A Framework for Adaptability, re-use and Deconstruction of Buildings, Aligned with the Principles of Circular Economy

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Abstract— **This article presents a framework that will bring a new perspective to circular economy products and processes within the construction industry. The framework will utilize Federated Enterprise Architecture approach that is traditionally used in the aerospace, automotive, and oil and gas industries, for built environment needs. The framework will address 5 main objectives : i) to analyze and develop a decentralized Federated Framework for construction and renovation processes; ii) to optimize the re-usability and recycling of building materials and components; iii) to investigate the validation process for framework solutions across large-scale pilots in diverse contexts ; iv) to promote and implement innovative tools for stakeholder collaboration and green finance integration; and v) to provide guidance for policy, standardization, and stakeholder adoption. This article acts as prerequisite to prepare the construction industry for transition to Federated Enterprise Architecture practices.**

Keywords-Federated framework; interoperability; adaptability; re-use and deconstruction of buildings, life cycle assessment; construction and renovation; circular economy; pilot studies

I. Introduction

It is estimated that half of the total CO_2 emissions of a building arise during the construction process and the production of the material components. Furthermore to reduce the construction industry's contribution to global warming, its immediate decarbonisation is necessary and cannot only depend on incremental CO_2 savings over the life cycle of a building but must include the planning and construction process. There is growing acknowledgement for circular construction as a means to develop, use, and re-use buildings, sites and infrastructure without unnecessarily exploiting natural ressources, polluting the environment and damaging ecosystems [1]. Moreover, The European Environment Agency recognizes that "almost 75% of the building stock is currently energy inefficient and more than 85% of today's buildings are likely to still be in use in 2050. Energy renovation of buildings is ongoing but at a very slow rate"[2]. In addition, 'Ecochain' has identified that in many industries, the supply chain accounts for more than 80% of the environmental impact and in addition the supply chain managers that source from different suppliers contribute to a massive impact on their product footprint [3]. In 2018, 'The European Commission' led an intiative to focus on supporting regions and EU countries to develop national bioeconomy strategies that will enhance knowledge on biodiversity and ecosystems, monitor progress towards a sustainable bioeconomy, promote good practices to operate the bioeconomy and enhance the benefits of biodiversity. In order to unlock investments and markets, the commission mobilised stakeholders in developing sustainable biobased solutions while launching a €100 million circular bioeconomy thematic investment platform [4]. According to the World Economic Forum 'Bioeconomy is emerging as a transformative force for sustainable development, leveraging biological resources and innovative technologies to address global environmental challenges [5]. Building upon these challenges and initiatives there is a growing need for solutions that extend the service life of buildings, support material reuse and recycling, and improve stakeholder collaboration through shared data and digital tools. This article outlines the development of a Federated Enterprise Architechure framework for developing solutions, methods and processes to meet the outlined objectives and align with the European Comission's Built4People Partnership [6] contributing to : (1) Increased adaptability of buildings, (2) Reduction of Waste, (3) Support for local and regional economic development, and (4) Policy evolution. The article has three main sections covering the design of the framework (objectives etc.) in Section II, the methodlogy in Section III and Section IV highlights the potential demonstrations. The acknowledgement and conclusions close the article.

II. Designing A Framework

The main goal of the framework is to deliver a comprehensive and sustainable framework for circular construction and renovation, ensuring adaptability, reuse, and deconstruction of building components while minimizing environmental impact and maximizing stakeholder value. The outcome is an innovative approach that integrates digital technologies, advanced processes, and novel materials into an interoperable and decentralized Federated Framework for (de)construction and renovation. This framework shifts away from monolithic, proprietary systems and creates an interconnected ecosystem where tools, platforms, and processes maintain autonomy while contributing to a unified, efficient workflow. The Federated Framework is designed to support decision-making across all stages of a building's life cycle from design and construction to reuse and deconstruction.

A. Objectives and Ambition

The overall objective is to deliver a more sustainable framework for circular construction and renovation, ensuring adaptability, reuse, and deconstruction of building components while minimizing environmental impact and maximizing stakeholder value. The project proposal leverages cutting-edge digital technologies, advanced methodologies, and innovative materials to align with the European Union's goals for a sustainable, people-centric built environment. The framework adopts a holistic and decentralized approach, integrating federated architectures, life-cycle-based methods, and participatory design processes to address the challenges of resource efficiency, carbon reduction, and material circularity. This vision is realized through a suite of interoperable tools, validated across diverse geographical and climatic contexts. The Strategic Objectives (SO) that will enable the achievement of the framework are described below:

a) To analyze and develop a decentralized Federated Framework for construction and renovation processes (objective 1): This objective focuses on creating an interoperable architecture that integrates advanced digital solutions, such as graph technology, Digital Twins (DTs), and blockchain-based systems. The federated framework facilitates interoperability and information sharing between semi-autonomous de-centrally organized Line of Businesses (LOBs), in particular reference to AI & Agents.

b) To optimize the re-usability and recycling of building materials and component (objective 2): The framework will enhance the traceability and performance of sustainable materials, prioritizing bio-based, CO2-storing, and modular solutions such as, the use of waste wood, bio-based insulation, Supervisory Control and Data Acquisition (SCADA) controls, Heating, Ventilation, and Air Conditioning (HVAC) for energy management systems, and product inventories for supply chains. Through advanced Life Cycle Analysis (LCA) and predictive maintenance tools, the framework will establish best practices for disassembly and reuse, enabling a shift towards a circular construction model.

c) To investigate the validation process of the Framework solutions across large-scale pilots in diverse context (objective 3): Two pilot sites across Portugal and Slovenia, and one virtual pilot study (referring to test simulations for example interoperability issues of shared models) between Romania and Denmark, will perform the adaptability and performance analysis of the Federated Framework under real-life and close to real life conditions. These pilots will focus on delivering test solutions in residential and non-residential settings, enhancing adaptability, resource efficiency, and scalability.

d) To promote and implement innovative tools for stakeholder collaboration and green finance integration (objective 4): This objective involves creating a virtual living lab and green finance platform to connect investors with sustainable building initiatives. It integrates digital building logbooks and financial models to enhance the scalability and economic viability of circular practices. The outcome is to provide support and knowledge on investment opportunities, such as ‘Growth and Income Fund’ and ‘Feeder Fund’ [7] (one of many smaller investment funds that pool investor money, which is then aggregated under a single centralized fund, allowing for reduced operation and trading costs).

e) To provide guidance for policy, standardization, and stakeholder adoption (objective 5): The framework will deliver actionable recommendations for regulatory bodies, certification authorities, and industry stakeholders to support the standardization and scaling of circular construction practices. Moreover, the framework will engage in 6 key stewardship of activities such as: standard identification and monitoring; collaboration with standards and policy bodies; gap analysis and recommendations development; advisory policy framework working group; workshops and stakeholder engagement; and policy briefs and contributions, that will increase awareness on best practices for design, adaptability, reuse and deconstruction.

Table 1 explains the various challenges that will be applied to each objective and its evaluation defined through measurement.

TABLE I. REQUIREMENTS & MEASUREMENTS

Evaluation		
Objectives	***Requirements***	***Measurable Key Performance Indicators (KPIs)***
1: Framework	The Enterprise Architecture incorporates methods and processes that focus on operational analysis – what the stakeholders need to accomplish and system analysis – what the system has to accomplish for the stakeholders.	KPIs include increased reuse rates of construction materials by 30% and a 25% reduction in embodied carbon across pilot projects.
2: Reusability & Recycling	The framework will demonstrate how to optimize Building Management Systems (BMS) by using Agentic AI to minimise GHG emissions during the full building operational life cycle that are essential for maintaining high levels of user comfort and well-being, which directly translate into high User QoE (Quality of Experience) KPIs.	The challenges that exist particularly for building systems is that electronic systems or products such as consumer products become obsolete long before the device wears out or fails and are simply discarded and sent to landfill. KPIs include a 40% increase in material recovery rates and a 20% cost reduction in renovation projects.
3: Validation	After the demonstrations the framework will create Impact Assessment Methodology (IAM) that will score the demonstrations based on the solutions validation requirements for both embodied and operational	KPIs include successful deployment of solutions in a shopping mall in Portugal with a total area of ~200,000 m2 that hosts over 150 stores on 5 floors and a small site 40 m² of built space targeting quantified reductions in

Evaluation		
Objectives	***Requirements***	***Measurable Key Performance Indicators (KPIs)***
	carbon.	embodied carbon by 40% and operational carbon by 50 – 75% respectively.
4: Green Finance	The overall objective for framework is to provide a one-stop shop [8] of information and support for SMEs in the local value chain but to also encourage larger companies to invest in disruptive technologies.	KPIs include engaging 50+ SMEs in local value chains and connecting them with funds/Venture Capitalists (VCs) to secure green investments.
5: Policy Guidance	The framework will contribute to the activities of the Built4People partners and to the Built4People network on innovation clusters through the achievements of the demonstration.	KPIs include the publication of 5 policy briefs and engagement with over 300 stakeholders.

B. *The scope of the Framework*

The Federated Framework consists of 16 interconnected modules that encompass key enabling tools, processes, and methods. These include advanced IT solutions such as graph technologies, digital twins, distributed ledger systems (blockchains), and Common Data Environments (CDEs), as well as methodologies like LCA, Model-Based Systems Engineering (MBSE), and business process mapping. Each module addresses specific aspects of circular construction, such as material traceability, predictive maintenance, and user-centric design.

TABLE II. FRAMEWORK: INNOVATIVE TOOLS, PRODUCTS & TECHNIQUES, PROCESS & METHODS

Framework		
Innovative Tools (INNT)	***Products and Techniques (P&T)***	***Process and Methods (P&M)***
INNT1) AI, IoT and Agents for BMS	P&T1) Digital Building Logbooks including DPP, BRP and MP	P&M1) Buinsess Process Mapping
INNT2) Graph Technology	P&T2) Security Transactions including Data Encryption, and Payments Certs (eIDAS) etc.	P&M2) Life Cycle Analysis including SCBA
INNT3) Large Language Models including LangChain - GenAI, and Chat models	P&T3) Open Source: Open LCA and Open API	P&M3) Federated Architectures including Linked Data CDE
INNT)4 Digital Twins, BIM and GIS Platform	P&T4) Semantic Analysis Techniques, RAG and Indexes	P&M4) MBSE
INNT)5 Distributed Ledger Technologies / Blockchains		P&M5) ETL Data Integration
INNT6) Preventative and Predictive Maintenance - RAM		P&M6) Real-Time Linked Data Space

a. Legends (Digital Product Passport – DPP; Building Renovation Passport – BRP; Material Passport – MP)

The semi-autonomous federated systems architecture will support State of the Art LOBs that uniquely provide solutions and by integrating them with products, techniques, processes and methods they will pioneer co-creation (see table 2). Furthermore, the pilot studies will transition the Use Cases (see table 4), which are bundle of selected technology advancements, products, techniques and methods & processes from Table 2 at the demonstrations initial conceptual stage to an advanced operational development stage based on constant evolution and learning. Moreover, using the Federated Architecture will present simulations of the decentralized platforms' abilities to connect with each other in a “common data-space” of open collaboration pooling of information. At pilot level, the framework will encapsulate three very different pilot studies, for which two of them are very much real-life scenarios representing residential (Slovenia) and non-residential projects (Portugal). The other Pilot study comprises of two countries (Denmark and Romania) working on virtual models to test their CDE platforms and interoperability. The impact of these Pilot studies will be evaluated at city council level in the Ukraine to provide added value to the project circular economy results.

III. METHODOLOGY

The methdology section comprises of four sections addressing an exploratory research stage; i) the framework vision, ii) the process, iii) the phases, and iv) the use cases.

A. *The frameworks vision*

The framework’s vision is the development of products/materials/services including those that contribute to disassembled and reused, and CO2-storing materials etc. and also the cyphering of materials via Graph Technology. Moreover Graph Technology (ISO/IEC 39075:2024) Information Technology, Database Languages and GQL defines data structures [9]. The framework will provide structured and unstructured data from existing Relational Database and web services such as ECO Building Materials Suppliers Catalogs, deconstruction – reuse warehouse of materials, certified environmental product declaration catalogs and product environmental profiles in compliance with ISO 14025 standard [10], community engagement platforms, European circular economy stakeholder platforms, and environmental monitoring and IoT platforms.

The integrating advances of bio-based materials manufacturing technology for example Ceramics and Glass and the use of digital solutions (AI, property and Knowledge Graphs (KG), Large Language Models (LLMs), Retrieval-Augmented Generation (RAG), LangChain) with economy principles i.e. targeting VCs, Angel funds to provide investment opportunities to enterprises that develop and reuse, deconstruction materials in a life-cycle optimization and circular economy perspective, will offer solutions that not only mitigate environmental impacts, but also drive economic growth and societal well-being.

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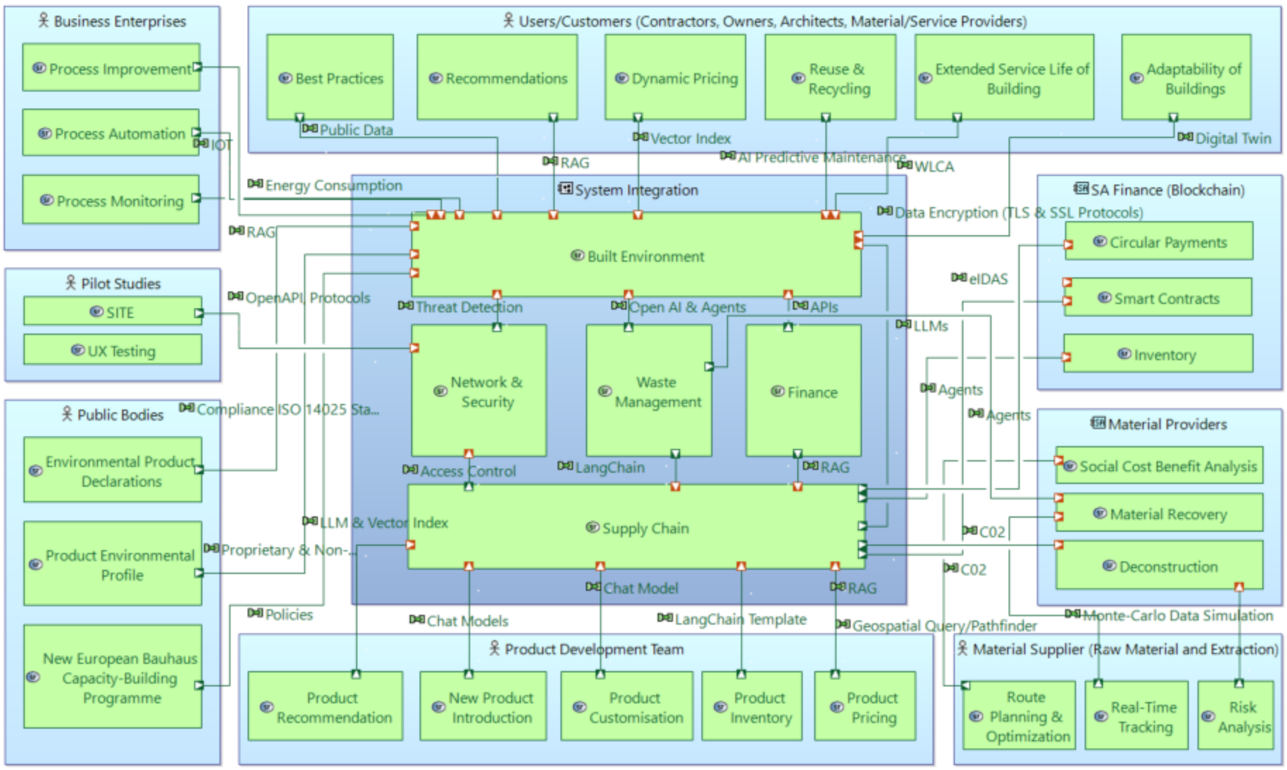

Figure 1. The Framework MBSE for Federated Enterprise Architecture.

B. The Process

The goal of the framework is to bring a new perspective to circular economy products and processes. However, fostering strategies and roadmaps is not enough and the framework will utilize Federated Enterprise Architecture approach that is traditionally used in the aerospace, automotive, and oil gas industries, for built environment needs.

Figure 1 illustrates the use of MBSE, which is a process offered in the framework to define the solution design. The pilot studies will transition from the initial conceptual stage (pilot study demonstrators original assumptions) to an advanced operational development stage based on constant evolution and learning. In the context of the framework Figure 1 defines the solutions need analysis, it is an integrated systems open architecture identifying components (e.g., material providers), functions (e.g., supply chain), and exchange items (CO2 carbon content, policies, predictive & preventive maintenance, etc.) pooling of information.

In comparison to traditional architectures that highlight connections of how various components such as ontologies are used and interchanged with semantic platforms and where over ambitious proposals identify lots of connected applications, the framework project builds on a system design approach. It will promote iteration to accommodate the pilot studies' ever changing needs.

In addition, new knowledge through the project's evolving research techniques can be implemented and tested to provide better practices and recursion to reach a level to finalize market readiness. Such analysis captures opportunities for disruptive and innovative solutions, processes and methods.

Furthermore, the Market Key Results Investment Platform, New Business Models, and Policy Recommendations will build upon private investments initiatives such as SMEs involvement in the project. Their presence shall extend contribution measures to local and regional value chain approaches, in order to increase innovation buy-in from users. This initiative has driven the proposal to focus on leveraging green finance investment and creating Scale & De-Risk Accelerators for bio-based materials and products (financial simulations). The impact is to not only provide sustainability, standardization, and governance but to also deliver a shared digital connected infrastructure for supporting decision makers with real monetary opportunities 'Bankability' reflecting and helping the circular economy.

C. The Phases

To successfully demonstrate this concept and enable a posterior replication of the results obtained within such a project, a clear and well-defined methodology has been defined, which consist in the following 5 phases: Operational Analysis – Define Stakeholder Needs and

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Environment; Solution Analysis – formalize solutions requirements; logical architecture – develop solutions logical architecture; physical architecture – develop solutions physical architecture; and End Product Breakdown Structure (EPBS) – formalize solutions component requirements.

a) Phase 1: Identify specific needs for reuse & recycling of building elements and products (Operational Analysis) - this phase involves establishing the project's base-line while capturing and consolidating operational needs from the stakeholders for correct development and later deployment of the solutions. Moreover, it can be related to "Concept operations" where assumptions on the characteristics of the pilot studies have been made.

b) Phase 2: Model and support the circular economies supply to extend service life of buildings (Solution Analysis) - the data from P1 will contribute to P2 development of a Federated Architecture framework enabling the adoption/adaption of the existing methods and processes by identifying the boundary of the solutions, processes and consolidate the requirements. This phase can be referred to as the "operational concept" stage. The progress is more precise for individual pilots such as defining the business case, what the solutions must accomplish for the users, while also modeling functional data flows and dynamic behavior for integration approaches aligned with federated CDE and innovative tools. Whereas the previous phase investigates the overall intent of the pilot studies, OpsCon identifies what they will do (ISO/IEC/IEEE29148) [11].

c) Phase 3: Design and implement inclusive, accessible, sustainable, resilience, performant (energy, cost, etc) solutions for the built environment (Logical Architecture) - P3 represents a "white box" where models, methods are designed to be transparent, allowing the pilot study demonstrators to understand the internal workings of solutions. This phase built upon the information of P1 and the process and architecture of P2, will provide visibility into the pilot studies decision-making process, making it easier to identify the key features and rules contributing to their development. Moreover, P3 will define how the individual architectures will work to fulfill expectations such as the successful deployment of solutions to prove their capability.

d) Phase 4: Configure and integrate solutions in local and regional value chains (Physical Architecture) - P4 concentrates on using the knowledge of how the solutions will be developed to actually testing them in the 3 pilot studies. These 3 pilot studies consist of collecting real data from the field and deploying the practices to be replicated solutions, products, techniques, methods and processes based on platform assessment to the Ukraine (similar to the DAREED platform [12]). All specifications of interfaces deployment configurations, trade-off analysis of the integrated solutions is tested and evaluated.

e) Phase 5: Increase awareness on best practices for design for adaptability, reuse and deconstruction – the managing of the industrial criteria and integration strategy based on the impact outcomes of the pilot studies are assessed for market segment and commercial success. In addition, the outreach of solutions are analysed and considered to propose business models and recommendations to legislators.

D. Use Cases

The defined set of innovative solutions developed during the framework will be tested via 8 use cases addressing different target groups. Use cases will represent an already proven concept for the viability of combining these solutions, products & techniques, and process & methods towards achieving increased availability, access, and management of lifecycle data in the built environment. These use cases are one of the cornerstones of the project, as its conception fosters replication, bringing framework to a larger public and set of users.

TABLE III. SET OF INNOVATIVE SOLUTIONS DEVELOPED & TESTED

Use Cases		Innovation Tools						Products and Techniques				Process and Methods						Markets		
		1	2	3	4	5	6	P&T1	P&T2	P&T3	P&T4	P&M1	P&M2	P&M3	P&M4	P&M5	P&M6	M1	M2	M3
UC1	Circular Construction and Reuse Framework		X		X						X	X	X						X	X
UC2	Digital Platform		X		X				X					X		X	X			
UC3	Real-Time Linked Data-Space		X		X			X									X			
UC4	RAM Knowledge Platform	X					X	X					X							
UC5	Cybersecurity and Supply Chain Transparency					X			X											
UC6	LCA Models for Renovation Planning and Design		X	X	X		X	X	X	X			X	X	X		X			
UC7	Operational Carbon Management Systems	X	X		X		X	X		X				X	X		X			
UC8	Accelerator for Green Finance Investments		X		X	X		X	X		X	X						X	X	X

Table 3 maps and aligns with Table 2 Framework: Innovative Tools, Products and Techniques, Process and Methods, including Markets where the 8 Use Cases provide a combination of the frameworks modules for selection during the pilot studies, i.e., several modules can be applied to each UC.

TABLE IV. EIGHT USE CASES

A Combination of Framework Modules	
Use Cases	***Proposed Solutions, Products & Techniques, and Process & Methods***
UC1	*Circular Construction and Reuse Framework*: demonstrates different circular and sustainable building solutions to make building and infrastructure better, e.g., following circular and sustainability requirements such as design for adaptability, re-use, and durability. Using Al and graph technology (tracking) UC1 will help source materials locally that travel shorter distances, consuming less fuels and fewer carbon emissions. The preference will be to source reused materials or alternatively materials that are bio-based. UC1 will advise supporting local businesses through local sourcing which, can lead to economic growth and job creation, and social benefit. In addition, the sourcing of financing mechanisms, green insurance and micro-credit for sustainable development via Carbon Platform will provide enterprises with incentive to adapt to greener solutions connected to green finance thus providing a win-win situation.
UC2	*Digital Platform of Solutions*: aligned with CDE to improve collaboration, planning, management and automation within construction projects. The concept of Federated CDE is connected to the project's overall methodology of Federated Architecture Approach. The platform functionality for the framework requires solutions and technologies for

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A Combination of Framework Modules	
Use Cases	***Proposed Solutions, Products & Techniques, and Process & Methods***
	development to include: i) folders with documentation, ii) a platform providing a list of materials and tasks, while also mapping to standards where all materials and tasks are awaiting for implementation in the early phases such as selected bills of materials and structures by assemblies. In addition, functions that can provide business intelligence reporting of sales and inventory while also connecting the quantified data with processes that have been identified as a bottleneck.
UC3	*Real-Time Linked Data-Spac***e** [13] [14]: use case focuses on integrating supply chain monitoring data analysis, such as data from sensors and IoT devices in existing or similar buildings, into an interoperable digital twin knowledge graph. This integration supports real-time visualization of embodied carbon, indoor climate metrics, and the adaptability of building systems. The focus of this approach is on optimizing supply chain processes to align with circular economy objectives. Knowledge graphs further enhance this system by linking data on materials, supply chains, environmental performance, and stakeholder roles, thereby enabling informed decision-making. Financial tools, such as agents for circular payments, product pricing, and commercial contracts, ensure that supply chain operations align with circular economy principles.
UC4	*RAM Knowledge Platform* [15]: will demonstrate the potential of preventative and predictive maintenance algorithms and systems to enable calculations on mechanical systems incurred by wear from the moment they are activated. The RAM knowledge platform identifies the useful service life of a system, product, or service by applying real-time monitoring against the preventative and predictive models, extended by proactive, Just-in-Time (JIT) sequence of preventive and corrective maintenance actions and upgrades. The RAM knowledge platform supports information/calculations on system configuration identification elements such as existing, internally developed, reusable components that may consist of Commercial Off-the-Shelf (COTS) products, and Non-Development Items (NDP – hardware and software configuration). Such processes are aligned with early defects detection "Poka-Yoke" [16] and reduce electronic and mechanical materials sent to landfills.
UC5	*Cybersecurity and Supply Chain Transparency*: use case reflects how blockchains will trace the sourcing of CO2-storing materials such as sustainably sourced long-lived bio-based materials and products and innovative lower emission materials/aggregates. In fact each transaction or exchange of information is recorded in a "block", which is then validated by network members before being added to the existing chain. Once validated, information becomes immutable and traceable. This technology offers unique guarantees in terms of security, transparency and traceability of exchanges, without the need for a centralized trusted intermediary. In UC5 Blockchains will create digital "product passports", containing all the information on a product's composition, manufacture and use. Furthermore according to [17] the concept of "decentralized AI" (DeAI) envisions open source, transparent AI through several blockchain technologies. Decentralized storage and distributed computing networks enhance data integrity, while smart contracts ensure transparent model access and tracking.
UC6	*LCA models for Renovation Planning and Design*: use case will demonstrate how tools developed under the framework will empower building stakeholders to streamline processes, enhance efficiency, and drive sustainable transformations. CO2 studies can be directly imported into openLCA [18] and standard LCA repositories, enabling UC6 users to assess flows and processes in their impact evaluations. UC6 will store all

A Combination of Framework Modules	
Use Cases	***Proposed Solutions, Products & Techniques, and Process & Methods***
	relevant data on a platform incorporating Digital Building Logbooks, which include Building Renovation Passports, BIM-based information, DPP, MP and GIS data. This integrated approach facilitates informed decision-making while ensuring compliance with the Corporate Sustainability Reporting Directive (CSRD). To advance beyond standard LCA principles, UC6 will adopt MBSE. The Carbon platform will generate life cycle inventories and evaluate the environmental impacts of material choices through comprehensive life cycle assessments.
UC7	*Operational Carbon Management Systems*: demonstrates the power of AI agents for energy monitoring and optimization including dynamic Pricing. The operational carbon management systems access real-time feeds and data from captured sensors (IoT) related to energy consumption of building elements and products. The introduction of AI agents and graph technology enhances IoT capabilities and across diverse energy systems. The approach applied to smart buildings is reliant on AI agents for controlling lighting and optimizing energy consumption as they are programmed to learn from their environment and improve over time. The framework will analyse patterns of electricity usage and optimize it such as turning off lights in unoccupied rooms or adjust the HVAC systems based on current occupancy, thus providing Occupant well-being. Furthermore, it will facilitate environmental sustainability by tracking energy performance, carbon emissions, and environmental impact.
UC8	*Accelerator for Green Finance Investments*: Green finance appears to be one of the leading technology solutions which, will further promote the increase in regulating environmental impact activities [19]. Therefore, the asset holders, bondholders, and issuers, among others, will have to refocus their efforts to guarantee that green finance is more useful, significant, inclusive, and environmentally protection oriented. UC8 will focus on Getting Buy-In to advance Green Infrastructure – Creative solutions for green infrastructure are only as viable as those who back them.

IV. DEMONSTRATIONS

To test these innovations and use cases, the demonstrations will cover a spectrum of many items included in the EU policy and market trends regarding data management in the built environment. This broad coverage aims to ensure that the proposed solutions offer high replication potential thanks to a demonstration plan. In this sense, the framework UCs will be tested by scenarios of different building typologies, energy grids and data architectures, via the involvement of a living lab (TRL6) and 2 large-scale pilots (TRL7-8) covering a variety of use cases and target users and 1 virtual pilot that will act as 'Development, Test and Evaluation (DT&E)' before the 2 large-pilots regarding 'Operational, Test & Evaluation' (OT&E) [20]. In addition, ISO 31000 Risk Management Plan will also be used to monitor the project progress [21].

A. *Virtual Pilot Study: Denmark*

The Danish virtual pilot will focus on a fully digital demonstration, leveraging advanced DT technology and BIM tools to address challenges in interoperability, circular construction, and supply chain integrity. This pilot aligns with the proposals objectives by simulating circular economy principles in construction and renovation processes. The

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virtual demonstrator will integrate open standards (Industry Foundation Classes ISO 16739-1:2024) [22], Information Container for linked Document Delivery under ISO 21597-2:2020 [23], Cybersecurity measures, and lifecycle optimization methodologies to showcase adaptability, reuse, and practices focused on carbon emission reduction. The primary aim of this pilot is to establish effective systems for sourcing materials locally, enabling businesses to develop robust recycling and reuse frameworks. This approach reduces reliance on resource-intensive production processes, minimizes waste generation, and fosters sustainable practices. Local sourcing is encouraged by transparency and decision-making capabilities enabled by the platform. The Carbon platform, equipped with graph technology conforming to ISO/IEC 39075:2024, will enable precise tracking and sourcing of materials, prioritizing reused materials and bio-based alternatives.

B. Pilot Study Slovenia

The demonstration planned for Cirkulane (Slovenia), is a prefabricated, residential wooden house, addressing the challenges of Build4People topics, including circularity and sustainability. The demonstrator ‘GORSKO’ aims to focus on:

- Development of ecological modular walls designed for sound and thermal insulation.
- Reduce the carbon footprint and resources by using wood as a main structural material, including the use of waste wood, bio-based (wood, wood fibres, wood chips, straw, clay, sheep wool) insulation, also insulation based on waste textile, and focusing on providing locally produced materials and products.
- Extend the prefabrication processes: In addition to the wooden elements, there is designs to implement a BIM connection to automated production with CNC machines of insulation panels (wood fibre-based).
- Source products inventory and identification to optimize transport and installation.
- Optimisation of preparation and installation process: 3D scanning, e-site, AR/VR use for installation/supervision.
- Developing a smart building (IoT, Digital twin) and setting up smart management and maintenance as a service.

The Expected outcomes planned are related to improve adaptability of building design and solutions for different uses, increased reuse of buildings components and increasing the end-of-life value, extend services life by smart maintenance services, and increase awareness and deploy best services in the demonstrators supply chain.

C. Pilot Study: Portugal

The Portuguese demonstration will concentrate on the Mechanical and Electrical (M&E) components that contribute to operation costs. The challenges relate to current SCADA systems that collect and manage data from a building's Command & Control infrastructure, which oversees major energy systems such as lighting, HVAC, and power distribution. These systems operate in an event-based manner, meaning that human operators manually analyses data, respond to alarms, and make real-time decisions based on detected anomalies, incidents, or diverse operational needs. While this approach allows for direct human oversight and control, it also is reactive, and carries low efficiency, leading to potential delays in optimizing energy usage and system performance. In the To-Be scenario, new energy analytics services will be implemented, such as load forecasting, energy sourcing classifications, anomaly detection, and virtual consumption dis-aggregation to generate meaningful data & insights to be fed into the vertically embedded Agentic AI that will orchestrate building management system. The AI-driven system will utilize endogenous building information extracted from the internal active building management systems, as well as exogenous energy grid information incoming from the local energy Transmission System Operator/Distribution System Operator.

V. Conclusion and Future Work

This paper focused on a Federated Enterprise Architecture approach to integrate digital technologies, via advanced processes, with novel materials into a decentralised Framework for (de)construction and renovation. The existing challenges of non-interconnected frameworks associated with monolithic, proprietary system provided the initiative to design an interoperable ecosystem for tools, platforms, and processes that maintained autonomy. The article outlines 5 objectives and their potential requirements and measurable KPIs. The methodology examines in detail the use of MBSE as a process offered in the framework to define the solution design. Furthermore, the methodology describes the evaluation of research methods and their philosophical assumptions in five phases, where each is aligned to MBSE.

The concept of the pilot studies is to facilitate the transition of the selected UCs bundle from the initial conceptual stage to an advanced operational development stage based on constant evolution and learning. The framework’s adaptive process will be measurable based on the outcomes of the demonstrations. Furthermore, the anticipated results of the process will provide a long lasting impact on our understanding of how an efficient design for adaptability, re-use and deconstruction of buildings should be approached, as well as to support EU regulation on those issues. Within the context of the paper’s output it has identified how to increase adaptability of buildings and the reduction of waste via the Federated Enterprise Architecture, while analyzing supporting structures such as leveraging green finance investment for local and regional economic development, and moreover providing sustainability, standardization, and governance towards the circular economy policy evolution.

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