Blast and Fire Resistant Material

B A M

EXCELLENCE/0421/0137

DELIVERABLE D5.1

TECHNOECONOMIC EVALUATION

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Table of Contents

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1. Executive Summary

This document serves as Deliverable 5.1 of Work Package 5, titled "Technoeconomic Evaluation," within the BAM project (EXCELLENCE/0421/0137). The BAM project is implemented under the social cohesion program "THALIA 2021-2027," co-funded by the European Union through the Research and Innovation Foundation. The primary objectives of this evaluation are to assess the technical feasibility and economic viability of HLM, focusing on its production processes, market potential, and cost-effectiveness compared to conventional materials.

The evaluation aims to analyze the production process and technical characteristics of HLM, assess its market potential and economic benefits, compare its cost-effectiveness with traditional materials, and provide recommendations for optimizing production and enhancing market competitiveness. The findings from the technical assessment reveal that the production of HLM involves two distinct lines: Fire Resistant Geopolymer (FRG) and Ultra-High Performance Fiber Reinforced Concrete (UHPFRC). These materials are combined through a specialized adhesion process to form the hybrid laminate. The adoption of advanced automation technologies, such as Programmable Logic Controllers (PLCs) and robotic systems, is proposed to enhance the efficiency and precision of the production process. This technological integration ensures consistent quality, reduces labor costs, and decreases production time, thereby increasing overall productivity.

The economic assessment highlights significant market potential for HLM in various industrial applications, particularly in sectors demanding high-performance, fire-resistant materials. Despite the initial investment in advanced manufacturing technologies, the long-term benefits include reduced operational costs and higher market competitiveness.

Key recommendations include incorporating advanced automation technologies to improve production efficiency and reduce labor costs. Evaluating alternative production configurations is crucial to identifying potential cost savings and efficiency improvements. Additionally, focusing on industries that demand high-performance, fire-resistant materials can maximize market potential, and targeted marketing strategies can highlight the long-term cost benefits and superior performance of HLM. Continuous improvement through monitoring production processes and market trends, alongside investing in research and development, is essential to enhance the material's properties and production methods further.

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This techno-economic evaluation demonstrates that HLM is both technically feasible and economically advantageous. The integration of cutting-edge automation in its production process is expected to drive efficiency and cost-effectiveness, positioning HLM as a competitive player in the market. This report provides a foundational step towards the successful commercialization of HLM, with key recommendations for optimizing production and enhancing market competitiveness. Future evaluations should include alternative configurations to ensure the most cost-effective and efficient production setup.

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2. Introduction

The focus of this deliverable is the techno-economic evaluation of the materials developed within the BAM project (EXCELLENCE/0421/0137). This evaluation encompasses a thorough technical viability analysis, informed by findings from other work packages, particularly WP3. The outcomes described in D3.1: Designed and Developed Hybrid Laminated Material (HLM) are integral to this assessment. The aim of this evaluation is to provide a comprehensive understanding of the economic boundary conditions relevant to the building materials market.

The primary objective of the techno-economic evaluation is to conduct a comprehensive analysis of the newly developed materials, focusing on both technical and economic aspects. This analysis seeks to identify key performance indicators and economic factors that will aid in determining the market viability and operational efficiency of the HLM.

The technical assessment aims to evaluate the performance of the developed materials compared to existing commercial fire-resistant and blast-impact-resistant materials. This involves a detailed examination of the manufacturing plan, including equipment specifications, performance parameters, and operational considerations. The economic assessment seeks to determine the feasibility of the developed materials by analyzing capital expenditure (CAPEX), operational expenditure (OPEX), and installation costs, ultimately providing a comprehensive financial analysis.

Additionally, the evaluation aims to identify and suggest alternative configurations and optimization strategies to enhance performance and cost-efficiency. The scope of the assessment includes conducting feasibility studies, cost assessments, and analyzing key financial indicators. A comparative analysis is also performed to benchmark the developed materials against a commercial alternative – one reference material assessing economic viability.

It's important to note that this techno-economic analysis is conducted under a Technology Readiness Level (TRL) of 4. As further advancements are made in material development, particularly in enhancing properties and production techniques, future revisions of this analysis will be necessary to incorporate these improvements and their potential impact on economic feasibility and market competitiveness.

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Through this comprehensive evaluation, the project aims to analyze the production process and technical characteristics of HLM, assess its market potential and economic benefits, compare its cost-effectiveness with traditional materials, and provide recommendations for optimizing production and enhancing market competitiveness.

3. Technical Evaluation

3.1. Manufacturing Plan

The production of Hybrid Laminate material (HLM) involves a meticulously structured process comprising two distinct production lines: one dedicated to the production of Fire Resistant Geopolymer (FRG) and the other to Ultra-High Performance Fiber Reinforced Concrete (UHPFRC). Both lines operate in parallel, ultimately converging in a specialized adhesion procedure that combines the two materials into a single, high-performance composite.

The FRG production line focuses on creating large blocks of Fire Resistant Geopolymer. Each batch results in blocks measuring 0.5 m wide, 0.5 m long, and 1.5 m high. The production process for FRG includes several key steps:

- Mixing: Raw materials are blended to form the geopolymer mixture.
- Casting: The mixture is poured into large moulds to shape it into blocks.
- Initial Curing: Panels cured in ambient conditions for 24 hours within the moulds to develop initial strength.
- Demoulding: Blocks are carefully removed from the moulds after the initial curing period.
- Curing: Demoulded blocks undergo a 6-day curing in ambient conditions to achieve optimal mechanical properties.
- Cutting: Once curing period passed, the blocks are precision-cut into thinner panels, each of 0.02 meters thick.

The UHPFRC production line focuses on directly creating panels due to the challenges associated with cutting fibre-reinforced materials. The production process involves the following stages:

- Mixing: High-performance concrete mix is prepared, integrating reinforcing fibres.
- Casting: The mix is poured into moulds designed specifically for panel production.

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- Initial Curing: Panels cured within the moulds to develop initial strength.
- Demoulding: Panels are carefully removed from the moulds after the initial curing period.
- Water Curing: Demoulded panels undergo a 14-day submersion in a water tank with controlled temperature stages during the curing period:

  a) Temperature gradually rose from 20°C to 90°C by the 3rd day.

  b) Maintained at a steady temperature of 90°C for 11 days.

  c) Temperature reduced to 20°C on the 14th day.

  -> This controlled process ensures the panels achieve optimal mechanical properties.

Due to the extended curing requirements of UHPFRC, the mixing and casting process is organized into sessions, with eight sessions scheduled per month. Table 1 below summarizes the production capacity of HLM panels per session and per month in terms of square meters (m^2) over the first 5 years of production. This structured approach ensures a continuous supply of cured panels ready for the final adhesion process in HLM units production.

Table 1- Production capacity of HLM units over the first 5 years of production

Production Capacity	Year 1	Year 2	Year 3	Year 4	Year 5
HLM (m^2) / session	55	59	64	69	75
HLM (units) / session	220	238	257	277	299
HLM (m^2) / month	440	475	513	554	599
HLM (units) / month	1760	1901	2053	2217	2395

APPENDIX illustrates the manufacturing line plan for the production of the HLM panels.

3.2. Equipment List

Table 2 provides a comprehensive list of all the equipment necessary for establishing the production line and the total initial investment cost. The equipment list is divided into five distinct sections, each distributing equipment according to its respective production line for the two materials. Section 1 includes a common water tank supplying water to both production lines. Section 2 lists equipment for the production line of FRG, while Section 3 lists equipment for the production line of UHPFRC. Section 4 covers the absolute necessities automations in production line procedure. Finally, Section 5 details the installation of a photovoltaic system to support and cover the large amount of energy consumption, primarily due to the curing procedure of UHPFRC.

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Table 2: Equipment list and initial investment cost for establishing the production line

Section	Equipment required for each section	Cost per item	Cost per Section
1	Tap Water Tank (1000L)	€ 200.00	€ 200.00
	Hose	€ 150.00	€ 150.00
2.1	Two Fly Ash Silos (10 tons)	€ 13,000.00	€ 17,800.00
	Screw Conveyor (5.5 kW)	€ 3,000.00	
	Screw Pipe System	€ 1,000.00	
	Industrial Load Cell	€ 800.00	
2.2	GGBFS Silo (5 ton)	€ 3,000.00	€ 7,300.00
	Screw Conveyor (5.5 kW)	€ 3,000.00	
	Screw Pipe System	€ 500.00	
	Industrial Load Cell	€ 800.00	
2.3	Storage Tank for NaOH Solution (1000L)	€ 200.00	€ 1,575.00
	Industrial Agitator Mixing Blades (5kW)	€ 1,000.00	
	Aqueous Solution Pump (3.75 kW)	€ 175.00	
	Hose	€ 200.00	
2.4	Storage Tank for Na Solution Water Glass (1000L)	€ 300.00	€ 675.00
	Aqueous Solution Pump (3.75 kW)	€ 175.00	
	Hose	€ 200.00	
2.5	Planettary Mixer 2m^3 (45kW)	€ 13,000.00	€ 13,000.00
2.6	Two Steel Molds (0.5x0.5x1.5m)	€ 1,000.00	€ 1,000.00
2.7	Wire Saw Cutting Machine	€ 25,000.00	€ 25,000.00
3.1	Cement Silo (5 tons)	€ 3,000.00	€ 7,300.00
	Screw Conveyor (5.5 kW)	€ 3,000.00	
	Screw Pipe System	€ 500.00	
	Industrial Load Cell	€ 800.00	
3.2	Microsilica Silo (5 tons)	€ 3,000.00	€ 7,300.00
	Screw Conveyor (5.5 kW)	€ 3,000.00	
	Screw Pipe System	€ 500.00	
	Industrial Load Cell	€ 800.00	
3.3	Reference Sand Storage Tank (10 tons)	€ 2,500.00	€ 4,300.00
	Conveyor Belt (5.5 kW)	€ 1,000.00	
	Industrial Load Cell	€ 800.00	
3.4	Planettary Mixer 2m^3 (45kW)	€ 13,000.00	€ 13,000.00
3.5	Molds (0.5x0.5x0.04m)	€ 6,000.00	€ 6,000.00
3.6	Water Curing Tanks (9.0x0.8x0.8m)	€ 20,000.00	€ 20,000.00
4	Automations	€ 5,000.00	€ 5,000.00
5	Photovoltaic System Installation	€ 28,000.00	€ 28,000.00
		Total Investment:	**€ 160,000.00**

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3.3. Alternative Configurations – Recommendations

To enhance the efficiency, productivity, and flexibility of the HLM production process, we propose exploring various alternative configurations that integrate advanced automation technologies and optimize the production workflow. These configurations aim to reduce manual labor, minimize errors, and improve overall process control.

PLCs for Control and Monitoring: PLCs offer precision control in the FRG and UHPFRC production processes, ensuring consistency and accuracy. Real-time monitoring capabilities allow for immediate adjustments to maintain optimal conditions, while fault detection systems reduce downtime and prevent defective batches.

Robotic Systems for Material Handling: Integrating robotic systems in casting and demoulding stages streamlines production, reducing the risk of panel damage and enhancing throughput. Robotic cutting and finishing further ensure uniform thickness and superior surface quality.

Integrated Quality Control: Automated quality control systems maintain high standards and consistency throughout production. In-line quality inspection continuously monitors material quality, swiftly detecting defects in real time.

Optimized Production Scheduling: Efficient production scheduling is achieved through dynamic algorithms that adjust schedules based on real-time data. These algorithms consider factors such as inventory levels, equipment availability, and demand forecasts, aligning production with actual requirements. Just-in-time (JIT) production principles are applied to minimize inventory costs and reduce waste by producing panels only as needed.

Implementing these alternative configurations involves increased initial investment (CAPEX). However, this investment enhances the HLM production process, making it more efficient, cost-effective, and adaptable to future technological advancements and market demands.

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3.4. Reference Material

In response to the current market's scarcity of readily available materials with combined fire and blast resistance properties, we have chosen to integrate Knauf Type X Fire Rated Gypsum Wall Board (GW-TX) with high-strength reinforced concrete as the reference material.

Knauf Type X gypsum board typically provides one hour of fire resistance. To enhance its capability to withstand fire for 1.5 hours, the thickness was adjusted accordingly. This enhanced fire resistance is complemented by 30 cm thick high-strength concrete, which adheres to the maximum 4% reinforcement limit specified in the European standard EN 206-1. The selection of this particular thickness was made after discussions with Cyprus Army Officers and based on current practice. However, it is important to note that this practice is not based on precise calculations (on behalf of the Army) and is likely insufficient as a structural element for the specific purpose (i.e., increased thickness to be required). Nevertheless, to provide a conservative approach for the economic comparison between the current practice and the newly developed material, the specific thickness of 30 cm was adopted for this study.

Therefore, selecting this combination of established products as a reference material to compare with HLM as detailed in D3.1 - Hybrid Laminated Material (HLM), and aligns with the validation stage outlined in D4.1 - Validation of Materials in the Laboratory, ensuring a fair comparison in terms of mechanical properties.

However, there are differences between the reference material and HLM in terms of physical properties, density, thickness, as well as production and installation methods of the materials. HLM consists of precast panels manufactured under controlled conditions to ensure uniformity and precision in dimensions and properties. The HLM panels have a density 1500 kg/m^3 and are available in standard thicknesses of 60 mm. These two layered panels are engineered to provide high fire resistance (Fire Resistant Geopolymer in 20 mm thickness) and structural strength due to the incorporation of Ultra-High-Performance Fiber-Reinforced Concrete in 40 mm thickness. The production process involves casting the panels in a controlled environment to achieve consistent quality and performance. Installation of HLM panels requires careful handling and precise assembly on site to maintain their integrity and meet structural requirements. Furthermore, the most significant difference between HLM and the reference material is that high-strength concrete is extremely brittle, whereas UHPFRC exhibits highly ductile behaviour.

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This distinction is crucial in the event of a blast or impact scenario, as concrete spalling can be a major cause of casualties and deaths.

In contrast, the reference material combines GW-TX with high-strength reinforced concrete, which is poured onsite. The selected GW-TX, with adjusted thickness of 23.85 mm is commonly used in interior wall applications. The main challenge with the reference material lies in the onsite pouring of high-strength concrete. Pouring concrete onsite involves logistical complexities such as ensuring proper mix consistency, placement, and curing conditions to achieve the desired strength and durability. Factors like weather conditions and site accessibility can influence the quality and performance of the concrete.

Furthermore, the precast panels used in HLM offer advantages in terms of production efficiency and quality control. Fabricated under controlled conditions, precast panels minimize variability and ensure uniformity in physical properties and dimensions. In contrast, onsite pouring of concrete requires meticulous planning and coordination to overcome challenges such as weather sensitivity and access limitations, which can impact the overall construction timeline and quality assurance measures.

This techno-economic analysis primarily focuses on comparing production costs and selling prices between the reference material and Hybrid Laminated Material (HLM), ensuring both offer comparable mechanical characteristics.

4. Economic Assessment

4.1. Market Study

The global market for blast and fire-resistant materials is undergoing rapid growth across key sectors including construction, oil & gas, transportation, and industrial applications. This expansion is fuelled by heightened awareness of explosion and fire safety, stringent building codes, and continuous advancements in materials technology.

In this dynamic market, traditional cementitious materials, renowned for their reliability in construction, coexist with a growing adoption of advanced materials such as steel, composites, and specialized coatings. These innovations provide versatile solutions tailored to withstand and mitigate the impact of blasts and fires, ensuring enhanced safety and minimizing damage to structures and assets.

Blast and fire-resistant materials play a vital role in safeguarding infrastructure and assets from explosions and fires, serving critical needs in both industrial and construction applications. The market is further propelled by increasing industrial safety regulations, heightened global security concerns, and substantial investments in infrastructure projects.

In North America, the blast and fire-resistant materials market is experiencing robust growth, particularly driven by heightened demand within the construction sector. According to Fortune Business Insights, these factors are contributing to a positive outlook for the region's market.

Meanwhile, the Asia-Pacific region dominates the global market, holding a significant revenue share and expected to grow at a compound annual growth rate (CAGR) of 7.7%. Key drivers of this growth include stringent fire safety regulations, ongoing infrastructure developments, and strong demand from the construction industries, as highlighted by Grand View Research.

In Europe, market growth is supported by increasing awareness of fire safety measures and regulatory frameworks, such as initiatives from the U.K.'s Health and Safety Executive business plan, as noted by Fortune Business Insights. These factors collectively underscore a promising trajectory for the blast and fire-resistant materials market across different regions, driven by diverse regulatory landscapes and sector-specific demands.

As the market evolves, segmentation of blast and fire-resistant materials encompasses concrete, steel alloys, advanced composites incorporating materials like fiberglass and carbon fiber, and specialized coatings designed for optimal blast and fire protection characteristics. This diversity underscores the market's adaptability and commitment to advancing safety standards globally.

The market can be analyzed using Porter's Five Forces model as follows (Figure 1):

- **Threat of New Entrants (Barrier to Entry):** <u>Moderate to high</u>. Developing and commercializing BAM HLM material requires specialized knowledge of materials science, access to raw materials (such as fly ash, GGBFS, sodium hydroxide, sodium silicate etc.), and significant investment in research and development. Regulatory approvals and establishing a market presence are additional challenges.

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- **Bargaining Power of Suppliers (Raw Materials):** Moderate. Suppliers of raw materials (such as fly ash, GGBFS, sodium hydroxide, cement, microsilica, and steel fibers) may have moderate bargaining power depending on their availability and the number of suppliers in the market. However, the uniqueness and specific requirements of these materials could also give suppliers some leverage.
- **Bargaining Power of Buyers (Construction Firms & Industrial Companies):** Moderate to high. Buyers in the construction and industrial sectors have options for alternative materials and technologies. They seek cost-effective solutions without compromising on quality and performance. The differentiation and performance benefits could influence buyer decisions but pricing and performance will be critical factors.
- **Threat of Substitute Products or Services (Existing Blast & Fire-Resistant Materials):** Moderate. The market already offers a variety of blast and fire-resistant materials, including traditional cementitious products and advanced composites. The unique combination of fire resistance and blast resistance may provide a competitive edge against substitutes, depending on its performance and cost-effectiveness.
- **Industry Rivalry (Competitive Landscape):** High. The market for blast and fire-resistant materials is competitive with established players and continuous innovation. Companies compete on factors such as product performance, durability, safety standards compliance, pricing, and customer service. Differentiating through technological advancements and marketing strategies will be crucial for gaining market share.

Figure 1- Brief 5 forces of Porter analysis

The newly developed materials offer innovative solutions by combining fire resistance and blast resistance. Their success in the market will depend on effectively managing the dynamics of Porter's Five Forces. This includes overcoming barriers to entry, negotiating with suppliers, meeting buyer expectations, distinguishing themselves from substitutes, and competing effectively in a crowded market landscape.

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4.2. Financial Analysis

Following a comprehensive assessment, we have formulated two strategic approaches, denoted as "PLAN A" and "PLAN B," to guide the financial analysis of the BAM project and its innovative blast and fire-resistant material.

- "PLAN A" proposes securing investment to patent the BAM materials and associated technology. This strategy is deemed the most advantageous, envisioning the sale of licenses to distributors. The plan involves granting a five-year exclusive license initially, followed by offering more affordable licenses to additional distributors. Charging a licensing fee ranging from 10% to 15% of the sales price makes this approach an attractive and lucrative option.
- "PLAN B" presents an alternative pathway, serving as a contingency plan involving direct sales which will necessitate additional costs for partners. This approach entails an increase in personnel for sales, technical support, and traveling. Existing staff will also need to allocate additional efforts towards administrative and legal tasks. Both technical and sales teams play pivotal roles in this scenario, underscoring our commitment to flexibility and adaptability in achieving project objectives. To evaluate the financial viability of this approach, a comprehensive financial analysis was conducted over a 5-year period following the project's conclusion. This analysis scrutinized potential profitability and investment using economic indicators, taking into account CAPEX and OPEX costs.

Table 3 - Fixed Cost Categories used in Financial Analysis

Category	Description
Web Host Fees	Costs related to the development and upkeep of the product website.
Accounting, Legal	Costs for accounting and legal services.
Depreciation	Spreading the cost of an asset over its useful life.
Insurance	Payments for insurance coverage.
Manufacturing	Expenses directly linked to manufacturing processes involving raw materials.
Payroll	Wages for office employees.
Rent	Payments for leasing and using a property or space for a specific period.
Supplies	Costs of materials and resources used in production. (Detailed described in on section 5.3 - Comparative Economic Analysis)
Taxes	Payments for corporate taxes.
Utilities	Costs for essential services like, water, gas, waste disposal and Telecommunications. Electricity cost excluded as photovoltaic installation required on initial investment.
Labor	Salaries for labor personnel.
Patent & CE Marking	Costs associated with obtaining and maintaining patents and CE marking certifications to ensure compliance with regulatory standards and protect intellectual property rights.

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Table 4 - Variable Cost Categories used in Financial Analysis

Category	Description
Cost of Goods Sold	Costs related to the packaging and delivery of goods.
Overhead	Administrative costs and other general operating expenses necessary to support overall business operations.
Maintenance	Costs of ensuring the proper functioning and upkeep of machinery and equipment.

In the realm of financial analysis, five (5) critical indicators take center stage when assessing the viability and profitability of investments or projects. The **Internal Rate of Return (IRR)** serves as a dynamic indicator, pinpointing the rate at which the **Net Present Value (NPV)** of the cash flows associated with the investment is equated to zero. In simpler terms, the IRR represents the rate of return that an investment is anticipated to generate throughout its lifespan, factoring in the timing and magnitude of its cash flows. IRR values are typically categorized into three ranges:

- **Pessimistic Range:** IRR values in this range are negative or very low, often near zero, indicating scenarios where the project may struggle to break even or generate positive returns. These situations are deemed pessimistic due to heightened risk or unfavorable market conditions. Typical Range: -∞ to 5%.
- **Moderate to Realistic Range:** IRR values within this range are positive and typically fall between 5% to 25%. They suggest scenarios where the project is expected to generate feasible returns aligned with market expectations. This range is commonly seen in stable industries with managed risks and reasonable growth prospects. The upper limit can vary based on industry standards and economic conditions.
- **Optimistic Range:** IRR values above 25% indicate scenarios where the project is expected to perform exceptionally well financially. This could result from highly favorable market conditions, innovative product offerings, or exceptionally efficient operational strategies. Such scenarios represent opportunities with potentially high returns, often associated with strong market demand or disruptive innovations.

The NPV calculates the disparity between the present value of cash inflows and the present value of cash outflows over the entire duration of the investment, providing a comprehensive financial assessment. **Return on Investment (ROI)** offers a straightforward ratio for gauging profitability relative to the investment cost, crucial for decision-making. The **Break-Even Point (BEP)** signifies the year when cumulative net income after tax turns positive, covering the initial investment and indicating profitability. Lastly, the **Payback Period (PP)** indicates the duration required to recoup the initial investment, offering insight into liquidity and risk. Together, these indicators form a comprehensive toolkit, guiding prudent financial decisions and strategic investments in diverse economic landscapes.

4.2.1. Analysing price scenarios and their impact on investment sensitivity

In a comprehensive evaluation of the IRR and its significance in investment decision-making, an analysis of five (5) distinct selling price scenarios was undertaken to assess their impact on investment sensitivity. The primary objective was to maintain a NPV of zero across various scenarios and explore the sensitivity of the IRR %. This assessment included several scenarios affecting the IRR (%) over a five-year financial period, with constant sales prices and varying initial sales volumes. Each scenario assumed a consistent initial investment of €160,000.00, with monthly sales volumes ranging from 400 m² to 800 m², increasing annually by 8%. The results of this analysis are presented in Figure 2.

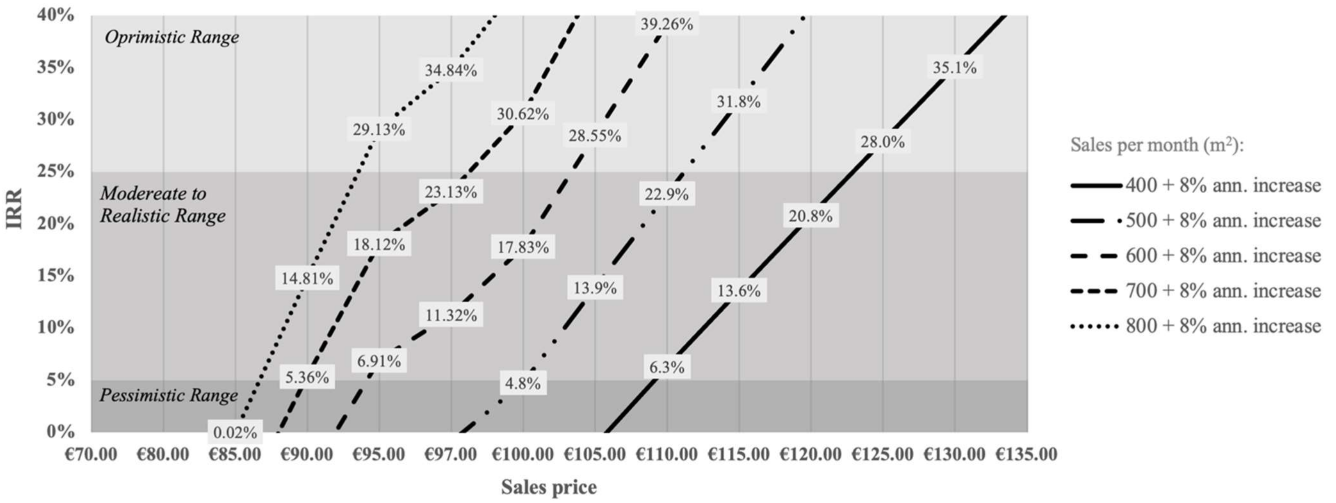

Figure 2 - Sensitivity analysis of Internal Rate of Return (IRR) across five price scenarios over a five-year period with varying initial sales volumes and annual increases

The summary of the key findings presented in Table 5 highlights the scenarios analyzed to ensure that the IRR remains high within the "Moderate to Realistic Range".

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Table 5 – Key findings maintaining IRR in high level within the "Moderate to Realistic Range" (5% - 25%)

Scenario	1	2	3	4	5
Sales per month	**400 m²**	**500 m²**	**600 m²**	**700 m²**	**800 m²**
Constant Sales Price	**€ 122.00**	**€ 110.00**	**€ 102.00**	**€ 97.00**	**€ 93.00**
NPV	0	0	0	0	0
Initial Investment	-€ 160,000.00	-€ 160,000.00	-€ 160,000.00	-€ 160,000.00	-€ 160,000.00
FY1 Profit	-€ 171,217.60	-€ 173,260.00	-€ 175,302.40	-€ 172,670.80	-€ 171,908.80
FY2 Profit	€ 133,261.59	€ 131,496.96	€ 129,732.33	€ 132,006.03	€ 132,664.40
FY3 Profit	€ 148,204.12	€ 146,298.32	€ 144,392.51	€ 146,848.11	€ 147,559.15
FY4 Profit	€ 164,342.05	€ 162,283.78	€ 160,225.51	€ 162,877.56	€ 163,645.48
FY5 Profit	€ 181,771.01	€ 179,548.08	€ 177,325.15	€ 180,189.36	€ 181,018.72
IRR	**23.69%**	**22.91%**	**22.13%**	**23.13%**	**23.42%**

Scenarios 1 and 5, characterized by sales prices of €122.00/m² and €93.00/m² respectively, along with monthly sales volumes of 400 m² and 800 m², stand out with the highest IRR of 23.69% and 23.42%. These scenarios illustrate optimal profitability within the analyzed range, showcasing how strategic adjustments in sales pricing can significantly influence financial performance over time. Scenario 1, with a higher sales price and lower sales volume, and Scenario 5, with a lower sales price but higher sales volume, both demonstrate strong returns. This indicates that both pricing strategies can be effective, depending on the market conditions and the company's ability to penetrate the market and handle competitive pricing dynamics.

However, while Scenarios 1 and 5 demonstrate strong returns, their practical implementation would need to consider several factors. For Scenario 1, penetrating the market with a higher-priced product might require a strong value proposition and robust marketing efforts to justify the price to customers. For Scenario 5, achieving high sales volumes at a lower price necessitates an efficient production process and a broad customer base.

The remaining scenarios, with IRRs ranging from 22.13% to 23.13%, also highlight the sensitivity of financial outcomes to changes in sales prices and volumes. These scenarios, with initial monthly productions from 500 m² to 700 m², show that even slight adjustments in pricing and volume can lead to noticeable differences in profitability.

This variability underscores the importance of dynamic pricing strategies and accurate volume forecasts in shaping financial projections and strategic decision-making. In the context of setting a dynamic, realistic and competitive pricing strategy for the new innovative material, it is crucial to account for inflation. Inflation is the rate at which the general level of prices rises, consequently reducing the purchasing power of money. Historically, inflation rates in stable economies have varied as follows:

- **Low Inflation:** 0% to 2%, indicating very stable economic conditions with controlled price increases. Examples include some advanced economies like Japan experiencing prolonged periods of low inflation.
- **Moderate Inflation:** 2% to 3%, considered a healthy rate reflecting manageable price increases in a growing economy. This range is commonly targeted by central banks in Western economies, including the US and EU.
- **High Inflation:** Above 3%, which can signify an overheating economy or economic instability. Sustained high inflation can erode purchasing power and savings, as seen in rapidly growing or economically unstable regions.

For our varying pricing strategy, we have chosen to apply a 2.7% annual inflation rate, which falls within the moderate inflation range. The reasons for selecting a 2.7% rate include:

- Historical Context: Recent years have seen many developed economies experiencing inflation rates fluctuating around 2% to 3%, making 2.7% a reasonable expectation.
- Economic Growth: A 2.7% inflation rate suggests healthy economic growth without extreme overheating, ensuring that the pricing adjustments are realistic.
- Cost of Living Adjustments: Businesses frequently use similar rates to adjust wages and prices, keeping pace with the cost of living.

Considering the IRR % and the inflation rate, the scenario which is most realistic and easier to penetrate the market involves varying the selling price over the five-year analysis period. By adjusting the selling price each year in alignment with market conditions and inflation, this dynamic pricing strategy not only helps maintain profitability but also accommodates changes in market demand and cost pressures. This approach ensures that the project remains competitive and financially viable, leading to sustained high returns and smoother market penetration. For instance (Table 6), a scenario with monthly sales volumes increasing from 440 m² to 599 m² over five years (8% annually increase), and corresponding selling prices starting at €107.00 per m² and rising to €119.00 per m², exemplifies this strategy, achieving an IRR of 16.59%.

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Table 6 - Scenario with dynamic pricing strategy

Sales per month – FY1 **Sales price**	**440 m^2** **Varying**
NPV	0
Initial Investment	-€ 160,000.00
FY1 Profit	-€ 211,296.16
FY2 Profit	€ 109,294.92
FY3 Profit	€ 133,834.22
FY4 Profit	€ 161,257.79
FY5 Profit	€ 191,870.07
IRR	**16.59%**

4.2.2. Discount factor scenarios

To further refine our financial projections, we applied a discount rate of around 5% to dynamic pricing scenario to calculate the present and current values. This discounting process adjusts for the time value of money, ensuring that future profits are appropriately valued in today's terms. A uniform discount rate of around 5% is applied. The discount factors decrease over time, starting at 0.95 in the first year and reducing to 0.78 by the fifth year.

Table 7 - Discount scenarios analysis at 5% Discount Rate over year period

Sales per month – FY1 **Sales price**	**440 m^2** **Varying**
Discount Factor 1 – FY1	0.95
Discount Factor 2 – FY2	0.91
Discount Factor 3 – FY3	0.86
Discount Factor 4 – FY4	0.82
Discount Factor 5 – FY5	0.78
Discount Rate	**5%**
Present Value	**€ 296,512.72**
Current Value	€ 384,960.85

By discounting the scenarios at around 5% provides a clearer picture of their long-term financial viability. Dynamic scenario, with its balanced approach of moderate sales volume and varying sale price, remains the most practical and financially sound choice. This scenario ensures a steady increase in profitability and a reasonable present value, confirming its suitability for implementation.

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4.2.3. Financial Analysis - Outcomes

Table 8 summarizes BAM's financial analysis over a 5-year timeframe following project completion, incorporating varying sales prices as determined from sensitivity analysis.

Table 8 - Financial Projection after the end of the Project

Financial Projection	Annually Sales: 8% increase every year starting from 440m^2 / month									
		FY1		FY2		FY3		FY4		FY5
Selling price per m^2:	€	107.00	€	110.00	€	113.00	€	116.00	€	119.00
Sales volume m^2 (annually):		5280.00		5702.40		6158.59		6651.28		7183.38
Turnover	€	564,960.00	€	627,264.00	€	695,920.90	€	771,548.41	€	854,822.42
FIXED COSTS										
Advertising (1% on turnover)	€	5,649.60	€	6,272.64	€	6,959.21	€	7,715.48	€	8,548.22
Web hosts fees	€	1,000.00	€	500.00	€	500.00	€	500.00	€	500.00
Accounting, Legal	€	11,299.20	€	12,545.28	€	13,918.42	€	15,430.97	€	17,096.45
Depreciation	€	564.96	€	627.26	€	695.92	€	771.55	€	854.82
Insurance	€	5,000.00	€	5,000.00	€	5,000.00	€	5,000.00	€	5,000.00
Manufacturing (2% on turnover)	€	11,299.20	€	12,545.28	€	13,918.42	€	15,430.97	€	17,096.45
Payroll (hire a manager - 1/3 of time)	€	13,000.00	€	13,000.00	€	13,000.00	€	13,000.00	€	13,000.00
Rent	€	14,400.00	€	14,400.00	€	14,400.00	€	14,400.00	€	14,400.00
Supplies (48.00€ / m^2)	€	253,440.00	€	273,715.20	€	295,612.42	€	319,261.41	€	344,802.32
Taxes (real estate, etc.)		20%		20%		20%		20%		20%
Utilities (2.00€ / m2)	€	10,560.00	€	11,404.80	€	12,317.18	€	13,302.56	€	14,366.76
Labor (operator/labour staff) (the industry will be formed in sucha way that no further staff or working hours will be required)	€	24,000.00	€	24,000.00	€	24,000.00	€	24,000.00	€	24,000.00
Patents & CE Marking	€	10,000.00	€	10,000.00	€	10,000.00	€	10,000.00	€	10,000.00
VARIABLE COSTS										
Cost of Goods Sold (2% on turnover)	€	11,299	€	12,545	€	13,918	€	15,431	€	17,096
Overhead (10% on turnover)	€	56,496.00	€	62,726.40	€	69,592.09	€	77,154.84	€	85,482.24
Maintenance (2% on turnover)	€	28,248.00	€	31,363.20	€	34,796.04	€	38,577.42	€	42,741.12
Total Cost (TC= FC + VC)	**€**	**616,256.16**	**€**	**490,645.34**	**€**	**528,628.12**	**€**	**569,976.17**	**€**	**614,984.84**
Initial Investment	€	160,000.00	€	-	€	-	€	-	€	-
Cost per m^2	€	116.72	€	86.04	€	85.84	€	85.69	€	85.61
EBIT (earnings before interests and taxes)	€	(211,296.16)	€	136,618.66	€	167,292.78	€	201,572.24	€	239,837.58
TAX (20%)										
NIAT (net income after tax – Profit)		**-€211,296.16**		**€109,294.92**		**€133,834.22**		**€161,257.79**		**€191,870.07**
Return of Investment (ROI)		-32%		68.31%		83.65%		100.79%		119.92%
Break-even point (BEP)		Year 3								
Payback period (PP)		Year 1- 3								

The ROI illustrates significant growth over the project's duration, projecting a return that exceeds the initial investment by approximately 119.92% by the end of Year 5. The PP, estimated at three years, indicates that by the conclusion of Year 3, the initial investment of €160,000.00 is expected to be fully recovered from the project's cash flows. Additionally, the BEP occurs in Year 3,

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marking the milestone where cumulative net income after tax turns positive. This pivotal point signifies the project's financial viability and transition into profitability.

4.2.4. Sensitivity analysis of cost variations and strategic management

To further refine our understanding and anticipate potential risks, we will conduct a sensitivity analysis focusing on both fixed and variable costs. This analysis involves adjusting each cost category by ±20% to observe the impact on the final year (FY5) profit and Internal Rate of Return (IRR). This helps to identify the most sensitive cost elements and provide insights into managing these risks effectively. The results of the sensitivity analysis are summarized in Table 9 below.

Table 9: Sensitivity Analysis of Cost Categories on FY5 Profit and IRR

	Figures at FY5		**IRR**	**Variation**	
Baseline scenario	**€**	**191,870.07**	**16.59%**	**Compare to BAS FY5**	**Compare to BAS IRR**
Expected Sales +20%	€	240,948.08	30.43%	125.58%	13.84%
Expected Sales -20%	€	150,971.72	4.61%	78.68%	-11.98%
Manufacturing+20%	€	189,134.63	15.74%	98.57%	-0.84%
Manufacturing-20%	€	194,149.59	17.29%	101.19%	0.70%
Payroll +20%	€	189,790.07	15.77%	98.92%	-0.81%
Payroll -20%	€	193,603.40	17.26%	100.90%	0.68%
Supplies +20%	€	136,701.69	-1.75%	71.25%	-18.33%
Supplies -20%	€	237,843.71	31.59%	123.96%	15.01%
Utilities +20%	€	189,571.38	15.83%	98.80%	-0.75%
Utilities -20%	€	193,785.63	17.21%	101.00%	0.63%
Labor +20%	€	188,030.07	15.09%	98.00%	-1.50%
Labor -20%	€	195,070.07	17.84%	101.67%	1.25%
Maintanance +20%	€	185,031.49	14.47%	96.44%	-2.11%
Maintanance -20%	€	197,568.88	18.34%	102.97%	1.75%

The sensitivity analysis reveals that sales volume and supplies costs are the most impactful factors on both FY5 profit and IRR. Specifically:

- A 20% increase in sales volume results in the highest positive impact, increasing FY5 profit by 125.58% and IRR by 13.84%.
- A 20% decrease in supplies costs results in a substantial increase in FY5 profit by 123.96% and IRR by 15.01%.

Conversely, a 20% increase in supplies costs has the most negative impact, reducing FY5 profit by 71.25% and IRR by 18.33%.

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In order to mitigate the impact of cost fluctuations identified in the sensitivity analysis, several strategic management approaches can be implemented. Maximizing sales volume involves expanding market reach through targeted marketing initiatives and diversifying product offerings to attract a broader customer base. Optimizing supplies costs entails negotiating favorable terms with suppliers, leveraging bulk purchasing opportunities, and exploring alternative sourcing options to achieve cost efficiencies without compromising quality. Cost control measures include conducting regular financial reviews to monitor expenditures, investing in operational efficiencies through technology and process improvements, and implementing stringent controls to minimize wastage and operational redundancies. These strategies aim to bolster profitability and enhance overall financial resilience in varying market conditions.

4.3. Comparative Economic Analysis

In this section, a comparative analysis is performed to evaluate the economic viability of the HLM, the combination of the FRG with UHPFRC, against a reference scenario involving a combination of GW-TX and high-strength concrete. This comparative analysis aims to provide a clear understanding of how the new innovative material compares to established products in the market, highlighting both strengths and areas for improvement.

To effectively present the cost of materials and their comparison, the analysis will focus on the detailed cost components of each material, including raw material costs and mass per m², taking into account the total thickness of each material as provided below:

The HLM consists of a 0.02 m (2 cm) thick layer of FRG combined with a 0.04 m (4 cm) layer of UHPFRC. This dual-layer structure of 0.06 m (6 cm) total thickness aims to optimize both the fire-resistant and structural properties of the HLM.

The reference material configuration includes a 0.0157 m (1.57 cm) thick GW-TX paired with a 0.30 m (30 cm) layer of high-strength reinforced concrete. The 0.357 m (35.7 cm) substantial thickness of the reinforced concrete is designed to provide significant structural integrity, while the gypsum board offers fire resistance.

These thicknesses directly influence the material mass and overall cost per square meter, which are critical factors in the economic viability assessment. The following tables (Table 10 & Table

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11) provide a detailed breakdown of the costs for the HLM and the reference material in respectively.

Table 10: Cost breakdown for Hybrid Laminate Material (HLM)

HLM	Componets	Mass per m² (kg)	Euro/Unit	Euro/m²
FRG	Fly Ash	57.6	€ 0.05	€ 2.88
	GGBFS	6.4	€ 0.04	€ 0.26
	NaOH Pellets	3.25	€ 0.19	€ 0.62
	Water	12.8	€ 0.00	€ 0.00
	Na Water Glass	7.04	€ 0.40	€ 2.82
UHPFRC	Cement	35.2	€ 0.15	€ 5.28
	Microsilica	8.8	€ 0.50	€ 4.40
	Reference sand	33.32	€ 0.55	€ 18.33
	Water	6.88	€ 0.00	€ 0.00
	Superplasticizer	2.68	€ 2.00	€ 5.36
	Steel fibres 6 mm	3.2	€ 1.20	€ 3.84
	Steel fibres 13 mm	3.2	€ 1.20	€ 3.84
	PVA fibres	0.52	€ 0.50	€ 0.26
	Total per m²	**180.89 kg**	-	**€ 47.88**

Table 11: Cost breakdown for reference material (GW-TX and High Strength Reinforced Concrete)

Reference material	Components	Mass per m² (kg)	Euro/Unit	Euro/m²
Knauf Type X Gypsum Board	Board size: 2400x1220x15.9mm	19.65	€ 6.19	€ 24.75
High Strength Reinforced Concrete	Cement 52.5	150.00	€ 0.15	€ 22.50
	Microsilica	12.00	€ 0.50	€ 6.00
	Superplasticizer	1.50	€ 2.00	€ 3.00
	Retarder	0.75	€ 0.006	€ 0.0004
	Diabase Agg. 8/20 mm	195.00	€ 0.012	€ 2.34
	Diabase Agg. 4/10 mm	100.50	€ 0.012	€ 1.21
	Diabase sand 0/4mm	84.00	€ 0.013	€ 1.09
	Limestone sand	129.00	€ 0.015	€ 1.94
	Water	49.5	€ 0.00	€ 0.00
Reinforcement	4% of concrete volume	94.2	-	€ 75.36
	Total per m²	**836.1 kg**	-	**€ 138.18**

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This analysis highlights that the Hybrid Laminated Material (HLM) offers a lower total material cost per square meter (€47.88) compared to the commercial alternative, with a significant reduction in overall mass. The commercial alternative, typically constructed on-site, contrasts with HLM's precast manufacturing process. This difference not only affects material costs but also influences transportation and handling expenses, potentially yielding additional savings.

5. Conclusion

In conclusion, this techno-economic evaluation of the Hybrid Laminated Material (HLM) within the BAM project has provided valuable insights into both its technical feasibility and economic viability. The technical assessment revealed that HLM, consisting of Fire Resistant Geopolymer (FRG) and Ultra-High Performance Fiber Reinforced Concrete (UHPFRC), offers promising performance characteristics compared to existing fire-resistant and blast-impact-resistant materials. The integration of advanced automation technologies, such as Programmable Logic Controllers (PLCs) and robotic systems, has been identified as crucial for enhancing production efficiency and maintaining consistent quality standards.

From an economic standpoint, while the initial investment in advanced manufacturing technologies presents a challenge, the long-term benefits include reduced operational costs and enhanced market competitiveness. The comparative analysis with commercial alternatives has shown favorable cost-effectiveness under current conditions, although continuous monitoring and optimization of production processes are recommended to maximize efficiency and cost savings further.

Based on the evaluations conducted, several actionable recommendations are proposed. Firstly, further research and development efforts should focus on enhancing material properties and optimizing production techniques to potentially lower production costs and improve overall performance. Incorporating lifecycle assessments and conducting environmental impact analyses will also be beneficial in positioning HLM as a sustainable choice in the construction materials market.

Looking forward, as the technology matures and advances beyond its current Technology Readiness Level (TRL) of 4, periodic revisions of this techno-economic evaluation will be essential to incorporate advancements in material science and manufacturing technologies. This iterative

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approach will ensure that HLM remains competitive and aligned with industry standards and market demands.

In conclusion, the techno-economic evaluation underscores the potential of HLM as a viable alternative in sectors requiring high-performance, fire-resistant materials. By leveraging technological innovations and strategic investments, HLM stands poised to contribute significantly to the advancement of sustainable building solutions, meeting both regulatory requirements and market expectations.

6. Disclaimer and limitations

This technoeconomic evaluation study, prepared by RECS Civil Engineers and Partners LLC (RECS), is presented in accordance with the agreed Terms of Reference and is addressed to the BAM project (EXCELLENCE/0421/0137), hereinafter referred to as 'BAM' or 'Consortium.' The development of this study involved sourcing information primarily from the Consortium and leveraging the collective experience gained during the project's execution.

The foundation of this study relies on a set of assumptions and data provided by the Consortium. The Consortium emphasizes that it does not bear responsibility for the realization of these assumptions and information, and there can be no liability in the event that the any other party incurs losses due to reliance on the contents of this study.

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APPENDIX

MANUFACTURING LINE PLAN

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