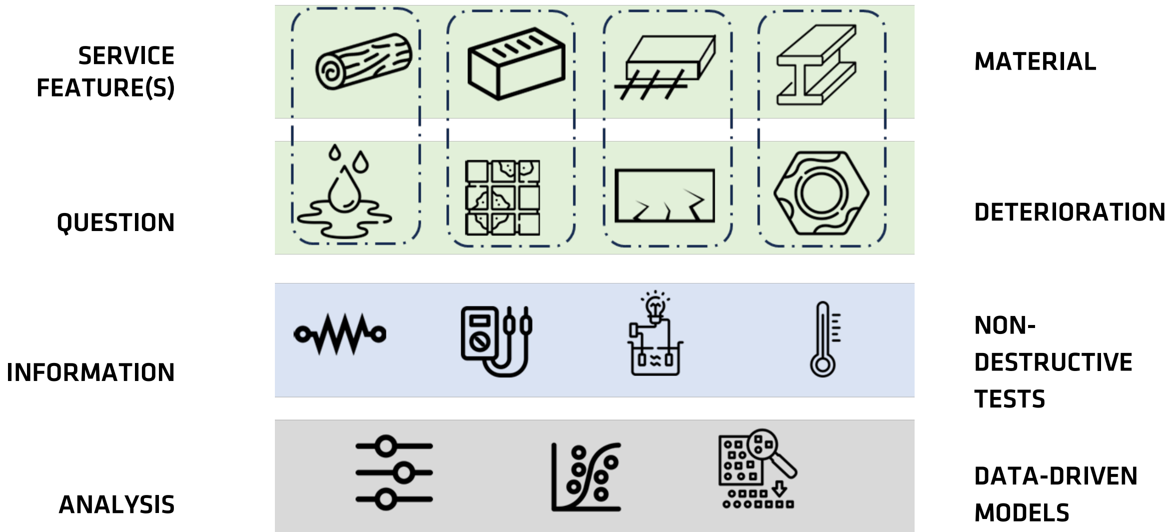

Figure 6. Steps of the methodology of using NDT as a lifecycle assessment and extension tool.

In instances where precise information on a construction component's condition relative to its building performance is unavailable, conservative decisions are often made, potentially underestimating the component's durability. Therefore, a critical improvement strategy for decision-making regarding the status of a building element or system is the provision of objective material's condition information. This necessitates the application of non-destructive testing (NDT) techniques to gather material or component data. Furthermore, key NDT methods for examining construction materials concerning known deterioration phenomena are outlined.

Data from NDTs may be augmented with details from the material or component manufacturer (e.g., density, composition, maximum compression) and even with complementary data from destructive tests (e.g., ultimate compression or flexural strength), constituting a comprehensive dataset for analysis. Subsequently, an interpretation model is required to correlate this data (NDT + additional information sources) with the material's condition in relation to a specific deterioration phenomenon. These analytical data-driven models, under continuous development and research by material scientists and civil engineers, are chosen based on the comprehensive catalogue of decay factors with associated NDTs mentioned earlier.

Having introduced the three tiers - deterioration phenomena, nondestructive testing, and data-driven models - a methodology grounded on a tripartite decision-making process is formulated

(Fig. 6). This involves determining the material and associated deterioration phenomena for investigation, identifying the NDT methods appropriate for gathering relevant data, and selecting the models that leverage this data to yield conclusive outcomes.

We also introduce adaptive sampling approaches which can markedly reduce the number of samples required for many deterioration processes, e.g. corrosion in reinforced concrete. By intelligently selecting the most informative data points, this approach concentrates on areas of highest uncertainty, thereby eliminating the need for exhaustive sampling across the entire dataset. More details on the efficiency of adaptative sampling can be found in [3]. This significant decrease not only conserves resources but also enhances the efficiency of the inspection process.

4. MATERIAL RECYCLING THROUGH AI

The shift towards a circular economy highlights the necessity for new methods in evaluating and recycling materials at the end of their life. Traditional approaches, focusing on the purity and consistency of primary resources, fail to manage the intricacies of secondary material flows. This issue is especially evident in concrete recycling, aiming for adaptable material formulations to achieve high-quality, performance-compliant outputs. The Reincarnate project leads this innovative charge, employing digital technologies to revolutionize the evaluation of recycled materials. The project aims to establishment a data-driven methodology for the design of waste-based materials that satisfy key performance criteria: compressive strength, workability, and durability. The development began with the compilation of a detailed dataset featuring the characteristics of waste-based materials derived from laboratory tests, alongside environmental aspects [4]. Through meticulous curation, the dataset was cleansed of redundancies, enriched with Life Cycle Assessment (LCA) data, and purged of unverifiable information, laying a solid foundation for subsequent analytical and innovative endeavours.

The materials design methodology has been established through the implementation of a robust benchmarking framework. This framework facilitates a direct quantitative comparison between the performance of AI-driven designs and that of traditional laboratory methods. The benchmarking results show that the application of machine learning notably diminishes the complexity inherent in laboratory testing, streamlining the process. Moreover, the integration of carbon estimation methods empowers the prioritization of materials that are not only sustainable but also economically valuable [5]. Although the focus is on waste-based concrete, the methodology's design ensures adaptability to other materials, including glass, steel, and ceramics.

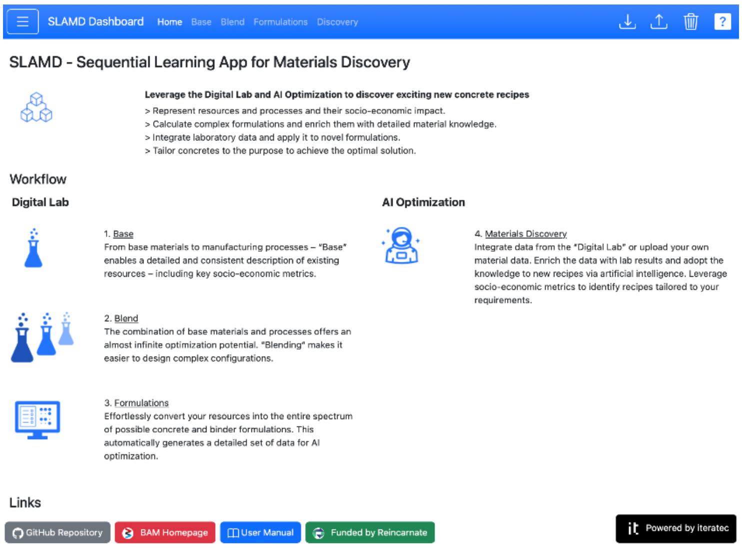

Figure 7: SLAMD landing page. left: Digital Lab. right: AI-Optimization.

The methodological breakthroughs achieved by the Reincarnate project culminate in the development of SLAMD [6, 7], a user-friendly web application that epitomizes one of the project's key innovations. SLAMD encompasses a digital lab twin and AI-driven design dashboards, facilitating the precise specification of material requirements by laboratory personnel (Fig. 7). This interactive platform enables the identification of the most promising material compositions from an extensive array of complex options, significantly enhancing eco-efficiency and operational efficiency in materials laboratories.

To maximize the utility and reach of SLAMD, a comprehensive suite of supporting resources has been developed and are summarized in the code repository [7] This package includes in-depth documentation, a technical journal paper offering a deeper insight into the underlying methodology, and an AI chatbot for instant query resolution.

The Reincarnate project's contribution to the sustainable construction industry through digital innovation in recycled material assessment is a significant stride towards the realization of a circular economy. By harnessing the power of data-driven methods, machine learning, and user-friendly digital tools, we are not just revaluating the worth of recycled materials but also equipping stakeholders with the knowledge to make informed, sustainable material choices.

5. CONCLUSIONS

The Reincarnate project epitomizes the widespread interest, particularly within the Horizon 2020 framework, in adopting circular economy principles within the construction sector. This initiative adopts a comprehensive approach, encompassing industry, market, social, and scientific-technical perspectives. This paper specifically illustrates the scientific-technical aspect through the deployment of CP-IM, non-destructive testing, and data-driven methodologies in practical scenarios. Furthermore, it demonstrates the significant role of data-driven techniques in advancing the development of new construction materials that leverage recycled content. A cornerstone of the emerging circular economy, as highlighted in this study, is the acquisition and dissemination of precise information to facilitate informed decision-making.

ACKNOWLEDGMENTS

We gratefully acknowledge support from the European Union's Horizon Europe research and innovation program under grant agreement No. 101056773 for funding this work under the Reincarnate project.

REFERENCES

[1] van den Berg, M., Voordijk, H., & Adriaanse, A. (2020) Recovering building elements for reuse (or not): Ethnographic insights into selective demolition practices. *Journal of cleaner production*, *256*, Article 120332. https://doi.org/10.1016/j.jclepro.2020.120332

[2] Wahlström, M., Bergmans, J., Teittinen, T., Bachér, J., Smeets, A., Paduart, A. (2020) Construction and Demolition Waste: challenges and opportunities in a circular economy. Eionet Report - ETC/WMGE 2020/1

[3] Zia, G. A., Völker, C., Moreno Torres, B., Kruschwitz, S. (2024) Unlocking circular economy: an upscaling approach for assessing material's circular potential with non-destructive testing (ndt), Proceedings of the RILEM Spring Convention 2024

[4] Moreno Torres, B., Völker, C., Firdous, R. (2023) Concreting a Sustainable Future: A Dataset of Alkali-Activated Concrete and its Properties. Available at SSRN: https://ssrn.com/abstract=4420176 or http://dx.doi.org/10.2139/ssrn.4420176

[5] Völker, C., Torres, B. M., Rug, T., Firdous, R., Zia, G. A., Lüders, S., Kruschwitz, S. (2023). Data driven design of Alkali-activated concrete using Sequential Learning. *Journal of Cleaner Production*, https://doi.org/10.1016/j.jclepro.2023.138221.

[6] Völker, C. Moreno Torres, B., Zia, G. A., Firdous, R., Rug, T., Böhmer, F., Stephan. D., Kruschwitz, S. (2023) Presenting SLAMD – A Sequential Learning Based Software for the Inverse Design of Sustainable Cementitious Materials. Nano World Journal, https://doi.org/10.17756/nwj.2023-s2-032

[7] Völker, C., Rug, T., Zia, G. A., Lüders, S., Lisdero Scaffino, H., Höpler, M. (2023) Sequential Learning App for Materials Discovery ("SLAMD") - Web Version, 31 01 2023. [Online]. Available: https://github.com/BAMresearch/WEBSLAMD.