Program Profile		
Program	Program name	Comprehensive Assessment of Geopolymer-Based UHPC: Strength, Durability, Microstructure, and Sustainability.
	Category	A8

Summary of Program	
Program Name	Comprehensive Assessment of Geopolymer-Based UHPC: Strength, Durability, Microstructure, and Sustainability.
Category	A8
Abstract of Program	Concrete is the world's most widely used construction material, yet it poses significant environmental and sustainability challenges. Ordinary Portland Cement (OPC), the primary binder in both conventional concrete and Ultra-High-Performance Concrete (UHPC), produces approximately 0.83 tons of CO_2 per ton of clinker, contributing nearly 8% of total global emissions. Although UHPC achieves compressive strengths of 150–200 MPa and demonstrates excellent durability, its use of extremely high cement contents (750–1200 kg/m^3) and silica fume results in substantial environmental impact and cost, limiting large-scale adoption. This proposal seeks to develop Geopolymer-Based Ultra-High-Performance Concrete (G-UHPC) as a sustainable, high-performance alternative. Instead of OPC, the program will utilize aluminosilicate binders derived from fly ash, ground granulated blast furnace slag (GGBFS), and metakaolin, activated by alkaline solutions such as sodium hydroxide and sodium silicate. The experimental program will optimize binder-activator ratios, fibre content (0 - 2% steel fibres), and water-to-binder ratios. Mechanical properties including compressive, tensile, and flexural strengths will be evaluated at 7, 28, 56, and 90 days. Durability performance will be assessed through chloride penetration, sulphate resistance, alkali–silica reactivity, and shrinkage tests. Microstructural analysis using SEM, XRD, and porosity measurements will establish correlations between binder chemistry and performance. Additionally, a life-cycle assessment (LCA) will quantify carbon and energy savings compared to OPC-based UHPC. Early studies and literature confirm that optimized G-UHPC mixes can reduce embodied carbon by 50–70%, while achieving compressive strengths up to 176 MPa, flexural strengths above 20 MPa, and improved toughness due to fibre reinforcement. Building on these findings, this project is expected to deliver optimized G-UHPC mixes ≥150 MPa, durability results confirming resistance to aggressive environments, and LCA findings demonstrating substantial CO_2 reduction.

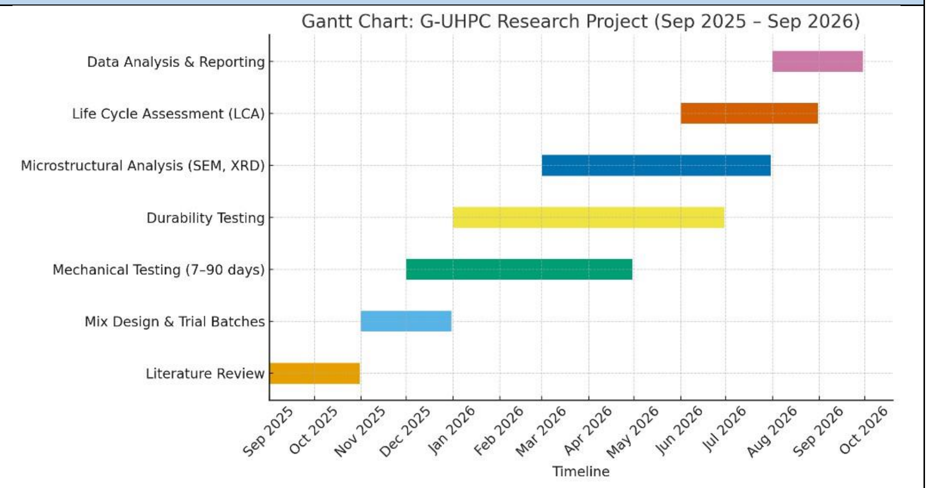
		Aligned with WURI categories A3 and A8, and directly supporting SDG 9, SDG 11, and SDG 13, this initiative enhances WUB's research capacity and contributes to global efforts for greener, more resilient infrastructure.
Details of Program		
Planning		
Objectives	Long-term Goals	• To establish WUB's research capacity in low-carbon, geopolymer-based concretes through sustained experimental and analytical studies. • To develop a comprehensive database of mix proportions, mechanical and durability performance, and microstructural characteristics of G-UHPC to serve as a foundation for future development. • To develop collaborations with local industry and government agencies to explore pilot-scale applications in selected infrastructure projects. • To strengthen student training and skill development in sustainable construction materials through theses, workshops, and lab-based learning.
	Short-term Targets	• To optimize G-UHPC mix proportions by adjusting binder–activator ratios, fibre dosage, and water-to-binder ratios. • To conduct comprehensive mechanical property testing (compressive, tensile, flexural) at 7, 28, 56, and 90 days. • To assess durability performance through chloride penetration, sulphate resistance, shrinkage, and alkali–silica reactivity tests. • To perform microstructural analysis (SEM, XRD, porosity) to correlate material phases with performance. • To complete a life-cycle assessment (LCA) quantifying CO_2 and energy savings relative to OPC-UHPC.
	Rationale	Ordinary Portland Cement-based UHPC, though capable of exceeding 150 MPa strength, is environmentally unsustainable, requiring 750–1200 kg of cement per cubic meter and contributing to nearly 8% of global CO_2 emissions. Geopolymer-based UHPC (G-UHPC) offers a promising alternative by using fly ash, GGBFS, and metakaolin as binders, potentially reducing embodied carbon by 50–70% while reaching compressive strengths up to 176 MPa and offering superior durability against chloride, sulphate, shrinkage, and thermal effects. Despite this promise, adoption is limited by the absence of standards, curing requirements, and activator handling issues. This project addresses these gaps by generating reliable experimental data, life-cycle assessments, and microstructural insights, ultimately contributing to scalable applications and supporting both Bangladesh's infrastructure sustainability goals and global carbon reduction efforts.
Subject (Leader)	Initiator(s)	PROVASHA, Afra Anam
	Champion(s)	PROVASHA, Afra Anam

	Major team member(s)	RAHMAN, Taimur; MOMIN, Md. Farhad; HASAN, Md. Hasibul
Environment	Nature/Society	Bangladesh's natural and social environment creates both challenges and opportunities for this program. High humidity, saline exposure in coastal regions, and sulphate-rich soils increase the demand for durable materials, making G-UHPC highly relevant. At the same time, rapid urbanization and population growth drive societal pressure for sustainable, long-lasting infrastructure. Public awareness of climate change and the need to reduce carbon emissions also creates a favorable context for adopting innovative, low-carbon concretes. However, societal familiarity with conventional materials means that acceptance of new alternatives will require awareness-building and demonstration projects.
	Industry/Market	The construction industry exerts a strong influence on this program by creating demand for durable and sustainable materials. The ready availability of industrial by-products such as fly ash and GGBFS provides a cost-effective raw material base that supports research on G-UHPC. At the same time, the industry's reliance on conventional cement, the absence of design codes, and limited market awareness act as restrictions on rapid adoption. Demonstrating the performance, cost-benefit, and scalability of G-UHPC through this project will help reduce these barriers and prepare the market for future use.
	Citizen/Government	Government priorities in Bangladesh emphasize climate action, sustainable cities, and resilient infrastructure, which strongly support this program. Policies encouraging the use of industrial by-products in construction also create a favorable environment for G-UHPC research. Citizens, on the other hand, are increasingly aware of the need for safer, longer-lasting, and environmentally responsible infrastructure, which builds societal acceptance. However, the absence of formal standards and regulatory frameworks for geopolymer concretes currently imposes a limitation on widespread implementation. This program, by generating reliable data and demonstrating performance, can help pave the way for future policy inclusion and broader public acceptance.
Resources	Human resources	The program is driven by a competent faculty team comprising lecturers and experienced assistant professors from the Department of Civil Engineering at WUB. Together, they bring expertise in structural engineering, concrete technology, and sustainability, ensuring comprehensive coverage of both experimental and analytical aspects. The team has a proven track record of collaborative research and publications, which strengthens the program's capacity to deliver reliable outcomes. The current composition of faculty and supporting researchers is well-suited to meet the objectives of the project.
	Financial resources	At present, the program does not have sufficient dedicated financial resources to fully cover all aspects of experimental research and advanced testing. While basic laboratory expenses can be managed through limited institutional funding, additional financial support will be necessary to expand the scope, especially for durability studies, microstructural analysis, and life-cycle assessment. This highlights the importance of pursuing external grants and industry collaborations to ensure the program's continuity and growth.
	Technological resources	The Department of Civil Engineering at WUB is equipped with facilities for mixing, curing, and standard mechanical strength testing, which are sufficient

		for carrying out the initial stages of this program. However, advanced durability tests and microstructural analyses (such as SEM, XRD, and porosity studies) require specialized equipment that is not currently available in-house. To address this, the program recognizes the importance of building collaborations with external laboratories and institutions. Such partnerships will enable access to advanced testing facilities, ensure comprehensive evaluation of G-UHPC, and enhance the credibility and impact of the program's outcomes.
Mechanism	Strategy (Weight/Sequence)	The program gives the greatest weight to the subject (45%), emphasizing faculty expertise and leadership in sustainable concrete research as the foundation for progress. The second priority is resources (35%), focusing on the effective use of existing laboratory facilities, financial support, and collaboration with external laboratories to strengthen research capacity. Finally, the environment (20%) - including societal demand for durable infrastructure and government emphasis on low-carbon materials - provides a supportive backdrop that ensures long-term relevance. This weighting sequence reflects a practical balance, where subject expertise drives the program, resources enable reliable execution, and environmental alignment enhances impact and acceptance.
	Organization	The program is carried out within the Department of Civil Engineering at WUB, where faculty members contribute where faculty members work collaboratively. The existing departmental framework encourages collaboration and provides the academic structure needed to coordinate activities, ensuring that the program's strategies are supported and effectively implemented.
	Culture	The university's culture is supportive of research in sustainable and innovative construction materials. Faculty members are encouraged to engage in collaborative projects, publish their findings, and align their work with global challenges such as climate action and sustainable infrastructure. This culture promotes experimentation, interdisciplinary cooperation, and student involvement, which collectively strengthen the execution of the program.
Doing		
Launch date		October, 2025.
Responsible organization		Department of Civil Engineering, World University of Bangladesh (WUB)
Program content and process		This program seeks to develop Geopolymer-Based Ultra-High-Performance Concrete (G-UHPC) as a sustainable alternative to conventional UHPC, which relies heavily on cement and contributes significantly to global CO_2 emissions. The content of the program is designed around four integrated components: mix design optimization, mechanical and durability testing, microstructural evaluation, and life-cycle assessment. Together, these provide both performance data and sustainability insights to support future industrial adoption. The implementation process begins with the design of trial mixes incorporating industrial by-products such as fly ash, ground granulated blast

	furnace slag (GGBFS), and metakaolin as binders, activated by sodium hydroxide and sodium silicate solutions. Mix variables include binder–activator ratios, steel fibre content (0 - 2%), and water-to-binder ratios. These mixes are cast into standard specimens and subjected to curing under both ambient and accelerated conditions. Mechanical testing is carried out at 7, 28, 56, and 90 days, covering compressive, tensile, and flexural strength, along with toughness and stress–strain behavior. Selected mixes are further examined for durability performance, including chloride penetration, sulphate resistance, shrinkage, and alkali–silica reactivity. To understand material behavior at the micro level, advanced techniques such as SEM, XRD, and porosity analysis are applied, linking binder chemistry and fibre bonding with observed performance. The final stage of the process involves a life-cycle assessment (LCA), which quantifies embodied carbon and energy demand of G-UHPC compared to OPC-based UHPC. Results will be compiled to demonstrate carbon savings of up to 50–70%, alongside equivalent or improved mechanical and durability performance. Through this structured sequence, the program ensures that both scientific rigor and practical relevance are maintained, ultimately producing knowledge that strengthens WUB's research profile while contributing to sustainable construction practices in Bangladesh and beyond.
Key highlights of the content/process	Key highlights of the content: 1. Sustainable binders: Replacement of cement with fly ash, GGBFS, and metakaolin to lower embodied carbon by 50–70%. 2. High-performance outcomes: Target compressive strength ≥150 MPa with improved durability under chloride and sulphate exposure. 3. Integrated assessment: Combination of mechanical, durability, microstructural, and life-cycle evaluation for comprehensive performance insights. Key highlights of the process: 1. Systematic experimental design: Stepwise optimization of binder–activator ratios, fibre dosage, and curing conditions. 2. Standards-based testing: Use of ASTM/ACI protocols for reliability and comparability of results. 3. Collaborative approach: Faculty-led initiative involving interdisciplinary inputs and research-driven teamwork within WUB.
Differences from traditional approaches	Traditional UHPC relies on very high cement content (750–1200 kg/m^3) and silica fume, resulting in high cost and significant CO_2 emissions. In contrast, this program develops geopolymer-based UHPC, where industrial by-products such as fly ash, GGBFS, and metakaolin replace cement. This shift is expected to reduce embodied carbon by 50–70%, lower dependence on resource-intensive materials, and improve durability against chloride, sulphate, and shrinkage-related damage. While conventional UHPC focuses mainly on mechanical strength, this program integrates life-cycle assessment, microstructural analysis, and sustainability metrics into the design process, ensuring that performance and environmental impact are addressed together.

Progress as of today	The program has completed planning, literature review, and preliminary mix design. Full experimental work is scheduled to begin after July 2025, according to the project timeline.
Problems in implementation	The program is limited by in-house facilities, which allow only mixing, curing, and basic strength testing, while advanced durability and microstructural analysis require external access. Handling and cost of alkaline activators present safety and logistical challenges. Consistent sourcing of industrial by-products is uncertain due to regional variations. In addition, the absence of established codes and standards for geopolymer concretes restricts wider acceptance.
Approaches to solve the problems	To address laboratory limitations, the program focuses first on tests that can be reliably conducted in-house, while planning collaborations to access advanced durability and microstructural facilities as needed. Safety concerns with alkaline activators are managed through strict lab protocols, protective equipment, and controlled handling procedures already established in materials research. For material sourcing, multiple suppliers are being identified to ensure consistency and quality, supported by preliminary testing of raw materials before mix design. Finally, in the absence of specific standards, the program follows ASTM and ACI procedures as benchmarks, ensuring that results remain credible and comparable until geopolymer-specific codes are developed.
Completion date, if completed	The program is currently in the literature review stage, with the experimental phase scheduled to begin in October 2025. The first phase, which will include mix design, mechanical and durability testing, and preliminary analysis, is expected to be completed by March 2026. Progress will then be reviewed against the stated objectives.
Seeing	
Impacts on students	The program will provide students with exposure to advanced materials research, training in experimental methods, and opportunities for theses and publications. This will strengthen their skills in sustainable construction practices and enhance employability.
Impacts on professors	Faculty involved in the program gain opportunities to publish, collaborate, and advance their expertise in geopolymer and UHPC research, enhancing their academic profile and research capacity.
Impacts on university administration	The program contributes to WUB's research visibility and aligns with its goal of promoting sustainable engineering solutions. Successful outcomes are expected to enhance the university's standing in both national and international academic communities.
Responses from industry/market	Industry interest is anticipated due to the program's focus on cost-effective, durable, and low-carbon materials. Demonstrated results could lead to pilot-scale collaboration in infrastructure projects.
Responses from citizen/government	The program supports Bangladesh's climate action and infrastructure resilience goals. Positive responses are expected from government agencies

	and citizens as the research aligns with sustainability and community development needs.
Measurable output (revenues)	At this stage, no direct revenue has been generated. Future outputs may include research grants, industry funding, and collaborative projects.
Measurable input (expenses)	The initial phase of the program is being supported mainly through personal funding by faculty members, with limited backing from the university. These contributions cover essential costs such as raw materials, specimen preparation, and standard mechanical testing. While adequate for conducting the core experimental work, advanced testing and large-scale studies will require additional external support in the future.
Cost-benefit analysis for effectiveness	The program requires substantial funding to conduct the full scope of experimental work, including durability and microstructural studies. Although the initial costs are higher than conventional concrete research, the expected outcomes make the investment worthwhile. By achieving compressive strengths above 150 MPa, reducing embodied CO_2 by 50–70%, and extending the service life of infrastructure, G-UHPC offers significant long-term economic and environmental benefits. When considered over the entire life cycle, the projected savings from reduced maintenance and enhanced durability outweigh the upfront financial requirements, indicating a favorable cost–benefit balance.
Future Planning	
Where does the project go from here?	After the first phase concludes in March 2026, the program will advance to more detailed durability and microstructural investigations, utilizing advanced testing through external collaborations. Efforts will also be directed toward securing external research grants and government or industry funding to strengthen financial and technological capacity. In the longer term, the outcomes will feed into guideline development, and training workshops, equipping future engineers with expertise in low-carbon concrete technologies. Through these steps, the program aims to establish WUB as a recognized center for sustainable concrete research in Bangladesh, while contributing to national climate goals and global sustainability initiatives.
Addendum	
Exhibits, pictures, diagrams, etc.	

Reports, mimeos, monographs, books, etc.	N/A
Others which may help explain the program (including website links)	N/A