Blast and Fire Resistant Material

B A M

EXCELLENCE/0421/0137

DELIVERABLE D1.3

FINAL REPORT

Co-funded by the European Union

Republic of Cyprus

RESEARCH & INNOVATION FOUNDATION

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Project Information

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PROGRESS REPORT

RESTART 2016-2020 Programme for Research, Technological Development and Innovation

RESEARCH AND INNOVATION FOUNDATION

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A.1. GENERAL PROJECT INFORMATION	
Project Protocol Number:	EXCELLENCE/0421/0137
ESIF Number:	
Project Title:	Blast and Fire Resistant Material
Project Title in Greek:	Υλικό Ανθεκτικό σε Έκρηξη και Πυρκαγιά
Host Organisation:	Frederick Research Center (FRC)

A.2. DESCRIPTION OF THE WORK CARRIED OUT BY ALL BENEFICIARIES DURING THIS REPORTING PERIOD. *(Maximum Recommended 3 pages)*

The **General Objective (GO)** of the BAM project was to design, develop, and validate at a laboratory scale two innovative smart materials that are resistant to fire, blast, and impact. These materials were to be manufactured using two different methods: i) the conventional casting method and ii) 3D-printing. The two materials, produced by both methods, were evaluated in terms of their thermal, mechanical, impact, and blast properties.

The two main **Scientific Objectives (SO)** of the BAM project were:

SO-1: Design and Development of a **Hybrid Laminated Material (HLM)** with combined resistance to blast, impact, and fire.

SO-2: Design and Development of a **Smart Composite Geopolymeric Concrete (SCGC)** with simultaneous resistance to blast, impact, and fire.

Both materials were intended to resist fire at temperatures encountered in building applications, up to 1050 °C, as shown in the ISO-834 fire curve. Additionally, the materials were designed to withstand explosive and impact loads, validated through experimental (drop-weight loads) and analytical methods (Finite Element Analysis - FEA).

Based on the these SO, the project's **Technological Objectives (TO)** were:

TO-1: Validate the produced materials at a laboratory scale in terms of mechanical and durability properties, using existing standard tests for fire resistance.

TO-2: Validate the produced materials against blast and impact resistance using three methods:

- Testing material specimens against impact loading (e.g., drop hammer tests in the lab). These tests also serve as indirect indicators of the materials' resistance to blast loads.
- Achieving specific mechanical properties essential for satisfactory blast and impact response (as described in the relevant literature).
- Conducting finite element analysis (FEA) of the materials' blast resistance.

TO-3: Validate the produced materials through techno-economic and cost-benefit analyses, benchmarking them against commercially available materials.

The BAM project work plan consisted of **five distinct Work Packages (WPs)**, encompassing activities such as project management and coordination (WP1), dissemination, communication and exploitation of the project results (WP2), material design and development (WP3), material production and validation in a laboratory environment and through analytical methods (WP4), and techno-economic and cost-benefit analysis (WP5). The successful completion of all the WPs resulted to the achievement of all the project objectives.

During the Second Reporting Period (2RP), the consortium and the collaborating research team made significant efforts to address unavoidable delays experienced during both the First and Second Reporting Periods. Their goal was to ensure the seamless execution of the project and the achievement of all project objectives as outlined in the original schedule detailed in Annex I of the Contract. This report pertains to **Deliverable D1.3 - Final Report**, providing an overview of the activities conducted within the BAM project during the Second Reporting Period (2RP). This period covers April 2023 through March 2024, as well as the subsequent 3-month extension from April 1st, 2024, to June 30th, 2024, which was requested and approved for the project. The extension was necessary to address delays caused by difficulties in identifying suitable external laboratories capable of conducting the required impact and fire tests within the project timeframe and available budget. Additionally, delays occurred in receiving responses for articles submitted to scientific journals.

The following provides an overview of the activities conducted during the Second Reporting Period (2RP) to achieve the project objectives. Active participation and contributions from all project beneficiaries were instrumental in executing these tasks. Specific details regarding the work undertaken in each Work Package (WP) of the project can be found in Section "A.3. EXPLANATION OF THE WORK CARRIED OUT PER WORK PACKAGE (WP)" of this report. In summary, the progress of each individual WP towards the successful attainment of project objectives is outlined below:

- WP1: The Host Organization (FRC) and the Project Coordinator ensured continuous and methodical coordination of all contractual tasks and obligations during the Second Reporting Period (2RP) to achieve the timely and successful completion of all project objectives. The overall scientific coordination of project activities was managed and monitored continuously by the Project Coordinator, in close cooperation with WP and Task Leaders. Numerous working meetings were held between the coordinator and the involved research teams to address research issues and plan dissemination events. Several meetings of the Technical Steering Committee, with the participation of all beneficiaries, were organized to discuss and plan important research tasks. Many online working meetings with the Foreign Organisation (University of Brighton) also took place. Additionally, a project General Assembly meeting was organized towards the project's closure; project progress was presented and discussed among the partners, leading to the decision to apply for a three-month project extension to fulfil all project obligations. All deliverables related to WP1 (Minutes of Meetings (D1.2) and Final Report (D1.3)) were prepared on time and revised by assigned internal peer reviewers according to the project's quality assurance plan.
- WP2: WP2 continuously provided information on project activities and achievements through regular communication channels established since the First Reporting Period (1RP), including the dedicated project website and social media accounts. The wide promotion of project innovations and the dissemination of its results were also conducted through the organization of scientific and demonstration events (e.g., dissemination event in WP2) with the participation of researchers and stakeholders. The project's results were presented at a prestigious international scientific conference (fib Symposium 2023, Building for the Future: Durable, Sustainable, Resilient, Istanbul, Turkey, 05-07 June 2023) and submitted in prestigious (Q1) peer-reviewed scientific journals with high impact factors, in Gold Open Access mode (article published in Elsevier Results in Engineering and article under review from Springer Materials and Structures). Additionally, WP2 implemented several other activities to disseminate and communicate the project's results to a broader audience. For instance, seminars were organized for university students related to BAM project activities, and interactive presentations were given to high school students about the manufacturing of new materials using casting and 3D-printing. These activities were designed to maximize the dissemination, exploitation, and communication of the project's outcomes. All deliverables of WP2 (Dissemination Plan (D2.1), Project Website (D2.2), Social Media Accounts (D2.3), and Dissemination Event with Local Stakeholders (D2.4)) were prepared and submitted on time, after revision by assigned internal peer reviewers as described in the project's quality assurance plan.
- WP3: The research team dedicated considerable effort to Work Package 3 (WP3), with each participating researcher contributing significantly to achieving WP3 objectives. Within this

framework, the involved partners successfully designed two new materials, namely Hybrid Laminated Material (HLM) and Smart Composite Geopolymeric Concrete (SCGC), intended to withstand fire scenarios according to ISO-834 used in building structures and urban tunnels, as well as blast and impact loads as per the project's validation methods. During the second reporting period (2RP), the partners engaged in WP3 successfully optimized the design and development of a geopolymer fire-resistant material under the coordination of FRC and an UHPFRC impact-resistant material under the coordination of UCY. Additionally, the research team successfully created the Hybrid Laminated Material (HLM), which integrated the optimized versions of the individual materials, offering both fire and impact/blast resistance properties. The innovative Smart Composite Geopolymeric Concrete (SCGC) was also successfully designed, developed and optimized. During this study several challenges were encountered regarding the incorporation of fibres in the matrices of geopolymer mixtures, leading to interesting conclusions. Beyond the contractual obligations, a parallel study was implemented under the coordination of the Foreign Organisation, the University of Brighton. This study focused on the development of a Fibre Reinforced Geopolymer Concrete (FRGC), which shows promising properties for withstanding impact and blast loads. The most crucial properties of HLM, SCGC and FRGC were tested at the lab scale. Moreover, the processes of 3D printing and conventional casting used to produce geopolymers in the project were optimized and validated at the lab scale. The most significant experimental results achieved in WP3 were submitted for publication in a peer-reviewed scientific journal (Springer Materials and Structures) and presented at a relevant international conference (fib Symposium 2023, Building for the Future: Durable, Sustainable, Resilient, Istanbul, Turkey, 05-07 June 2023). All the deliverables of WP3 (Design and Development of a Hybrid Laminated Material (HLM) (D3.1), Design and Development of a Smart Composite Geopolymeric Concrete (SCGC) (D3.2), Publication in Open Access Journal (D3.3), and Publication at Relevant Conference (D3.4)) due in the 2RP were prepared and submitted on time, after internal peer-reviewing according to the project's quality assurance plan.

- WP4: WP4 initially focused on manufacturing the two materials using both conventional casting and 3D-printing methods, including appropriate modifications to the syntheses to achieve optimal production results and final properties. Additionally, WP4 was dedicated to validating the developed materials' properties through both laboratory testing (i.e., experimental methods) and analytical methods (Finite Element Analysis). Within WP4, the precast manufacturing of both HLM and SCGC was successfully implemented and optimized. Similarly, the challenges encountered in the 3D-printing manufacturing of the two geopolymer materials (i.e., the fire-resistant layer of the HLM and the unreinforced SCGC) were successfully addressed. However, the printing of UHPFRC and fibre-reinforced SCGC materials faced significant challenges due to the large volume of fibres required in the mixtures (to increase ductility and achieve high impact and blast resistance), combined with limitations of the consortium's available printing equipment. The comprehensive experimental validation of the produced materials confirmed their ability to withstand fire as well as blast and impact loads. Moreover, the analytical validation of the developed materials' blast resistance using Finite Element Analysis (FEA) was completed successfully, yielding very interesting results that will be useful for designing structures using these materials for protection against blast loads. Overall, WP4 was completed successfully, meeting its objectives. All the deliverables of WP4 (Flowsheet of Materials Production (D4.1), Validation of Materials in the Laboratory (D4.2), Numerical Analysis of Materials' Blast Resistance (D4.3), Publication in Open Access Journal (D4.4), and Publication at Relevant Conference (D4.5)) consist of high-quality reports and publications and were prepared and submitted on schedule.

- WP5: WP5 aimed to evaluate the developed materials in terms of cost, efficiency, and environmental impact through techno-economic and cost-benefit analyses. WP5 continuously received information and results from technical WPs (3 and 4), including updated material recipes, manufacturing processes, consumption of electricity, the cost of raw materials, etc. The objective of WP5 was to assess the feasibility of producing the new materials on a commercial scale and to evaluate the economic impact of the manufacturing processes. Both the Techno-economic Evaluation (D5.1) and the Cost-Benefit Analysis (CBA) (D5.2) were successfully produced based on these results. It is important to note that the consortium, coordinated by RECS, went beyond its contractual obligations by conducting a comprehensive and detailed Life Cycle Assessment (LCA) of the developed materials. This effort required a significant additional investment of time from the research team. The LCA provided a clear understanding of the competitive advantages of these materials, revealing their potential environmental benefits and sustainability. The results of the LCA are also included in Deliverable D5.2: Cost Benefit Analysis. As a result, a manuscript detailing the LCA findings is currently being drafted and will be submitted for publication in The International Journal of Life Cycle Assessment (Springer Nature) in golden open access mode.

Throughout the Second Reporting Period (2RP), all beneficiaries exerted considerable effort to successfully fulfil the tasks and contractual obligations. Each research team dedicated substantial resources to prevent delays and ensure the successful and timely completion of their assigned tasks. Despite these efforts, a 3 months' extension was deemed necessary, as elaborated in this report. The collaboration among beneficiaries was characterized by harmonious teamwork, with several parties coming together to submit proposals for funding new projects. These proposals were conceived as a natural continuation of the BAM project, showcasing the cooperative spirit and commitment to ongoing collaboration among the project participants.

In conclusion, the BAM project has successfully achieved its objectives, reaching the following milestones:

- Creation of multiple versions of novel fire-resistant materials, including some derived exclusively from Construction and Demolition Waste (CDW).
- Development of optimized UHPFRC materials, achieving a balance between minimizing the number of fibres (and thus cost) and maximizing properties.
- Development of self-compacting UHPFRC materials, broadening the range of possible applications.
- Utilization of 3D printing technology to produce novel materials.
- Experimental validation of the materials’ mechanical performance, as well as fire resistance and resistance against impact loading.
- Analytical investigation of the blast resistance of the developed materials, which will be useful for designing structures to protect against blast loads.
- Evaluation of the technoeconomic feasibility and the cost-benefit analysis of the developed materials.
- Investigation of the environmental benefits and sustainability of the new products through Life Cycle Assessment (LCA).
- Publication of several manuscripts in prestigious journals and conferences.

- Exploitation of the project results through engagement with local governmental authorities, standardization bodies, stakeholders, and relevant local and international industries.
- Effective communication of the project's results to the wider public.
- Facilitation of efficient collaboration between project partners and identification of new research avenues.

A.3. EXPLANATION OF THE WORK CARRIED OUT PER WORK PACKAGE (WP). *(Maximum Recommended 3 pages per WP)*					
Work Package Number:	**1**	**Start Month:**	**1**	**End Month:**	**27**
Work Package Title	**Project Management**				
Work Package Leader	**Frederick Research Center**				
Partner Role	**FRC**	**UCY**	**RECS**		
Person Months	**2**	**2**	**1**		

Work Package Objectives as described in Annex I of the Contract.

WP1 is responsible for the overall project management, which includes monitoring, coordinating, and addressing all management issues. This work package supports all other work packages of the project and has the following objectives: 1. Maintain the consortium agreement among partners and organize meetings. 2. Serve as an interface with the Research and Innovation Foundation (RIF) management team. 3. Monitor the project's progress. 4. Execute the dissemination strategy, track deliverables and milestones, and identify and mitigate potential risks. Additionally, WP1 ensures that: (i) All project objectives are achieved within the agreed time, quality, and cost. (ii) Specific scientific and technical objectives for each work package are met. (iii) Innovation and intellectual property rights are effectively managed.

Work Description and Key Results

WP1 was led by the Host Organization, the Frederick Research Center (FRC), with the support and active involvement of all consortium partners. Dr Demetris Nicolaides, the Project Coordinator, held overall responsibility for ensuring the smooth execution of all legal and contractual matters, financial and administrative management, intellectual property management, and technical and scientific aspects of the project. To achieve these objectives, Dr Nicolaides was supported by the BAM project's committees, the HO's administrative mechanisms, the WP and Task leaders, and all other consortium partners.

Within the scope of WP1, the research team aimed to meet the requirements and obligations of the following two tasks:

- **Task 1.1**: General Project Management (including (a) Legal and Contractual Management, (b) Financial and Administrative Management and (c) Scientific Management and Technical Project Coordination)
- **Task 1.2**: IP Management

A summary of the activities undertaken in WP1 during the second reporting period (2RP) of the project is as follows:

- **Conducting Consortium Meetings:** Throughout the 2RP, both formal and informal meetings were organized to address various technical, scientific, administrative, and financial issues. These meetings aimed to monitor project progress, review the quality of results, plan next steps, ensure compliance with the Grant Agreement and other terms stipulated by the Research and Innovation Foundation (RIF), address legal matters, and uphold the Consortium Agreement. During this period, five steering committee meetings, a general assembly meeting, and numerous informal meetings involving WP and task leaders, small research groups, or individual researchers were held. The Project Coordinator was responsible for drafting and issuing invitations and agendas, preparing meeting minutes, and submitting them for approval for formal meetings. These practices were not applied to informal meetings.

- **Quality Assurance for Deliverables:** Several meetings were conducted with the Quality Manager and designated internal reviewers to comprehensively assess the prepared deliverables and confirm their compliance with the standards set by the project consortium.
- **Recruitment of New Researchers:** At critical stages of the project, the consortium needed to hire new researchers due to the resignation of existing team members. The management team responded proactively, employing a rigorous process to identify and hire suitable candidates.
- **Regular Communication with Foreign Organisation (University of Brighton) of the Project**: The management team consistently held meetings with Dr Andreas Lampropoulos and Dr Ourania Tsioulou from the University of Brighton to coordinate the work undertaken by the FRO, discuss key findings, and ensure the seamless execution of assigned tasks.
- **Engagement in Formal and Informal Communication with RIF Officers:** The project coordinator maintained communication with the designated RIF officer(s) to address project-related issues and prepared and submitted one project amendment pertaining to project extension (12/02/2024).
- **Monitoring Financial Management:** The director and staff of the FRC Research Office (i.e., the Host Organization - HO) monitored the project's financial management and provided continuous support to the consortium regarding applicable RIF regulations.
- **IP Management:** The HO with extensive experience in intellectual property management, oversaw IP management for the project. The Consortium Agreement, prepared and signed by all partners at the project's outset, outlined the rules and procedures governing IP management, including decision-making protocols, conflict resolution procedures, and confidentiality considerations.

All deliverables related to WP1 were prepared on time and reviewed by the assigned internal peer reviewers according to the quality assurance plan. A list of the deliverables prepared under WP1 during the second reporting period of BAM is summarized below.

Deliverables

D1.2: Minutes of Meetings (minutes of Steering Committee meeting held on 01/03/2024).

D1.3: Final Report. A comprehensive report summarising the progress of the project throughout the second reporting period.

Work Package Number:	2	Start Month:	1	End Month:	27
Work Package Title	**Dissemination Activities**				
Work Package Leader	**Frederick Research Center**				
Partner Role	**FRC**	**UCY**	**RECS**		
Person Months	**2.34**	**2**	**3.5**		

Work Package Objectives as described in Annex I of the Contract.

WP2 aims to define strategies for the exploitation and dissemination of the project's results, including dissemination activities and communication measures, targeting to the widest possible promotion of the project results across Cyprus, EU and worldwide.

Work Description and Expected Key Results

WP2 was managed by the Frederick Research Center (FRC), with active involvement and support from the Dissemination Manager, Dr Pericles Savva (RECS), and all consortium partners. Dr Nicolaides (Project Coordinator) and Dr Savva were responsible for ensuring the smooth implementation of all dissemination, communication, and exploitation activities. They were supported by the BAM project committees, HO administrative mechanisms, WP and Task leaders, and other consortium partners. Within WP2, the research team aimed to meet the requirements and obligations of Task 2.1: Dissemination and Communication of Project Results. Below is a summary of the activities implemented in WP2 during the second half of the project.

Numerous meetings were conducted in the latter half of the project to monitor WP2 activities and gather essential information from the consortium to fulfil the work package requirements. WP and Task leaders maintained consistent communication with the Project Coordinator and the Dissemination Manager to keep them informed about the progress of the relevant WPs and Tasks. To support this objective, various materials created in the previous phase (1RP) were updated and shared within the consortium to ensure they accurately reflected the project's progress by its conclusion. These materials included the "Dissemination Plan," an updated "Contact List" and "Project Team Directory," the project “Document Template,” “Presentation Template,” and “Deliverables Template,” as well as the RIF guidelines for the Call communication of results (e.g., Acknowledgements, Logos, etc.).

To enhance the project's visibility, a dedicated BAM website was designed and launched during the first half of the project. The website aimed to increase visibility among stakeholders and the public, serving as a reference point for updates during and after the project period, and to reduce paper use for dissemination. It provides information on the project's objectives, the technology used, conducted work, public deliverables, and key outcomes. The website was consistently updated with new content.

Additionally, the team developed social media accounts for BAM on LinkedIn, Instagram, and Facebook (Facebook, LinkedIn and Instagram) to engage the public and promote project results. These accounts were continuously updated with project news and served as outlets for engaging content dissemination, reaching a wide audience.

Over the past 15 months (2RP), non-scientific articles were also prepared and released. The primary objective of these documents was to offer regular updates about the BAM project to a diverse audience, including the scientific community, stakeholders, and the broader public. Specifically, the following documents have been prepared:

- Project Brochures
- Project Posters

The documents can be found in the project's website and social media accounts.

The research team also organized a Demonstration and Dissemination Event on Wednesday, May 22, 2024, from 10:00 to 13:00 at RECS Civil Engineers & Partners LLC premises. The event aimed to present the methodological approach used in the design, development, and validation of two new building materials that offer resistance against blasts, impacts, and fire. A demonstration of the fire performance of these materials was conducted to showcase their potential and performance, encouraging participant engagement and discussion.

Fire Testing setup illustrating the placement of thermocouples for monitoring temperature fluctuations inside specimens.

Invitations were sent to selected academics, researchers, stakeholders (including the Federation of Building Contractors Association Cyprus, Cyprus Recycling Organisation, Cyprus Chamber of Commerce and Industry), members of relevant governmental organizations (such as the Public Works Department, Mines Service of the Ministry of Agriculture, Natural Resources and Environment, Department of Environment), members of standardization bodies (including the Cyprus Organisation for Standardisation, CYS), and representatives from various companies in the sector.

In addition, the research team organized the following internal workshops:

Workshops for WP2: To ensure the successful completion of WP2, the Dissemination Manager, Dr Pericles Savva, organized a series of three meetings with partners grouped according to their respective technical work. The primary objective of these meetings was to gather the necessary input and collaboration required to fulfil the deliverables of WP2.

Consortium members participated in various public events to present the ideas, objectives, and key findings of the BAM project, as well as its potential impact on the daily lives of citizens. These events included:

- Demonstration of BAM materials preparation using 3D-printing and casting to a group of high school students on April 13th, 2023
- Participation in the European Researchers' Night, held in Nicosia on September 29th, 2023
- Presentations as part of the MSc Seminar Series at Frederick University on March 19th, 2024, and May 15th, 2024, for different student audiences

The project coordinator requested a meeting with high-ranking officers from the Cyprus Army and the Ministry of Defence. This meeting took place in the Ministry of Defence on March 5th, 2024, during which Dr Nicolaides delivered a comprehensive presentation on the research conducted within the BAM project. He emphasized the potential applications of the new materials for both military and civil purposes. The officers showed great interest in the presentation and asked Dr Nicolaides to organize additional meetings to explore collaboration opportunities further. After the March 5th meeting, Dr Nicolaides was invited to present the consortium research at a conference organized by the Cyprus Army and the Ministry of Defence on May 22nd, 2024. The conference was attended by numerous stakeholders, researchers, industry representatives, and potential end users. Subsequent meetings with the officers aimed to identify specific, tangible applications of the new materials on a pilot scale. During one such meeting, held on June 18th, 2024, it was decided to conduct blast tests to investigate the materials' performance under different conditions, such as varying amounts of TNT explosive, distances from the target, and specimen thicknesses. Unfortunately, these tests could not be conducted within the project's timeframe because the Cyprus Army suspends relevant activities during the summer months due to high temperatures and the associated risk of fire accidents. These tests are now scheduled for October 2024. This collaboration is significant to the consortium, as it will allow the research team to validate the new materials' capabilities under actual conditions. Consequently, this will elevate the Technology Readiness Level (TRL) of the materials and increase interest in their wider adoption for specialized applications.

In October 2023, Dr Nicolaides and Professor Petrou presented part of the project findings in lectures to faculty members and researchers at Fuzhou University in China. The presentations garnered significant interest, leading to discussions for further collaborations.

Additionally, the BAM project established connections with the research consortium of the "DEFEAT: Development of an Innovative Insulation Fire Resistant Façade from Construction and Demolition Waste, 2020-2023" project. Both projects participated in dissemination events organized by the Research Offices of Frederick Research Center, Frederick University, and the University of Cyprus.

During the first reporting period, the project led to the publication of two conference articles, which are available on the project’s website:

1. Giannopoulou, I., Robert, P., Polydorou, T., Demetriou, D., Tsioulou, O., Lampropoulos, A., Petrou, M. and Nicolaides, D. Novel blast and fire-resistant composite materials: design and preliminary results. Proceedings of fib Symposium 2023, Building for the future: Durable, Sustainable, Resilient, Istanbul, Turkey, 05-07 June 2023.
2. Demetriou, D., Polydorou, T., Oikonomopoulou, K., Savva, P., Giannopoulou, I., Robert, P., Tsioulou, O., Lampropoulos, A., Nicolaides, D. and Petrou, M. Optimising Ultra High-Performance Fibre-Reinforced Concrete for Impact Resistance. Proceedings of fib Symposium 2023, Building for the future: Durable, Sustainable, Resilient, Istanbul, Turkey, 05-07 June 2023.

In the second reporting period, the project achieved the preparation and submission of the following scientific articles to peer-reviewed journals: 1. Momeni, M., Demetriou, D., Papadakis, L., Bedon, C., Petrou, M. and Nicolaides, D. Damage Investigation of Blast Loaded UHPFRC Panels with Optimized Mixture Design using Advanced Material Models. Results in Engineering, 23, 2024. 2. Polydorou, T., Robert, P., Giannopoulou, I., Demetriou, D., Oikonomopoulou, K., Nicolaides, D. and Petrou, M. Development and Validation of an Innovative Hybrid Laminate Material for the Blast and Fire Protection of Structures. (Submitted to Materials and Structures – Evaluation Stage) Beyond the project's contractual deliverables, the research team conducted a comprehensive Life Cycle Assessment (LCA) of the developed materials. Currently, a manuscript titled "Life Cycle Assessment of Novel Fire-Resistant Composites Developed Through Geopolymerization" is being drafted. This manuscript will be submitted for publication in The International Journal of Life Cycle Assessment (Springer Nature, Q1 ranking, Impact Factor of 5.4) as a golden open access article. This submission is not a contractual requirement of the project. All deliverables related to WP2 (formal and informal) were prepared on time and reviewed by the assigned internal peer reviewers according to the quality assurance plan. A list of the formal deliverables prepared under WP2 during the second reporting period of BAM is summarized below.
Deliverables
D2.4: Dissemination Event with Local Stakeholders. The event targeted local stakeholders, including companies, academia, governmental organizations, standardization bodies, and other related fields. The aim was to showcase novel materials developed with blast, impact, and fireproof characteristics.

Work Package Number:	3	Start Month:	1	End Month:	22
Work Package Title	Design of Materials				
Work Package Leader	Frederick Research Center / RECS Engineering				
Partner Role	FRC	UCY	RECS		
Person Months	11.96	5.50	10.20		

Work Package Objectives as described in Annex I of the Contract.

WP3 targets the design of the 2 new materials, i.e., Hybrid Laminate Material (HLM) and Smart Composite Geopolymeric Concrete (SCGC). Both materials are designed in order: i) to resist under the fire scenario of ISO-834 which is used in all building structures, as well as in urban tunnels, ii) to resist under blast and impact loads, as per the validation methods described in the proposal.

Work Description and Expected Key Results

WP3 is dedicated to the development of two new materials, namely the Hybrid Laminated Material (HLM) and the Smart Composite Geopolymeric Concrete (SCGC). HLM is comprised of a superficial layer of fire-resistant geopolymeric concrete and an impact/blast resistant Ultra High Strength Concrete (UHSC) layer. The SCGC is a dual fire and blast/impact-resistant material. The work performed during the 2nd Reporting Period (2RP) is summarised below:

Task 3.1 - Design of Hybrid Laminate Material (HLM) has been successfully completed in the 2RP of the project. The blast/impact-resistant UHPFRC layer of the HLM was developed and optimized in the First Reporting Period (1RP) of the project. The UHPFRC layer of the HLM was developed as an optimized version of a previously created material by the research team. Various mix differentiations were examined before concluding that formulations containing 2% steel and 1% PVA fibres, along with the replacement of local sand with standard silica sand, were selected as the most cost effective that met the project's minimum strength requirements. The formulations surpassed the project's minimum compressive strength requirement of 150 MPa and demonstrated the highest flexural strength value of 22.64 MPa, surpassing the required target of 20 MPa. In addition, a self-compacting version of the 2% steel and 1% PVA UHSC was developed, which exhibited a 16.51% decrease on compressive strength, and 18.43% decrease on flexural strength.

During the 2nd Reporting Period, the optimization of the fire-resistant geopolymeric layer (FRG) of the Hybrid Laminated Material (HLM) was successfully completed. The fire resistance of the optimized FRG material was preliminarily assessed by testing its thermal stability and mechanical performance at elevated temperatures (Partner FRC). The optimized FRG material developed an adequate compressive strength of about 25 MPa and demonstrated excellent thermal stability and mechanical performance at high temperatures up to 1050°C. Details of the optimization process, the properties of the optimized material, and the experimental results of the fire-resistance assessment are provided in Deliverable "D3.1 - Design and Development of Hybrid Laminated Material (HLM)".

The bonding strength between the blast/impact-resistant UHPFRC layer and the fire-resistant FRG layer of the Hybrid Laminated Material (HLM) was evaluated using pull-off adhesion tests conducted in accordance with standard EN1542 (Partners FRC and UCY). These tests assessed the resistance of the two materials to separation (adhesive bonding) by measuring the pull-out force and examining the failure mode of the tested specimens. A total of 15 specimens, each with average dimensions of 150 mm x 150 mm x 80 mm, were prepared for the HLM material. This included 150 mm x 150 mm x 30 mm for the FRG material and 150 mm x 150 mm x 50 mm for the UHPFRC material. Out of the fifteen specimens tested, four detached during the core drilling process. None of the remaining specimens experienced cohesive failure of the substrate; instead, failure occurred at the bond interface between the two layers. This indicated that the tensile bond strength achieved with the use of geopolymeric paste at the interface between the FRG and UHPFRC was significantly weaker than the strength of each layer individually. Specifically, the adhesion bond did not meet the minimum requirement for tensile bonding strength of 2 MPa. As a result, it was decided to use a fire-resistant adhesive epoxy resin to bond the two layers of the HLM, a method successfully implemented in similar cases in the past. This adhesive bond exceeded the targeted value, causing failure to occur in the weaker of the two layers, which was the fire-resistant geopolymer. The Deliverable "D3.1 - Design and Development of Hybrid Laminated Material (HLM)" presents the experimental results of these tests, along with details on the adhesion bond between the two layers of the HLM.

A significant volume of the experimental results from Task 3.1 was included in a joint open access journal paper by FRC and UCY, thereby fulfilling the requirements of Deliverable "D3.3 – Publication in Open Access Journal." The manuscript, titled "Development and Validation of an Innovative Hybrid Laminate Material for the Blast and Fire Protection of Structures," has been submitted for evaluation to the Springer journal Materials and Structures.

In the frame of **Task 3.2 - Design of Smart Composite Geopolymeric Concrete (SCGC)**, the innovative SCGC with blast/impact and fire resistance was successfully developed and optimized during the second reporting period of the project. This material was based on an industrial by-product, ground granulated blast-furnace slag, and a sodium-based alkaline activator (NaOH and Na_2SiO_3 solutions). The solid-to-liquid ratio (S/L) in the geopolymer paste and the concentration of sodium hydroxide solution in the alkaline activator were identified as the most crucial parameters for achieving high compressive and flexural strength in the SCGC. The optimized SCGC was thoroughly characterized in terms of mechanical properties (compressive and flexural strength), physical properties, and durability (e.g., density, water absorption). The material achieved a compressive strength of 132 MPa and a flexural strength of 8.6 MPa, indicating potential for blast and impact resistance. In addition, the thermal stability and mechanical performance against fire were assessed after exposure to elevated temperatures. Specifically, samples with dimensions 50 x 50 x 50 cm^3 were placed in the furnace and heated with a constant heating rate of 4.4 °C / min, until to reach the desired temperature (600, 800 or 1050 °C), where they left for 2 hours. The samples were then removed from the furnace and allowed for cooling down to room temperature in open air conditions, before the performance of any measurement or testing. The samples exposed to the elevated temperatures were assessed in terms of their compressive strength, density, mass loss and linear shrinkage. Moreover, their structural integrity was macroscopically investigated.

Moreover, the Foreign Organisation of the project, i.e., the University of Brighton (UoB) has successfully investigated the design and development of another fiber reinforced geopolymer concrete (FRGC) with strain hardening characteristics. The geopolymer matrix of this material was based on a ternary binder of Fly Ash (FA), Ground Granulated Blast-Furnace Slag (GGBS), and Silica Fume (SF) mixtures with potassium silicate alkaline activator. The mechanical properties of FRGC, the impacts of fibre type, volume percentage, and fibre aspect ratio were investigated; tests for the compressive, tensile, and flexural strengths were carried out to determine the mechanical properties of FRGC. Scanning electron microscopy

(SEM) was also employed to evaluate the microstructure of geopolymer mixes under investigation. The addition of steel and PVA fibers to the FRGC significantly increased its flexural and tensile strength, enhanced its energy absorption, and enabled strain hardening characteristics. These improvements indicate its potential as a blast and impact-resistant material.

Details on the experimental activities conducted to develop and optimize these materials, along with the resulting data and scientific findings, are provided in Deliverable "D3.2 - Smart Composite Geopolymer Concrete (SCGC)".

In **Task 3.3 – Properties of the Manufacturing of Materials**, the consortium determined the necessary properties for producing the developed geopolymeric materials (FRG and SCGC) through casting and 3D printing methods. By controlling the rheology of the geopolymer paste, the desired viscosity and setting time were achieved for both processes. The rheological characteristics of the geopolymer paste were studied by testing the effects of viscosity and setting time on the solidification of the geopolymer materials with each production method. A set of process parameters considered optimal for 3D printing was applied, leading to the successful additive manufacturing of the geopolymer materials developed in the BAM project.

All deliverables related to WP3 were prepared on time and reviewed by the assigned internal peer reviewers according to the quality assurance plan. A list of the deliverables prepared under WP3 during the second reporting period of BAM is summarized below.

Deliverables

D3.1: Design and Development of Hybrid Laminated Material (HLM).

A detailed report on the design, development and optimization of the two layered materials, the UHPFRC and the FRG, composing the new HLM.

D3.2: Design and Development of Smart Composite Geopolymeric Concrete (SCGC).

A report describing the activities performed for the design and development of the SCGC, including the efforts for its optimization.

D3.3: Publication in Open Access Journal.

A scientific article with the experimental results for the design and development of the innovative Hybrid Laminated Material (HLM) has been prepared by Partners FRC and UCY. The manuscript, titled "Development and Validation of an Innovative Hybrid Laminate Material for the Blast and Fire Protection of Structures," has been submitted for evaluation to the Springer journal Materials and Structures.

D3.4: Publication in Relevant Conference.

A manuscript with title "Optimising Ultra High-Performance Fibre-Reinforced Concrete for Impact Resistance" has been submitted and presented in the international conference "fib Symposium 2023, Building for the future: Durable, Sustainable, Resilient, Istanbul, Turkey, 05-07 June 2023".

Work Package Number:	4	Start Month:	6	End Month:	27
Work Package Title	Manufacturing and Validation of the Designed Materials				
Work Package Leader	University of Cyprus / RECS Engineering				
Partner Role	FRC	UCY	RECS		
Person Months	8.03	5.47	12		

Work Package Objectives as described in Annex I of the Contract.

WP4 aims to manufacture both materials using casting and 3D printing methods, as well as to validate them through laboratory and analytical methods.

Work Description and Expected Key Results

To achieve the objectives of WP4 the following activities were carried out during the 2RP: (i) control of the most significant process parameters affecting the properties of the HLM and SCGC materials produced by both 3D printing and casting; (ii) validation of the HLM material properties at lab-scale, including the impact resistance of the UHPFRC layer and the fire resistance of the FRG layer based on the standard ISO 834 fire curve; and (iii) validation of the SCGC material properties at lab-scale, including fire resistance according to the standard ISO 834 fire curve. The work performed during the 2RP is summarised below:

In **Task 4.1 - Precast Manufacturing** and **Task 4.2 - 3D Printing Manufacturing**, the rheological characteristics of the geopolymer pastes were designed and controlled for production via casting and 3D printing methods. Partner FRC studied these characteristics through tests focusing on the relationship between viscosity, setting time, and solidification of the materials in both production methods. This study investigated key process parameters, such as the ratio of the solid precursor to the alkali activator, the concentration of the alkali hydroxide solution in the activator, and the molar ratios of Si/Alkali and Si/Al, in relation to the viscosity of the geopolymeric paste. For each production method, whether casting or 3D printing, a set of optimal process parameters was identified and used for laboratory production of the materials. For HLM, blast- and impact-resistant UHPFRC and fire-resistant geopolymer FRG are produced separately and then combined using a suitable fire-resistant adhesive epoxy resin. In the 3D printing process, selecting the appropriate pattern, controlling key process parameters, and continuously monitoring the viscosity of the printed pastes are crucial for successful implementation. In conclusion, both casting and 3D printing can be used separately or in combination to produce SCGC (without fibres) and the fire-resistant layer of HLM from a technical standpoint. However, 3D printing of fibre reinforced SCGC and UHPFRC was not practically feasible due to the large volume of steel fibers, despite significant efforts by the research team. The detailed flowsheets for producing each material via casting and 3D printing methods were developed and included in Deliverable “D4.1 - Flowsheet of Materials Production.”

In **Task 4.3 - Validation of Materials**, the optimized UHPFRC and FRG layers of the HLM, as well as the SCGC materials, were characterized in terms of their mechanical and physical properties. The impact resistance of the UHPFRC layer and the fire resistance of the FRG layer of the HLM and the SCGC were also validated. Specifically, the consortium validated the blast and impact resistance of the UHPFRC layer of the HLM in the lab using the drop hammer test to assess impact capacity and strain rate effects. Additionally, FRC validated the fire resistance of the SCGC and the FRG layer of the HLM in the laboratory, following the standard ISO 834 time-temperature curve. Partner RECS conducted a comparative analysis of the fire resistance between the newly developed materials (HLM and SCGC) and standard concrete. Details on the validation of the materials' properties and the resulting data are included in Deliverable "D4.2 - Validation of Materials in the Laboratory". It was concluded that the use of geopolymer materials as protective layers on new or existing concrete buildings and structures can improve their fire performance. The findings support the potential of these materials in enhancing structural safety and durability in fire-prone environments. In addition, the developed UHPFRC materials exhibited excellent performance against impact loads, making them a promising and reliable protective material against blast and impact loading.

The blast performance of the developed materials was validated through analytical methods using Finite Element Analysis with LS-DYNA software. This analysis aimed to understand the dynamic behaviour of UHPFRC panels under blast and impact loadings and included a comparative analysis between UHPFRC and normal strength concrete (NSC) panels, both with and without reinforcement. The study also focused on constructing UHPFRC panels as protective barriers, emphasizing the determination of the minimum thickness required for effective blast resistance. This determination followed a specific strategy based on regulations and aimed to ensure minimal damage to the panel. Additionally, a sensitivity analysis identified the influential parameters for the numerical model. These insights provided a comprehensive understanding of UHPFRC's dynamic behaviour under blast conditions, offering valuable considerations for future applications and design implementations in this evolving field. The project also examined the behaviour of similar panels made with smart composite geopolymer concrete (SCGC) material under impact and blast loading.

All deliverables related to WP4 were prepared on time and reviewed by the assigned internal peer reviewers according to the quality assurance plan. A list of the deliverables prepared under WP4 during the second reporting period of BAM is summarized below.

Deliverables

D4.1: Flowsheet of Materials Production.
A report detailing the production flowsheets of HLM and SCGC materials using casting and 3D printing methods, including synthesis and curing conditions.

D4.2: Validation of Materials in the Laboratory.
A report summarizing the experimental results of the laboratory-scale validation of the mechanical characteristics, impact resistance, and fire resistance of the developed HLM and SCGC materials.

D4.3: Numerical Analysis of Materials' Blast Resistance.
A detailed report on the blast performance of the developed materials through analytical methods using Finite Element Analysis with LS-DYNA software.

D4.4: Publication in Open Access Journal.
A scientific article with the analytical validation of the blast performance of the developed UHPFRC has been prepared by Partners FRC and UCY. The manuscript, titled "Damage Investigation of Blast Loaded UHPFRC Panels with Optimized Mixture Design using Advanced Material Models" has been accepted for publication to the Elsevier journal Results in Engineering.

D4.5: Publication in Relevant Conference.
A manuscript with title "Novel blast and fire-resistant composite materials: design and preliminary results" has been submitted and presented in the international conference "fib Symposium 2023, Building for the future: Durable, Sustainable, Resilient, Istanbul, Turkey, 05-07 June 2023".

Work Package Number:	5	Start Month:	6	End Month:	27
Work Package Title	Technoeconomic Evaluation and Cost-Benefit Analysis				
Work Package Leader	RECS Engineering				
Partner Role	FRC	UCY	RECS		
Person Months	2.09	2	4		

Work Package Objectives as described in Annex I of the Contract.

WP5 aims at: (i) performing the techno-economic evaluation of the developed materials; (ii) performing a cost-benefit analysis (CBA).

Work Description and Expected Key Results

Task 5.1: Technical and Economic Evaluation focused on the assessment of the technical feasibility and economic viability of the developed material, focusing on its production processes, market potential, and cost-effectiveness compared to conventional materials.

The evaluation analyses the HLM's production process, market potential, economic benefits, and provides recommendations for optimizing production and market competitiveness. Advanced automation technologies, like PLCs and robotic systems, are proposed to enhance efficiency, ensure quality, reduce labour costs, and decrease production time.

The economic assessment highlights significant market potential in industries demanding high-performance, fire-resistant materials. Despite initial investments in advanced manufacturing technologies, the long-term benefits include reduced operational costs and increased market competitiveness.

Key recommendations include incorporating automation to improve efficiency and reduce costs, evaluating alternative production configurations for cost savings, targeting high-demand industries, and implementing marketing strategies to highlight HLM's benefits. Continuous improvement through monitoring and R&D is essential for further enhancement.

In conclusion, HLM is both technically feasible and economically advantageous, with automation expected to boost efficiency and cost-effectiveness, positioning it as a competitive market player. Future evaluations should consider alternative configurations to ensure the most efficient production setup.

Task 5.2: Cost-Benefit Analysis (CBA)

Task D5.2 aimed to conduct a comprehensive Life Cycle Assessment (LCA) and Cost-Benefit Analysis (CBA) for the Hybrid Laminated Material (HLM) over a five-year production period. The LCA focused on evaluating the environmental impacts associated with the production of HLM boards, while the CBA assessed the project's financial viability. The functional unit for the analysis was defined as the mass of HLM product required to produce a specified number of boards over the five-year period. The life cycle stages examined included raw material acquisition, transportation, and manufacturing of the HLM product. Data collection involved utilizing the Ecoinvent database alongside literature sources to address gaps in data, particularly for materials like steel fibers and PVA fibers. The environmental impact categories were analysed using the

EPD 2018 method, which encompasses factors such as Global Warming Potential, Water Scarcity Footprint, and Acidification Potential. The results indicated that the HLM product outperformed the Alternative Market Model in terms of Global Warming and Photochemical Oxidation. However, it exhibited higher impacts in other areas, notably Water Scarcity.

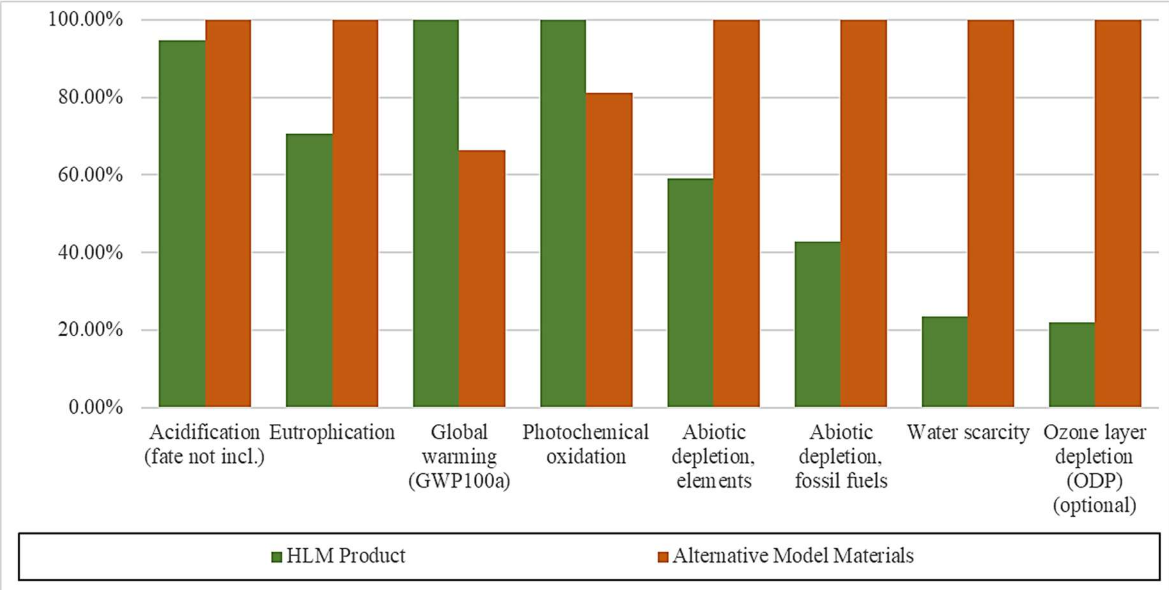

Figure 1: Comparison between HLM product and Alternative Market Model (EPD method – 1st year)

The CBA study assessed the financial viability of the Hybrid Laminated Material (HLM) project through direct sales and a comprehensive tech analysis. Key financial factors such as Net Present Value (NPV) and Benefit-Cost Ratio (BCR) were calculated, incorporating environmental impact costs integrated from the LCA study. The findings revealed a positive Net Benefit and a favorable BCR, demonstrating both financial viability and a strong economic return on the initial investment. The total NPV of benefits exceeded the NPV of costs, with the first financial year yielding a positive outcome of €106,725.53 and a substantial Net Benefit of €281,087.81 by the end of the five-year period. This indicates that the project is profitable relative to the initial investment of €160,000.00. The BCR for the first year was 1.22, improving to 1.42 by the end of the analysis period, highlighting the project's stability and profitability.

Table 1: CBA study final NPV, NB and BCR factors.

	FY1	FY2	FY3	FY4	FY5
NPV COST	496,309.92 €	533,989.10 €	575,460.93 €	620,815.88 €	669,569.30 €
NPV BENEFIT	603,035.46 €	730,533.25 €	800,526.07 €	873,707.35 €	950,657.12 €
NB	106,725.53 €	196,544.15 €	225,065.14 €	252,891.47 €	281,087.81 €
BCR	**1.22**	**1.37**	**1.39**	**1.41**	**1.42**

The LCA and CBA study collectively underscore the project's potential for positive environmental and economic outcomes, with specific recommendations for future research project with higher TRL focus at enhancing its environmental and financial performance.

All deliverables related to WP5 were prepared on time and reviewed by the assigned internal peer reviewers according to the quality assurance plan. A list of the deliverables prepared under WP5 during the second reporting period of BAM is summarized below.

Deliverables
D5.1: Technoeconomic Evaluation. A report detailing the assessment of the technical feasibility and economic viability of the developed material, focusing on its production processes, market potential, and cost-effectiveness compared to conventional materials. D5.2: Cost-Benefit Analysis. A report aimed to conduct a comprehensive Life Cycle Assessment (LCA) and Cost-Benefit Analysis (CBA) for the developed material over a five-year production period.

A.4. TABLE OF WORK PACKAGES					
		Contract		Actual Implementation	
Work Package	Work Package Title	Start Month	End Month	Start Month	End Month
WP1	Project Management	1	24	1	27
WP2	Dissemination and Exploitation Activities	1	24	1	27
WP3	Design of Materials	1	16	1	22
WP4	Manufacturing and Validation of the Designed Materials	6	24	6	27
WP5	Technoeconomic Evaluation and CBA	6	24	6	27

A.5. EXPLOITATION OF RESULTS AND ADDED VALUE (This section only applies for final reports)

The BAM project has successfully achieved its objectives, significantly advancing the design and development of innovative building materials. The section below briefly outlines the added value of the project results and the measures implemented to exploit these outcomes effectively. The impact is consistent with the expectations described in the initial proposal, including scientific, technological, social, economic, and environmental progress.

Scientific and Technological Advances

The BAM project has developed 2 innovative materials (HLM and SCGC) with dual behaviour, enhancing fire and blast/impact resistance. This innovation not only improves structural safety but also stimulates further research in the field of building materials, especially within the European research community. To the best of the authors' knowledge, there are currently no other materials on the market, nor any similar research, that focus on developing materials with both blast/impact and fire resistance properties. The integration of 3D printing in the development of these materials has opened new research avenues, particularly in Cyprus, positioning it as a hub for advanced materials research and application. The successful application of geopolymerisation technology, an innovative and environmentally friendly method, also represents a significant advance. This technology substantially reduces the environmental footprint compared to traditional cement industry practices, reinforcing the EU's commitment to sustainable development. The research consortium has gained valuable experience and expertise in geopolymerisation technology and 3D printing of cementitious materials, resulting in several new research opportunities. These include a new funded proposal (ENTERPRISES/ENERGY/1123: DIAS) and three other proposals (VITRUVIUS 3D, WASTE4CAST, INSUMAT proposals) currently under evaluation in the RIF EXCELLENCE/0524. Additionally, the consortium has submitted proposals on relevant topics that were not funded (RIF CODEVELOP-REPowerEU/1223: ECOMBINE, GEOSHELL proposals, HORIZON-WIDERA-2023-ACCESS-07-01 — Excellence Hubs: PLETHORA proposal and HORIZON-WIDERA-2023-ACCESS-02-01: ACTIVE proposal), established collaborations with local and international research groups (7), published in prestigious scientific journals (2) and conferences (2), and trained young researchers (5).

Social Impacts

The resilience of infrastructures can be significantly enhanced, providing efficient protection against fire and blast incidents. This advancement ensures the safety of buildings, tunnels, and other critical structures, thereby safeguarding human lives and reducing potential casualties. The project has elevated the technological expertise of Cypriot human resources, fostered new researchers and strengthened research institutions (FRC and UCY) and companies (RECS) in the region. This boost in technological expertise is vital for the ongoing development and commercialization of innovative safety solutions. The BAM project has generated new economic activities and job opportunities, directly creating at least three new positions within the participating organizations. This contributed to the broader economic growth and technological advancement of Cyprus.

Economic Impacts

Post-project, Cyprus participating research institutions (FRC and UCY) and companies (RECS) are now key actors in infrastructure safety. They possess specialized knowledge for innovative materials, enabling them to offer advanced services and products. This positions Cyprus as a competitive player in the global market, with potential to bring important economic benefits. The developed fire resistant materials are estimated to have a cost advantage of at least 30% over existing solutions, due to the use of metallurgical and other wastes and the low-cost geopolymerisation production method. This cost efficiency enhances their potential marketability and adoption, providing significant economic advantages.

Environmental Impacts

The project has addressed the severe environmental consequences of fire and blast incidents. By developing materials that mitigate such events, the project contributes to the reduction of pollution and the safe management of solid wastes. Geopolymer materials developed within the project have a significantly lower CO_2 emission profile, estimated to be 40% less than portland cement concretes. This environmental benefit aligns with global efforts to combat climate change and promote sustainable construction practices.

Exploitation Measures

- Knowledge Transfer: The project results have been disseminated through prestigious journal publications (2), conferences (2), workshops (3) and demonstration/dissemination events (1).
- Stakeholders Collaboration: Partnerships with important stakeholders (e.g., Ministry of Defence and Cyprus Army) have been established to integrate the new materials into real-world critical applications. It was mutually decided to conduct blast tests to investigate the materials' performance under different conditions, such as varying amounts of TNT explosive, distances from the target, and specimen thicknesses. These tests are now scheduled for October 2024. These tests are crucial for validating the materials' performance and scaling their production. This collaboration is significant to the consortium, as it will allow the team to validate the new materials' capabilities under actual conditions. Consequently, this will elevate the Technology Readiness Level (TRL) of the materials and increase interest in their wider adoption for specialized applications.
- Educational Programs: The knowledge and technologies developed through the project will be integrated into the curricula at Frederick University and the University of Cyprus, offering relevant education to both students and researchers. Additionally, presentations were given as part of the MSc Seminar Series at Frederick University on March 19th, 2024, and May 15th, 2024, targeting different student audiences. These initiatives will ensure the ongoing development of expertise in materials engineering and advanced manufacturing technologies.
- Sustainability Initiatives: Efforts to promote the environmental benefits of the geopolymer materials are ongoing, with initiatives aimed at encouraging the adoption of these eco-friendly solutions in the construction industry.

The BAM project has successfully delivered on its promise of scientific, technological, social, economic, and environmental progress. The innovative materials and technologies developed have not only enhanced infrastructure safety but also provided important economic and environmental benefits. The exploitation measures implemented ensure that these advancements will continue to benefit the European research community and industry, positioning them at the forefront of sustainable and resilient construction practices.

As a result of the project, the following summarised outcomes have been achieved:

- New job positions (as Full Time Equivalent) created or retained: 3
- Collaboration with organisations abroad (for the participation in follow-up R&D projects): 7 (UCLA, KU Leuven, University of Trieste, University of Padova, Technical University of Crete, Imperial College, Aristotle University of Thessaloniki)
- Number of new products: 2 new materials (HLM and SCGC), validated in laboratory environment
- Number of proposals submitted under Horizon 2020 and/or any other European Programme: 8 (DIAS, VITRUVIUS 3D, INSUMAT, WASTE4CAST, ACTIVE, PLETHORA, GEOSHELL, ECOMBINE)
- Amount of funding received from Horizon 2020 and/or any other European Programme: €199,760.00 (ENTERPRISES/ENERGY/1123: DIAS)
- Number of standards in which project results were incorporated, indicating the Standardisation Body for each one: too many EN, ASTM and ISO standards for the development and validation of the new materials

B.1. ADDITIONAL INFORMATION (OPTIONAL)

During the second reporting period, the consortium pursued one project amendment as outlined below:

- 12-02-2024: A major modification was made to the project activities. This change was associated with extending the project duration by three months to address delays by difficulties in identifying suitable external laboratories capable of conducting the required impact and fire tests within the project timeframe and available budget. Additionally, delays occurred in receiving responses for articles submitted to scientific journals. The funding agency approved this request.

It is important to note that, despite the challenges faced during the project, the consortium successfully overcame all obstacles and effectively achieved all the objectives outlined in the contract.

B.1. ADDITIONAL INFORMATION (OPTIONAL)

The achievements accomplished within BAM have been documented through the publication of a significant number of peer reviewed papers in esteemed journals and reputable conferences. The list of publications resulting from the BAM project is provided below:

1. Momeni, M., Demetriou, D., Papadakis, L., Bedon, C., Petrou, M. and Nicolaides, D. Damage Investigation of Blast Loaded UHPFRC Panels with Optimized Mixture Design using Advanced Material Models. Results in Engineering, 23, 2024.
2. Polydorou, T., Robert, P., Giannopoulou, I., Demetriou, D., Oikonomopoulou, K., Nicolaides, D. and Petrou, M. Development and Validation of an Innovative Hybrid Laminate Material for the Blast and Fire Protection of Structures. (Submitted to Materials and Structures – Evaluation Stage)
3. Giannopoulou, I., Robert, P., Polydorou, T., Demetriou, D., Tsioulou, O., Lampropoulos, A., Petrou, M. and Nicolaides, D. Novel blast and fire resistant composite materials: design and preliminary results. Proceedings of fib Symposium 2023, Building for the future: Durable, Sustainable, Resilient, Istanbul, Turkey, 05-07 June 2023.
4. Demetriou, D., Polydorou, T., Oikonomopoulou, K., Savva, P., Giannopoulou, I., Robert, P., Tsioulou, O., Lampropoulos, A., Nicolaides, D. and Petrou, M. Optimising Ultra High-Performance Fibre-Reinforced Concrete for Impact Resistance. Proceedings of fib Symposium 2023, Building for the future: Durable, Sustainable, Resilient, Istanbul, Turkey, 05-07 June 2023.

It is important to highlight that, beyond the project's contractual deliverables, the research team has conducted a comprehensive and detailed Life Cycle Assessment (LCA) of the developed materials. Currently, a manuscript titled “Life Cycle Assessment of Novel Fire-Resistant Composites Developed Through Geopolymerization” is being drafted. This manuscript will be submitted for publication in The International Journal of Life Cycle Assessment (Springer Nature, Q1 ranking, and Impact Factor of 5.4) as a golden open access article. It is noteworthy that this submission is not a contractual requirement of the project.

The status of the manuscripts prepared in the frame of BAM project are summarised in table below:

	Published	**Under Review**	**Drafting Stage**
Journal Papers	**1**	**1**	**1**
Conference Papers	**2**		

B.2. FOLLOW-UP OF RECOMMENDATIONS AND COMMENTS FROM PREVIOUS PROJECT EVALUATION **(Only applicable for the Final Report of Large Projects)**
Include in this section the list of recommendations and comments from the interim project evaluation and give information on how they have been followed up.

Notes:

Collection and processing of personal data is carried out according to the RIF's Policy for the Protection of Personal Data. The RIF's Policy is posted on IRIS.

Acknowledgements

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