

D2.4 – Renovation evaluation metrics survey

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Executive Summary

Bio-based building materials are derived from renewable sources such as plants, trees, and agricultural waste, and they offer several environmental benefits compared to traditional construction materials. Bio-based building materials that are dealt with in BIO4EEB include:

Posidonia panels and fibres

Complex polyelectrolytes

PLA (polylactic acid) and bio-polyurethane, e.g. in Bio-based windows

Pre-fabricated façade elements

When it comes to apply materials or products there is a need to qualify the performance based on characteristic features for material, products and components to be applied on building sites. Therefore, it is important to create key performance indicators (KPIs) based on metrics for bio-based building materials and components in construction projects.

In order to avoid any problems in the ongoing implementation process on demonstration sites and even applicable for future projects this deliverable is meant to assure the compliance with metrics and KPIs applicable at country, national and international level.

Furthermore, the application of the building project phase oriented 4M analysis process - Mapping, Modelling, Making, Monitoring- including the essential metrics and KPIs that focus on technical, environmental and economic criteria enables the partners to follow a standardised workflow process. These evaluation metrics will be developed reflecting on the specific real and virtual demonstration cases' needs as a use case in order to create a KPI dashboard that covers all cases.

An MCDA (Multi-Criteria-Decision-Analysis) deducted from collected KPIs helps the clients and the applying companies to rate the specific results of the application of bio-based material. Technical and environmental KPIs will cover building physics and material data as e.g., U-values, sound insulation potential, fire resistance classification, reduced net prime energy, lowered embodied energy or improved indoor environmental quality. Economic KPIs compare the efficiency and effectiveness of the investment related to various performance qualities.

Furthermore, the created inventory of KPIs should help to close the quality demand gap in terms of lack of metrics for producers that are eager to exploit their innovative bio-based products internationally.

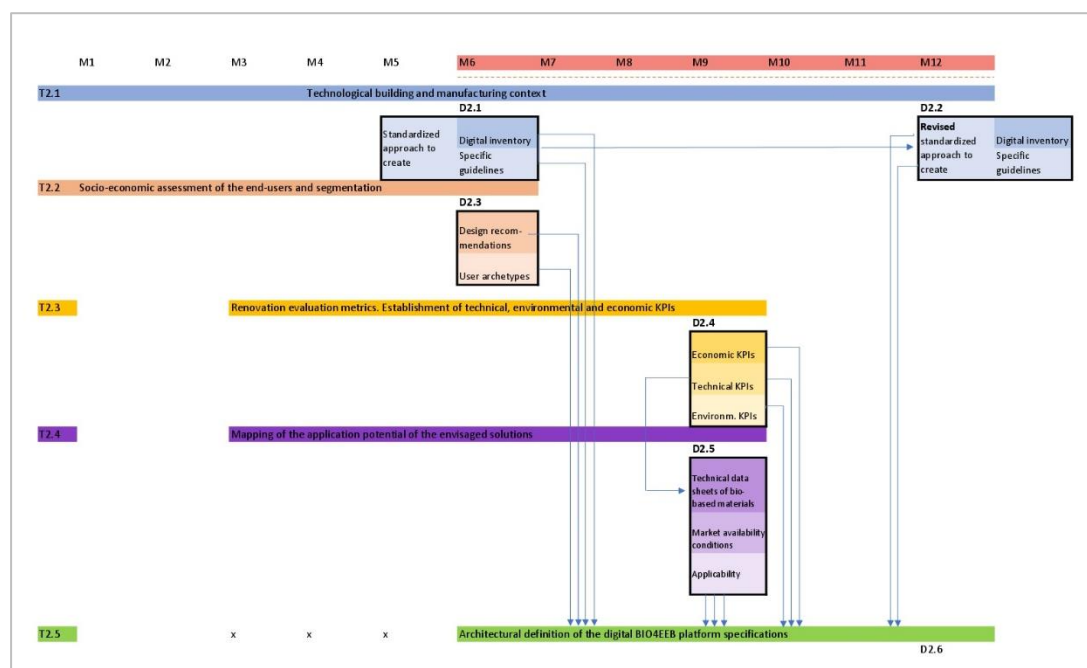


Figure 1: MS1 Masterplan of interaction WP2

Considering the interaction with other work packages and as important input this extensive overview created in D2.4 provides the exhaustive input for D4.2 Implementation plan and Management due at M09, M24, M36, M42 considering that the implementation plan is a living document reacting on continuous adjustments caused by the project development and availability of data details at the different milestones. As a result, the dashboard balancing the identified KPIs related to the demo cases is prepared and will be applied in WP4. It is expected that the application of metrics and KPIs is following the applicability caused by specific demo case demands and will continuously influence the further development of them. The updates of the implementation plan will document possible adjustments and changes.

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Abbreviations and Acronyms

Abbreviation	Description
3D	Three-dimensional
4M approach	Mapping Modelling Making Monitoring
AHP	Analytical Hierarchy Process
BIM	Brussels Institute for Environmental Management
CAP rate	Capitalization rate
CH ₄	Methane
CO ₂	Carbon dioxide NO ₂
ELECTRE	Élimination Et Choix Traduisant la REalité ("Elimination and Choice Translating Reality")
EPC	Energy Performance Certificate
GWP	Global Warming Potential
IEQ	Indoor Environmental Quality
IRR	Internal Rate of Return
JIT	Just In Time
KPI	Key Performance Indicator
LCA	Life Cycle Analysis
LCCA	Life Cycle Cost Analysis
LoD	Level of Detail
MCDA	Multi Criteria Decision Analysis
MEP	Mechanical, Electrical and Plumbing
NO ₂	Nitrogen dioxide
NOI	Net Operating Income
NPV	Net Present Value
PDCA	Plan-Do-Check-Act
PLA	Polylactic acid
PnP	Plug and Play
PU	Public
PROMETHEE	Preference Ranking Organisation Method for Enrichment Evaluations
ROI	Return Of Investment
TCO	Total Cost of Ownership
VOCs	Volatile Organic Compounds
WSM	Weighted Sum Method

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BIO4EEB project overview

Buildings are responsible for approximately 40% of energy consumption and 36% of CO₂ emissions in the EU. Deep Renovation of existing old buildings has the potential to lead to significant energy savings and a tremendous carbon footprint shrinkage. The current EU climate targets open an ample opportunity for exponential growth in the thermal insulation building materials market owing to the increasing number of new residential buildings and current deep renovation needs.

The target is to support residential buildings' construction performance extraordinary at all three hierarchical levels of construction parts simultaneously (building, component, material) by creating an amplified positive impact and reducing additionally VOC emissions. BIO4EEB will apply non-hazardous bio-based material as e.g., Posidonia and various bio-based foams to develop and to proof the marketability of smart components for external and internal use as material application, pre-fab panels or windows. The efficiency and effectiveness is quite important to match with market demands and establish a unique selling proposition including a seven years ROI!

BIO4EEB will close the increasing gap of insulation material shortage caused by the regular growing demand and the mismatch caused by lacking production potential and the outcome of the current energy crisis by boosting the use of available bio-based qualified materials as alternative solutions.

The objective is to substitute using fossil resources for components and replace them at a comparable price value positioning. New business models utilizing the complete economic value chain open the market for bio-based BIO4EEB solutions and products uplifting the generic bio-based material use and qualifying their application at a circular economy approach for creating a much greener EU building and construction industry real estate stock.

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1 Introduction

As described in the framework of WP2 D2.4 prepares the quality control monitoring process based on selected KPIs and metrics and the quality assurance in different phases of the realisation of the seven demonstrators. Applying the building project phase oriented 4M analysis process -Mapping, Modelling, Making, Monitoring- the essential KPIs are identified and listed that focus on technical, environmental and economic criteria following the regular realisation timeline. More information about the 4M process is available at chapter 2.

The evaluation metrics and developed Key Performance Indicators (KPIs) will be reflecting on the specific real and virtual demonstration cases' needs as use cases in order to create a KPI dashboard that covers all specific needs. In chapter 3 the KPI identification is done based on three different criteria: Technical, environmental and economic performance indicators.

The selection of appropriate and characteristic KPIs is transformed in order to create a KPI dashboard. During the implementation phase the dashboards are designed to qualify and quantify the outcome of BIO4EEB solutions and products' application. The dashboard needs and development are covered in chapter 4.

A Multi-Criteria Decision Analysis (MCDA) deducted from collected KPIs helps the client/owner/user/designer to rate the specific results of the application of bio-based solutions and to pick out fitting and appropriate options. Technical and environmental KPIs cover building physics and material data as e.g., U-values, sound insulation potential, fire resistance classification, reduced net prime energy, lowered embodied energy or improved indoor environmental quality. Economic KPIs in building renovation are essential for assessing the sustainability of the built environment from a financial and economic perspective. These KPIs help stakeholders evaluate the economic viability, cost-effectiveness, and economic impact of renovation projects, while considering their long-term sustainability objectives (close interaction with WP6-Advisory Board foreseen after establishment and integrated in D4.2 updates).

An MCDA is a decision-making methodology that allows individuals or groups to systematically evaluate and compare different options or alternatives based on multiple criteria or factors. It is particularly useful in situations where decisions are complex – e.g. applying different technical solutions - and involve multiple objectives or considerations.

The MCDA involves a structured and systematic approach to decision-making, which helps to ensure transparency, fairness, and accountability in the decision-making process. It helps decision-makers to clarify their preferences and priorities, consider a wide range of factors, and weigh the relative importance of each criterion. The MCDA approach of BIO4EEB is dealt with in chapter 5.

2 4M approach

The application of the building project phase oriented 4M analysis process -Mapping, Modelling, Making, Monitoring- including the essential metrics and KPIs that focus on technical, environmental and economic criteria enables the partners to follow a standardised process of quality assurance. The selected evaluation metrics are identified reflecting on the specific real and virtual demonstration cases' needs as a use case in order to support the creation of a KPI dashboard that covers all cases.

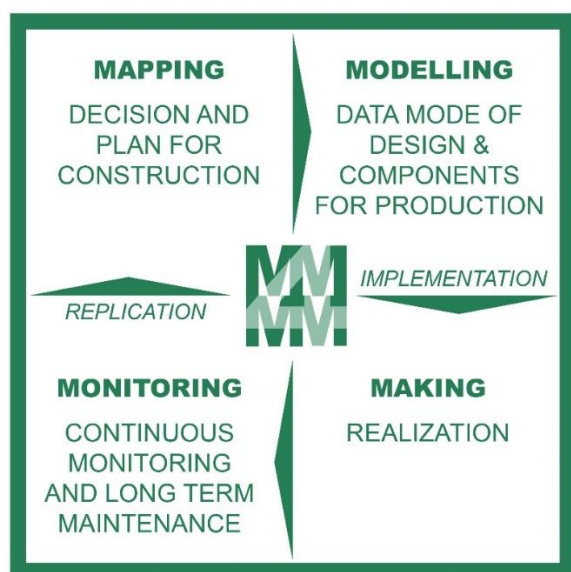


Figure 2: BIO4EEB 4M approach

The mapping enables all working groups responsible for their demonstrators to collect data and create sophisticated project plans. The purpose of this step is to develop a detailed technical plan and economic feasibility report for the realisation of new buildings and deep renovation at the same time as a starting point for the design including conversion of building function or typology when relevant. Within this step, the activities conducted off-site are: real-estate valuation and investment appraisal of the existing building; an economic feasibility study based on Total Cost of Ownership; and a holistic scenario development. Simultaneously, the innovative on-site activities are: condition assessment based on available self-inspection or other technologies, assessment of the functional qualities and potential of the existing building. Through online interactions processes between on-site and off-site processes, this step conducts comparative analysis based on similar project references.

The time duration of this step for a typical residential building (e.g. single-family house or low-rise apartment) is 1-2 weeks. When applied for a typical public building (e.g. small-scale / low-rise office), the time duration is 1-2 weeks.

The purpose of 'modelling' is to develop the applicable design ready for execution. This step will result in case-oriented fitting and easy applicable data models of the existing buildings considering designs with energetic properties, including architectural, structural and MEP (mechanical, electrical and plumbing) systems and parametric BIMs of the prefab renovation components for manufacturing, optional application of local factories (e.g. 3D printing if applicable), and to develop a digital solution library. Within this step, the activities conducted off-site are: Data model creation and check of e-Marketplace applicability for e.g. procurement

processes. Simultaneously, the innovative on-site activities dependent on the demand are e.g.: combined 3D data capturing and thermal scanning. Through online interaction processes between on-site and off-site processes, this step conducts performance simulations of innovative market solutions. The time duration of this step for a typical residential building (e.g. single-family house or low-rise apartment) is 1-2 weeks. When applied for a typical public building (e.g. small-scale / low-rise office), the time duration is 2-3 weeks.

The purpose of 'making' is to execute the building activities. This step will result in improved, tested and implemented innovative materials and plug and play (PnP) prefab components ready for large-scale production and commercialization. Within this step the activities conducted off-site are: Just-in-time (JIT) and lean factory production process of components based on combined product-process information in applicable and appropriate data format; manufacturer and supplier engagement; and coordination through e-Marketplace application. Furthermore, the applicable innovative on-site activities are: delivery of components and solution packages ready for assembly; rapid and low-disturbance building component assembly based on combined product-process information in applicable and appropriate data format; assembly using available self-instruction and self-inspection system for construction actors; calibration and operating and when needed for large scale application, setting-up of a local assembly factory as an option for large scale application. Through online interaction processes between on-site and off-site processes, this step enables to establish a brokerage platform for suppliers, skills and labour force – significantly encouraging local employment and training; and development of an optimized logistics and assembly plan for reducing transport movements to a minimum. The time duration of this step for a typical residential building (e.g. single-family house or low-rise apartment) is less than 1 week. When applied for a typical public building (e.g. small-scale / low-rise office), the time duration is 1 week. The time needed for implementation of district renovation depends on the scale.

The purpose of 'monitoring' is to monitor and guarantee the high-quality execution of the construction works, and to monitor the Indoor Environmental Quality (IEQ) and Energy performance after the realisation. This step will result in "as-built" models making use of integrated sensory systems and software tools for continuous performance monitoring and long-term maintenance and optimisation. Within this step, the activities conducted off-site are: establishing contracts for performance guarantee; best practices descriptions and user evaluations of manufacturers, suppliers and contractors available in the e-Marketplace. Simultaneously, the innovative on-site activities are indoor environmental quality (IEQ) monitoring by 3D thermal scanning devices; data-based self-inspection by the end-users (craftsmen) using mobile devices as well as self-instruction for optimal use of the renovated building and its MEP systems through instructions for correct system utilisation by end-users. Through online interaction processes between on-site and off-site processes, this step conducts e.g. 3D laser scanning and thermal imaging connected to the data model for real-time quality control and prevention of building errors; updating data format to 'as-built' for maintenance and Facility Management; digital lifecycle maintenance planning and Total Cost of Ownership (TCO) optimisation; and managing the feedback loop for systemic improvements of prefab component designs and processes based on collected sensor and user data through continuous monitoring of the energy performance after realisation.

The time duration of this step for a typical residential building (e.g. single-family house or low-rise apartment) is ongoing during the construction period and for a minimum of 1 year during the operational phase of the building. The same timeframe applies for typical public buildings (e.g. small-scale / low-rise office). The validated demonstration projects with confirmed interest and commitment from all stakeholders will become ready for EU-wide project replications.

3 KPI identification reflecting on virtual and real demo cases

This chapter's purpose is to identify an accurate list of KPIs to evaluate during the building or retrofitting activities. These KPIs can provide a comprehensive view of the impact and success of building and retrofitting efforts, helping stakeholders weigh the effectiveness of their investments in energy efficiency, sustainability, and occupant well-being. It's important to tailor the KPIs to the specific goals of the project and to continuously monitor and analyse the data to drive ongoing improvements.

3.1.1 General information

The following table presents a list of general KPIs to be evaluated in a retrofitting intervention.

1. General information							
Cod.	KPI	Description	Reference	UdM	Target ¹	Value chain ²	Bio4EEB relevance
1.1	Time	Time reduction of construction site	RenoZEB ³	[%]	>50%	Design	✓
1.2	People dislocating	Avoiding the people dislocation during the construction site	RenoZEB	Y/N	Y	Construction site	✓
1.3	Number of actors	Reduction of partners involved in the building intervention	RenoZEB	[%]		Design Construction site	✓
1.4	Supplier Performance Rating	Rate the performance of suppliers based on factors like quality, reliability, and timeliness, comparing it to a benchmark for supplier excellence	(R, 2021)	[Scale of 1-5]	4	Manufacturing Construction site Operating	
1.5	Occupant Comfort Surveys	Assess the level of comfort and satisfaction with indoor environmental conditions	(McGinley et al., 2022)	[%]		Operating	✓
1.6	Client Satisfaction Score	Collect client feedback and rate their satisfaction with the project's outcome	(McGinley et al., 2022)	[Scale of 1-5]		Operating	✓
1.7	Project Stakeholder Collaboration Index	Measure the level of collaboration and communication between various stakeholders on a project and compare it to a benchmark for effective teamwork.	(Abbas, 2023)	[Scale of 1-5]		Design Construction site	
1.8	Industrialization	Industrialization level while keeping a high aesthetical appealing	RenoZEB	[Scale of 1-5]		Design	✓
1.9	Compare alternatives	Project information available, easy to understand, easy to compare alternatives	RenoZEB	[Scale of 1-5]		Design	
1.10	Replicability	Level of intervention's replicability	RenoZEB	[%]		Design	✓

¹ The missing target will be defined within the project designing phase.

² Design, Manufacturing, Construction site, Operating.

³ RenoZEB – H2020_ GA 768718 - RenoZEB aims to unlock the nZEB renovation market leveraging the gain on property value through a new systemic approach to retrofitting – Task8.2

1.11	Durability	Level of interventions during lifetime	RenoZEB	[Scale of 1-5]		Operating	✓
1.12	Maintenance	Reduction of the number of maintenance interventions	RenoZEB	[%]		Operating	
1.13	Disassembling	Increasing of disassembling potential		[%]		Operating	✓

Table 1: List of general KPIs

3.1.2 Architectural information

Architectural Key Performance Indicators (KPIs) act as recognizing metrics, guiding the analysis and enhancement of designs to ensure they embody both elegance and functionality. These KPIs examine into the field where creativity meets utility, offering a systematic way to measure a building's efficiency, occupant satisfaction, accessibility, and ingenuity. This exploration unveils the pivotal role of architectural KPIs, empowering architects, designers, and stakeholders to shape spaces that seamlessly fuse artistic brilliance with utilitarian excellence, ultimately redefining the art of architecture. The following section collects information about the architectural solutions adopted in the building:

2. Architectural information							
Cod	KPI	KPI Description	Reference	UdM	Target	Value chain	Bio4EEB relevance
2.1	Historical Features preserved	Calculate the percentage of preserved historical features	(Andrea Urbinati et al., n.d.)	[%]		Design	✓
2.2	BIM Integration Level	Rate the integration level of BIM technology in the design process, comparing it to a benchmark for advanced BIM utilization	-	[Scale of 1-5]	2	Design	✓
2.3	Customization	Level of flexible adoption of customized finishing materials	RenoZEB	[Scale of 1-5]	3	Design	✓
2.4	Aesthetic needs	Meeting aesthetic needs (e.g., transparency, color, reflectance, etc.)	RenoZEB	[%]		Design	✓
2.5	Integration of Smart Building Technologies	Assess the retrofitting's ability to accommodate and integrate advancements in building automation and technology	(Al Dakheel et al., 2020a)	[%]		Design	
2.6	Design Concept Realization	Assess how well the final building outcome aligns with the original design concept and intentions.	("Key Performance Indicators in Retrofitting Projects," 2018)	[Scale of 1-5]	3	Construction site	✓
2.7	Natural Light Utilization	Assess the increase in natural light penetration and its positive impact on indoor illumination.	-	[%]		Design Operating	
2.8	Design and As built	Compliance of design and as built	("Key Performance Indicators in Retrofitting Projects," 2018)	[%]		Construction site	✓
2.9	Integration with facade	Ensuring integration with other façade systems and subsystems (e.g. material choice, etc.)	-	[Scale of 1-5]		Design Construction site	✓

Table 2: architectural information

3.2 Technical KPIs

Technical Key Performance Indicators (KPIs) offer a range of measurable metrics that provide insights into a building's efficiency, sustainability, and functionality. These metrics empower decision-makers to align with sustainability goals, regulations, and user expectations. By understanding these KPIs, professionals gain the knowledge to navigate the intersection of technology, sustainability, and functionality in building practices. Focus goes in the building envelope since it divides the indoor and the outdoor, its characteristics contribute to guarantee the energy performance.

Technical KPIs provide the technological specification of the components used in the technological systems of the building such as:

- Energy performance
- Energy production
- Building Automation and Control – Determine if there are any automation or control systems for managing energy consumption and building performance.
- Regulatory framework and standards involve a selection of legal obligations, industry codes, and best practices designed to maintain the integrity of structures, protect occupants, and harmonize with environmental concerns. KPIs designed to this aspect provide a structured approach to quantifying a building's alignment with these critical benchmarks. The present section collects information about the regulatory requirements and standards adopted in the building such as:
 - o National and Regional Norms: Research and documents that are applicable as national and regional regulations, codes, and standards related to building construction and energy efficiency,
 - o Compliance: Assess the building's compliance with relevant regulations and standards, highlighting any deviations or non-compliance.
- Building envelope – identify the technological solutions adopted for the building envelope including windows, opaque façade, roof. Define layers, dimensions, technical and material characteristics.

3. Technical information							
Cod.	KPI	KPI Description	Reference	UdM	Target	Value chain	Bio4 EEB relevance
1. Energy performance							
3.1.1	Energy Consumption Reduction	Measure the decrease in energy consumption after realisation considering all building life	Bio4EEB GA	[%]	5%	Operating	✓
3.1.2	Energy Performance Index (EPI)	A benchmark that compares a building's energy use to a baseline or industry standard.	(Li et al., 2020)	[%]		Operating	✓
3.1.3	Energy Performance Rating	Assign a numerical energy performance rating and compare it to a benchmark for energy-efficient buildings or industry standards.	(C.A. Balaras et al., 2015)	[%]		Operating	
3.1.4	Renewable Energy Utilization	Measure the percentage of a building's energy consumption that comes from renewable sources like solar or wind.	Bio4EEB - GA	[%]		Operating	

3.1.5	Daily energy use	Daily energy use after the retrofitting intervention	(Li et al., 2020)	[kWh/day]		Operating	✓
3.1.6	Renewable Energy Source	Renewable Energy Source -	Bio4EEB - GA ⁴	Y/N		Operating	
3.1.7	Reduced net prime energy	Reduced net prime energy -	Bio4EEB - GA	[%]		Operating	
3.1.8	Lowered embodied energy	Lowered embodied energy -	Bio4EEB - GA	[%]		Operating	
3.1.9	Reduction of energy consumption for	Heating		[kWh/year]		Operating	
3.1.10		Cooling		[kWh/year]		Operating	
3.1.11		Domestic Heat Water (DHW)		[kWh/year]		Operating	
3.1.12		Lighting		[kWh/year]		Operating	
3.1.13		Electricity		[kWh/year]		Operating	
3.1.14		Gas		[kWh/year]		Operating	
3.1.15	Daylighting Effectiveness	Assess how well natural daylight is utilized to reduce the need for artificial lighting within the building	(Li et al., 2020)	Lux		Operating	
2. Automation							
3.2.1	Building Automation and Control System Utilization	Measure the degree to which the building's automation and control systems are effectively managing various functions like lighting, HVAC, and security	(Al Dakheel et al., 2020a)	[%]		Design Operating	
3.2.2	Integration of sensors and control system	Sensor integration for the data collection and building automation	(Al Dakheel et al., 2020a)	[#]		Design Operating	✓
3. Regulatory framework and standards							
3.3.1	Compliance Score with Building Codes	Assign a compliance score and compare it to a benchmark for regulatory adherence or industry standards.		[%]		Design Operating	✓
3.3.2	Fire	Reaction to fire	EN 13501-1	[%]		Design	✓
3.3.3		Improvement of fire-retardant performances-	EN 13501-1	[%]	> 15%	Design	✓
3.3.4	Water	Water tightness				Design	✓
3.3.5		Water vapor permeability				Design	✓
3.3.6	Mechanical features	Load bearing capacity of the structure with pull and shear performances information				Design	
3.3.7		Overloading mechanical resistance				Design	
3.3.8		Wind load resistance				Design	
3.3.9		Seismic actions resistance				Design	
3.3.10		Dynamic load resistance; large soft body impact				Design	
3.3.11		Dynamic load resistance; small hard body impact				Design	
3.3.12		Eccentric vertical load resistance				Design	
3.3.13		Mechanical resistance				Design	✓

⁴ Bio4EEB – HE_GA-101091967

3.3.14	Sound insulation	Airborne sound insulation	Bio4EEB GA	dBA		Design	✓
3.3.15	Transmittance	Thermal transmittance		W/m ² K		Design	
4. Building Envelope							
3.4.1	Building Envelope Efficiency	Evaluate the effectiveness of the building envelope in maintaining thermal comfort and minimizing energy loss	(Al Dakheel et al., 2020b)	[%]	40%	Design	✓
3.4.2	Increasing energy production	Integration of active technologies for the energy production	(C.A. Balaras et al., 2015)	[kWh/y]		Operating	
3.4.3	Replacement	Ensuring easy components replacement, cleaning, and maintenance	RenoZEB Bio4EEB	[#]		Design	✓
3.4.4	Plug&Play fixing	Ensuring Plug&Play fixing components	RenoZEB Bio4EEB	[#]		Design	✓
3.4.5	Long-lasting	Ensuring a long-lasting component		[years]		Operating	✓
3.4.6	Industrialization	Reducing the number of façade typologies – increasing the industrialization	RenoZEB Bio4EEB	[#]		Design	
3.4.7	Integration of active technologies	Evaluate the number of active technologies integrated within the façade system		[#]		Design	
3.4.8	Smart Technology Integration Level	Rate the integration level of smart technologies for energy management, lighting control, and occupant comfort.		[Scale of 1-5]		Design	
3.4.9	Sound insulation potential	Sound insulation potential	Bio4EEB - GA	dBA		Design	✓
3.4.10	U-Value improvement	Improvement rate of U-value of the building components and insulation properties	Bio4EEB - GA	[%]	> 20%	Design Operating	
3.4.11	Reused and/or recycled	Façade components	Bio4EEB - GA	[%]	>20%	Designing Operating	
5. Comfort							
3.5.1	Indoor comfort	Increasing the indoor comfort – considering the hygrothermal parameters	(Andrea Urbinati et al., n.d.)	[%]		Operating	
3.5.2	Acoustic comfort	Increasing the acoustic comfort	(Ho et al., 2021)	dBA		Operating	
3.5.3	Indoor Air Quality (IAQ)	Measure improvements in air quality through better ventilation and filtration system	(Andrea Urbinati et al., n.d.)	[Scale of 1-5]		Operating	
3.5.4	Indoor Environmental Quality (IEQ)	Evaluate the improvement in the environmental quality like ventilation, pollutant levels, and occupant comfort	(McGinley et al., 2022)	[Scale of 1-5]		Operating	
3.5.5	Harmful substances	Reduced the indoor carbon dioxide levels	-	(ppm)		Design Operating	
3.5.6	Environmental quality	Improved indoor environmental quality	Bio4EEB - GA	[%]		Design Operating	✓
6. Materials							
3.6.1	U-value materials	Selection of materials with a low u-value	Bio4EEB - GA	[%]		Design Operating	✓

3.6.2	Humidity absorptivity	Selection of materials with high humidity absorptivity value	-	[%]		Design Operating	✓
3.6.3	Biological attack	Selection of materials with high resistance to biological attack value	-	[%]		Design Operating	✓
3.6.4	Local sources	Selection of local sources and materials	Bio4EEB - GA	[%]		Design Operating	✓
7. Water management							
3.7.1	Water Consumption Reduction	Measure the decrease in water usage resulting from water-efficient fixtures and systems	(Ahmed et al., 2023)	[liters]		Operating	
3.7.2	Water storage	Integration of water storage system	(Ahmed et al., 2023)	Y/N		Operating	
3.7.3	Water Use Efficiency	Calculate water consumption per occupant or per unit of area to assess efficient water usage after the intervention	(Ahmed et al., 2023)	[Liters per Area]		Operating	

Table 3: Technical information

3.3 Environment KPIs

Environmental Key Performance Indicators (KPIs) play a critical role in assessing and improving the environmental impact of buildings. By tracking and measuring various aspects of a building's environmental performance, KPIs provide a valuable tool for setting targets, monitoring progress, and implementing sustainable practices. The relevant headlines for KPIs to be adapted related to BIO4EEB needs are listed and explained below:

1. **Energy consumption:** Buildings account for a significant portion of global energy consumption. Measuring and reducing energy usage is crucial for reducing carbon emissions and mitigating climate change. KPIs can include metrics such as total energy consumption (electricity, heat), energy usage per square meter, or energy intensity per unit of output. Additionally, tracking the use of renewable energy sources, such as solar panels or wind turbines, can help evaluate the building's contribution to a low-carbon future.

2. **Environmental impacts:** Ozone depletion potential describes the degrading effect of substances in the stratosphere on the ozone layer, weakening the ozone layer's ability to prevent excessive ultraviolet radiation from reaching Earth's surface. KPIs include the amount of anthropogenic halogenated compounds, biotic and abiotic resource depletion, acidification, and eutrophication potential, and the human toxicity potential. Acidification potential is the amount of acidifying substances, such as sulphur dioxide and nitrogen oxides, that can contribute to acid rain and acidification of ecosystems during the life cycle of each solution component. The eutrophication potential indicator quantifies the potential for eutrophication in the assessed system or product's life cycle. It considers the nutrient inputs, such as phosphorus and nitrogen, that can lead to excessive algal growth, oxygen depletion, and ecological imbalances in aquatic and terrestrial ecosystems. The human toxicity potential reflects the potential harm of a unit of chemical released into the environment, is based on both the inherent toxicity of a compound and its potential dose.

3. **Greenhouse gas emissions:** Greenhouse gas emissions, primarily carbon dioxide (CO₂), contribute to global warming and climate change. Measuring and managing these emissions is essential for sustainable building practices. KPIs can include tracking CO₂ emissions from energy use, transportation, and building materials, as well as monitoring other greenhouse

gases like methane and nitrous oxide. By setting reduction targets and implementing energy-efficient strategies, buildings can significantly reduce their environmental footprint.

4. **Water usage:** Water scarcity is a growing concern in many regions. Managing water consumption is crucial for sustainable building operations. KPIs can include tracking total water consumption, water usage per occupant, or water efficiency measures such as water usage intensity per unit of output. Additionally, monitoring and minimizing water leakage or implementing water recycling and rainwater harvesting systems can further enhance the building's water sustainability.

5. **Waste management:** The construction and operation of buildings generate significant amounts of waste. Proper waste management practices can greatly reduce environmental impacts. KPIs can include tracking waste generation (hazardous, radioactive, and non-hazardous), recycling rates, the percentage of waste diverted from landfills, and the proper disposal of hazardous materials. Implementing waste reduction strategies, such as recycling programs and construction waste management plans, helps minimize the building's overall environmental footprint.

6. **Indoor air quality:** Ensuring good indoor air quality is vital for occupant health and well-being. Poor indoor air quality can lead to various health issues. KPIs can include monitoring levels of pollutants such as volatile organic compounds (VOCs), particulate matter, and carbon dioxide in indoor spaces. Regular ventilation, proper air filtration systems, and the use of low-emitting materials contribute to healthier indoor environments.

7. **Sustainable materials:** Assessing the use of sustainable and environmentally friendly materials in building construction and renovation is becoming increasingly important. KPIs can include measuring the percentage of recycled or renewable materials used, the certification of materials (e.g., Forest Stewardship Council-certified wood), and considering the embodied carbon of materials. Choosing materials with lower environmental impacts, such as recycled content or locally sourced materials, can significantly contribute to sustainable building practices. Sustainable materials include bio-based materials.

Bio-based materials are derived from renewable sources such as plants, animals, or microorganisms. These materials have a lower environmental impact compared to traditional materials derived from fossil fuels. They can be used in various applications, ranging from construction materials like bio-based plastics, bio-composites, and bio-based insulation, to furniture, textiles, and packaging. The use of bio-based materials helps reduce carbon emissions, supports the transition to a circular economy, and promotes the use of renewable resources. This aspect is very important related to BIO4EEB material and product application.

Environmental KPIs are essential for evaluating and analysing the environmental performance and sustainability efforts. Indicators can be used to monitor energy consumption, reduce greenhouse gas emissions, manage waste generation and avoidance, observe water consumption patterns, and enhance indoor air quality and focus on the material choice in terms of sustainability. These KPIs also contribute to the preservation of biodiversity, ensuring environmental regulatory compliance, and promoting renewable energy usage. Furthermore, they aid in increasing material and resource efficiency.

Environmental KPIs have been distinguished into 3 scales following the life cycle perspective to assess the environmental impacts of building materials, component, and buildings. The 3 scales are as follows:

1. Scale - Building material
2. Scale - Building component
3. Scale – Building”

4. Environment information						
1. Scale - Building material						
Cod.	KPI name	KPI description	Reference	UdM	Target	Bio4 EEB relevance
4.1.1	Waste land occupation	The total area required for waste generated in the end-of-life cycle.	Milà i Canals, L., Clift, R., Basson, L. et al., 2006	m ² per FU		
4.1.2	Hazardous waste	The total amount of hazardous waste generated during extraction, manufacturing, and disposal.	Rockwool, 2021; Coelho, A. and Brito, J., 2013	kg		
4.1.3	Radioactive waste	The total amount of radioactive waste generated during extraction, manufacturing, and disposal (total level of radioactivity).	Rockwool, 2021; Coelho, A. and Brito, J., 2013	kg		
4.1.4	Non-hazardous waste	The total amount of non-hazardous wastes generated during extraction, manufacturing, and disposal.	Rockwool, 2021; Coelho, A. and Brito, J., 2013	kg		
4.1.5	Carbon sequestration	The amount of potential carbon sequestration per FU over specific amounts of years.	Pawelzik, M. et al., 2013	gigatons		
4.1.6	Ozone depletion potential (ODP)	Describes the degrading effect of substances in the stratosphere on the ozone layer, weakening the ozone layer's ability to prevent excessive ultraviolet radiation from reaching Earth's surface. The sum of Ozone Depletion Potentials gases (ODP), e.g., anthropogenic halogenated compounds – CFCs.	ISO 1997c; EN15804+A2 EU standard	kg CFC-11 eq.		
4.1.7	Acidification potential	Potential environmental impact is a calculation of to the emissions of acidifying substances, such as sulfur dioxide (SO ₂) and nitrogen oxides (NO _x), which can contribute to acid rain and ecosystem acidification through the lifecycle of each solution component.	EN15804+A2 EU standard; Schulte, M. et al., 2021; EEA, 1997; The Carbon Leadership Forum, 2019.	kg SO ₂ eq.		
4.1.8	Eutrophication Potential	Eutrophication is enrichment of aquatic ecosystems with nutrients leading to increased production of plankton algae and higher aquatic plants leading to a degradation of the water quality and a reduction in the value of the utilization of the aquatic ecosystem. The Eutrophication Potential (EP) indicator quantifies the potential for eutrophication in the assessed system or product's life cycle. It considers the nutrient inputs, such as phosphorus (P) and nitrogen (N), that can lead to excessive algal growth, oxygen depletion, and ecological imbalances in aquatic and terrestrial ecosystems.	EN15804+A2 EU standard; Schulte, M. et al., 2021; EEA, 1997.	kg PO ₄ eq.; kg N eq		
4.1.9	Biotic depletion - raw material consumption	Quantity of biotic resources utilized as raw materials during the production, use, and end-of-life stages of the materials.	EN15804+A2 EU standard; EEA, 1997.	kg or m ³ or MJ		
4.1.10	Abiotic depletion -	Consumption of abiotic resources, such as fossil fuels, mineral ores, aquifers,	EN15804+A2 EU standard; EEA, 1997.	MJ		

	raw material consumption	sediments, clay, peat, gravel, throughout the life cycle of the bio-isolating materials.				
4.1.11	Water consumption	KPI's aim to assess water usage.	EN15804+A2 EU standard; Pawelzik et al, 2013; Heravi, G. & Abdolvand, M. M., 2019; Mannan, M. and Al-Ghamdi, S.G., 2022	m3		
4.1.12	Energy consumption (electricity)	The energy consumption (electricity) is the total amount of electricity consumed in each period.	Li, H. et al., 2019	kWh		
4.1.13	Energy consumption (heat)	The energy consumption (heat) is the total amount of heat consumed in each period.	Li, H. et al., 2019	kWh		

Table 4: Environmental information

2. Scale - Building component						
Cod.	KPI name	KPI description	Reference	UdM	Target	Bio4 EEB relevance
4.2.1	Lifetime with no service	The same thermal resistance R over a set area for a set number of years of service lifetime without any service or maintenance interventions.	Stefan Fuchs, Felix Rheude, Hubert Röder, 2022; Aktas, C.B., Bilec, M.M., 2011; Abdul Rauf, Robert H. Crawford, 2015.	Time in years and months		
4.2.2	Lifetime with service and periodic maintenance	The same thermal resistance R over a set area for a set number of years of service lifetime with regular service and periodic maintenance activities implemented.	Stefan Fuchs, Felix Rheude, Hubert Röder, 2022; Aktas, C.B., Bilec, M.M., 2011; Abdul Rauf, Robert H. Crawford, 2015.	Time in years and months		
4.2.3	Waste land occupation	The total area required for waste generated in the end-of-life cycle.	Milà i Canals, L., Clift, R., Basson, L. et al., 2006	m ² per FU		
4.2.4	Hazardous waste	The total amount of hazardous waste generated during extraction, manufacturing, and disposal.	Rockwool, 2021; Coelho, A. and Brito, J., 2013	kg		
4.2.5	Radioactive waste	The total amount of radioactive waste generated during extraction, manufacturing, and disposal (total level of radioactivity).	Rockwool, 2021; Coelho, A. and Brito, J., 2013	kg		
4.2.6	Non-hazardous waste	The total amount of non-hazardous wastes generated during extraction, manufacturing, and disposal.	Rockwool, 2021; Coelho, A. and Brito, J., 2013	kg		
4.2.7	Carbon sequestration	The amount of potential carbon sequestration per FU over specific amounts of years.	Pawelzik, M. et al., 2013	gigatons		
4.2.8	Carbon dioxide (CO ₂)	Emissions of CO ₂ from all stages of the life cycle of each material (non-electricity & energy and transportation related).	EEA, 1997.	kg CO ₂ eq.		
4.2.9	Methane (CH ₄)	Emissions of CH ₄ from all stages of the life cycle of each material.	EEA, 1997; EN15804+A2 EU standard.	kg CO ₂ eq.		
4.2.10	Nitrous oxide (N ₂ O)	Emissions of N ₂ O from all stages of the life cycle of each material.	EEA, 1997; EN15804+A2 EU standard.	kg CO ₂ eq.		
4.1.11	Other gases with GWP (specified each separately) e.g.: HFCs, PFCs, SF ₆	Emissions of other gases such as hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulfur hexafluoride (SF ₆), volatile organic compounds (VOCs) and others (specified gases).	EEA, 1997; EN15804+A2 EU standard.	kg CO ₂ eq.		
4.2.12	Ozone depletion potential	Describes the degrading effect of substances in the stratosphere on the ozone layer, weakening the ozone	ISO, 1997c; EN15804+A2 EU standard.	kg CFC 11 eq.		

		layer's ability to prevent excessive ultraviolet radiation from reaching Earth's surface. The sum of Ozone Depletion Potentials gases (ODP), e.g., anthropogenic halogenated compounds – CFCs.				
4.2.13	Acidification potential	Potential environmental impact is a calculation of to the emissions of acidifying substances, such as sulfur dioxide (SO ₂) and nitrogen oxides (NO _x), which can contribute to acid rain and ecosystem acidification through the lifecycle of each solution component.	EN15804+A2 EU standard; Schulte, M. et al., 2021; EEA, 1997; The Carbon Leadership Forum, 2019.	kg SO ₂ eq.		
4.2.14	Eutrophication Potential	Eutrophication Potential (EP) indicator quantifies the potential for eutrophication in the assessed system or product's life cycle. It considers the nutrient inputs, such as phosphorus (P) and nitrogen (N), that can lead to excessive algal growth, oxygen depletion, and ecological imbalances in aquatic and terrestrial ecosystems.	EN15804+A2 EU standard; Schulte et al, 2021; EEA, 1997.	kg PO ₄ eq.; kg N eq		
4.2.15	Biotic depletion - raw material consumption	Quantity of biotic resources utilized as raw materials during the production, use, and end-of-life stages of the materials.	EN15804+A2 EU standard; EEA, 1997.	kg or m ³ or MJ		
4.2.16	Abiotic depletion - raw material consumption	Consumption of abiotic resources, such as fossil fuels, mineral ores, aquifers, sediments, clay, peat, gravel, throughout the life cycle of the bio-isolating materials.	EN15804+A2 EU standard; EEA, 1997.	MJ		
4.2.17	Water consumption	KPI's aim to assess water usage.	EN15804+A2 EU standard; Pawelzik et al, 2013; Heravi, G. & Abdolvand, M. M., 2019; Mannan, M. and Al-Ghamdi, S.G., 2022	m ³		4.1.1 7
4.2.18	Energy consumption (electricity)	The energy consumption (electricity) is the total amount of electricity consumed in each period.	Li, H. et al., 2019	kWh		4.1.1 8
4.2.19	Energy consumption (heat)	The energy consumption (heat) is the total amount of heat consumed in each period.	Li, H. et al., 2019	kWh		4.1.1 9

Table 5: Scale - Building component

3. Scale - Building						
Cod.	KPI name	KPI description	Reference	UdM	Target	Bio4 EEB relevance
4.3.1	Lifetime with no service	The same thermal resistance R over a set area for a set number of years of service lifetime without any service or maintenance interventions.	Füchsl, S., Rheude, F., Röder, H., 2022; Aktas, C. and Bilec, M., 2011; Rauf, A. and Crawford, R., 2015.	Time in years and months		
4.3.2	Lifetime with service and periodic maintenance	The same thermal resistance R over a set area for a set number of years of service lifetime with regular service and periodic maintenance activities implemented.	Füchsl, S., Rheude, F., Röder, H., 2022; Aktas, C. and Bilec, M., 2011; Rauf, A. and Crawford, R., 2015.	Time in years and months		
4.3.3	Waste land occupation	The total area required for waste generated in the end of life-cycle.	Füchsl, S., Rheude, F., Röder, H., 2022; Aktas, C. and Bilec, M., 2011;	Time in years		

			Rauf, A. and Crawford, R., 2015.	and months		
4.3.4	Hazardous waste	The total amount of hazardous waste generated during extraction, manufacturing, and disposal.	Rockwool, 2021; Coelho, A. and Brito, J., 2013	kg		
4.3.5	Radioactive waste	The total amount of radioactive waste generated during extraction, manufacturing, and disposal (total level of radioactivity).	Rockwool, 2021; Coelho, A. and Brito, J., 2013	kg		
4.3.6	Non-hazardous waste	The total amount of non-hazardous wastes generated during extraction, manufacturing and disposal.	Rockwool, 2021; Coelho, A. and Brito, J., 2013	kg		
4.3.7	Ozone depletion potential	Describes the degrading effect of substances in the stratosphere on the ozone layer, weakening the ozone layer's ability to prevent excessive ultraviolet radiation from reaching Earth's surface. The sum of Ozone Depletion Potentials gases (ODP), e.g., anthropogenic halogenated compounds – CFCs.	ISO, 1997; EN15804+A2 EU standard.	kg CFC 11 eq.		
4.3.8	Water consumption	KPI's aim to assess water usage.	EN15804+A2 EU standard; Pawelzik et al, 2013; Heravi, G. & Abdolvand, M. M., 2019; Mannan, M. and Al-Ghamdi, S.G., 2022	m3		
4.3.9	Energy consumption (electricity)	The energy consumption (electricity) is the total amount of electricity consumed in each period.	Li, H. et al., 2019	kWh		
4.3.10	Energy consumption (heat)	The energy consumption (heat) is the total amount of heat consumed in each period.	Li, H. et al., 2019	kWh		
4.3.13	Operational energy	GWP attributed to operation and use of the building.	Casas Ledón, Y. et al., 2020 Kovacic, I. et al., 2018; The Carbon Leadership Forum, 2019.	kWh		
4.3.14	Embodied energy	GWP attributed to materials and energy used in the construction and maintenance of buildings.	Papadopoulos, A. and Gama, E., 2006; The Carbon Leadership Forum, 2019.	kWh		
4.3.15	Occupant safety	Assessment of human health and occupational safety, indoor air quality associated with the use stage of life. Required data from the occupational exposure limits for hazardous substances, indoor air quality measurements and workplace safety protocols and practices.	IEA, 2001.			
4.3.16	Human Toxicity Potential (HTP)	Human toxicological impacts depend on exposure to and effects of chemical and biological substances.	IEA, 2001.	kg 1,4-dichloro benzen e (1,4-DB) eq.		

Table 6: Scale - building

There is a big variety of environmental KPIs for buildings. The selection of specific KPIs depends on the goals, size, and type of building being assessed. It's important to customize KPIs to align with sustainability targets and local environmental priorities. Regular monitoring, analysis, and improvement based on these KPIs can help to drive sustainability practices and create greener, more environmentally friendly buildings. The selection of applicability for

BIO4EEB demonstrators will be based on the project characteristics and embedded in the next version of D4.2 Implementation Plan and Management due at M24.

3.4 Economic KPIs

Economic Key Performance Indicators (KPIs) in building renovation are essential for assessing the sustainability of the built environment from a financial and economic perspective. These KPIs help stakeholders evaluate the economic viability, cost-effectiveness, and economic impact of new buildings and renovation projects, while considering their long-term sustainability objectives. Here are some of the most relevant economic KPIs for building renovation sustainability, along with short explanations for each:

Return on Investment, ROI (%): Measures the financial return from the renovation project, often calculated by dividing the net profit gained from the renovation by the total investment cost. This indicator provides a clear understanding of the financial performance of a renovation project and helps determine whether it offers a positive financial outcome, considering initial costs and long-term savings.

Payback Period (years): Represents the time it takes for the accumulated savings from the renovation to equal the initial investment. A shorter payback period indicates a quicker return on investment, which is often preferred for economically sustainable projects.

Net Present Value, NPV (€): Calculates the present value of all future cash flows (savings and costs) associated with the renovation project, adjusted for the time value of money. This indicator assesses whether the project's cash flows, when discounted to present value, result in a positive or negative impact on the organization's financial position.

Internal Rate of Return, IRR (%): Represents the discount rate at which the net present value of the renovation project's cash flows becomes zero. A higher IRR suggests a more attractive investment opportunity, indicating a greater potential for financial gain.

Cost-Efficiency Ratio (€/unit of improvement): Compares the cost of renovation to the achieved improvement in energy efficiency, water efficiency, or other relevant sustainability metrics. This ratio helps assess the cost-efficiency of the renovation in achieving sustainability goals, allowing for comparisons between different projects.

Operating Cost Reduction (€): Measures the reduction in annual operating costs, such as energy, water, maintenance, and operational expenses, resulting from the renovation. Lower operating costs contribute to the economic sustainability of a building, making it more cost-competitive and efficient.

Incremental Property Value (€): Estimates the increase in property value resulting from the renovation. A higher property value not only signifies a financial gain but also encourages investment in sustainable renovation by increasing the asset's worth.

Life Cycle Cost Analysis, LCCA (€): Considers the total cost of ownership, including initial investment, operating costs, and maintenance over the building's expected lifespan. LCCA helps stakeholders make informed decisions by comparing the total economic impact of different renovation options throughout the building's life cycle.

Sustainable Job Creation: Quantifies the direct and indirect jobs generated as a result of the renovation project, particularly in the green building and sustainability sectors. Sustainable job

creation supports economic growth and can be an important economic KPI for governments and communities.

Economic Multiplier Effect: Evaluates the broader economic impact of the renovation project by assessing how additional economic activity is generated in the surrounding community. Understanding the economic multiplier effect helps stakeholders gauge the project's contribution to local economic development.

Below you can find listing of BIO4EEB economic KPIs with high relevance.

Cod.	KPI name	KPI description	Reference	UdM	Target	Bio4EEB relevance
5.4.1	Payback Period, PP	A shorter payback period indicates a quicker return on investment.	Grant Agreement	years	<7 years	High
5.4.2	Return on Investment, ROI	Financial return from the renovation project. This indicator determines whether it offers a positive financial outcome, considering initial costs and long-term savings.	Grant Agreement	%		High
5.4.3	Net Present Value, NPV	Calculates the present value of all future cash flows (savings and costs) associated with the renovation project, adjusted for the time value of money.	Grant Agreement	€		High
5.4.4	Internal Rate of Return, IRR	Discount rate at which the net present value of the renovation project's cash flows becomes zero. A higher IRR suggests a more attractive investment.		%		High
5.4.5	Cost-Efficiency Ratio	This ratio helps assess the cost-efficiency of the renovation in achieving sustainability goals, allowing for comparisons between different projects		€/unit of improvement		High
5.4.5	Operating Cost Reduction	Lower operating costs contribute to the economic sustainability of a building, making it more cost-competitive and efficient.		€		High
5.4.6	Incremental Property Value	Estimates the increase in property value resulting from the renovation.		€		High
5.4.6	Economic Multiplier Effect	Understanding the economic multiplier effect helps stakeholders gauge the project's contribution to local economic development.		-		High

Table 7: Economic KPIs

In summary, economic KPIs in new building construction and renovation are crucial for assessing the financial sustainability of projects. They provide valuable insights into the economic benefits, costs, and overall impact of sustainability initiatives. By considering these KPIs, stakeholders can make informed decisions that align with their sustainability goals while ensuring the long-term economic viability of renovation projects. These KPIs play a significant role in balancing environmental and economic considerations in building renovation projects for a more sustainable built environment.

3.5 Project specific KPIs

The BIO4EEB Project-Specific Requirements assist as a comprehensive evaluation of the potential paths for enhancement within the building demonstrator, with a particular focus on its energy performance, sustainability quotient, and alignment with circular economy principles. By investigating this segment, a meticulous examination is conducted to determine areas where the building's performance can be elevated, thus supporting its overall efficacy within

the context of the BIO4EEB project. These specifications form a foundational framework, encompassing several crucial facets including the delineation of *expected impact* where in the precise transformative effects and achievements envisaged by the BIO4EEB project for the building demonstrator are expounded upon (Task 4.1). Another pivotal aspect is the *LCA parameters* where the multifaceted realm of Life Cycle Assessment is navigated (Task 4.5). Additionally, the Circularity Parameters aspect, derived from T4.6, reports a crucial layer of understanding on the circular economy dimensions embedded within the BIO4EEB project.

BIO4EEB KPIs
General KPIs
KPI #1 - Time Reduction (1.1)
KPI #2 - Occupant Comfort Surveys (1.5)
KPI #3 - Client Satisfaction Score (1.6)
KPI #4 - Industrialization (1.8)
KPI #5 - Replicability (1.10)
KPI #6 - Durability (1.11)
KPI #7 - Disassembling (1.13)
Architecture KPIs
KPI #8 - Historical Features preserved (2.1)
KPI #9 - BIM Integration Level (2.2)
KPI #10 - Customization (2.3)
KPI #11 - Aesthetic needs (2.4)
KPI #12 - Integration of the façade system (2.9)
Technical KPIs
KPI #13 - Energy Consumption Reduction (3.1.1)
KPI #14 - Energy Performance Index (EPI) (3.1.2)
KPI #15 - Daily energy use (3.1.5)
KPI #16 - Integration of sensors and control system (3.2.2)
KPI #17 - Compliance Score with Building Codes (3.3.1)
KPI #18 - Reaction to fire (3.3.2)
KPI #19 - Improvement of fire-retardant performances (3.3.3)
KPI #20 - Water tightness (3.3.4)
KPI #21 - Water vapor permeability (3.3.5)
KPI #22 - Mechanical resistance (3.3.6)
KPI #23 - Sound insulation (3.4.14)
KPI #24 - Building Envelope Efficiency (3.4.1)
KPI #25 - Replacement (3.4.3)
KPI #26 – Plug & Play fixing (3.4.4)
KPI #27 - U-value materials (3.6.1)
KPI #28 - Humidity absorptivity (3.6.2)
KPI #29 - Biological attack (3.6.3)

KPI #30 – Bio-based materials impact (3.5.6)
KPI #31 - Selection of local sources and materials (3.6.4)
Environmental KPIs
KPI #32 - Waste land occupation (4.1.1) Scale - Building material
KPI #33 - Hazardous waste (4.1.2) Scale - Building material
KPI #34 - Radioactive waste (4.1.3) Scale - Building material
KPI #35 - Non-hazardous waste (4.1.4) Scale - Building material
KPI #36 - Carbon sequestration (4.1.5) Scale - Building material
KPI #37 - Ozone depletion potential (4.1.6) Scale - Building material
KPI #38 - Acidification potential (4.1.7) Scale - Building material
KPI #39 - Eutrophication Potential (4.1.8) Scale - Building material
KPI #40 - Biotic depletion - raw material consumption (4.1.9) Scale - Building material
KPI #41 - Abiotic depletion - raw material consumption (4.1.10) Scale - Building material
KPI #42 - Water consumption (4.1.11) Scale - Building material
KPI #43 - Energy consumption (electricity) (4.1.12) Scale - Building material
KPI #44 - Energy consumption (heat) (4.1.13) Scale - Building material
KPI #45 - Lifetime with no service (4.2.1) Scale - Building component
KPI #46 - Lifetime with service and periodic maintenance (4.2.2) Scale - Building component
KPI #47 - Waste land occupation (4.2.3) Scale - Building component
KPI #48 - Hazardous waste (4.2.4) Scale - Building component
KPI #49 - Radioactive waste (4.2.5) Scale - Building component
KPI #50 - Non-hazardous waste (4.2.6) Scale - Building component
KPI #50 - Carbon sequestration (4.2.7) Scale - Building component
KPI #51 - Carbon dioxide (CO ₂) (4.2.8) Scale - Building component
KPI #52 - Methane (CH ₄) (4.2.9) Scale - Building component
KPI #53 - Nitrous oxide (N ₂ O) (4.2.10) Scale - Building component
KPI #54 - Other gases with GWP (specified each separately) e.g.: HFCs, PFCs, SF ₆ (4.2.11) Scale - Building component
KPI #55 - Ozone depletion potential (4.2.12) Scale - Building component
KPI #56 - Acidification potential (4.2.13) Scale - Building component
KPI #57 - Eutrophication Potential (4.2.14) Scale - Building component
KPI #58 - Biotic depletion - raw material consumption (4.2.15) Scale - Building component
KPI #59 - Abiotic depletion - raw material consumption (4.2.16) Scale - Building component
KPI #60 - Water consumption (4.2.17) Scale - Building component
KPI #61 - Energy consumption (electricity) (4.2.18) Scale - Building component
KPI #62 - Energy consumption (heat) (4.2.19) Scale - Building component
KPI #63 - Lifetime with no service (4.3.1) Scale - Building

KPI #64 - Lifetime with service and periodic maintenance (4.3.2) Scale – Building
KPI #65 - Waste land occupation (4.3.3) Scale – Building
KPI #66 - Hazardous waste (4.3.4) Scale – Building
KPI #67 - Radioactive waste (4.3.5) Scale – Building
KPI #68 - Non-hazardous waste (4.3.6) Scale – Building
KPI #69 - Ozone depletion potential (4.3.7) Scale – Building
KPI #70 - Water consumption (4.3.8) Scale – Building
KPI #71 - Energy consumption (electricity) (4.3.9) Scale – Building
KPI #72 - Energy consumption (heat) (4.3.10) Scale – Building
KPI #73 - Operational energy (4.3.11) Scale – Building
KPI #74 - Embodied energy (4.3.12) Scale – Building
KPI #75 - Occupant safety (4.3.13) Scale - Building
KPI #76 - Human Toxicity Potential (HTP) (4.3.14) Scale - Building
Economical KPIs
KPI #77 - Net Present Value, NPV (5.4.3)
KPI #78 - Return of Investment, ROI (5.4.2)
KPI #79 - Payback Period, PP (5.4.1)
KPI #80 - Internal Rate of Return, IRR (5.4.4)

Table 8: Shortlist of project specific KPIs

4 KPI dashboard development

4.1 Goal of KPI dashboard:

The primary aim of the KPI dashboard is to offer a comprehensive visualization of key performance indicators (KPIs) to facilitate informed decision-making. It is designed to integrate seamlessly with the input generated by the Multi-Criteria Decision Analysis (MCDA) method. This enables users to compare different solutions effectively. The dashboard needs to offer the following capabilities:

- Exploration of individual KPIs
- Analysis of the relationship between KPIs and organizational objectives
- Comparison of alternative design decisions
- Ranking of design options based on various metrics

By accomplishing these objectives, the dashboard can empower stakeholders to make swift and confident decisions, streamlines the data analysis process, and helps identify the most effective interventions for specific scenarios.

4.1.1 KPI dashboard logic:

Creating a dashboard that visually represents complex data for decision-making and performance evaluation is no small feat. To ensure logical and effective data presentation, the dashboard adopts Schneiderman's Visual Information Seeking Mantra: "Overview first, zoom and filter, then details-on-demand" (Schneiderman, 1996).

Thus, the dashboard is structured across multiple levels of detail (LOD):

Overview or Building Level: Provides a high-level snapshot of indicators, serving as a starting point for stakeholders to explore a wealth of simulated and real-time data. This level helps users define and select their focus areas and allows stakeholders to sift through and explore large datasets.

Building Component Level: Provides the most detailed data, enabling users to compare various options and understand the interactions between different parameters.

Furthermore, the interactions between data and its visual representation, as well as the interaction between users and the visual representation, plays a pivotal role. These interactions are crucial in ensuring that the dashboard is not only informative, but also user-friendly and intuitive. The development process can be therefore broadly divided into two main components based on interaction: visualization of data and user interface.

4.1.2 Visualization of data:

Several methodologies and frameworks already exist, to guide the selection of the most appropriate visualization techniques (Eckerson, 2011; Jia & Chong, 2021; Vera-Piazzini et al., 2023). These methodologies often consider the following factors:

Project Goals: Every project has a unique set of objectives. The visualization method should align with these goals to provide clear insights.

Nature of the Data: Data can be categorical, numerical, time-series, or hierarchical, among others. The nature of the data dictates the type of visualization that will be most effective. For instance, a pie chart might be suitable for categorical data, while a line graph is more apt for time-series data. Furthermore, data can be either metered or simulated and can come in different time resolutions.

Type of Analysis: The kind of analysis to be conducted also influences the choice of visualization. Sensitivity analysis on data might require different visualization techniques than for example comparative analysis.

4.1.3 User Interface:

Once the most effective visualization techniques are identified, the next step is to integrate them into the dashboard's user interface. It's crucial to define how the dashboard and its users will interact and influence each other (Vera-Piazzini et al., 2023).

Before implementing these components, it's important to clarify certain aspects of the data, the user requirements, and the overarching goals of the project.

User Interaction: A dashboard is not a passive tool. Depending on the user, they might want to have simpler easy to understand visual representation, or being able to drill down into specific data points, and customize views according to their needs. The interface should be tailored to user needs.

Feedback Loop: The relationship between the dashboard and its users is symbiotic. As users interact with the dashboard, they might uncover insights that can lead to further refinements in the visualization or the data itself. This feedback loop is essential for continuous improvement.

Accessibility and Usability: The dashboard should be accessible to all intended users, regardless of their technical expertise. Its design should be intuitive, with clear labels, legends, and instructions. The choice of colours, fonts, and layout plays a significant role in enhancing usability.

To create a complete KPI dashboard that can deal with all the above described aspects, the key points are addressed in the following sections considering end users and goals, nature of the data and KPIS as well as visualization type.

4.2 End users and goals:

The KPI dashboard is designed to cater to a diverse range of stakeholders, each with varying levels of expertise. From the dashboard's perspective, users can be broadly categorized into two groups: expert users and non-expert users. The distinction is crucial, as it influences the dashboard's capabilities, data sparseness, and visual language.

When separating the most important users defined (designers, contractor/construction companies, owners and/or occupants, material and solution providers as defined in D2.3). Exact categorization of users will happen later on a case-by-case basis.

The dashboard usage varies significantly between these two groups, mainly due to the assumed goals they have.

For non-expert users, widgets, icons, and figures offer a quicker and more straightforward understanding of the data, as supported by previous studies (Nimbarte et al., 2021; Salmon et al., 2016). Additionally, 3D visualizations and floor maps can enhance comprehension. On the other hand, expert users benefit from more complex visualization techniques like scatterplots and boxplots, as well as the use of colour coding to explore multiple variables simultaneously.

In terms of end goals, KPI dashboards typically serve two primary purposes: decision-making and motivation

However, in the context of BIO4EEB, the focus is primarily on decision-making. Decision-making is usually the domain of expert users, although it doesn't necessarily exclude non-experts. The dashboard must effectively communicate information to help identify key issues, compare different metrics, and prioritize critical data. It should offer simplified visualizations for complex data sets and act as a natural bridge between the collected data and the MCDA algorithm in use. Motivational aspects, which often address user behaviour, are particularly relevant for end-users. The dashboard aims to educate and motivate users to adopt behaviours that positively impact building energy consumption (Francisco et al., 2018; Masoodian et al., 2015).

Figure 3 presents the visualization techniques cited in the literature collected by Vera-Piazzini et al (Vera-Piazzini et al., 2023), linking them to different stakeholders, goals, and data availability. As previously mentioned, in BIO4EEB, in the figure, the parts related to decision-making, sensitivity analysis, and detailed results are of utmost importance.

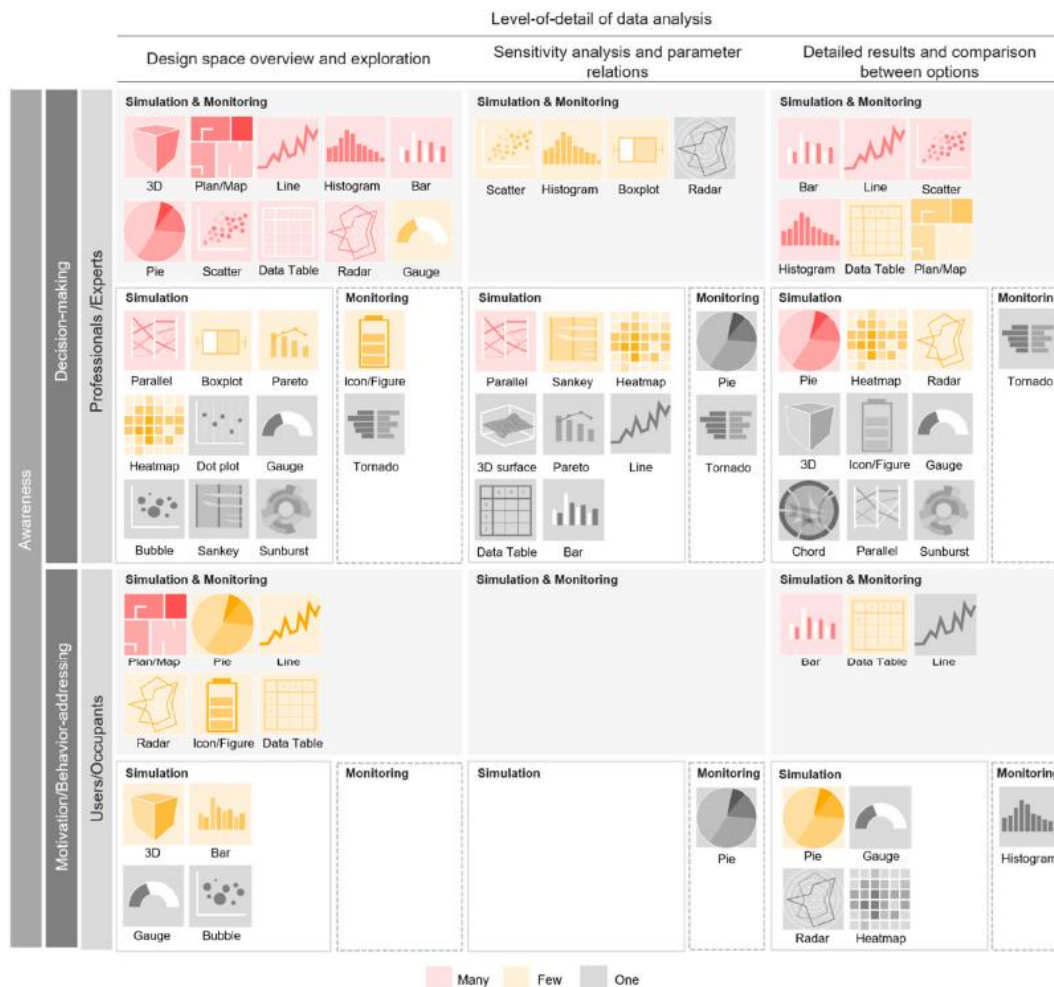


Figure 3: Most used visual techniques in relation to users, goals and level of detail (Vera-Piazzini et al., 2023)

4.3 Nature of the data and KPIs

According to Tufte et al., the key attributes of effective graphical representation are clarity, precision, and efficiency (Tufte, 2001). The organization and selection of data largely hinge on the goals of the analysis, the intended audience, and the availability of data.

Based on the abovementioned review by Vera et al., the most common visualization types for specific KPIs are identified as shown in Table x (Vera-Piazzini et al., 2023):

KPI	Visualization type
Environmental	
Temperature/Comfort	Line chart
Relative humidity	Line chart
Air quality	Line chart
Daylight/Luminance/glare	3D visualization
Ventilation	Line/bar chart
Noise values	Widgets/Icons/Figures
Building	
Geometry	3D visualization
Envelope	Data table
Occupancy	Line chart
HVAC equipment	Line chart
Energy	
General consumption	Line chart
Equipment	Line chart
Lighting	Line/box plot
Heating/Cooling	Box plot, /Pie/Donut chart
Water consumption	Gauge, Line/Pie/Donut chart, Widgets/Icons/Figures
Gas consumption	Gauge, Line/Pie/Donut chart, Scatter plot
Costs	Bar/Pareto chart, Sankey/Tornado diagram, Scatter plot, Widgets/Icons/Figures
Renewable energy	Bar chart, Data table, Heatmap

Table 9: The most common visualization types for listed KPIs (Vera-Piazzini et al., 2023)

Furthermore, the selection of visualization techniques often hinges on the nature of the data. For simulation data, experts tend to favor intricate visualizations like heatmaps and parallel coordinates, particularly. Conversely, for real-time monitoring aimed at a broader audience, simpler, dynamic visual elements like gauges and widgets are more commonly employed (Vera-Piazzini et al., 2023).

4.4 Types of Visualizations Used:

Short description of the available visualization types commonly used in KPI dashboards dealing with energy, environmental and other sustainability related data.

Line and Bar Charts: These are the most used types of data visualization, cited extensively in scientific literature. They are particularly useful for displaying energy consumption data and are a staple in real-time monitoring for users keen on understanding peak consumption patterns.

Scatter Plots and Histograms: These versatile graphs serve multiple purposes. Scatter plots are invaluable when correlating various variables to specific objectives, allowing for pattern recognition and anomaly detection. Histograms excel in comparing consumption over different time frames, such as hourly, daily, or monthly, and can also plot historical performance and design variables.

Heatmaps, Parallel Coordinates, and Radar Charts: These are the go-to options for comparing parameters or analysing sensitive, multidimensional data. They are particularly useful in simulating building energy performance, offering insights into data distributions, potential relationships, and pattern.

3D Visualizations and Floor Plans: These add a contextual layer to quantitative graphics and are often paired with more complex visualizations to enhance comprehension.

Widgets, Icons, and Figures: These elements are particularly useful for non-expert users, offering quick, at-a-glance interpretations and aiding in data comprehension.

4.5 Decision Framework:

To decide which visualization to use, the framework developed by Piazzini et al. (Vera-Piazzini et al., 2023) can be applied.

The first step involves defining the goals of the analysis. While Piazzini et al. (Vera-Piazzini et al., 2023) outline goals like decision-making, awareness, and behavior modification, the focus of the current project is primarily on **decision-making**.

Next, the Level of Detail (LOD) for data presentation must be determined. This involves selecting the appropriate granularity of data to avoid overwhelming or cluttering the visualizations. For BIO4EEB both **sensitivity analysis** and **option comparison** are applicable.

Finally, the type of data—whether simulated or monitored—should be specified. Understanding the nature of the data helps in selecting the most appropriate visualization techniques. In this case, there is a need to help in visualizing **both simulated and metered data**.

4.5.1 Suggestion for indicator visualization:

To summarize, for certain KPIs certain indicators can be used. As during the writing of this chapter, the indicators are still unknown, a general suggestion is provided in table 12 based on the available information.

KPI topic	Timescale	Visualization type
Technical KPIs	N/A	Boxplot
	N/A	Data table
	Monthly	Bar chart*
	Annual	Sunburst chart
	Seasonal	Sankey diagram
Environmental KPIs		
	Sub-hourly/Hourly/Daily/Monthly	Line chart*
	Hourly/Daily/Monthly	Heatmaps
	Sub-hourly	Gauges
	Sub-hourly	Histograms*
	Hourly/Daily	Data tables

Economic KPIs	Daily/Monthly/Annually	Bar charts
	Sub-hourly/Hourly/Daily	Widgets/Icons/Figures
	Monthly/Annual	Bar chart
	Annual	Pareto chart
	Seasonal	Sankey diagram
	Annual	Scatter plots*
	Annual	Tornado diagram
	Annual	Widgets/Icons/Figures

Table 10: General suggestion for individual indicator visualization based on literature and KPIs identified for BIO4EEB

*In line with Figure X. most used visual techniques for relevant goals and LOD levels marked.

4.5.2 Suggestions for dashboard interface development:

The main question regarding the dashboard interface is whether or not to make it dynamic. There are compelling arguments both for or against dynamic dashboards in the literature. According to the research, graphical representations are essential for effectively understanding energy results, whether those results are derived from simulations or real-time monitoring (Vera-Piazzini et al., 2023). The choice of the most appropriate graph depends on various key factors such as the data source, the goals of the energy analysis, and the target user. A dynamic dashboard allows for this level of customization, enabling users to interact with the data and focus on specific KPIs that are most relevant to them (Shneiderman, 1996).

Moreover, the fluid integration of different types of graphs is crucial for comprehensive data interpretation (Vera-Piazzini et al., 2023). Dynamic dashboards excel in this aspect by allowing various graphs to complement each other. They can be presented in a hierarchical manner, which aids in emphasizing important results and prioritizing some graphs over others (Stavropoulos et al., 2014). This hierarchical approach was notably proposed by Gadelhak et al., who designed an interface that provides both an overview and detailed data through different types of graphs as presented in figure 4. (Gadelhak et al., 2017)

However, it's essential to consider some of the challenges associated with dynamic dashboards. For instance, their complexity can be overwhelming for users who are not familiar with the data or metrics (Alhamadi, 2020). They are also more resource-intensive to develop and maintain, which could be a concern for smaller organizations. Additionally, the effectiveness of a dynamic dashboard is highly dependent on the quality of the data fed into it, and poor data quality can lead to misleading insights.



Figure 4: Screenshot of a dynamic visualization tool from Gadelhak et al. (Gadelhak et al., 2017)

All in all, the advantages outweigh the challenges for decision making purposes, specifically for expert users. Developing an interactive, integrated dashboard can significantly enhance MCDA methods implemented, helps in creating customizable representations of data for multiple stakeholders and provide quick, dynamic feedback for users.

After carefully selecting the relevant KPIs to be monitored and the MCDA method to be implemented, the best visual representation will be chosen for every indicator, as well as the most fitting dashboard layout for the complete dashboard. This solution will be later implemented into the BIO4EEB user friendly, multidisciplinary platform and specified related to needs of demonstrators in D4.2 Implementation Plan and Management 2nd version due at M24.

5 MCDA analysis

The BIO4EEB project aims to enhance the energy performance of buildings through the development and implementation of bio-based insulation materials and circular economy approaches.

The generic MCDA process typically involves several steps. First, the decision-makers identify the criteria that are relevant to the decision at hand. These criteria could be quantitative (such as cost, time, or efficiency) or qualitative (such as environmental impact, stakeholder preferences, or social equity). The criteria are often selected based on their relevance to the decision problem and the decision-makers' goals.

Once the criteria are identified, decision-makers assign weights or importance to each criterion to reflect their relative importance. This step is crucial as it helps decision-makers to prioritize

the criteria according to their preferences or objectives. The weights can be determined through various methods, such as analytical hierarchy process (AHP), swing weighting, or direct rating.

After assigning weights to the criteria, decision-makers evaluate the different alternatives or options against each criterion. This evaluation can be done quantitatively (using numerical data) or qualitatively (using subjective judgments or ratings). The evaluation process may involve collecting data, conducting experiments, or consulting with experts.

Once the evaluation is complete, MCDA techniques help in aggregating the evaluations and calculating an overall score or ranking for each alternative. This aggregation can be done using various methods, such as the weighted sum model, the weighted product model, or the outranking methods like the PROMETHEE and ELECTRE.

The final step in the MCDA process involves interpreting the results and making a decision based on the rankings or scores obtained. The decision-makers can use the results to compare the alternatives, identify the most preferred option, or even explore trade-offs between different criteria. The transparency and systematic nature of MCDA helps decision-makers communicate and justify their decisions to stakeholders or other parties involved.

Overall, MCDA provides a framework for structured decision-making, considering multiple criteria and preferences. It is widely used in various fields such as engineering, environmental management, healthcare, and public policy, where decisions often involve complex and conflicting objectives. By incorporating multiple perspectives and weighing the importance of different factors, MCDA helps decision-makers make informed and balanced decisions.

To effectively assess the project's impact and to measure various aspects of the project's outcomes, the KPIs identified and the integrated analysis of MCDA are integrated in the dashboards. In this section, the possibilities are explored of using MCDA within the context of soft computing to enhance the utilization of KPIs and provide a platform for enhanced decision-making. Included in this report you will find an overview of identified samples of MCDAs (see Annex 1).

5.1 MCDA agents

MCDA can be a powerful decision-making tool that allows for the evaluation and ranking of alternatives based on multiple criteria during early design stage and following regular milestones for products selection and construction work. In the context of the BIO4EEB project it can play a vital role in consolidating the diverse KPIs to provide a comprehensive understanding of the project's performance and potential impact. The choice of MCDA overall approach can be simplified in 3 key agents involved in the process:

Stakeholders – definition of the target audience, identifying possible stakeholders interested in the process and related expectations for a MCDA deployed by a decision support tool. Different stakeholders look for different KPIs and only the ones objects of specific targets should be calculated and presented because interested to specific end users. The targeted stakeholders for the project are designers, contractor/construction companies, owners and/or occupants and material and solution providers.

Context – definition of the object of intervention, identifying opportunities as well as constraints or limitations to be considered in the decision process. Based on specific context MCDA addresses specifically KPIs. In particular aspects such as regulatory frameworks, technical constraints, social acceptance, economic aspect, define the context to conduct the MCDA.

BIO4EEB solutions – definition of BIO4EEB solutions at the different scale object of analysis (building product, building system, building) to understand the KPIs and their impact. The solutions used in the MCDA will be the ones elaborated within WP3 and WP4 activities.

5.2 MCDA soft computing approach

Based on these 3 agents, MCDA adopted will be based on a soft computing approach (deployed within the BIO4EEB platform), rather than hard computing, so to enable KPIs and support decision considering multiple aspects. The reason of soft computing is that is a more agile approach and refers to computational methods that can handle complexity while reducing uncertainty, imprecision, and ambiguity at early stages. This is particularly relevant in multidisciplinary and complex scenarios in order to enable the project to better handle complex and uncertain data, improving the overall decision support process.

There are several classifications of MCDA techniques, each suitable for different types of decision-making problems. For these reasons, some commonly used MCDA classifications include:

Compensatory vs. Non-compensatory Methods: Compensatory methods allow trade-offs between criteria, while non-compensatory methods have strict thresholds that must be met for each criterion.

Weighting vs. Non-weighting Methods: Weighting methods assign weights to criteria to represent their relative importance, while non-weighting methods treat all criteria equally.

Value Function vs. Outranking Methods: Value function methods involve defining utility functions to evaluate alternatives, while outranking methods compare alternatives against each other to determine dominance.

The integration of MCDA with soft computing opens various opportunities for interaction and feedback in the decision support process. By incorporating feedback loops, stakeholders can continuously update and refine their preferences and priorities. Furthermore, the use of fuzzy logic and uncertainty analysis can handle imprecise data, allowing for a more robust decision-making process.

For the BIO4EEB project, a hybrid soft computing approach to MCDA will combine analytic hierarchy process (AHP) to define the propriety for the stakeholders, theory of change with fuzzy logic and Choquet integral. This hybrid approach can effectively handle the diverse and uncertain data collected from KPIs. Fuzzy logic enables the representation of vague and ambiguous information supported by complexity traced thanks to theory of change, while AHP allows for the structuring and prioritization of criteria. Choquet integral, a non-linear aggregation method, accounts for interactions between criteria, providing a more comprehensive evaluation of alternatives.

Here is a more detailed explanation of each component of the hybrid approach which will be within the project:

1. **Analytic hierarchy process (AHP)** and **Weighted Sum Method (WSM)** will be linked together to structure and prioritize the criteria (Al-Bayati and Al-Zubaidy, 2020). The former will be used to establish the weight for the criteria in the WSD providing more systematic and data-driven way, while the latter will be used to evaluate the alternatives based on the criteria. The weighting sum methods is divided in three categories: Subjective weighting depending on the preference of the decision maker (AHP) (i); Objective weighting based on the quantitative measured data (ii); Combination of subjective and objective weighting methods (iii) (Khadra et al., 2020).

The Weighted Sum Method (WSM) is recognized as the most suitable one for the assessment of renovation projects due to its simplicity but has a disadvantage of not integrating multiple preferences (Khadra et al., 2020). However, if there would be assigned weights for each stakeholder preferences, this method seems as suitable. Using Weighted Sum Method (WSM) (Khadra et al., 2020):

1. **KPIs structure** with a goal of rating the specific results of the application of bio-based material is developed.

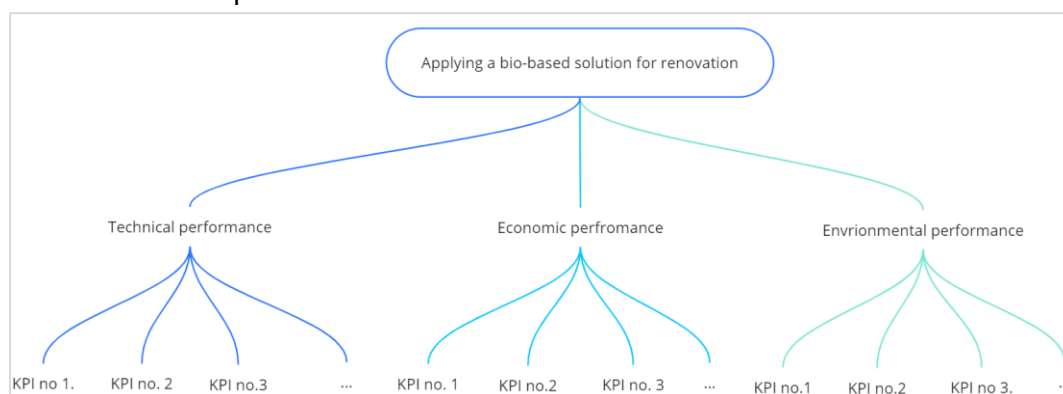


Figure 5: Structure of KPI application

For each KPI determine the minimum/ maximum requirement levels. If the data is qualitative conversion scale could be generated to quantify the KPI (e.g. comfort- 1- average, 2- good, 3- very good, 4- excellent).

2. **Theory of change** is a framework for understanding how a program or intervention is expected to achieve its goals. It identifies the key assumptions and causal relationships that are necessary for the program to be successful.
3. **Mathematical approach** – Fuzzy logic deals with uncertainty and ambiguity. It allows for the use of fuzzy sets, which can represent concepts that are not easily defined or measured. ELECTRE-Tri
4. **Choquet integral** is a non-linear aggregation method that accounts for interactions between criteria. It provides a more comprehensive evaluation of alternatives than traditional linear aggregation methods.

The hybrid approach combines the strengths of each of these methods to provide a more robust and flexible decision-making framework. The use of fuzzy logic allows for the representation of vague and ambiguous information, which is often present in KPI data. The use of AHP and WSM allows for the structuring and prioritization of criteria, which is essential

for making informed decisions. The use of Choquet integral accounts for interactions between criteria, which provides a more comprehensive evaluation of alternatives.

Overall, the hybrid approach to MCDA is a promising tool for supporting decision-making in the BIO4EEB project. It can effectively handle the diverse and uncertain data collected from KPIs, and it provides a more comprehensive evaluation of alternatives than traditional methods. This can help decision-makers to make better decisions that are more likely to be successful.

To deploy the MCDA with soft computing approach effectively, a user-friendly and multi-disciplinary platform will be developed. This platform will integrate the diverse KPIs from the BIO4EEB project, allowing stakeholders to explore different scenarios and make informed decisions. The platform will provide visualizations, sensitivity analysis, and interactive tools to enhance user engagement and understanding.

5.3 MCDA use cases platform

There are several sister projects that have served and will serve us in the design of MCDA-related use cases. A couple of concrete examples are the assessments included in the EnergyMatching and Innoqua platforms.

EnergyMatching MCDA aims to help designers and other professionals and stakeholders maximize the use of renewable energy sources in their buildings or communities. The MCDA tool allows the users to detect optimal configurations and compare settings, being a useful tool to be considered before any renovation or retrofit. The MCDA tool uses about 20 different inputs to calculate the outputs. Only a part of the inputs is mandatory, the others, if not provided, can be estimated based on market values. The MCDA tool outputs some metrics and KPIs related to consumption and ROI, along with the best BIPV configuration. All supported with 3D models and a report detailing the self-sufficiency and cash flow of the investment over the lifetime of the system.

The image below shows some of the data that the user has to enter, together with the results derived from the multi-criteria analysis, and finally the result in visual form. In this result the 3D model is shown, on which the optimal configuration of the solution is displayed.

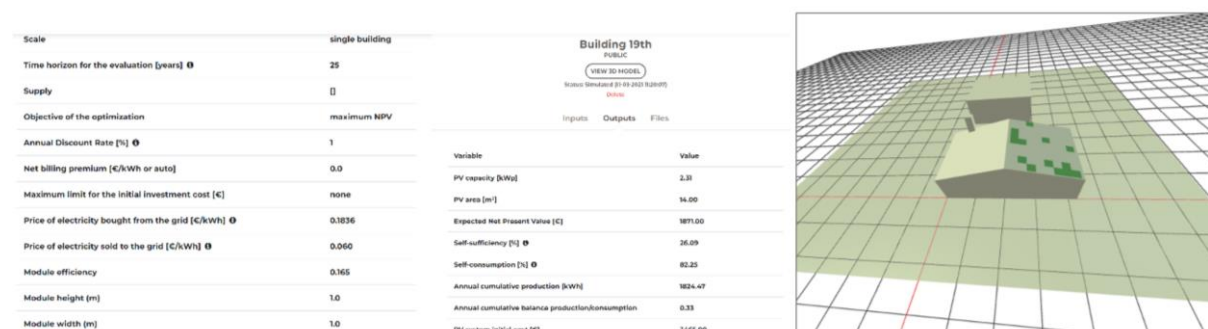
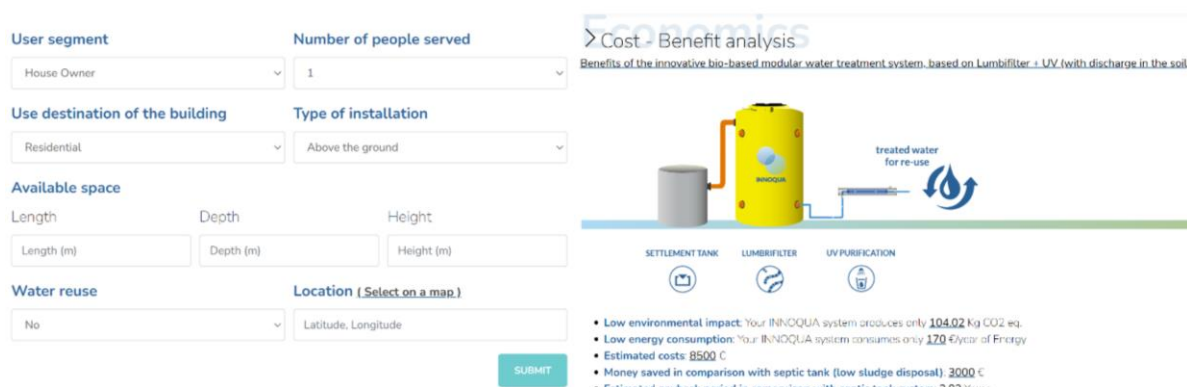


Figure 6: Example of MCDA interface and visual result

In relation to BIO4EEB's MCDA, the EnergyMatching platform provides several interesting ideas. On the one hand, the management of multiple input values, splitting between key and optional values. On the other hand, the representation of data in a way that is understandable for both elementary and expert users. On the improvement side, the EnergyMatching platform requires long waiting times due to the complexity of the calculations. In BIO4EEB it is necessary to learn this lesson in order to produce a computable analysis in a short time.

The second MCDA platform is that of Innoqua. Innoqua presents an MCDA that analyses the installation possibilities of nature-based solutions for wastewater treatment. The user is asked to provide information about the user segment where he/she resides, information about the residents and location in Europe (selectable on a map). It is also necessary to include dimensional information about the available space or whether the solution is intended to be installed underground. With all this data, various calculations are performed to indicate whether the installation of such a solution is possible and recommend various configurations of components that could be installed. Regulatory information is also provided, related to the type of installation and size. Finally, indicators of cost, environmental impact and return on investment are offered.

In regard to BIO4EEB's MCDA, Innoqua's MCDA provides lessons in terms of simplicity of use and quickness of results. Also, in the possibility of offering the user different optional configurations, while being accompanied by relevant indicators.



User segment

House Owner

Number of people served

1

Use destination of the building

Residential

Type of installation

Above the ground

Available space

Length (m) Depth (m) Height (m)

Water reuse

No

Location (Select on a map)

Latitude, Longitude

Cost - Benefit analysis

Benefits of the innovative bio-based modular water treatment system, based on Lumbifilter + UV (with discharge in the soil)

Diagram: SETTLEMENT TANK → LUMBIFILTER → UV PURIFICATION → treated water for re-use

- **Low environmental impact:** Your INNOQUA system produces only **104.02** kg CO2 eq.
- **Low energy consumption:** Your INNOQUA system consumes only **170** €/year of Energy
- **Estimated costs:** 8500 €
- **Money saved in comparison with septic tank (low sludge disposal):** 3000 €
- **Estimated payback period in comparison with septic tank system:** 2.83 Years

Figure 7: Screenshots from INNOQUA platform

Both solutions are developed as software components integrated in web platforms. This makes it easy for users to use them without the need to install elements on their devices. This approach is interesting in order to reach more users and evolve the platform and MCDA over time.

6 Conclusion

The application of the building project phase oriented 4M analysis process -Mapping, Modelling, Making, Monitoring- including the essential metrics and KPIs that focus on technical, environmental and economic criteria enables the partners to follow a standardised process of quality assurance. The selected evaluation metrics are identified reflecting on the specific real and virtual demonstration cases' needs as a use case in order to support the creation of a KPI dashboard that covers all cases.

An accurate list of relevant KPIs has been identified to evaluate during the building or retrofitting activities. These KPIs provide a comprehensive view of the impact and success of building and retrofitting efforts, helping stakeholders weigh the effectiveness of their investments in energy efficiency, sustainability, and occupant well-being. It's important to tailor the KPIs to the specific goals of the project and to continuously monitor and analyse the data to drive ongoing improvements.

E.g. technical Key Performance Indicators (KPIs) offer a range of measurable metrics that provide insights into a building's efficiency, sustainability, and functionality. These metrics empower decision-makers to align with sustainability goals, regulations, and user expectations.

Environmental Key Performance Indicators (KPIs) play a critical role in assessing and improving the environmental impact of buildings. By tracking and measuring various aspects of a building's environmental performance, KPIs provide a valuable tool for setting targets, monitoring progress, and implementing sustainable practices.

Key Performance Indicators (KPIs) for economic buildings, such as those related to businesses or real estate, can vary depending on the specific goals and objectives of the organization or individual. Aspects as Net Operating Income (NOI), Return on Investment (ROI), Operating Expenses Ratio, Capitalization Rate (Cap Rate), Energy Efficiency and Maintenance and Repair Costs are covered.

These KPIs are customized to suit the specific needs and objectives of building owners, investors, or property managers are based on BIO4EEB characteristics and are regularly tracked and analysed to make informed decisions and optimize the performance of economic buildings.

The primary aim of the BIO4EEB KPI dashboard is to offer a comprehensive visualization of key performance indicators to facilitate informed decision-making. It is designed to integrate seamlessly with the input generated by the Multi-Criteria Decision Analysis method. This enables users to compare different solutions effectively. The dashboard needs to offer the following capabilities:

- Exploration of individual KPIs
- Analysis of the relationship between KPIs and organizational objectives
- Comparison of alternative design decisions
- Ranking of design options based on various metrics

By accomplishing these objectives, the dashboard empowers stakeholders to make swift and confident decisions, streamlines the data analysis process, and helps identify the most effective interventions for specific scenarios

Multi-Criteria Decision Analysis is a decision-making methodology that allows individuals or groups to systematically evaluate and compare different options or alternatives based on multiple criteria or factors. It is particularly useful in situations where decisions are complex and involve multiple objectives or considerations. On behalf of BIO4EEB the interaction of different KPIs is special and complex. Therefore, the MCDA as developed is an essential tool to make the decision process transparent and trustable. It helps decision-makers to clarify their preferences and priorities, consider a wide range of factors, and weigh the relative importance of each criterion.

The MCDA process typically involves several steps. First, the decision-makers identify the criteria that are relevant to the decision at hand. These criteria could be quantitative (such as cost, time, or efficiency) or qualitative (such as environmental impact, stakeholder preferences, or social equity). The criteria are often selected based on their relevance to the decision problem and the decision-makers' goals.

There is a big variety of environmental KPIs for buildings. The selection of specific KPIs depends on the goals, size, and type of building being assessed. It's important to customize KPIs to align with sustainability targets and local environmental priorities. Regular monitoring, analysis, and improvement based on these KPIs can help to drive sustainability practices and create greener, more environmentally friendly buildings. The selection of applicability for BIO4EEB demonstrators will be based on the project characteristics and embedded in the next version of D4.2 Implementation Plan and Management due at M24.

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Annex 1: Samples of MCDA platform solutions

• AUTODESK FORMA (formerly Spacemaker) (at building project level)

Cloud-based software for early-stage planning and design = conceptual design and modeling tools and real-time analytics.

- <https://www.autodesk.com/products/forma/overview?term=1-YEAR&tab=subscription>
- <https://damassets.autodesk.net/content/dam/autodesk/www/products/autodesk-forma/fy24/overview/forma-sustainability.pdf>
- <https://www.autodesk.com/campaigns/forma-analysis-hub>

Interesting for the decision support with real-time analytics :

Uncover greater insights into your site and its surroundings in real time with AI powered analyses **for key factors such as sunlight, noise, daylight potential, wind, microclimate and area analysis.**

“Use conceptual design capabilities, predictive analytics, and automations to make solid foundations for your projects.

- Unlock efficiencies with intuitive project setup, design automations, and fluid connectivity with Revit
- Use data-driven insights in real-time to make fast, smart design decisions that reduce risk and improve business and sustainability outcomes
- Improve collaboration and secure buy-in by using data and visuals to tell a compelling design story that can help you win more bids”



Operational Energy

Explore the impacts of building design choices on energy consumption of HVAC, lighting, and plug-loads while you're designing



Microclimate

Improve urban site design and outdoor thermal comfort through microclimate analysis



Solar Energy*

Assess rooftop renewable energy potential of photovoltaic panel systems



Sun hours

Analyse the percentage of hours of direct sunlight on building façades and ground surfaces



Daylight Potential

Visualize daylight potential in context with the surrounding buildings and environment



Wind

Wind analysis illustrates building and site-influences on localized air flow patterns



Noise

Understand how noise impacts external surrounding conditions to evaluate potential risk of acoustic discomfort



Views*

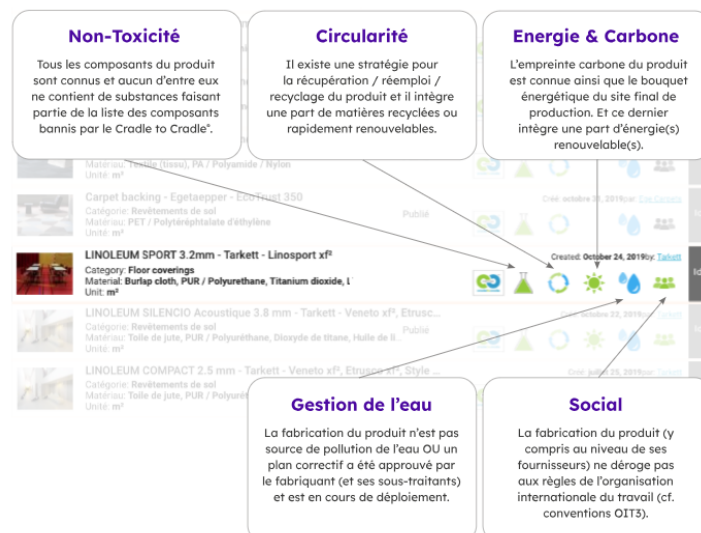
Visualize occupant sight lines and measure distances of exterior views and points of interest

*in development

- **myUpcyclea® (at product level)**

the decarbonization and circular resource management system: <https://upcyclea.com/en/>
<https://upcyclea.com/en/circular-passport-library/>

In a passport library, the tool offers an analysis of **products** according to different criteria : these passports describe the **composition**, the **non-toxicity**, the **recycled/biobased part**, the next lives, the **LCA**, the **labels**, and a **social criterion** (respect for the rules of the international labour organization) of the products.



Les preuves sont auto-déclaratives et ont été validées par Upcyclea.
 Les preuves ont été vérifiées par des tiers et validées par Upcyclea.

- **VIZCAB (Both product and building project levels)**

“More Data, Less Carbon”

<https://vizcab.io/>

At product level : <https://vizcab.io/vizcab-materiaux-construction>

At building project level :

- <https://vizcab.io/vizcab-eval>
- <https://vizcab.io/explo>
- <https://vizcab.io/observatoire>

“Vizcab is a SaaS platform that enables construction and real estate players to catalyse their carbon transition at the scale of the different phases of a project thanks to data science, based on a technology developed by the building 2050 group led by Thomas Jusselme at EPFL Fribourg and the Building 2050 group by Thomas Jusselme;

The Vizcab range is positioned where current eco-design tools are no longer sufficient to take the step towards generalised Life Cycle Assessment.

Vizcab Explo: a decision support tool that enables project owners and their advisors to build secure and competitive carbon energy strategies, right from the upstream phases of real estate operations.

Vizcab Eval: LCA calculation software used by engineering firms and general contractors to optimise and validate the achievement of “regulatory” carbon levels.

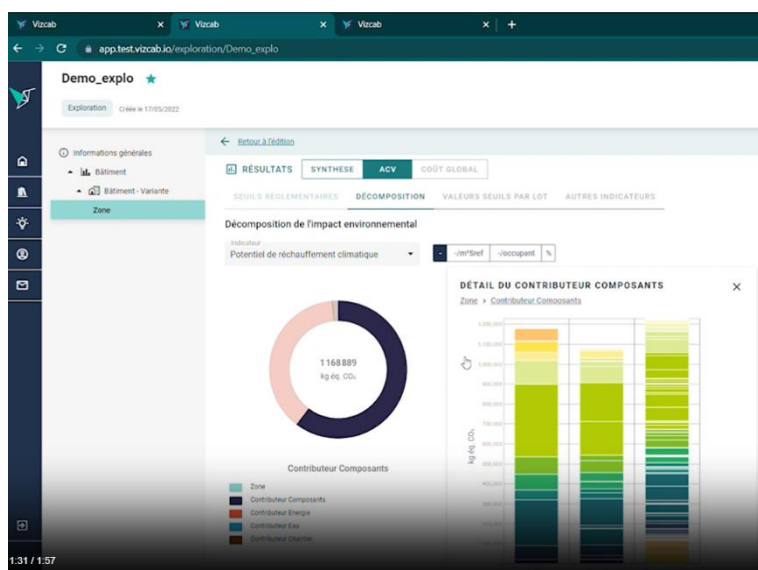
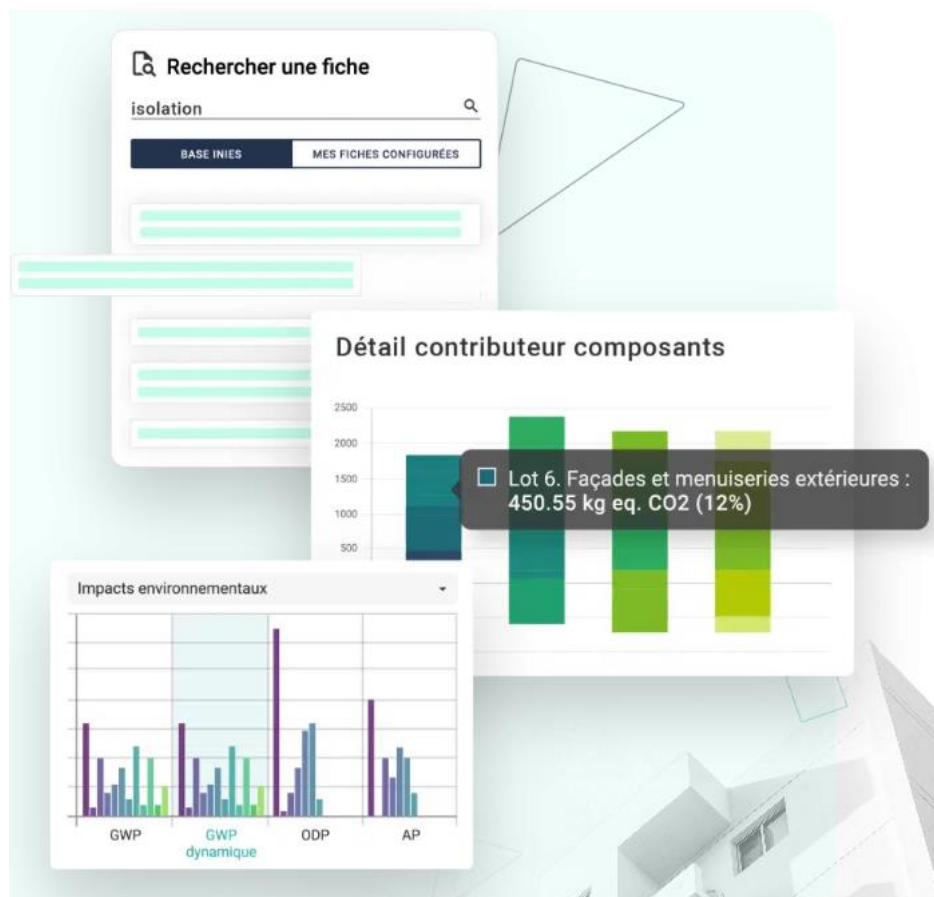
Vizcab Dashboard: a platform for capitalizing and reporting energy-carbon data from major real estate accounts, enabling them to manage and accelerate their carbon neutrality trajectory.

Vizcab Filtr: will produce environmental data scores which will be graded much like food warning labels for sugars and fats, giving everyone involved easily processed insight into how sustainable construction products are.

Contributing to the decarbonization of the real estate industry is part of A/O PropTech’s missions.

Vizcab illustrates the relevance of modeling and data science for low-carbon construction.”

D2.4





Appauvrissement de la couche d'ozone (kg CFC-11 eq.)



Acidification des sols et de l'eau (kg SO2 eq.)



Eutrophisation (kg (PO4)3- eq.)



Formation d'ozone photochimique (kg C2H4 eq.)



Épuisement des ressources abiotiques éléments (kg Sb eq.)



Épuisement des ressources abiotiques combustibles fossiles (MJ)



Réchauffement climatique (kg CO2 eq)

