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PRIN: PROGETTI DI RICERCA DI RILEVANTE INTERESSE NAZIONALE – Bando 2022
Prot. 2022BCL34N

PART A

1. Research project title

Sediments Eco-recycling Exploitation, Development and Sustainability [SEEDS]

2. Duration (months)

24 months

3. Main ERC field

PE - Physical Sciences and Engineering

4. Possible other ERC field

5. ERC subfields

1.	PE10_10 Mineralogy, petrology, igneous petrology, metamorphic petrology
2.	PE8_11 Environmental engineering, e.g. sustainable design, waste and water treatment, recycling, regeneration or recovery of compounds, carbon capture & storage
3.	

6. Keywords

nº	Testo inglese
1.	Mineralogy

2. Applied Mineralogy
3. Building Materials and Products
4. Geopolymers and Alkali-Activated Materials
5. Ceramics and glasses
6. Toxicology

7. Principal Investigator

VALDRE'
(Surname)

GIOVANNI
(Name)

Professore Ordinario (L. 240/10)
(Qualification)

PI - Certified E_mail (CEM)

giovanni.valdre@pec.unibo.it

Age limits derogation

The PI and/or the substitute PI are over 40 and they don’t intend to benefit from derogations to the age limits for the amount allocated to under 40 PI;

8. List of the Research Units

nº	Associated Investigator	Qualification	University/ Research Institution	Registered office (address)	Operating office (address)	e-mail address
1.	VALDRE' Giovanni	Professore Ordinario (L. 240/10)	Università degli Studi di BOLOGNA	Via Zamboni, 33 - BOLOGNA (BO)	City: Bologna (BO) Address Piazza di Porta San Donato 1	giovanni.valdre@unibo.it

2.	GUALTIERI Alessandro	Professore Ordinario	Università degli Studi di MODENA e REGGIO EMILIA	Via Universita', 4 - MODENA (MO)	City: Modena (MO) Address Via Giuseppe Campi 103	alessandro.gualtieri@unimore.it
3.	LANDI Elena	Dirigente di ricerca	Consiglio Nazionale delle Ricerche	Piazzale Aldo Moro, 7 - Roma (RM)	City: Faenza (RA) Address Via Granarolo 64	elena.landi@istec.cnr.it
4.	SCARFI' Sonia	Professore Associato (L. 240/10)	Università degli Studi di GENOVA	Via Balbi, 5 - GENOVA (GE)	City: Genova (GE) Address Corso Europa 26	soniascarfi@unige.it

9 - Substitute Principal Investigator (To be identified among one of the associated investigators participating in the project).

GUALTIERI
(Surname)

ALESSANDRO
(Name)

Professore Ordinario
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Substitute PI - Certified E_mail (CEM)

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10. Brief description of the proposal

The main target of SEEDS is to recover selected industrial sediments currently classified and treated as waste and re-use them into the production cycle of construction materials for building and infrastructure (Figure 1). More in detail, the idea is to use waste sediments as “reagents” in partial replacement of virgin raw materials to produce geopolymers and alkali-activated materials (AAMs), improving the eco-sustainability of the building materials production chain, but without compromising (indeed possibly increasing) the performance of the final products. Furthermore, the project will be integrated with parallel toxicity and carcinogenic studies, by effect-directed analysis (EDA) approach. The project is also in line with the objectives of the Italian “Piano Nazionale di Ripresa e Resilienza (PNRR)”, in particular with the missions “Green revolution and ecological transition” and “Infrastructures for a sustainable mobility".

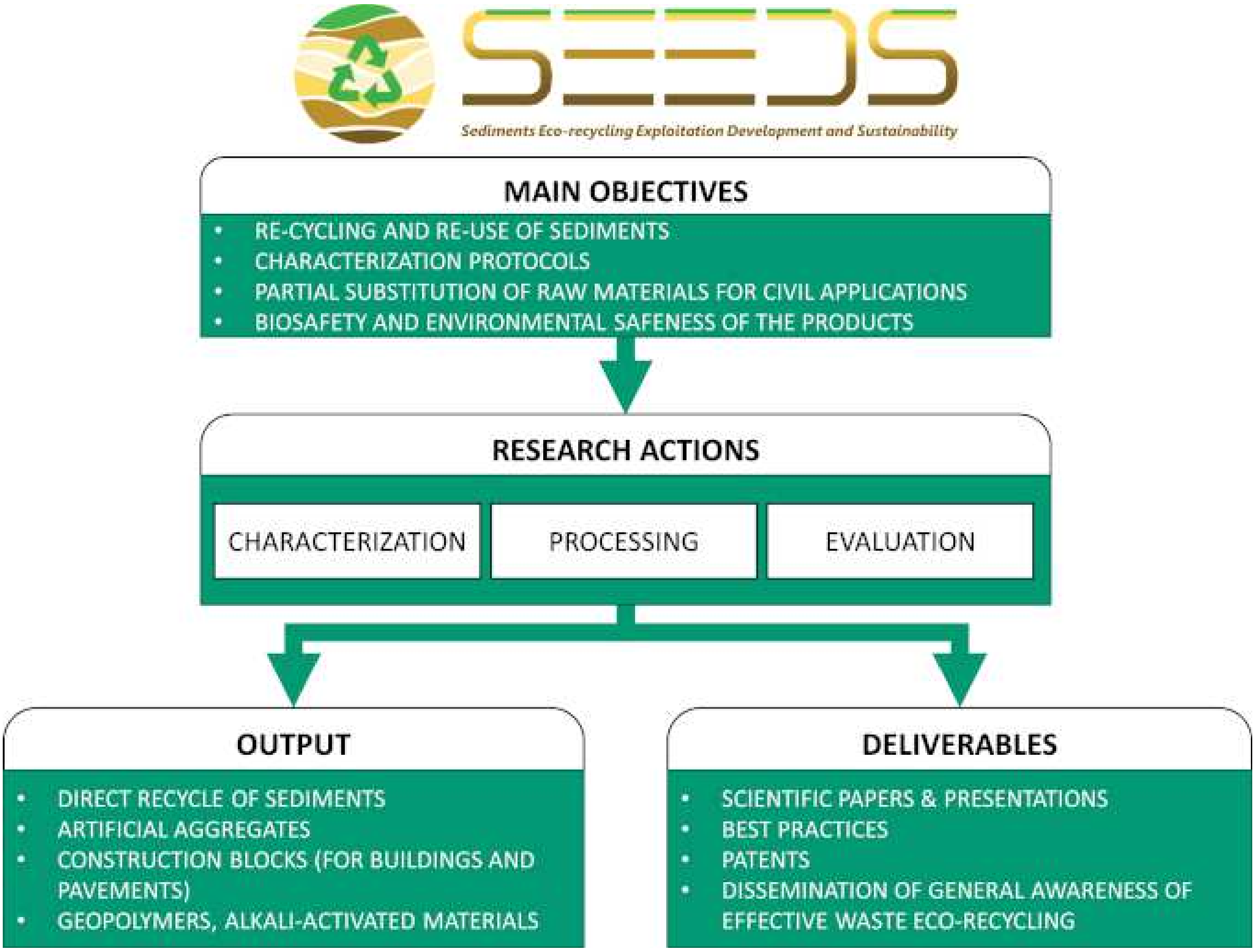

Figure 1. Project outline.

To this aim, a multidisciplinary method is proposed encompassing mineralogical, materials science, engineering and toxicological knowledge to gain eco-sustainable building materials with suitable characteristics for each specific application. Firstly, mineralogical knowledge on the selected sediments is necessary to develop suitable mixtures to produce the target materials; after, as these materials must satisfy the mechanical properties disciplined by specific standards, engineering knowledge is required. In fact, the use of sediments in the geopolymer matrix undoubtedly will lead to the modification of some properties of the consolidated material (e.g., strength, durability, etc.); nevertheless, these modifications could be linked to the mineralogical composition, which in turn can be properly modulated in mixture design.
To further improve the technological properties of the produced geopolymer/sediment composites, the possibility to include some fractions of other recovered materials (e.g., glass cullet and other inert materials from thermal treatments) could be considered. Some examples are already known for the industrial production of ceramics and could be extended to geopolymers as well.
It should also be stressed that the produced materials will be carefully characterized considering not only their chemical and physical properties, but also their safeness to assess the absence of risks for both human health and the environment, a step which is mandatory to plan the technology transfer.
The SEEDS project aims at obtaining a laboratory validation of the sediments-based products (Technology readiness level, TRL, of 4), with possible extension to preliminary industrial evaluations (TRL 5). Thus, SEEDS is not a mere methodological approach to a looming problem, but it is a new way of rethinking our waste.

11. Total cost of the research project identified by items

Associated Investigator	item A.1	item A.2.1	item B	item C	item D	item E	sub-total	Total
VALDRE' Giovanni	29.900	37.500	40.440	0	0	4.250	112.090	**112.090**
GUALTIERI Alessandro	19.450	23.929	26.027	0	0	4.500	73.906	**73.906**
LANDI Elena	21.165	23.889	27.032	0	0	5.000	77.086	**77.086**

SCARFI' Sonia	6.913	23.891	18.482	0	0	14.000	63.286	**63.286**
Total	**77.428**	**109.209**	**111.981**	**0**	**0**	**27.750**	**326.368**	**326.368**

N.B. The Item B and TOTAL columns will be filled in automatically

- item A.1: enhancement of months/person of permanent employees
- item A.2.1: cost of contracts of non-employees, specifically to recruit
- item B: overhead (flat rate equal to 60% of the total personnel cost, A.1+A.2.1, for each research unit)
- item C: cost of equipment, tools and software products
- item D: cost of consulting and similar services
- item E: other operating costs

PART B

B.1

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1. State of the art

Since the introduction of the circular and sustainable economy approaches into the construction processes, the partial substitution of conventional (lithic) raw materials with wastes has become of increasing importance. Most of the replacing materials are essentially derived from [1-14]:

i) the industrial activities and energy production (e.g. mining and quarrying, fly and bottom ashes, metallurgical slags, ceramic and brick production residues/discards, glass processing and recycling, construction and demolition wastes),
ii) the hazardous wastes inertization and storage (e.g. KryAs, ash from municipal waste incinerators, sewage sludges), and
iii) the interventions in hydraulic plants and connected sewage systems (e.g. fresh water and marine sediments of variable grain size and composition).

The re-use of ash is known since several time and significant amounts of waste are employed in the production of cementitious materials [1-8]; more recent, and not so far diffused is the re-use of sewage sludges in fabrication of construction and building materials [7], and of KryAs (i.e. the residue from thermal inertization of cement asbestos) as ceramic additive [9,10]. Less known and certainly not yet fully exploited is also the use of freshwater and/or marine sediments [13,14]. In contrast, significant volumes (more than one billion cubic meter) of dredged sediments are produced worldwide every year [11], being necessary to preserve the full functionality of the hydraulic plants, which regulate the flow and/or storage of water. If not contaminated, these sediments are usually stored or disposed at sea or, if they are from fresh water, as land-filler. In the last decades, because of their specific chemical and mineralogical characteristics, various studies [e.g. 12-18] proposed strategies for the valorisation in several fields, such as bricks, ceramics, lightweight aggregates, road construction materials and, to a large extent, mortars and concretes. Nevertheless, with some exceptions [e.g. 12, 16, 19-22], the detailed investigation of the specific rheological properties and of the possible long-term toxicological effects of the produced materials are less reported. In fact, the beneficial use of dredged material is strongly controlled by some parameters such as mineralogical composition, grain size distribution, chemical composition, total organic content and, in particular circumstances, the occurrence of pollutants. For instance, organic matter is known to delay setting and hinders the development of the strength of cement paste and mortars [23], whereas the presence of small shells reduces concrete strength owing to their flattened shapes and poor adhesion to cement paste [24]. The fine fraction of sediments also affects cement paste properties because limes and, mostly, clays reduce the workability due to their medium-high specific surface area and water retention [25].
An alternative to Portland cements is given by inorganic polymers, generally called “geopolymers”, obtained by converting Al- and Si-rich materials or by-products (i.e. slag, fly ash, silica fume, etc.) into value-added binders [26-27]. In this process, amorphous aluminosilicate materials are firstly dissolved by an alkaline activator solution (alkaline hydroxide or silicates) and then polycondensed and consolidated in a more stable Si–O–Al-type structure with high mechanical strength and chemical stability [28]. Despite these relevant developments, a still ongoing challenge is performing the polymerization reaction with low energy consumption.
The use of wastes in replacement of raw materials in mortars and concretes production is driven not only by economic reasons, but also by the pressing need to reduce the carbon footprint from concrete production, as it is responsible for about 7% of CO2 emissions of industrial origin [29]. In fact, high volume of clinker replacements sometimes results in losses in performance at early ages. One of the many challenges related with the introduction of so many new materials is finding methods to properly characterize them, to optimize the balance between an “environmentally cleaner” production and performance of the final product and last, but not least, its biosafety. It is intuitive that this objective can only be achieved through an appropriate characterization of the recycled materials, whose chemical and physical properties may vary over time and sites of production and whose potential risk to both human health and the environment must be tested, with the aim of delivering ready-to-use and safe products.

Such daunting and vital societal challenges are nowadays being tackled by EU investing huge efforts aimed to the challenge posed by the “zero waste” regime and transition to the Circular Economy. Towards such objectives, much is still to be done, in particular to bridge the specific properties of a waste with its possible large-scale applications.

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2. Detailed description of the project: methodologies, objectives and results that the project aims to achieve and its interest for the advancement of knowledge, as well as methods of dissemination of the results achieved

1. INTRODUCTION: OBJECTIVES AND PROJECT AIMS

The goal of the SEEDS project is to identify and develop new recycling methods for waste materials, with a specific focus on the discarded sediments of anthropic/industrial origin, integrated by an assessment of risk for human health and the environment by appropriate toxicological studies. As shown in Figure 1, the main project objectives are to introduce selected waste sediments in the circular economy chain of production and construction, by using them as substitutes for valuable primary raw materials for civil engineering applications (construction of infrastructures and buildings and similar).
Recycled sediments in the form of fillers (less than 2 mm diameter) or fines (less than 60 microns) have long been considered as possible valid constituents of bound or unbound mixtures for pavement layers and other transportation infrastructures. On the other hand, a different and more advanced approach would make the most of the chemical and mineralogical composition of some recycled sediments and use them in the creation of geopolymers or alkali-activated materials. Here the contribution of the precursor powders (even in a blend of powders) can be active in generating a binder that can harden with simple low-temperature curing and provide exceptional strengths and other valid features. These properties can be exploited in the creation of geopolymeric binders and composites to produce the above-mentioned infrastructure elements or, in a recently proposed idea, for the creation of engineered artificial aggregates.
Before delving into the intended actions, it is necessary to define the boundaries within which the SEEDS project operates. In fact, waste sediments generated from human activities are extremely numerous and very different from each other, and it would be unrealistic if a too large typology was considered for the project. For this reason, within this project two to four different sediments provided by a selected group of companies (Basalti Orvieto SrL and Sibelco SpA), which were produced during their extraction activity, will be made available to the project and considered as representative samples of the targeted materials to be recovered and recycled. The two companies are also very interested in the presented SEEDS project, not only for developing innovative recycling approaches and solutions for sediments and similar wastes and other building materials, but also because they are convinced that the interactions between the Companies and the University in this research field may also open new and different future collaborations and employments in the industry sector (see Letter of Interests by the companies at the end of this paragraph).

Basalti
Orvieto

ICMQ Certificazione sistema qualità
Certificato n°04888
EA: 2-Estrazione e lavorazione di aggregati lapidei

IQNet CERTIFIED MANAGEMENT SYSTEM
IT-35435

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1305-CPR-0076

EURO CERT
CERTIFIED M.S.
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462ITES

EURO CERT
CERTIFIED M.S.
OHSAS 18001:2007
393ITOH

To Prof. Giovanni Valdré
Alma Mater Studiorum – University of Bologna
Department of Biological, Geological, and Environmental Sciences
Piazza di Porta San Donato 1
40126, Bologna (BO), Italy

DECLARATION OF INTEREST

With reference to the project **"Sediments Eco-recycling Exploitation, Development and Sustainability (SEEDS)"**, to be submitted within the programme **Research Projects of Relevant National Interest (PRIN 2022)**, as Legal representative of Basalti Orvieto S.r.l., I hereby confirm our interest and willingness to follow the outcomes of the research activities Coordinated by the University of Bologna.

With this letter Basalti Orvieto S.r.l. wants to express its support for **SEEDS** being its principles and research aims fully in line with the today needs of our company and for the forthcoming future. Furthermore, the undersigned acknowledges that Basalti Orvieto S.r.l. intends to actively interact with its expertise with the project participants, within this network of outstanding quality.

Basalti Orvieto S.r.l. considers that **SEEDS** project will be of particular importance for moving towards innovative recycling approaches and solutions for sediments and similar wastes and other building materials. Basalti Orvieto S.r.l. will provide, were needed, laboratory quantities of materials to support the development of the testing protocols.

Finally, Basalti Orvieto S.r.l. is convinced that the interactions between the company and the research units involved in the project may also open new future collaborations, as well as new joint opportunities to be carried out within other national or international research calls.

Castel Viscardo, 19/01/2022

BASALTI ORVIETO S.R.L.
Legal Representative
Gianluca Pizzuti

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SIBELCO

To **Prof. Giovanni Valdré**
Alma Mater Studiorum – University of Bologna
Department of Biological, Geological, and Environmental Sciences
Piazza di Porta San Donato 1
40126, Bologna (BO), Italy

DECLARATION OF INTEREST

With reference to the project **"Sediments Eco-recycling Exploitation, Development and Sustainability (SEEDS)"**, to be submitted within the programme **Research Projects of Relevant National Interest (PRIN 2022)**, as an attorney of Sibelco Italia s.p.a., I Enrico Sopini hereby confirm our interest and willingness to follow the outcomes of the research activities Coordinated by the University of Bologna.

With this letter Sibelco Italia s.p.a. wants to express its support for **SEEDS** being its principles and research aims fully in line with the today needs of our company and for the forthcoming future. Furthermore, the undersigned acknowledges that Sibelco intends to actively interact with its expertise with the project participants, within this network of outstanding quality.

Sibelco Italia s.p.a. considers that **SEEDS** project will be of particular importance for moving towards innovative recycling approaches and solutions for sediments and similar wastes. Therefore, Sibelco Italia s.p.a. undertakes to support the project by providing, were needed, laboratory quantities of materials to support the development of the testing protocols.

Finally, Sibelco Italia s.p.a. is convinced that the interactions between the company and the research units involved in the project may also open new future collaborations, as well as new joint opportunities to be carried out within other national or international research calls.

Maranello
30/03/2022

Attorney
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It is necessary to evaluate the mineralogical, chemical, and physical properties of the starting material to properly design recycling solutions leading to products that are suitable for the different applications, considering also for the repeatability and standardization of the procedure.

2. RESEARCH ACTIONS AND INVOLVED METHODOLOGIES

A detailed scheme that illustrates the activities of the SEEDS project is shown in Figure 2, whose actions (within the rectangular boxes) are described in detail in the following. SEEDS has three lines of research and development, reported specifically in paragraphs 2.1-2.3.

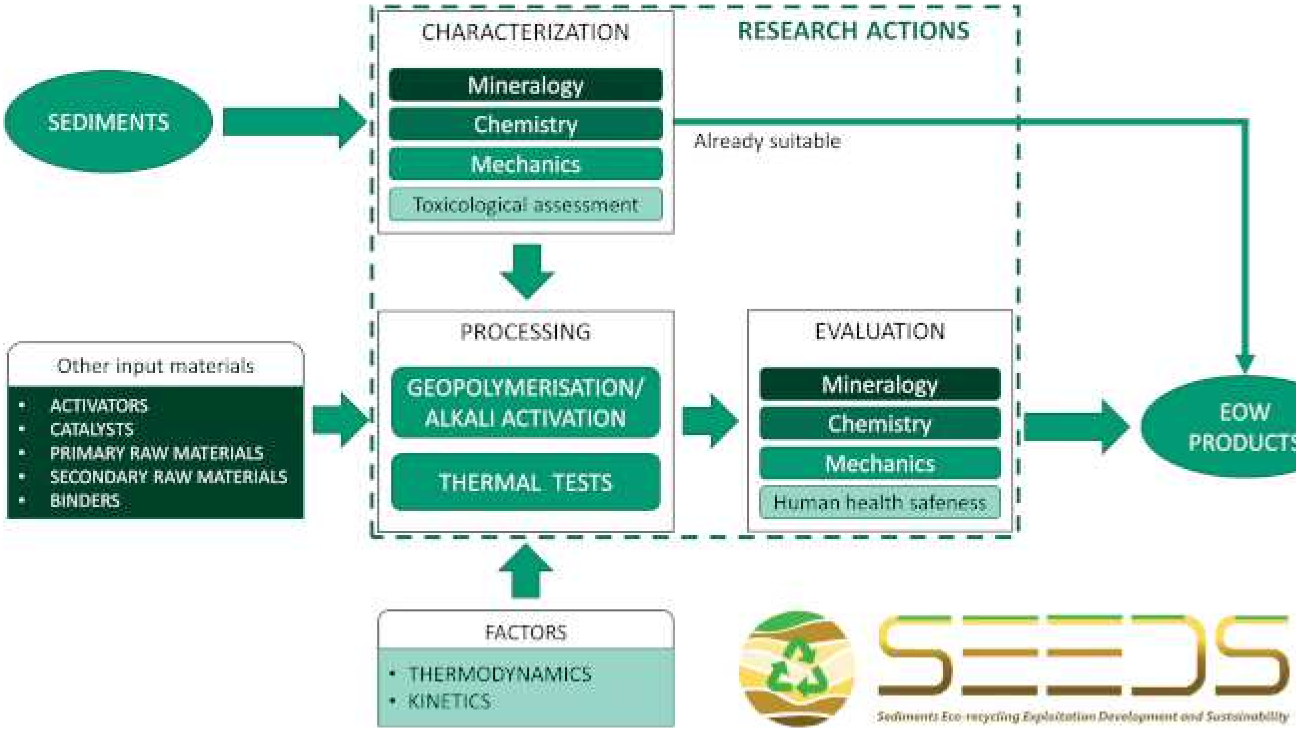

Figure 2. Research actions of the SEEDS project.

2.1 Characterisation of sediments

The first line of research and development is a detailed multi-methodological characterization of the sediments supplied by the involved companies. This is an important task, especially for what concerns the relationship between the mineralogical/chemical composition and the physical and mechanical properties of the sediments. In fact, the amount of different minerals in the sediment mixture strongly affects the properties of the starting material and the final products, influencing also the durability of the latter. For example, dredged freshwater sediments are generally expected to be rich in layered silicates, feldspars, and quartz, but also can contain significant amounts of organic matter. However, it is also possible to find significant variations in the concentration of each mineralogical phase, as well as of the amorphous, depending on the sampling position in both space and time. Likewise, important variations may also occur in the overall chemical composition. For all these reasons, a series of assessments is mandatory not only to provide a general estimation of the mineral and chemical components in the collected sediments, but also to understand their physical properties, in particular their thermal and rheological behaviour. The following methodologies will be applied:

• granulometry and particle size distribution (PSD), by both sieving analysis, image analysis, and the application of the Low Angle Laser Light Scattering for the analysis of the finest fraction;
• common classification protocols for soils and aggregates mixtures for infrastructural applications;
• X-ray powder diffraction (XRPD) at ambient and controlled temperature conditions and quantitative phases analyses (QPA) following the scheme, based on the Rietveld method, recently proposed to the scientific community [30];
• wavelength-dispersive X-ray fluorescence (WD-XRF) to obtain chemical analysis of both major and trace (ppm) elements with particular attention to the possible occurrence of heavy metals, and elemental analyses to carefully assess the content of nitrogen, carbon and sulphur;
• thermogravimetric / thermodifferential analyses (TGA/DTA) and thermogravimetric / differential scanning calorimetry analyses (TGA/DSC), both combined with the simultaneous analysis of evolved gases via mass spectrometry (MSEGA);
• scanning electron microscopy (FEG-SEM, FEG-ESEM, FEG-ESTEM) coupled with energy dispersive spectroscopy (EDS), scanning probe microscopy (SPM) and analytical transmission electron microscopy and diffraction (TEM). The combination of these techniques, including non-conventional methods applied to image analysis, can be adopted to determine textures and mineralogical, petrographic and chemical compositions of sediments, including organic fractions.

TGA/DTA and MSEGA measurements are also particularly suited to finely characterize compounds non-detectable through XRPD (i.e., amorphous and/or crystalline phases in low concentration). For example, the release of NO and CO_2 gases between 300°C and 500°C is usually indicative of the presence of residues of organic matter; similarly, the release of CO_2 between 600°C and 800°C indicates the presence of carbonates, while the release of SO_2 above 1150°C could be related to sulphates. This information will better detail results from elemental analyses and can be also cross-correlated with those from electron microscopy.

The evaluation of the potential risks to living organisms and the environment during exposure to new chemicals from the recycling of waste materials will be verified by the analysis of several biomarkers of risk for human health (i.e., operator workers and future residents) using in vitro alternative models to animals [31]. For example, 3D models of reconstituted organs (skin and nasal epithelia) which represent the first targets of cell damage (irritation and corrosion) and which mimic the “first line of defense” organs. The development of alternative methods is not only an ethical dogma but a scientific need, since the toxicological results obtained in animal models are often irrelevant for human extrapolation. Furthermore, the European legislation, through the REACH directive (CE n. 1907/2006), has imposed a series of restrictions on the use of animals for the prediction of the risk of the exposure of hazardous substances to humans. In anticipation of a specific regulation on the use of sediments in the recycling construction process, the proposed study aims to provide indicators for an evaluation of the intrinsically toxic potential or, conversely, a safety assessment of the waste sediments and of the new recycled materials.
All this preliminary and fundamental knowledge on the starting material is of utmost importance for the design and development of the re-cycling strategies for the collected sediments.

2.2. Processing

SEEDS intends to employ the recovered materials in the production of geopolymers, which are ceramic-like inorganic polymers synthesized at low temperature, usually less than 100°C, consisting of chains or networks of so-called “mineral molecules” linked with covalent bonds. For this application, a deep understanding of both the thermodynamic and kinetic factors controlling the geopolymerisation process is highly desirable. A typical reagent in geopolymerisation is metakaolin (MK), the dehydroxylation product of the mineral kaolinite.
MK is employed in mixtures with other aluminosilicates and/or alkali silicate aqueous solutions to obtain a Si:Al ratio that leads to a final product with desired physical, rheological and mechanical properties. A MK-based geopolymer formulation with a Si:Al ratio equal to 2, having the controlled and optimal stoichiometric structure of polysialate-siloxo type, will be considered as a reference mixture throughout the project activities [32].
A statistical Design of Experiments (DoE) approach will be adopted in the laboratory processes for the optimization of the mixtures, where the mix-design includes different variables (e.g. mix-proportions, mix of mineral constituents, pre-conditioning temperature, curing temperature and time and other relevant variables). In details, it is necessary to characterize different mixtures of sediments + other reactants/activators in terms of:

a. thermal activation and other thermodynamic features,
b. curing time/setting and
c. physico-mechanical properties of the geopolymers and/or AAMs.

The rheological/mechanical behaviour obviously dictates the possible employments of both the geopolymer/AAM paste and the final products.
The selected waste sediments should be used as potential (partial) substitute for the pure kaolinitic clays, traditionally used as precursors to produce geopolymeric materials. In fact, MK would represent a major cost in the development of geopolymers for high-volumes applications, as in the building and infrastructure fields. The determination of the amount of readily reactive amorphous alumino-silicate phases in the sediments will indicate their reactive potential within the geopolymerisation/alkali-activation process and significantly influence the formulation of the mixtures. Residues of a poorly reactive or partially inert nature will be eventually thermally or mechanically pre-treated, to enhance their reactivity degree, or be used as secondary fillers and inert phases in reference MK-based geopolymer mixtures.
Different mixtures will be formulated using the selected sediments, including various relative amounts of waste and pure feedstocks according to the materials’ reactivity within the alkali activation and/or geopolymerisation process. Leaching tests in alkaline conditions (NaOH 8M) will be carried out to determine the released elements active in the geopolymerization process, therefore assessing the reactivity potential of the materials. Lab-scale samples will be produced and characterized to identify the most suitable application paths, with the constant aim of formulating low-cost and sustainable solutions that can be used as an alternative to more traditional materials.
It will also be evaluated if the primary raw materials can be partially replaced not only by the reference target-waste (sediments), but possibly also with other wastes already successfully employed in the past and thus well-known, on the basis of the already available literature and materials characterization [9-10].
Together with the above experimental methodologies, theoretical modelling techniques will be developed and adopted to corroborate and extend the knowledge on the synthesized materials. In details, (a) quantum mechanics modelling will provide atomic-level characterization of structural, mechanical, and thermal properties of newly formed phases and (b) kinetic modelling will be adopted to better formulate (and ameliorate) the geopolymerisation processes.

2.3. Evaluation of the products

The produced materials will be characterized through lab-scale evaluations in their fresh, hardened, bound or unbound state, in terms of workability, castability and curing time, macro and microstructural features (structure, texture, phase composition), thermal, physical and mechanical properties, and toxicological potential. Aggregates and their mixtures will be tested according to specific standards for: unbound or hydraulically bound (EN 13242), cement concretes (EN 12620), bituminous bound (EN 13043),

mortars (EN 13139) and lightweight aggregates (EN 13055). Mixtures for layers, compacted layers and construction elements will be tested according to other standards or series of standards (for example EN 12697 series for asphalt layers, EN 14227-1 for cement bound layers and EN 1338 for paving blocks). At present, the classification and understanding of the possibilities of using these new materials will pass through the study of their physical (absolute and apparent density, water adsorptions for capillarity and at atmospheric pressure, porosity) and mechanical properties (uniaxial compressive strength and flexural strength on 4 cm x 4 cm x 16 cm specimens, Knoop microhardness, Leeb hardness, ultrasonic pulse velocity) and, subsequently, the classification of the materials based on these properties.
The development of highly stable materials with high polycondensation degrees and medium to high compressive strength will be preferentially pursued to meet the performance requirements needed for specific applications.
Alternative routes might be evaluated for the application of the developed materials in different application fields, requiring diverse functional properties, such as high flowability or high durability in aggressive environments. Hence, the obtained property sets will be considered as key parameters in determining the range of possible application fields for the produced materials, so that the most promising solutions can be suggested.
Like done on the original waste sediments, also the geopolymers and/or AAMs obtained by recycling them will be characterized at the mineralogical and chemical levels. For example, the thermal behaviour may indirectly provide an indication of the resistance to deterioration, as the thermal decomposition temperature is directly related to the bond strength. Here, the thermal characterization will be defined by comparing the results of TGA/DTA with those of XRPD at controlled temperature. The analysis by electron microscopy of the finished products, including image analysis, will allow to determine in detail the characteristics of the material, the degree of activation of the same, its porosity and the presence of crystalline phases, or possibly neoformation phases (which depend on any high temperature treatments), which could lead to a rapid degradation of the material or to the release of harmful elements into the environment. Likewise, the need to maintain alkalinity factors between pH 12 and 13, together with well-established Si:Al ratios, make mandatory to know the stoichiometry of the minerals involved in the dissolution and geopolymer re-aggregation processes of the new products.
Leaching tests will be also performed to verify which of the elements present in the initial system (i.e. before the geopolymerisation reaction and/or alkali-activated process) are preferably released both in weakly acidic and weakly alkaline environments. Leaching methods are usually distinguished in dynamic or static, depending on whether the leaching solution is periodically renewed or not during the experiments. Here the leachability will be tested in a dynamic way according to NEN 7345 method, but using both weakly acid and alkaline solutions. These measurements are complementary to those related to the mechanical properties (compliance with the quality criteria defined by current regulations) and will also provide useful indications for the biosafety evaluation.
Regarding the latter, indications will be given on the risk for human health to acute and chronic exposure to the materials (waste sediments and new recycled materials) reduced to a form of fine respirable dusts (mimicking the weathering), as well as to substances possibly released from the leaching during time (aqueous extract: elutriate).
In-vitro 2D and 3D human based models will be used to assess bioethically-compatible predictive testing in order to evaluate the effects of the studied materials. Therefore, the parameters investigated will be related to both acute toxic effects and chronic sub-toxic exposure that triggers cell damage signalling as an adaptive response. These events can lead to inflammation, oxidative stress, cell death/apoptosis, degenerative processes, and tumour induction.
The evidence of risk or safety assessment for human health through the following endpoints

- acute and chronic toxicity potential (skin and respiratory tract),
- oxidative damage potential,
- irritative/inflammatory potential,
- sensitization/allergenic potential,
- genotoxic potential,

will establish the immediate and long-term safety of the newly produced materials, which are subjected to weathering and/or leaching over time. The experimental models will also allow to study single parameters of a determined phenomenon and will provide quantitative, objective, and sensitive data: therefore, not just numbers, but also possible mechanisms of action of the materials under study if the risks of toxicity effects are proven.

3. EXPECTED RESULTS

The SEEDS project will allow developing and formulating competitive sustainable products from the eco-recycling of sediments and other wastes, for the building and infrastructure industry (construction materials).
In more details, the complete multidisciplinary approach proposed and presented in the SEEDS project will provide:

i) the knowledge of the transformation processes occurring in geopolymerisation and alkali-activated processes of waste sediments;
ii) the standardization of the procedure to eco-recycle the same type of waste sediment for the envisioned applications in building and construction industry;
iii) a set of competitive products for the building and construction industry.

4. DISSEMINATION STRATEGY

It is also important discussing and presenting the dissemination strategy of the SEEDS project. In the last years, together with the standard channels of scientific communication (papers, patents, workshops, congress meetings), other ones mainly related to the social media arose, such as ResearchGate, LinkedIN, Twitter, Instagram, Facebook and so on. While the academic world turns almost exclusively to the classic channels of peer reviewed journals, workshops and congresses, there is a large mass of the population, potentially interested in the results of public research, who are leveraging social media for their initial research of information. This is particularly true for what regards the environment, the eco-recycling, the green-world, the climate changes and the use of alternative methods to animal experimentation. Potential stakeholders, like small, medium and large companies, nestle among these, always looking for innovative materials to be used in their sectors. By providing them with datasheets of the developed materials and synthetic explanation of the patents through social media, we may encourage them to develop future collaborations, including further patenting, spin-offs and start-up creation.
An additional dissemination strategy will involve secondary school students and teachers. In fact, if the integration of the research results is a widespread practice in university courses, their diffusion in secondary schools is less practised. This will also be achieved through the many agreements already in place within the projects for Transversal Skills and Orientation Project (Italian PCTO) and teacher training.
The social character related to the non-expert public, presenting a green sensibility and curiosity towards the possibilities and characteristics of these new materials, is also worth to be considered. With a view to raising awareness of the use of materials and practices towards a “Circular Green Economy", it is necessary to count this "critical mass", which soon will be able to create a demand for this kind of products. Specific forms of social media communication will be dedicated to them.

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3. Project development, with identification of the role of each research unit, with regards to related modalities of integration and collaboration

The SEEDS project is subdivided into 6 Work Packages (WPs 0-5) that correspond to the main actions involved to reach the targeted outcomes (Figure 3). The architecture of WPs enables also a more streamlined management of the activities and coordination of the research units during the two-years duration of the project.

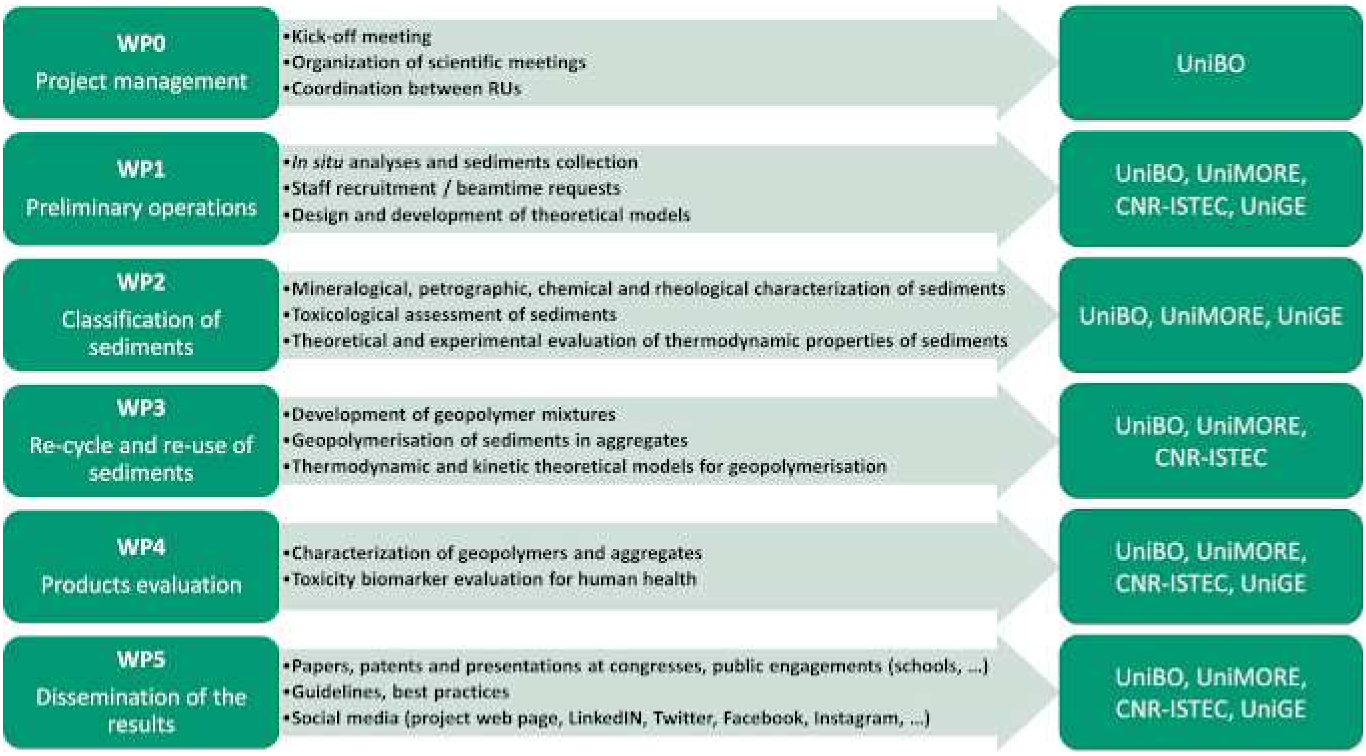

Figure 3. Work Packages of SEEDS, together with the involvement of each research unit.

The participation of each research unit (RU) to the different work package is also synthetically presented in Figure 3, whereas a Gantt chart showing the schematic timeline of the activities of the SEEDS project is reported in Figure 4. Then, it follows a brief description of the expertise, competencies and specific actions that each research unit brings to the scientific platform to attain the goals of the project.

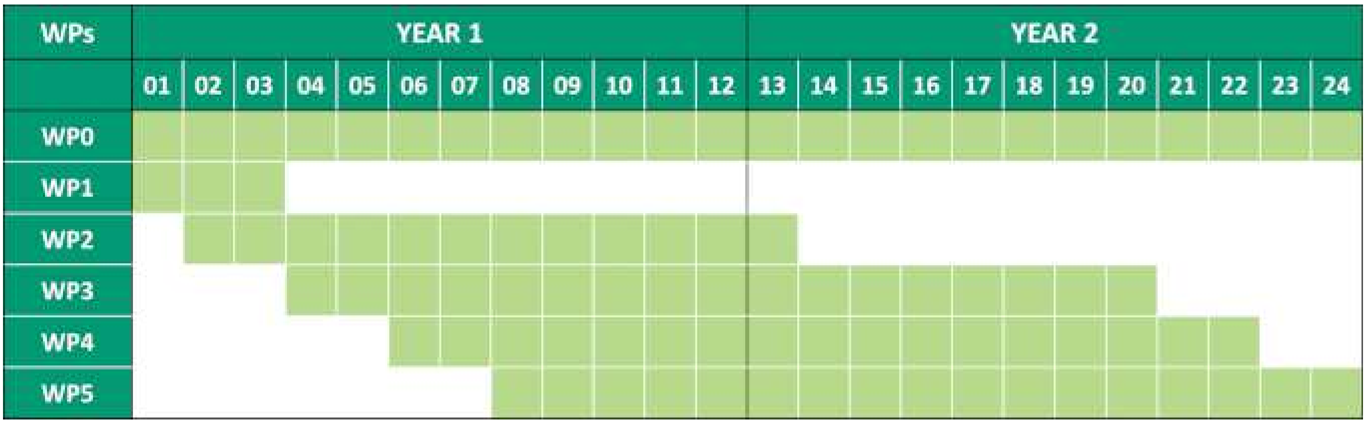

Figure 4. Gantt chart of SEEDS.

The UniBO RU is focused on both fundamental and applied research activities involving mineralogical and engineering aspects related to sediments recovering/re-cycle into geopolymers and/or alkali-activated materials for civil purposes. The UniBO adopts a cross-correlated experimental and theoretical approach to investigate the possibility to employ geopolymers/AAMs with tailored properties for aggregates and mortars/cements, the latter being in collaboration with CNR-ISTEC RU. In addition, UniBO provides theoretical support by means of both static and kinetic modelling. The activities that UniBO will carry out are:
1. In situ preliminary evaluation of the mineralogical and chemical characterization of sediments from different sources (detailed cross-correlated characterization will be done also by UniMORE).
2. Kinetic experimental characterization of geopolymerisation and/or alkali-activated processes between mixtures of metakaolin and sediments with different amounts of components.
3. Small and medium scale rheological and mechanical tests on both the recovered sediments and the geopolymers and/or alkali-activated materials for specific applications (e.g., aggregates, cement, and concrete).
4. Classical thermodynamic and kinetic modelling of crystallization and geopolymerisation and/or alkali-activated processes.
5. Theoretical characterization of the stability, reactivity and surface properties of selected phases occurring during geopolymerisation, by means of ab-initio Density Functional Theory and statistical mechanics [33].

The UniMORE RU boasts a consolidated experience in the chemical and mineralogical characterization of raw materials of different origin and employing various traditional and advanced analytical techniques and methods; moreover, UniMORE has already experimented techniques for the possible use of various types of waste and by-products (e.g., KryAs, glass, polluted clays, etc). The activities of UniMORE, schematically, will be centred on the:
1. Participation to the geopolymer mix-design, based on mineralogic and petrographic knowledge and expertise, and on the analytical results of the whole SEEDS research network, identifying possible composition of mixtures (with UniBO and CNR-ISTEC).
2. In close synergy and completeness with the UniBO unit, detailed mineralogical and petrographic characterizations of sediments.
3. Small-scale characterization of the geopolymers/AAMs. In particular, it will be evaluated the release of both cations and anions by leaching tests for environmental compliance and safety. On one side, if the products release toxic/harmful elements, this can affect the biocompatibility tests performed by UniGE. On the other side, if the degree of release of non-harmful elements is high, it will affect the long-term stability of the geopolymers/AAMs.

The CNR-ISTEC unit, in virtue of the specific expertise developed in years on the study and development of geopolymers/AAMs from waste sources and secondary raw materials, will be in charge of evaluating the potential use of waste sediments as source in geopolymerisation and alkali-activation processes. The final aim is developing new formulations for more sustainable, low-cost aggregates and binders. In details, CNR-ISTEC will provide:
1. Evaluation of the reactivity of the identified sediments in alkaline environments and identification of possible strategies and pre-treatments to enhance the materials reactivity within the alkali activation process.
2. Study of the application of geopolymerisation and alkali-activation processes in MK-based systems (taken as reference materials) integrated with different volumetric fractions of those identified as the least reactive sediments, for their reuse as inert or partially reactive fillers in AAMs. Production of lab-scale composite samples with different formulations (in collaboration with UniBO). Study of the application of geopolymerisation and alkali-activation processes in blended MK/sediments systems with total/partial replacement of the reactive aluminosilicate phase from metakaolin with the identified reactive/partially-reactive sediments. Production of lab-scale samples with different formulations (geopolymers design with UniBO and UniMORE).
3. Lab-scale characterization of the produced samples in terms of physical (He-picnometry, MIP) macro/microstructural (optical microscopy, FEG-ESEM, EDS, XRD), thermal (simultaneous thermal analysis TGA/DSC/MSEGA, linear dilatometry) and mechanical properties (compressive strength test).

The UniGE RU will provide the expertise and facilities to verify if the used sediments and new recycled materials (and elutriates) may trigger adverse effects on the "first target" human tissues (skin, respiratory tract and immune cells) by analysis of basal cytotoxicity, inflammation, oxidative and genotoxic biomarkers. To better predict the human risk several human in vitro models will be used to assess acute and chronic exposure effects. In particular, the following activities will be performed on human in vitro models:
1. 2D cultures of Human keratinocytes (HaCaT), human bronchial epithelial cells (16HBE), and human monocytes (THP-1).
2. 3D reconstructed human epidermis (RHE) models in compliance with the Organisation for Economic Co-operation and

Development (OECD) and 3D reconstructed human nasal epithelium and bronchial epithelium.
3. Point 1. And 2. In vitro models will be subjected to biochemical and molecular biology analyses of parameters associated with the following outcomes: acute and chronic toxicity potential (skin and respiratory tract), oxidative damage potential, irritative/inflammatory potential, sensitization/allergenic potential and genotoxic potential.
The UniGE RU is therefore responsible for the biosafety of the materials found and processed and, therefore, its activity will be all in full synergy with those of other RUs being necessary a deep knowledge of the material characteristics.

All the research units perform individual research actions and collaborate as an integrated research platform to reach the goals of the SEEDS project, in accordance with the work package list (Figure 3) and the platform scheme of Figure 5.

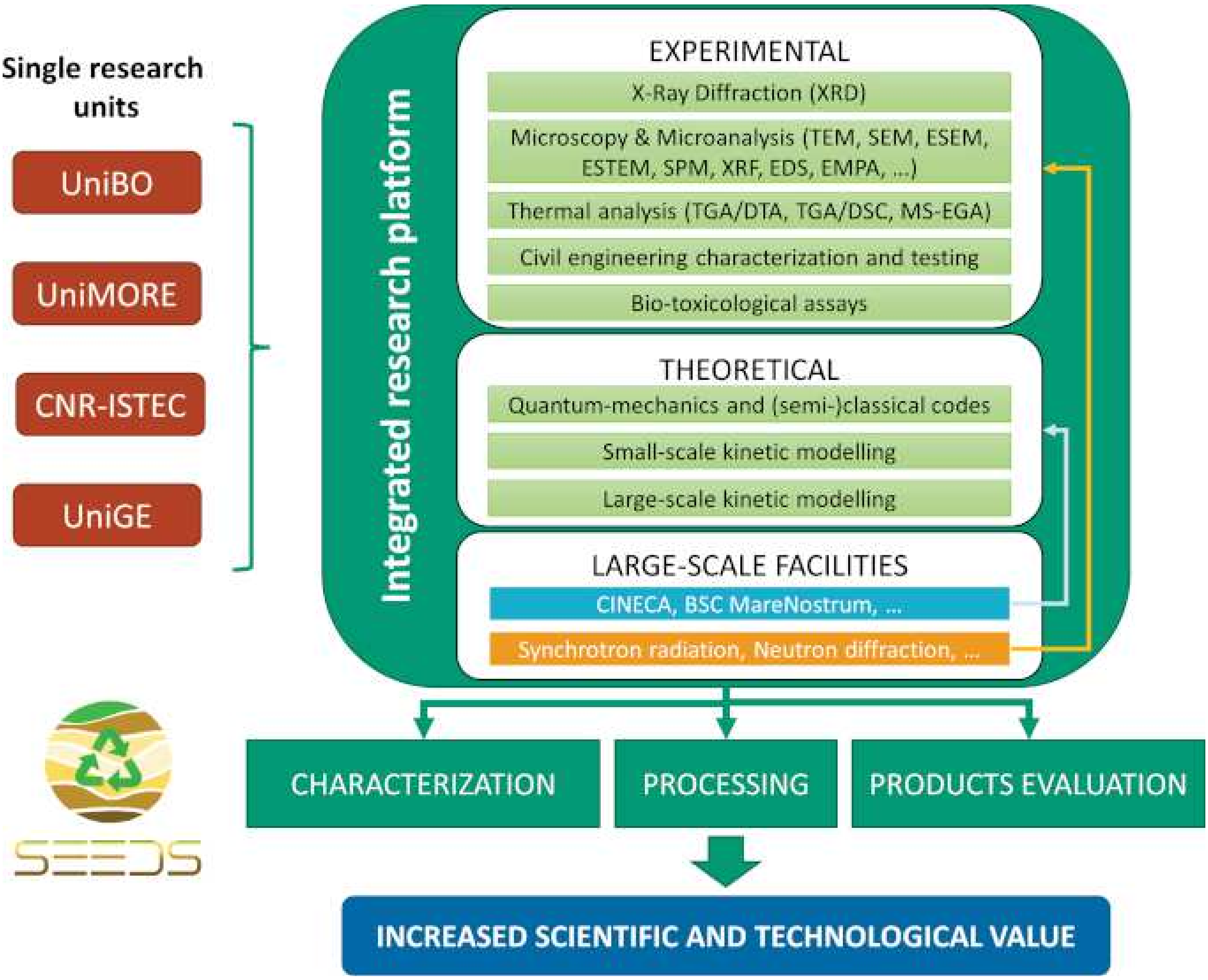

Figure 5. SEEDS integrated research platform.

The multidisciplinary character of the SEEDS research team is a key force and strength for the success and possible future developments of the project. In addition, the collaboration between the four RUs is not limited to sharing data, but also to the cross-exchange of expertise and teamworking to solve common issues that may arise during the project.
It is possible noting that some specific tasks are carried out by multiple RUs, particularly those related to the characterization of materials. This is a desired and planned feature because, on one side, the results obtained by independent laboratories with the same technique (e.g., XRPD) will strengthen their statistical meaningfulness. On the other side, different RUs bring specific, complementary analyses, for example chemical analyses performed by XRF and leaching tests tell what elements are contained and released by a sample, respectively.

4. Possible application potentialities and scientific and/or technological and/or social and/or economic impact

The industry of construction and construction materials is concerned about the present sustainable development goals because of the large environmental footprint that the industry itself creates. The strategies and solutions to meet the urgent environmental challenges can no longer ignore the use of recycled materials in place of virgin resources. To this end, SEEDS focuses on the recovering of selected sediments currently treated as waste and to safely recycle them into the production cycle of innovative and sustainable construction materials.

The possible application potentialities of SEEDS could be:

a) the realization of economically competitive construction materials and elements for ecologically sustainable (infra)structures;
b) the construction of models to predict both the formulation of geopolymer/AAMs precursors and their behaviour from waste sediments;
c) the standardization of the recycle procedure, to provide practical guidelines on the mix design to meet the required quality standards in term of resistance, durability and biosafety for different building materials;
d) the scale-up of the eco-recycling procedure of the waste sediments at the industrial scale through geopolymerisation and alkali-activated processes.

In addition, the targeted wastes are sediments, but as previously mentioned other wastes (glass, KryAs, but also can be considered fly- and bottom-ash) can also be potentially used for the intended purposes. This approach could lead to the design and production of new materials employing up to 50% of wastes, obtaining products with the same, or even better, quality of those made using virgin raw materials. It is important to underline that the use of different types of sediments and other wastes represents an absolute novelty in this scenario, which will certainly be a harbinger of a possible technological development in the different fields of construction and construction materials characterization and design. It can be foreseen that in the near future the outcomes of SEEDS may be applied to the recycling of other types of waste sediments that have not been tested until now (for example, marine sediments, hitherto little exploited as they present significant problems in controlling the diffusion of water-soluble anions and cations). Moreover, as a future perspective, it should be considered to develop circular economy strategies where the same materials produced through the SEEDS' approach could be recycled once their service life is completed (Figure 6).

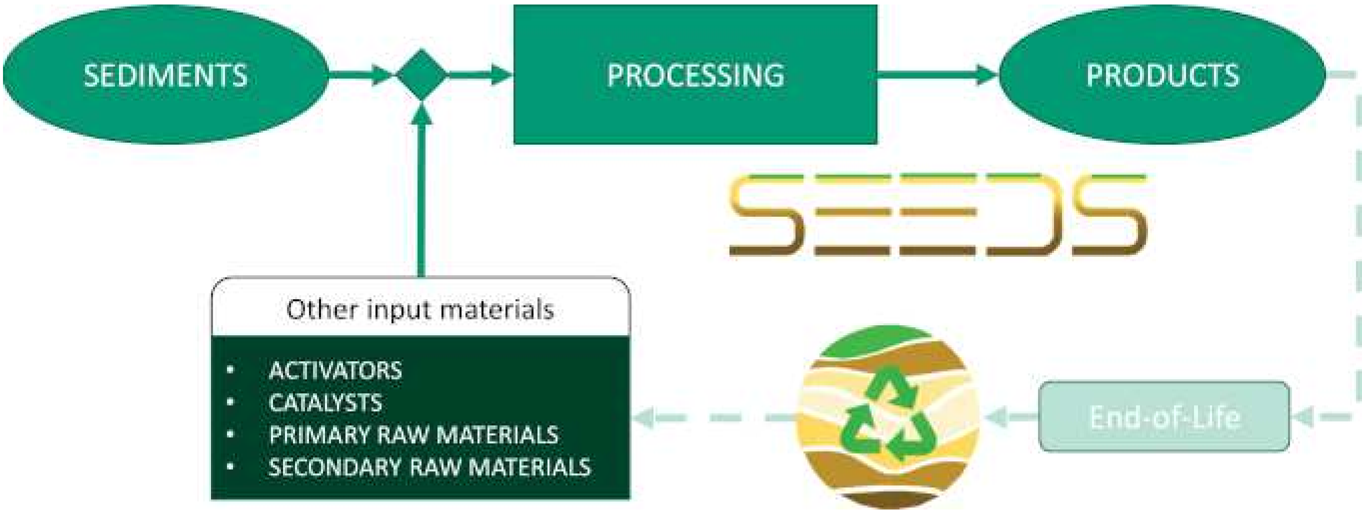

Figure 6. Scheme of the processing action of SEEDS, showing the possibility to re-cycle the products as secondary raw materials.

Scientific and technological impact

All the mentioned objectives of SEEDS are fully in line with the "Recycling" innovation theme of the EIT Raw Materials, with important repercussions on the "Processing" and "Mining" ones. Actually, SEEDS is focused on a technological readiness level at a laboratory scale (TRL 4 and, in some circumstances, TRL 5). However, the results of SEEDS will provide a solid basis, in terms of know-how and useful products for further development of ideas up to the highest levels of TRL (possible EU projects with TRL 6-8 objectives). The technological readiness of the project ranges from the selection and choice of the most suitable sediments to their use in construction materials for civil engineering applications, which possible use will be validated in the laboratory and possibly, in real scale trial sites (TRL 4 to TRL 5), as indicated in Table 1.

Expected impact	From TRL	To TRL
Improvement of the selection and separation methods of sediments	2	5
Individuation of the appropriate sediment for geopolymers and/or AAMs	2	4
Development of geopolymer and/or AAMs formulations	3	4
Tests of physical and mechanical properties of produced geopolymers and/or AAMs	4	5
Validation of sustainable construction materials for infrastructure and other civil engineering applications	4	5
Development of predictive toxicological risk assessment of sediments and new products for human exposure*	1	5

* For what concerns the biological studies, H2020 classification of TRL is considered

Table 1. Expected TRL advancements for the SEEDS project.

Furthermore, from the scientific point of view, the different research units of SEEDS will strengthen their cooperation by establishing a network of experts able to deal with present and future concerns related to the re-cycling interdisciplinary challenge (involving mineralogy, petrography, engineering, materials science and toxicology). As already mentioned, experimental and theoretical facilities offered by large-scale, National Research Infrastructures, will be contacted to increase the scientific outputs of the project and to extend the network of science. In fact, the scientists in charge at the research infrastructures (e.g., those defined in Part 2 of the ESFRI report like, for example, synchrotron radiation facilities, CPU centre, etc), may cooperate to the proposed project.

Social and economic impact

The reduction of the amount of waste material disposed in landfills and other sites is important not only for a successful waste management, but also as a pillar of the circular economy towards the EU sustainable development goals. In fact, SEEDS participants believe that the main economic and social contribution concerns the achievement of new scientific and technological steps towards the no-waste goal. Although sediments do not fall directly into the categories defined as industrial process waste, during the implementation of the project the directives from the REACH (Registration, Evaluation, Authorization and Restriction of Chemicals) regulations, which are known to provide additional opportunities for the achievement of the circular economy objectives, will be rigorously followed. In fact, a recovered waste, which is a waste that "ceases to be a waste" to become an EoW (End of Waste) material, falls within the scope of the REACH regulation. The application of the SEEDS' research approach also impacts on the exchange of information between the actors in the supply chain, thus facilitating further inputs to the advancement of knowledge. The interest of companies operating in the sector of waste management and recovery and with which collaborations have already been active is therefore very likely. It is to be highlighted that also the toxicological assessments will be in line with the REACH guideline on the use of in vitro models approved by the Organisation for Economic Co-operation and Development (OECD), alternative to animal testing, when possible.
The products of the SEEDS project aim to be obtained with low energy and costs, boosting the competitiveness of the companies and increasing the specific employment. In fact, the implementation of the SEEDS project will undoubtedly bring about a significant increase in job opportunities, in terms of highly specialized professionals for both the specific mining companies, building and construction industries, and for the creation of new university spin-offs and/or start-ups. In fact, very recently, at the School of Economics of the University of Bologna, at the Master degree level, the idea of a geopolymer-based spin-off was proposed by professors of the UniBO RU and mineral science and economy students, which was awarded by an expert panel of economists and business/entrepreneurship professionals.
The social impact could be reached through the planned dissemination strategy (see point 2). The dissemination of whole project and the results will pass not only through the traditional academic channels (e.g. scientific papers, workshops, conferences, etc.) and specific international public engagement events (e.g., EU Researcher Nights, KIC Raw Materials, etc.), but also through schools and social media (e.g. ResearchGate, LinkedIN, Twitter, Facebook, Instagram, etc.), which have the advantage of a worldwide coverage and being open to access (free of charge) both for publishers and users. Provided that the validation of scientific results must necessarily pass through a peer review process, it is important to remember that these social platforms may host discussion groups (well-known are those on ResearchGate).
Finally, the expected impact of the project will greatly increase the competitiveness of the Italian Scientific Research within the European scenario, in terms of technological transfer to new sectors, thanks to the close cooperation with European and International research networks, and relative important ethical impact on the society.

5. Financial aspects: costs and funding for each research unit

nº		Total cost (euro)	Co-funding (item A.1) (euro)	MUR funding (other items) (euro)
1.	VALDRE' Giovanni	112.090	29.900	82.190
2.	GUALTIERI Alessandro	73.906	19.450	54.456
3.	LANDI Elena	77.086	21.165	55.921
4.	SCARFI' Sonia	63.286	6.913	56.373
	Total	**326.368**	**77.428**	**248.940**

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5. Main staff involved (max 10 professors/researchers for each research unit, in addition to the PI or associated investigator), highlighting the time commitment expected

List of the Research Units

Unit 1 - VALDRE' Giovanni

Personnel of the research unit

nº	Surname Name	Qualification	University/ Research Institution	e-mail address	Months/person expected
1.	VALDRE' Giovanni	Professore Ordinario (L. 240/10)	Università degli Studi di BOLOGNA	giovanni.valdre@unibo.it	2,1
2.	SANGIORGI Cesare	Professore Associato (L. 240/10)	Università degli Studi di BOLOGNA	cesare.sangiorgi4@unibo.it	2,0
3.	ULIAN Gianfranco	Ricercatore a t.d. - t.pieno (art. 24 c.3-a L. 240/10)	Università degli Studi di BOLOGNA	gianfranco.ulian2@unibo.it	3,0

Possible sub-unit

Surname	Name	Qualification	e-mail address	Months/person expected

Unit 2 - GUALTIERI Alessandro

Personnel of the research unit

nº	Surname Name	Qualification	University/ Research Institution	e-mail address	Months/person expected
1.	GUALTIERI Alessandro	Professore Ordinario	Università degli Studi di MODENA e REGGIO EMILIA	alessandro.gualtieri@unimore.it	1,5
2.	MALFERRARI Daniele	Professore Associato (L. 240/10)	Università degli Studi di MODENA e REGGIO EMILIA	dmalf@unimore.it	1,0
3.	LEZZERINI Marco	Professore Associato (L. 240/10)	Università di PISA	marco.lezzerini@unipi.it	1,0

Unit 3 - LANDI Elena

Personnel of the research unit

nº	Surname Name	Qualification	University/ Research Institution	e-mail address	Months/person expected
1.	LANDI Elena	Dirigente di ricerca	Consiglio Nazionale delle Ricerche	elena.landi@istec.cnr.it	1,0
2.	GUALTIERI Sabrina	Ricercatore	Consiglio Nazionale delle Ricerche	sabrina.gualtieri@istec.cnr.it	2,3

Unit 4 - SCARFI' Sonia

Personnel of the research unit

nº	Surname Name	Qualification	University/ Research Institution	e-mail address	Months/person expected
1.	SCARFI' Sonia	Professore Associato (L. 240/10)	Università degli Studi di GENOVA	soniascarfi@unige.it	0,5
2.	BASSI Anna Maria	Ricercatore confermato	Università degli Studi di GENOVA	anna.maria.bassi@unige.it	3,0
3.	PASSALACQUA Mario	Professore Associato (L. 240/10)	Università degli Studi di GENOVA	Mario.Passalacqua@unige.it	0,6
4.	VERNAZZA Stefania	Ricercatore a t.d. - t.pieno (art. 24 c.3-a L. 240/10)	Università degli Studi di GENOVA	stefania.vernazza@yahoo.it	2,0

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6. Information on the new contracts for personnel to be specifically recruited

nº	Associated or principal investigator	Number of expected RTD contracts	Number of research grants expected	Number of PhD scholarships expected	Overall expected time commitment (months)
1.	VALDRE' Giovanni	0	1	0	18
2.	GUALTIERI Alessandro	0	1	0	12
3.	LANDI Elena	0	1	0	12
4.	SCARFI' Sonia	0	1	0	12
	Total	**0**	**4**	**0**	**54**

7. PI “Do No Significant Harm (DNSH)” declaration, in compliance with article n. 17, EU Regulation 852/2020. (upload PDF)

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