White Paper on Sustainable Material-based Solutions For Energy Efficient Buildings

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or CINEA. Neither the European Union nor the granting authority can be held responsible for them. Grant agreement 101075700

Document information

Name	Surname	Organisation
Gian Marco	Revel (Chair)	Università Politecnica delle Marche
Eugenia Maria	Rodriguez Sierra (Co-chair)	EURECAT
Cornelia	Partsch (Rapporteur)	ECTP
Task force members		
Marie-Pierre	Arnaud-Guiraudet	Ministere de la Transition ecologique et de la Cohesion des Territoires
Thomas	Biel	NET Nowak Energy & Technology Ltd./ (CETP TRI 7)
Mohamed	Boutouil	Builders Ecole d'Ingénieurs France
Gregor	Gluth	BAM
Alireza	Javadin	Karlsruhe Institute of Technology (KIT), Faculty of Architecture
Henrik	Madsen	EERA JP ESI
Thomas	Mueller	VDMA
Anna	Paraboschi	RINA Consulting S.p.A.
Irene	Rafols	Eurecat
Petra	Rüther	SINTEF
Nazanin	Saeidi	Karlsruhe Institute of Technology (KIT), Faculty of Architecture
Nowak	Stefan	NET Nowak Energy & Technology Ltd./ (CETP TRI 7)
Alain	Zarli	ECTP
Donato	Zangani	RINA Consulting S.p.A.

Document history	Date	
1	26/05/2023	Draft version for review of IWG5 members
2	09/06/2023	Updated version
3	12/06/2023	Updated version
4	29/06/2023	Updated version
5	20/07/2023	Final version

Contents

List of acronyms

AMI	Advanced Materials Initiative
AI	Artificial Intelligence
BIM	Building Information Model
CDW	Construction Demolition Waste
ECTP	European Construction Technology Platform
EIC	European Innovation Council
EMIRI	Energy Materials Industrial Research Initiative
EPBD	Energy Performance of Buildings Directive
ETP	European Technology Platform
ETCP	European Construction Technology Platform
EU	European Union
EUMAT	European Technology Platform on Advanced Engineering Materials and Technologies
GDP	Gross Domestic Product
GHG	GreenHouse Gases
IAQ	Indoor Air Quality
IMF	International Monetary Fund
IWG	Implementation Working Group
LCA	Life Cycle Assessment
LCCA	Life Cycle Cost Assessment
LTRS	Long-Term Renovation Strategies
M&S	Materials and Sustainability
MRL	Manufacturing Readiness Level
PFAS	Per- and Polyfluoroalkyl Substances
PV	Photovoltaics
QoL	Quality of Life
R&D	Research & Development
R&I	Research & Innovation
SDGs	Sustainable Development Goals
SET	Strategic Energy Technology
SHM	Structural Health Monitoring
SRIA	Strategic Research & Innovation Agenda
SSbD	Safe and sustainable by design
SSH	Social Sciences and Humanities
SusChem	European Technology Platform for Sustainable Chemistry
TRL	Technology Readiness Level
TWG	Temporary Working Group

Executive summary

This white paper aims at supporting the definition of research and development strategies on **sustainable material-based solutions** for **energy efficient buildings** with a 2030 horizon (the same set by the revised Energy Performance of Buildings Directive to achieve at least a 55% reduction in greenhouse gas emissions, as legally required under the 2021 European Climate Law). In particular, it wants to provide indications for the update of the *Implementation Plan of the Strategic Energy Technology (SET) PLAN*, which needs to keep up with market requirements and citizens' needs and acceptance, thus positioning itself as a pillar in the context of actions targeting the buildings energy efficiency, seen in a wider human-centred ecosystem. To do this, ongoing initiatives at EU level will be properly considered, evidencing gaps and needs also with a view to create proper education and skills on sustainable construction materials application.

The white paper has been produced by European materials scientists and technology experts, from both industrial and academic sectors, under the coordination of the *Implementation Working Group 5 (IWG5)* and is addressed to all the stakeholders involved in the development of materials for the construction sector, as well as to academic entities involved in construction materials research. The paper summarizes the conclusions from the experts' meetings, stresses the identified gaps and barriers, and proposes strategic actions for the forthcoming research roadmap in new sustainable materials for energy efficient buildings.

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or CINEA. Neither the European Union nor the granting authority can be held responsible for them. Grant agreement 101075700

Introduction

Construction materials play a pivotal role today, impacting on many different fields. At present European buildings account for 40% of energy consumption plus 36% of greenhouse gases (GHG) emissions [1]. A wise design of materials can significantly improve buildings energy efficiency, reducing both construction and operating costs. However, when choosing a material, we should take care not only of costs, but also of **sustainability** aspects: What is the environmental impact of our choice? Can we do more to support the transition towards **circular economy** and preserve resources? Industries for the production of construction materials are extremely energy- and resource-intensive; the whole production process, since the very early design phase, should be revised and innovated with a view to efficiency and reduction of environmental footprint.

The new trend in building construction is design to deconstruct, recycle, repair, and re-use. Prefabrication technologies and modular elements can reduce both construction times and costs, empowering on-site construction and local supply chain, limiting transportation to construction sites. Targeting a sustainable growth in construction industry is pivotal to achieve the EU's 2050 target of climate neutrality, supported also by the revision of the Energy Performance of Buildings Directive (EPBD) [2]. Materials life cycle needs to be maximised, also in terms of durability, sustainability, and circularity, reducing embodied energy from cradle to grave. Resources consumption must be sustainable, preventing waste and maintaining materials within the EU economy for as long as possible [3], also to cope with materials shortage due to multiple reasons (e.g., Ukrainian war, COVID-19 pandemics, etc.). Indeed, construction and demolition wastes (CDWs) represent a third of the total EU waste [4] and this needs to be managed wisely.

Research on (new) **energy efficient** and **low-carbon** sustainable materials should provide broader spectrum **material-centred solutions**, taking up current challenges and achieving circularity and sustainability targets, as well as supporting digital, energy, and green transitions. This contributes to achieve a more resilient, sustainable, and inclusive society, able to adapt to a **changing climate** that raises societal challenges in terms of people's **well-being** and **structural safety**, requiring an enhanced resilience towards natural events (e.g., floods, heat waves, etc.). Transversal technologies can help in this context; digitalization is a resource to track materials and optimise their life cycle, supporting the construction value creation in a circularity perspective and workforce upskilling/reskilling. Also, it can help fulfilling homologation and standardization requirements before new materials practical use, which are quite long procedures needing to be considered from the R&I phase.

Boosting **renovation** and **decarbonization** of buildings (now accounting for 10-20% of total carbon emissions [4]) can improve the citizens' **quality of life** (QoL) [4] and **well-being** can be fostered by investments in a climate- and carbon-neutral future. According to the European Green Deal, Europe must be climate neutral in 2050 [5]; the target is of 55% reduction in emissions, which could be achieved through -60% in GHG emissions, -14% in buildings final energy consumptions, and -18% in heating/cooling energy consumption [6], [7]. However, 97% of European buildings are not energy efficient yet [1], [8]. The Built4People partnership aims to develop human-centric innovations for a sustainable built environment [9]. There are many EU initiatives to scale-up renovations (ECTP targets a 4-5% renovation rate by 2027 [10]), such as Renovation Wave [11], aiming at energy efficiency, renovation, and decarbonization, and the New European Bauhaus [12], focusing on climate-friendly and inclusive architecture. Also, the Energy Performance of Building Directive (EU 2018/844) defined a framework for Long-Term Renovation Strategies (LTRS) to support renovations [6].

We should rethink the ways we use the built environment (e.g., home office), considering innovative materials: materials with thermal and moisture buffering capabilities, materials specific for ageing in place (129.8 billion people >65 years are expected by 2050, with a +56.1% in the 75-84 years with respect to 2019 [13]), optimal multi-domain comfort materials, phase change materials, and materials capturing air contaminants and pollutants (ensuring a better air quality).

Description of topic – Scope of the White Paper

The relevance of construction materials, with a particular focus on innovative and sustainable materials, is evident from many documents.

In 2018, the Temporary Working Group 5 (TWG5) on Energy Efficiency Solutions for Buildings released the *Implementation Plan* [3], which was endorsed by the SET-Plan Steering Group. That document reports relevant actions targeting the energy efficiency in buildings, identifying impact and expected deliverables, as well as ongoing projects for the different R&I activities. An entire action is focused exactly on new materials for buildings.

Also, the *Materials 2030 Roadmap* by signatories of the Materials 2030 manifesto [4], EUMAT, SUSCHEM, MANUFUTURE, and EMIRI invites all the interested stakeholders to contribute to a European materials agenda in a collaborative and fruitful manner. There is a section focused on materials for a **sustainable construction market**, highlighting the importance of materials for **improved energy efficiency**, to increase sustainability and circularity, to reduce carbon footprint, and to bring new functionalities (e.g., corrosion protection or increased comfort). Following this initiative, the Strategic Materials Agenda [5] was released in April 2023, intended to contribute to the discussion on the development of the Coordinated Plan of Action on advanced materials announced by the EC in the Communication “A secure and sustainable supply of critical raw materials in support of the twin transition” [6].

Furthermore, the *Position Paper* by the European Construction Technology Platform (ECTP) Materials and Sustainability (M&S) Committee gives an overview of R&I strategies recommended with a 2027 horizon to tackle several challenges, namely i) energy efficiency and decarbonisation, ii) resource preservation and circular economy, iii) industry transformation and digitalisation, iv) human health, user comfort and well-being, v) demography, and vi) evolving policy/regulatory framework. It delineates a wide range of approaches to reduce the overall environmental impact of construction sector.

Hence, it is clear that materials play a pivotal role and can have multi-faceted impacts on current key trends. Consequently, research on material-centred solutions including transversal technologies and tackling present challenges is fundamental.

The present *White Paper* aims at identifying gaps and barriers in the Implementation Plan by the TWG5, in order to provide relevant information to be transferred to the plan itself. In particular, the paper critically analyses the innovation targets related to the 5.1 subgroup “New materials and technologies for energy efficiency solutions for buildings”. A particular attention is put on current trends, measures, initiatives, and activities relevant in this context.

The innovation targets mentioned above could need to be updated on the basis of the current key trends, including those aspects that are now identified as gaps (see Implementation section). Also, the review process should start with the terminology employed in the documentation: is it correct to speak of “new” materials? When can a material be considered as new? Maybe it would be better to speak of **sustainable materials**, since sustainability is the keyword of many documents and presently used by a lot of initiatives and committees. Indeed, both the European Innovation Council (EIC) and the SET-Plan are focusing on sustainable materials [7,8]. Sustainability is a cross cutting issue and what some years ago was referred to as “smart” has now become “sustainable”; it is enough to consider previous “smart cities” and “smart materials” to confirm this trend. On another hand, according to the *Advanced Materials Initiative* [5], the new materials, with a better performance than natural ones, are categorised as “Advanced materials”. Also, reflecting on how to enhance existing materials could be relevant, alongside innovative sustainable (new) materials development.

But what should these materials be like? Specific priorities have been identified by the four contributing ETPs (i.e., EMIRI, EUMAT, SusChem, and MANUFUTURE) [4]; materials should contribute to energy efficiency, sustainability, circularity, decarbonization, and new functionalities provision. In particular, lightweight (e.g., composites, light metals, etc.), insulation capability (e.g., cellulose fibre panels, phase change materials, etc.), energy storage ability, and multifunctionality are properties desired for energy efficiency and indoor comfort enhancement (e.g., cool materials). **Green and eco-friendly materials** (e.g., biomaterials, recycled materials, etc. – also in a view of substituting non-environmentally and non-human friendly materials, such as Per- and Polyfluoroalkyl Substances (PFAS)-based products) are pivotal in a view of sustainability and circularity; a wise management of CDWs is fundamental, along with **industrial symbiosis** practices with other sectors. In this context sharing open-source data and life cycle tools to assess environmental, economic, and social sustainability of materials is essential for the buildings management. Concerning decarbonization, the electrification of production processes can play a relevant role, together with prefabrication and modular construction techniques, with a positive impact on climate change and, hence, a significant potential in **carbon handprint**. Also, enhancing durability is important to maximize the service life of materials and, hence, structures/infrastructures, ensuring their recyclability/reusability at the end-of-life stage. Formulation, manufacturing, and processing procedures could be optimized through the exploitation of Artificial Intelligence (AI) based tools. Finally, materials should provide **new functionalities** that can support the development of broader spectrum solutions; corrosion protection (e.g., green coatings and additives), structural health monitoring (SHM) capability, increased comfort (e.g., thermohygrometric control), energy harvesting capability, noise reduction, fire resistance, anti-slippery, and even biodiversity protection and enhancement are just a few examples.

Gaps should be identified from the analysis of both previous calls and present financed projects, in order to realign the Implementation Plan with a view of circularity and sustainability of construction materials. Previous and ongoing activities relevant in this context will be detailed in the Implementation section.

The final aim is to provide relevant indications on targets and potential actions on sustainable materials to foster energy efficiency in buildings, hence constituting the basis to set up a roadmap for R&D activities to be performed in a timeframe up to 2030.

The starting point of this White Paper is represented by the above-mentioned Position Paper by the ECTP Materials and Sustainability Committee, in order to include relevant items in the Implementation Plan, also updating the main targets of the (new) sustainable materials for buildings Activities Action. Indeed, at present there is a gap between the Position Paper and the Implementation Plan.

The focus is placed upon materials with a relevant potential in terms of **energy efficiency** and **carbon footprint reduction**; however, it is essential to adopt a *holistic approach*, in order to develop multidomain solutions, centred on materials but involving transversal technologies that can foster innovation in construction sector and speed up green, energy, and digital transitions. For example, digitalization (e.g., materials passport, BIM, digital twin, etc.) can be seen as an enabling technology pivotal to valorise materials, optimizing maintenance and enhancing potentiality in terms of energy efficiency and flexibility, decarbonisation, and circularity.

Design of buildings with a view to deconstruct and reuse/recycle should be the leading trend in construction, together with safe and sustainable by design (SSbD) materials. Given the limited raw materials production in a Europe progressively transitioning to climate-neutrality [5], research should focus on **sustainable durable materials**, with a significant service life, supporting resource preservation and guaranteeing lower embodied energy. In this scenario it would be fundamental to define new **durability indicators**, together with **standardized test protocols** for their assessment, guaranteeing the performance of newly developed materials. Digital tools can surely contribute to achieve this objective and improve the materials life cycle in a circular economy perspective, supporting their validation and performance assessment. Standardised Life Cycle Assessment (LCA) and Life Cycle Cost Analysis (LCCA) tools are pivotal in this context to properly evaluate the environmental impact and the financial costs of a product, respectively.

Indeed, at present the construction sector provides 18 million direct jobs (5% of European workers) and represents 9% of the Europe's Gross Domestic Product (GDP) [9]. However, construction industry is very energy-intensive and consumes a lot of raw materials (50% of the total extracted from the earth crust [10]), which is not consistent with sustainable production and circular economy principles aiming at limiting environmental damages. Hence, this industry needs to be innovated and to enhance its competitiveness in an environmentally friendly manner, for example reducing carbon emissions considering both embodied and operative energy. To achieve this objective, production technologies with a low-energy demand and exploiting digitalization should be adopted, such as additive manufacturing/3D printing and parametric design. Again, broad spectrum material-centred solutions are needed. In this scenario the necessary **technological skills** must be renewed and enriched in compliance with the European Skill Agenda [11], aiming at reaching a sustainable competitiveness, ensuring social fairness, and building resilience. Proper educational programmes and initiatives would also support a fast implementation of innovations in buildings.

On another hand, the European construction market has to deal with a relevant *population growth* (+1 billion citizens in 2030 with respect to 2022, United Nations report [12]), sided by a massive *urbanization*. In this context, innovation in materials and energetic renovation are pivotal in pushing for novel, digitally formed, and sustainably produced construction materials as well as sustainable implementation approaches, which can support both the urbanization trend and the increasing demand for new sustainable materials and construction technologies. **Smart building technologies** (e.g., building integrated photovoltaics – PV, advanced insulation and glazing, façade systems, etc.) can really make the difference in this context and their market is rapidly growing (expected to reach 80 billion € by 2023 and 116.8 billion € by 2030 [4]), with a potential 10% reduction of the overall Europe's energy consumption. A human-friendly built environment should be pursued through a wise design of energy efficient and healthy buildings.

Indeed, given the time and the context, the construction sector (together with many other realities) must necessarily innovate targeting sustainability and energy efficiency, from the very early design phase to construction and installation phases, also to enhance the well-being and the QoL of citizens, in both built environments and outdoor. Hence, it is necessary to focus on materials having a potential positive impact on multiple domains, always trying to design **human-centred solutions** (also with participative planning and design of buildings), including well-being optimization as the core of future innovations. Increasing energy efficiency and circularity of construction materials can foster the sustainability of the whole construction value chain. Moreover, health-related functional properties of innovative construction materials should be rigorously considered to ensure the acceptability of the proposed solutions in a field that can be sometimes reluctant to changes. Closing the gap between material innovation and material implementation in the construction sector should be a priority. It is extremely important to define smooth procedures speeding up the market uptake of innovative sustainable solutions, in order to maximise the impact of such material-centred technologies as early as possible, avoiding them to remain at low Technology and Manufacturing Readiness Levels (TRL and MRL, respectively). Sustaining start-ups and early-stage spin-offs from universities and research centres in this field could be helpful to support this aim.

It is worthy to underline that the present White Paper contributes to 8 **Sustainable Development Goals** (SDGs) [13], namely 3) Good Health and well-being, 7) Affordable and clean energy, 9) Industry, innovation and infrastructure, 11) Sustainable cities and communities, 12) Responsible consumption and production, 13) Climate action, 15) Life on land, and 17) Partnerships for the goals.

The Implementation section of the paper will evidence the gaps and barriers in the current activities, identifying possible targets and actions to be taken. Also, synergies with other topics and objectives will be outlined in a dedicated section. Finally, the conclusions will be drawn.

Implementation

As above-mentioned, the *Position Paper* by the ECTP'2 M&S Committee has been considered as the starting point of this work. The Position Paper objectives are partially overlapping with the Built4People partnership [14] topics of the work programmes 2021/2022 and 2023/2024 (to some extent based on the Built4People's and ECTP's Strategic Research and Innovation Agendas [15,16]); however, there are *gaps* related to *well-being* and *innovation in construction industry*. Also, *circularity* related aspects should be further stressed.

The importance of cross cutting priorities (e.g., Digital Agenda [17], Artificial Intelligence, New European Bauhaus [18], etc.) is evident and this promotes clustering and cooperation with other initiatives, such as Driving Urban Transitions (DUT) to a Sustainable Future [19]. Also, the contribution of Social Sciences and Humanities (SHH) is relevant to enhance the societal impact of these activities.

At first, the original innovation targets 5.1-T1 and 5.1-T2 of the R&I Activity 5.1-1 "New materials for buildings" have been analysed.

- The target T1 is focused on the reduction of primary energy of buildings (-60% in 2027 with respect to 2015); it aims at reducing total costs and payback time (10 years).
- The target T2 aims at reducing construction and maintenance costs (at least -10% with respect to 2015, with a target of -15%) through market ready solutions for Nearly Zero Energy Buildings (NZEB)/positive energy buildings.

Although **price** is prioritized in materials selection, especially with a focus on insulating materials, given the fact that **cost** plays an essential role in the construction industry, the main points of tapping on new resources (mainly from biological reserves and available wastes/by-products) should not be ignored with respect to their benefits in the adoption of **circular bioeconomy models** within this sector. T1 and T2 could be revised and updated considering current key trends to widen the target scenario. What is more, also **social costs** should be considered; in fact, pollution and global heating cause deaths and poor health, thus increasing the mere market costs. Sustainable construction materials could lighten this burden, for example contributing to decarbonization (e.g., limiting the use of fossil fuels, whose industry "adds fuel to the fire" of climate crisis – the International Monetary Fund (IMF) analysts said that over a third reduction in CO_2 emissions would be possible adapting fossil fuel prices to true costs, including environmental ones [20]).

In particular, **target T1** could include materials since its main statement; *embodied energy of materials*, as well as general *environmental impact*, should be considered in a perspective of decarbonization and energy efficiency, addressing climate change challenge. Specific targets on *carbon dioxide emissions* should be added to be reached by 2025, 2030, and 2050. To ensure comprehensive monitoring of the environmental impact associated with both conventional and newly developed building materials, it is crucial to incorporate certified LCA evaluations, alongside other relevant material properties, within their respective data sheets. This approach enables a thorough understanding of the environmental footprint of the materials, facilitating informed decision-making and promoting sustainable practices in the construction industry. At the end, also, the target T1 figures should be updated: <u>-40% of primary energy in 2030 with respect to 2023</u>.

Concerning **target T2**, *prefabrication* and *modularity* should be the leading forces to decrease not only *costs* (figures to be updated: <u>at least -10% of costs with respect to 2023, with a target of -15%</u>), but also *times* and *primary energy* involved in the construction process as a whole. This needs to be optimised and the *industrialization* of production can provide relevant benefits in this sense.

Moreover, the construction market should gradually move *away from fossil fuels*, since the very early production phase of construction materials.
One of the fundamental principles of the circular economy is **design for durability and disassembly**, as well as **design for repair**. It means creating products and buildings that can be easily repaired, reused, and that can be disassembled and recycled at the end of their life, making possible a second life for most of them, both in same and different application contexts. Digital tools should be exploited as a resource to guarantee **traceability** and **accountability** of materials, thus helping to maintain them in the economy for as long as possible, also scouting for **industrial symbiosis opportunities**. The adaptation to regenerative materials and digital construction processes could be a unique opportunity to lower the carbon footprint and minimize the overall health-associated risks and costs linked to industrialization within the construction sector, also providing a significant carbon headprint contributing to decarbonization.

Also, a third target dealing with sustainability and circularity aspects could be foreseen, supporting the use of sustainable innovative materials for construction, with impact also on smart materials, seismic metamaterials, etc. Thus, **target T3** should encompass materials consumption, pursuing a reduction ≥30-60% of primary raw materials (considering an interval covering different EU Countries, from the most virtuous to those moving first steps in the field of sustainability). There should be as well a stronger focus on the reuse/reusability of materials and components, sided by materials recycling, according to circular economy principles to achieve 30-60% of recycled/reused materials achieved by 2030 (according to the same reason mentioned above). Moreover, at least 30% of the total primary raw materials should be *bio-based* (currently 12%); indeed, the global bio-based materials market size is expecting to achieve USD 81.64 billion by 2028 with a CAGR of 25.10% [21], so their potentiality is very high. They could enhance not only sustainability, but also the citizens' QoL, hence bringing technical, social, and economic benefits. Such materials could be exploited in different parts of a building, with potential applications on both structural and non-structural components (e.g., insulation, façade, partition walls, floors, etc.), thus substituting less environmentally friendly and scarce construction materials. A greater use of biomaterials, regenerative materials (earth materials), and recycled materials could help in reducing the embodied energy associated to buildings construction and maintenance, at the end resulting in a significant cost reduction.

As well, innovative construction materials need to be certified and the long procedures to achieve this objective should be envisaged from the very beginning. Indeed, the practical implementation of innovative materials is rather slow, since the in-force regulations must be accomplished. It is fundamental to thoroughly consider **validation** and **performance assessment** procedures in order to gather information relevant for **standardization** path. Also, **funding schemes** to facilitate the ingress of start-ups in construction materials industry would be beneficial, supporting to cope with cost and regulation related issues and speeding up research in this field to implement new innovative materials within the construction sector.

In the *Activity Fiche* there is a description somehow focused on insulating technologies (e.g., panels, smart windows, polymer foils). This scenario should be widened, emphasizing the importance of circularity and sustainability challenges, with proper references to decarbonisation and digitalization. Although construction industry is the largest producer of GHG emission (39% of CO_2 emissions in 2018, whose 11% for manufacturing building materials and products [22]), very little changes have been implemented to tackle this issue in the last decade (even if as a matter of fact in recent years some companies started to commercialize new sustainable binders, for example). Innovative materials could have an impact on the building cooling/heating needs while in operation, thus contributing to energy efficiency and decarbonization.

Transversal technologies should be mentioned and considered as a tool to improve construction materials and, as a consequence, construction industry as a whole.

The R&I Activity 5.1-1: "New materials for buildings" has currently the following *topics*:

- *Environmental impact and sustainability* should be considered for modern buildings construction and refurbishment, together with more "traditional" aspects (i.e., energy performance, technical and handling issues).
- Materials supporting *energy efficiency* (e.g., vacuum isolation panels, structured isolation panels, smart windows or polymer foils).
- *Life Cycle Assessment* (LCA), considering energy from raw material to end of life.
- *Waste management*, to improve reusability and recyclability of construction materials (e.g., unfired clay, engineered wood, mineral foams, phase change materials, silicate aerogels, etc.).

Further topics should be added in the description of the Activity Fiche, namely:

- ➢ *Industrialization*: it can optimize both the fabrication and the use/reuse of materials, in a view of circular economy. Moreover, the aspects related to circular economy, just mentioned in the present Implementation Plan, need to be emphasized.
- ➢ *Quality control*: suitable quality control techniques can be exploited in both pre- and post-construction phases, in order to optimize aspects like energy consumption as well as adherence to design specifications also through real-time data processing tools (e.g., AI-based techniques).
- ➢ *Standardization* and *certifications* of innovative construction materials, dealing also with safety and health issues. This is required both to enter the construction market and to gather a wide acceptance by stakeholders.
- ➢ Citizens' *well-being*: material-centred solutions can impact also on the QoL of buildings occupants, for example enhancing indoor air quality (IAQ) through materials capturing moisture and air contaminants/pollutants, hence having a direct impact on the value creation.

Also, the final product foreseen in the deliverable of the activity should be widened in order to depict a broader product, envisaging the inclusion of transversal enabling technologies/trends (e.g., digitalization, circular economy, etc.), as well as focusing on currently relevant aspects (e.g., safety and durability).
Potential updates are reported in Table 1.

Table 1 Topics contributing to the deliverable of Activities Action 5.1

Current topic	**Update**
Innovative materials and technical solutions applicable for the construction of new buildings and/or refurbishment of existing buildings.	*Digitalization technologies* should be exploited to maximise the utility of information from buildings and support the circularity of the developed solutions (e.g., materials passport).
Innovative insulating construction systems with thermal performance (with respect to heating and cooling requirements) equal or better than contemporary state of the art level.	-
Compliance with existing structural, thermal, seismic and fire safety regulations.	Particular attention should be put on *seismic protection*.
Innovative thermal insulating construction system for building walls without any materials coming from fossil sources (petroleum, coke).	*Regenerative* and *bio-based* materials could be exploited. Also, the *carbon handprint* of innovative solutions should be assessed.
The majority of the used material (at least 80%) is recycled at the end of life of the building.	Materials *circularity indicators* should be developed to assess the adequacy of the solution to circular economy principle.

The used materials and technologies for construction support an easy and sustainable recycling process.	*Prefabrication*, *modularity*, and *design to reuse/recycle* technologies should be considered. Moreover, these materials efficiency must be proved also in terms of durability and safety.
Reduced material, construction and maintenance costs thanks to low embedded energy, prefabrication, standardization and recycling.	Exploitation of *low-energy* demand production technologies and *digitalized manufacturing methods* (e.g., additive manufacturing, 3D printing).
High potential for an implementation at European level.	Acceptability of innovative solutions has to be supported by proper *standardization* and *certification* activities, potentially speeding up the market uptake of innovative solutions.
-	*Industrialization* of materials fabrication to optimise the whole process.
-	*Quality control* tools to be exploited in both pre- and post- construction phases.
-	*Indicators* of the impact of materials on IAQ and well-being.
-	Common *assessment methodology* for durability and related indicators.

Synergies with other topics and objectives

Several ongoing initiatives in line with this White Paper topics worth to be mentioned, namely:

- Position Paper by the ECTP Materials and Sustainability Committee [23];
- Implementation Plan by TWG5 [3];
- Materials 2023 Roadmap by signatories of the Materials 2030 manifesto [4];
- New European Bauhaus [18];
- Horizon Europe, Cluster 4: Digital, Industry and Space of Horizon Europe initiative [24];
- Horizon Europe, Cluster 5: Climate, Energy and Mobility [25];
- EU Mission: Climate-Neutral and Smart Cities [26];
- Driving Urban Transitions (DUT) to a Sustainable Future [19];
- Revision of the Energy Performance of Buildings Directive (EPBD) [27];
- Strategic Materials Agenda by Advanced Materials Initiative (AMI) [5];
- Sustainable Development Goals by the United Nations [13].

Conclusion

Given the current key trends and the need to tackle present challenges, future R&D activities should address the following topics:

- **Broader spectrum solutions centred on advanced materials** paving the way for a significant change in the entire construction industry, triggering a positive ripple effect in multiple domains: not only energy efficiency, but also flexibility, sustainability, circularity, digitalization, people's well-being, and construction industry innovation.
- **Measurement and monitoring techniques** to regularly gather multi-domain information exploitable in development, transformation, and integration phases of innovative sustainable materials, making their life cycle optimized during use and beyond.
- **Citizens' well-being and quality of life**. It could be interesting to conduct a thorough analysis on the real costs of construction materials, including both social and environmental costs linked to the impact they globally have had since the very early stage of production. In fact, as the EPBD itself says, "The improvement of energy efficiency and energy performance of buildings through deep renovation has enormous social, economic and environmental benefits."

These actions are pivotal to enhance the Europe's **resilience, safety, and sustainability**. Indeed, the sustainable development of advanced materials can undoubtedly contribute to realize solid, resilient, and sustainable **value chains** in the EU. In order to consolidate the sovereignty of Europe in materials science as well as its competitiveness, joint and multidisciplinary skills, resources, and players are required. The **cooperation** among all the stakeholder is fundamental to timely achieve the current EU's objectives.

To achieve the EU's target in terms of renovation, circularity, decarbonization, and so on, actions to speed up both research on sustainable construction materials and the uptake of the developed solutions are required:

- **Funding schemes** easing the activities of **start-ups and research units** developing new materials for construction.
- Cross cutting funding schemes to support the **clean energy transition** while also taking into account the connected material transition, addressing the increased demand of minerals and metals for clean energy systems [28].
- Promotion of **dissemination and exploitation** activities, enhancing the citizens' engagement, awareness, and acceptance.
- Optimal management of the lessons learnt and the new knowledge, in a view of regularly **updating the skills** of the working force.

Finally, it is important to highlight the need of agreeing on a **common EU methodological approach**, valid at the different Country level. It should be developed to establish the rules and the procedures needed to guide both assessment and monitoring activities, properly quantifying performance indicators, thus supporting recycling and reuse of materials in the construction sector.

Bibliography

[1] Energy performance of buildings: climate neutrality by 2050 | Attualità | Parlamento europeo, (n.d.). https://www.europarl.europa.eu/news/it/press-room/20230206IPR72112/energy-performance-of-buildings-climate-neutrality-by-2050 (accessed March 14, 2023).

[2] A. Wilson, Energy Performance of Buildings Directive, Members' Research Service PE. 739 (2023) 377.

[3] Strategic Energy Technology PLAN Temporary Working Group 5 on Energy Efficiency Solutions for Buildings, (n.d.).

[4] Materials 2030 Roadmap, (2022).

[5] AMI2030, Strategic Materials Agenda, (2023).

[6] EC, A secure and sustainable supply of critical raw materials in support of the twin transition, (2023). https://circabc.europa.eu/rest/download/7ce37e41-1d9a-4f96-a24b-4f89207700bf (accessed April 18, 2023).

[7] TEMPLATE FOR EXPLANATORY DOCUMENTS ON ERA ACTIONS FROM THE ERA POLICY AGENDA Revamping the SET plan (Action 11-part 2) Contact point: Eirik LONNING (RTD C1)/Stela BALEVA (RTD C1) 1, (n.d.).

[8] Workshop on Advanced Materials and Environmental Sustainability Challenges with Member States representatives, (n.d.).

[9] Construction, (n.d.). https://single-market-economy.ec.europa.eu/sectors/construction_en (accessed March 14, 2023).

[10] What role do secondary materials play in new constructions and in buildings renovation? | European Circular Economy Stakeholder Platform, (n.d.). https://circulareconomy.europa.eu/platform/en/news-and-events/all-events/what-role-do-secondary-materials-play-new-constructions-and-buildings-renovation (accessed May 6, 2023).

[11] European Skills Agenda - Employment, Social Affairs & Inclusion - European Commission, (n.d.). https://ec.europa.eu/social/main.jsp?catId=1223&langId=en (accessed March 17, 2023).

[12] United Nations, World population projected to reach 9.8 billion in 2050, and 11.2 billion in 2100, UN Department of Economic and Social Affairs. (2019) 8–12.

[13] THE 17 GOALS | Sustainable Development, (n.d.). https://sdgs.un.org/goals (accessed May 16, 2023).

[14] Built4People - World Green Building Council, (n.d.). https://worldgbc.org/europe/built4people/ (accessed March 13, 2023).

[15] Built4People, (n.d.). https://www.ectp.org/built4people/ (accessed March 31, 2023).

[16] Publications, (n.d.). https://www.ectp.org/resources/publications/ (accessed March 31, 2023).

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or CINEA. Neither the European Union nor the granting authority can be held responsible for them. Grant agreement 101075700

[17] Digital Agenda for Europe | Fact Sheets on the European Union | European Parliament, (n.d.). https://www.europarl.europa.eu/factsheets/en/sheet/64/digital-agenda-for-europe (accessed March 31, 2023).

[18] New European Bauhaus: beautiful, sustainable, together., (n.d.). https://new-european-bauhaus.europa.eu/index_en (accessed March 13, 2023).

[19] Driving Urban Transitions - Sustainable future for cities | JPI Urban Europe, (n.d.). https://jpi-urbaneurope.eu/driving-urban-transitions-to-a-sustainable-future-dut/ (accessed March 31, 2023).

[20] Still Not Getting Energy Prices Right: A Global and Country Update of Fossil Fuel Subsidies, (n.d.). https://www.imf.org/en/Publications/WP/Issues/2021/09/23/Still-Not-Getting-Energy-Prices-Right-A-Global-and-Country-Update-of-Fossil-Fuel-Subsidies-466004 (accessed April 6, 2023).

[21] Bio-Based Materials Market Size, Growth, Global Trends, Forecast to 2028, (n.d.). https://www.fnfresearch.com/bio-based-materials-market (accessed May 23, 2023).

[22] Global Status Report for Buildings and Construction 2019 – Analysis - IEA, (n.d.). https://www.iea.org/reports/global-status-report-for-buildings-and-construction-2019 (accessed March 22, 2023).

[23] ECTP, ECTP Energy Efficient Buildings Committee - FP9 2021-2027 Position paper, (2018) 26.

[24] Cluster 4: Digital, Industry and Space, (n.d.). https://research-and-innovation.ec.europa.eu/funding/funding-opportunities/funding-programmes-and-open-calls/horizon-europe/cluster-4-digital-industry-and-space_en (accessed March 29, 2023).

[25] Cluster 5: Climate, Energy and Mobility, (n.d.). https://research-and-innovation.ec.europa.eu/funding/funding-opportunities/funding-programmes-and-open-calls/horizon-europe/cluster-5-climate-energy-and-mobility_en (accessed March 29, 2023).

[26] Climate-neutral and smart cities, (n.d.). https://research-and-innovation.ec.europa.eu/funding/funding-opportunities/funding-programmes-and-open-calls/horizon-europe/eu-missions-horizon-europe/climate-neutral-and-smart-cities_en (accessed March 29, 2023).

[27] European Parliament P9_TA(2023)0068 Energy performance of buildings (recast), (2023).

[28] S. Carrara, S. Bobba, D. Blagoeva, P. Alves Dias, A. Cavalli, K. Georgitzikis, M. Grohol, A. Itul, T. Kuzov, C.E.L. 1984- Latunussa, L. Lyons, G. Malano, T. Maury, A. 1987- Prior, J. Somers, T. Telsnig, C. Veeh, D.M.A.G. 1972- Wittmer, C. Black, D.W. 1968- Pennington, M. Christou, Europäische Kommission Gemeinsame Forschungsstelle, Supply chain analysis and material demand forecast in strategic technologies and sectors in the EU – A foresight study, (n.d.). https://doi.org/10.2760/386650.