DEVELOPING SUSTAINABLE INNOVATIVE WEATHER-RESISTANT CLADDING UNIT FOR BUILDINGS IN A TROPICAL CLIMATE

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ABSTRACT

Wall cladding units are expected to provide environmental, social, and structural benefits to building occupants and owners. However, the cladding systems currently in use do not offer adequate sustainability and structural benefits. This study aimed to use post-consumer plastic waste in a typical tropical climate to develop a sustainable weather-resistant wall cladding unit. In phase one of the study, a survey of 102 built environment professionals in Ghana (a tropical climatic zone) revealed that the effects of weather elements on cladding units in the study area are predominantly due to rain (moisture), temperature, and sunlight. Phase two involved the application of ASTM D618, D570, and D6954 laboratory procedures to design, mould, and test a plastic wall cladding unit of size 235 mm × 450 mm × 18 mm, resulting in the development of a weather-resistant and environmentally sustainable wall cladding unit. The selection of cladding units for buildings in tropical climates should be guided by water resistance and environmental performance. This study contributes to achieving the broader objectives of sustainable construction in developing countries.

KEYWORDS: *Cladding units, plastic waste, water-resistant materials, weather elements.*

1.0 INTRODUCTION

The construction industry has advanced significantly with the advent of wall cladding technologies, such as circular bio-based systems, glass curtain wall systems, aluminium composite panels (APC), and fiber-cement panels (Cascione et al., 2024; Li and Chen, 2022; Paktiawal and Alam, 2021). With these new affordable options, building or renovating a house on a low budget is becoming much easier. According to Darko et al. (2017), cladding is a solution that has significantly transformed the construction business by enabling property owners to rapidly and easily alter the durability and appearance of their properties. Claddings are constructional materials that are applied as lateral coverings of materials or the skin of the superstructure of buildings. Cladding is used to protect against weather elements, insulate buildings, and enhance their aesthetic value (Li and Chen, 2022). The first line of defence in a wall assembly is cladding. Therefore, safeguarding the inside of the building and the most delicate parts of the wall assembly is essential.

Cladding systems have many potential advantages when they are properly designed and built. However, these benefits can quickly be eroded if the cladding is not designed, manufactured, and installed correctly (Lopes et al., 2018). Most of the cladding systems in use allow for the penetration of weather elements, such as rain, snow, or hail, into the wall cavity (Lopes et al., 2018). Therefore, careful innovation and detailing are required to control the effects of moisture and other weather elements on the external surfaces of buildings. The wall and wall cladding systems used in Ghana and much of sub-Saharan Africa are predominantly heavy, cement-based, and poorly climate-responsive. This results in high embodied carbon, increased indoor heat gain, moisture-related deterioration, and limited long-term durability in tropical weather conditions (Opoku et al., 2020). In addition, cladding problems in the sub-region, that is, West Africa, including Ghana, go beyond the effects on the structural integrity of buildings to engender harmful disturbances on the health and well-being of building occupants, facilities, and the indoor environment (Oliver, 2007). Because of the varied effects of improper wall cladding systems, it is critical to investigate how weather elements affect cladding systems to develop innovative solutions. Although wall cladding systems are becoming increasingly popular in Ghana, there is no empirical data on their performance in tropical climates with high temperatures, constant humidity, and heavy rainfall. Most current cladding options are derived from designs for temperate climates and mostly rely on cement-based or composite materials, which are vulnerable to moisture intrusion, thermal inefficiency, and accelerated surface deterioration under extended wet-dry cycles and strong sun exposure. There is a significant knowledge gap in climate-responsive cladding solutions for tropical environments, since current studies mostly report failures without addressing the underlying mismatch between material attributes and local environmental needs (Halawa et al., 2018). Consequently, few studies have been conducted on regionally adaptable, sustainable materials that can improve environmental performance, durability, and weather resistance (Halawa et al., 2018). Our study fills this gap by creating and testing a weather-resistant wall cladding unit made from plastic waste that is especially suited to Ghana's tropical climate. Therefore, this study aims to ascertain the impact of weather factors, including wind, rain, sunlight, and temperature variations, on cladding units in Ghana and to design an innovative cladding unit that would effectively mitigate the situation.

2.0 LITERATURE REVIEW

2.1 Challenges Associated With Wall Cladding Systems

A cladding system may be affected by problems associated with cladding fixing. These problems include incorrect installation methods (which can lead to the pulling away of cladding from the substrate), improper sealing (which leads to water infiltration and damage), inadequate or improper fixing materials such as using the wrong type of screws or adhesives that cannot withstand weathering (causing cladding to loosen or fall off), uneven surfaces, and inappropriate load-bearing capacity of substrates (resulting in ineffective cladding attachment) (Hugney, 2013). Silva et al. (2018) also noted that failure in cladding units can be caused by factors such as: cladding construction problems; weather elements such as rain, wind, and temperature; the age of cladding units; and precision and dimensioning of cladding units. Corroded metal cladding causes brittleness in cladding units, leading to potential safety hazards. Where deterioration of materials occurs due to age or weathering, there is difficulty in removing cladding without causing further damage to the substrate (Isaacs et al., 2016).

Preventing moisture infiltration or accumulation, which can cause damage to the substrate or lead to the growth of mould or mildew, is very important in cladding construction (Colantonio and Desroches, 2005). Weather elements such as rain, wind, sunlight, and temperature fluctuations can cause stress on cladding units, leading to deformation, cracking, or detachment over time. Cladding construction problems include water infiltration, which can occur due to gaps or leaks in the cladding, leading to water damage and mould growth. Temperature fluctuations can cause cladding systems to expand and contract, leading to distortion, detachment, reduced insulation capabilities, cracking, and other forms of damage (Mishra et al., 2022). This is especially true for materials such as metals and glass, which have a high coefficient of thermal expansion (Mishra et al., 2022). Proper design and installation can help minimise the effects of temperature on cladding systems (Abu-Jdayil et al., 2019). Thermal expansion can cause the cladding to buckle or warp, potentially leading to structural issues. Wind loading can damage the cladding or loosen its attachment to the substrate (Douglas and Ransom, 2013). The age of cladding units can affect the overall integrity of the cladding system, as wear and tear, exposure to weather elements, and outdated materials may compromise the system's structural integrity and energy efficiency over time (Gaspar, 2017).

2.2 Driving Innovation and Sustainability in Wall Cladding

Following the discussion of the challenges associated with wall cladding systems, recent research emphasizes that innovation in materials is central to engendering sustainability and achieving weather resistance in tropical contexts. A convergent benefit of a weather-resistant cladding system is the reduction in operational cooling loads while minimising embodied impacts. Therefore, contemporary studies examine cladding not only as a finish but also as an active part of the building's thermal, material cycle, and service life strategy. For example, Ansah *et al*. (2020) show, through a BIM-enabled life-cycle comparison of façade options in Ghana, that the selection of façade systems (including stabilised earth block and insulated composite alternatives) can reduce cumulative energy demand and life-cycle cost while also altering global-warming potential. This illustrates how material choice and whole-life analysis drive sustainable outcomes for tropical building (Ansah et al., 2020).

The integration of digital workflows and multi-objective optimisation to trade off thermal performance, lifetime implications, and cost is the second area of innovation. To determine Pareto-optimal cladding assemblies for residential buildings, Atashbar and Noorzai (2023) presented a BIM + LCA framework in conjunction with a non-dominated sorting genetic algorithm (NSGA-II). Their findings show that parametric simulation connected to optimisation can yield cladding solutions that simultaneously reduce energy use and embodied impacts, making optimisation a useful design tool for climate-responsive cladding in hot and humid regions (Atashbar and Noorzai, 2023). The goal of this study, which is to create an "innovative" cladding unit, is directly supported by this method: optimisation and digital evaluation speed up the selection of material stacks and geometries that are sustainable and weather-resistant.

The third area of interest is material innovation and circularity. When durability and treatment issues are addressed, bio-derived insulations (such as sheep's wool, cellulose, and mycelium) and demountable panel design can achieve low U-values and significantly lower cradle-to-grave carbon in certain configurations, according to recent experimental and life cycle assessment work on circular bio-based wall panels (Cascione et al., 2024). According to these results, bio-based claddings (or hybrid systems that combine bio-based layers with robust external skins) may be practical for tropical façades if the assembly is designed to withstand moisture, rot, and a long service life.

In addition to material substitution, façade tactics unique to the tropics have also drawn attention. To reduce solar heat gain and building cooling demand, the concept of bio-cooling façades (BCF) combines biomaterials, shading, and ventilation. Empirical and simulation studies conducted in tropical settings show that BCF configurations, such as reduced window-to-wall ratios and the use of ventilated outer layers, can reduce solar ingress and energy consumption while increasing circularity when designed for disassembly (Fadhila, 2024). In tropical regions, where cooling accounts for the majority of energy consumption, these tactics offer a clear direction for weather-resistant cladding.

Finally, smart and dynamic façade technologies provide an additional method for balancing sustainability and weather resilience. Reviews of dynamic and adaptive façades show how automated ventilation, material albedo adjustment, and responsive shading can lower annual energy consumption and enhance thermal comfort—effects that are frequently greater in warm areas when façades actively regulate solar gains (Jamilu et al., 2024). Crucially for the current manuscript, these studies contend that the best chance for a low-impact, weather-resilient cladding unit in the tropics is to combine passive material innovation (insulating, breathable cladding) with low-energy active adaptation (movable screens, ventilated cavities).

Recent studies by Cascione et al. (2024), Fadhila (2024), and Jamilu et al. (2024) present the concepts of whole-life comparative Life Cycle Assessment (LCA), optimisation via BIM and LCA, circular bio-based prototypes, bio-cooling façade designs, and dynamic façade reviews as a coherent body of evidence necessitating innovation in the construction industry. To develop a sustainable, innovative, and weather-resistant cladding unit for tropical buildings, one must: (a) assess assemblies using whole-life metrics; (b) use parametric optimisation to find balanced trade-offs; (c) investigate bio-based and demountable panel technologies while guaranteeing durability; and (d) incorporate passive thermal strategies with suitable adaptive elements. The design criteria and assessment techniques used in this study were directly influenced by these ideas. This study focuses on the use of waste plastics to develop a sustainable product that drives efficient waste management and minimises environmental impact. The next section discusses the properties of plastics to elucidate their suitability for developing weather-resistant plastic cladding units.

2.3 Properties of plastics as building material

Based on the heating behaviour of plastics, they are grouped into thermoplastics and thermosetting plastics (Wu et al., 2014). Thermoplastics or heat non-convertible plastics are general terms applied to plastics because they harden after cooling when heated. The softening and hardening processes can be repeated for a definite number of times, provided that the temperature during heating is not too high to cause chemical decomposition (Christie and Abel, 2021). Thermosetting (heat-convertible) plastics were selected because of their behaviour when heat is applied to them. Thermosetting plastics solidify when moulded at the appropriate temperature and pressure. When they are heated in the temperature range of 127–177 °C, they set permanently, and further application of heat does not alter their forms or soften them; however, at a temperature of 343 °C, burning occurs (Boydston et al., 2018). Thermosetting polymers are composed of long chains of cross-linked molecules. Their structure is relatively stiff. Thermosetting plastics can be moulded, shaped, and compressed into various forms upon heating. After setting, they cannot be reshaped because they are permanently set (Vengatesan et al., 2018).

According to Pascault and Williams (2013), thermosetting and thermoplastics are essentially kinds of polytypes that are primarily distinguished by their molecular bond and heat response. The process of making items from plastic is illustrated in Figure 1. When comparing thermoplastic and thermosetting plastics, the primary distinction between the two is that thermoplastic materials usually have low melting points, which allow for easy recycling or additional remoulding. In contrast, thermosetting plastics are the complete opposite. They can withstand high temperatures, and once hardened, they cannot be reformed or recycled, even with the application of high levels of heat. Epoxy resin and melamine-formaldehyde are the most common examples of thermosetting plastics, whereas polystyrene, Teflon, acrylic, and nylon are common examples of thermoplastics (Vengatesan et al., 2018; Pascault and Williams, 2013).

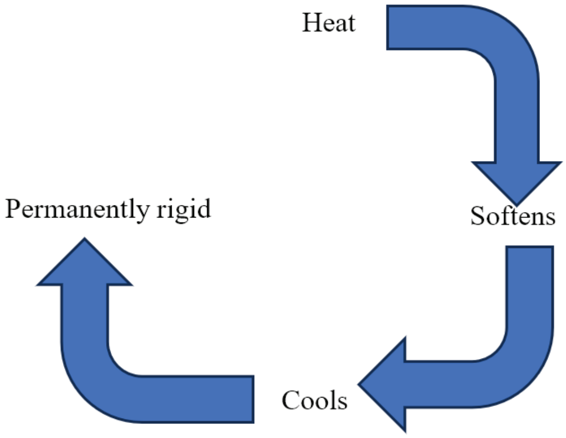

Figure 1: Plastic product formation through heat (Source: Boydston et al., 2018).

Table 1: The compelling differences between thermoplastic and thermosetting plastic for the material selection

Thermoplastics	**Thermosetting plastics**
Thermoplastic can be synthesised by the process called addition polymerisation	Thermosetting plastics are synthesised by condensation polymerisation
Injection moulding, extrusion, blow moulding, thermoforming, and rotational moulding are the methods used to process thermoplastic	Compression moulding and reaction injection moulding are two methods used to process thermosetting plastic.
Thermoplastics have secondary bonds between molecular chains	Strong cross-links and primary bonds between molecular chains hold thermosetting polymers together.
Thermoplastics have low melting points and low tensile strength	High melting temperatures and high tensile strength are characteristics of thermosetting polymers.
Thermoplastic is lower in molecular weight compared to thermosetting plastics	Thermosetting plastic is higher in molecular weight.

Source: (Vengatesan et al. (2018) and Pascault and Williams (2013)).

3.0 METHODS AND MATERIALS

The research design was a hybrid of survey and experimental designs. A quantitative method was used. Through the survey, quantitative data on the effects of cladding were collected from built-environment professionals. The experimental stage of the research allowed the formation of the cladding unit in the workshop and the conduction of tests in the laboratory. The workshop, laboratory processes, and procedures were developed based on the field data obtained and the state of the problem shown by Naoum (2012). Therefore, the aim of the laboratory and workshop activities was to design and form a good cladding unit for proper installation.

The wall cladding unit was made entirely of post-consumer plastic waste, primarily thermoplastic polymers that are frequently found in Ghana's municipal solid waste streams. High-density polyethylene (HDPE) and polypropylene (PP), which are frequently utilised in packaging, containers, and household goods, were the main polymer ingredients based on sorting and material identification before processing. These polymers were chosen because they have beneficial qualities for use in buildings, such as low water absorption, strong thermal stability, chemical resistance, and recyclability. According to earlier studies by Hopewell et al. (2009) and Awoyera and Adesina (2020), HDPE and PP can be extruded and moulded into long-lasting architectural elements, such as cladding systems and façade panels, especially in tropical climates, where moisture resistance is crucial.

The plastic debris used in this study was processed as a single-phase homogeneous material without being blended with fibres, fillers, or additives. After shredding, cleaning, and melting at temperatures suitable for HDPE/PP processing, the polymers were moulded into cladding units with consistent measurements (235 mm × 450 mm × 18 mm). The goal of this study was to demonstrate the viability of creating a weather-resistant cladding unit entirely from plastic waste. Therefore, rather than optimising the material mixes at this stage of development, no change in the component proportions was implemented. This study separated the effects of polymer properties on weather resistance, dimensional stability, and manufacturability by maintaining a constant material composition. This method is in sync with early stage material development research by Pacheco-Torgal (2017) and Silva et al. (2018), where the baseline performance is determined before parametric optimisation, including hybridisation or additives.

The study employed variables structured across both the survey-based and experimental phases of the research. The independent variables included weather elements affecting the cladding performance, such as rain/moisture, wind, sunlight, and temperature variations. The dependent variable was the perceived degree of failure of the cladding systems, as rated by built-environment professionals. This variable structuring aligns with established material-development approaches that combine perception-based diagnostics with laboratory-based validation (Neville 1995; Creswell and Clark, 2017).

This study adhered to globally accepted standards for material processing and testing relevant to construction goods made of polymers. Established standards for plastics and façade materials served as references for fabrication and performance checks, even though the study concentrated on prototype development rather than comprehensive certification testing. These standards include:

- Principles of thermoplastic processing in accordance with American Society for Testing and Materials (ASTM) D618 (Standard Practice for Conditioning Plastics for Testing).
- Water resistance and exposure considerations conforming to ASTM D570 (Standard Test Method for Water Absorption of Plastics), which informs the assessment of moisture resistance relevant to façade applications.

These protocols are widely accepted in construction material research, such as Ashby et al. (2018), and provide a scientifically defensible basis for evaluating early stage façade products prior to advanced mechanical and durability testing that meets globally accepted standards (ASTM, 2010; 2013).

The surface stability of the proposed plastic cladding unit under mildly acidic and alkaline conditions was qualitatively observed through preliminary chemical exposure checks. These tests were not meant to serve as comprehensive, uniform chemical resistance tests; instead, they were restricted to brief exposure and visual inspection for surface softening, discoloration, or degradation. As a result, the observations are presented as suggestive rather than conclusive performance results.3.1 Population, sampling technique and sample size

Table 2: Occupational profile and years of work experience of professionals

OCCUPATION/RANK/ POSITION	NO. IN CATEGORY	%	YEARS OF WORK EXPERIENCE				
			5-10 YEARS	11-15 YEARS	16-20 YEARS	21-25 YEARS	ABOVE 25 YEARS
Site engineer	42	41.18	14	17	8	2	1
Foreman	19	18.63	3	16			
Contractor	13	12.75		9	3	1	
Quantity surveyor	7	6.86	4	2	1		
Project manager	7	6.86	1	4		1	1
Architect	5	4.90		5			
Civil engineer	5	4.90		5			
Structural engineer	4	3.92		3	1		
TOTAL	102	100	22	61	13	4	2

Source: Field survey (2024)

The study population comprised built environment professionals. For this research, the issue to be addressed was to ascertain the impact of weather factors, including wind, rain, sunlight, and temperature variations, on cladding units in Ghana and to design a solution that would effectively mitigate the situation. With that in mind, the population considered was built environment professionals, as presented in Table 2. These built environment professionals were selected using a purposive sampling technique. The inclusion of a respondent was based on confirmation of the professionals' knowledge and experience in cladding unit development and use in the Ghanaian construction industry. The purposive sampling technique was appropriately adopted as it aided in reaching professionals with relevant knowledge about the subject matter (cladding unit development), as recommended by Borjian Yazdi (2023). A minimised representation is that the sample size of the larger population chosen for the study was a finite part of a statistical population whose properties were studied to gain information about the entire population (Flick, 2015). Data relating to materials for developing wall cladding units (Pacheco-Torgal, 2017; Silva et al., 2018) and weather effects (Neville 1995; Creswell and Clark, 2017). were collected from built environment professionals in Ghana through a face-to-face survey.

3.2 Data analysis

The field data collected were analysed using measures of central tendencies such as central tendency use the mean (sometimes called the arithmetic mean), median, and mode to identify the results. For example, a construction company might use measures of central tendency to determine the average age of its employees (Prasad, 2023). The survey items were created as independent diagnostic indicators to capture professionals' perceptions of the relative influence of particular weather elements (rain, temperature, sunlight, and wind) on cladding performance, instead of being a unidimensional psychometric scale meant to measure a single latent construct (Jamieson, 2004). Because internal consistency measures such as Cronbach's alpha are only useful when items are assumed to be highly correlated and jointly assess the same underlying variable, their use was not a requirement. To assess the perceived relative importance of distinct weather-related aspects, measures of central tendency—specifically, mean ratings—were adequate and methodologically sound. This approach is frequently used in construction management and built environment perception research. Concerning the objective to achieve for this research, the data was analysed by making use of the arithmetic mean. The arithmetic mean is given as

$$\overline{X} = \frac{X_1 + X_2 + \ldots X_n}{n}$$

Where:

x = sum of all observations

n = number of observations

3.3 Laboratory and workshop activities

The laboratory and workshop processes and procedures were developed based on the American Society of Testing and Materials (ASTM) D618 (Standard Practice for Conditioning Plastics for Testing) and D570 (Standard Test Method for Water Absorption of Plastics). Therefore, the laboratory and workshop activities were focused on designing and forming a good cladding unit and its proper installation to curb the situation.

To reduce production errors, the following methods were used:

- The formwork was designed and dimensioned appropriately for the effective functioning of the cladding units.
- The appropriate workmanship required in the production process was acquired and applied.

The dimensions chosen for designing the sample cladding unit are listed in Table 3. The purpose of this composition was to develop a product suitable for cladding applications in construction. This was done to address the following characteristics:

- Formation shape and dimensions for unit design;
- Assembling (jointing and fastening) methods;
- Material type for unit and mass production; and
- Surface finish (rough or smooth textured)

Table 3: Design dimensions of cladding unit

	Parameter	Dimension
1	Length	450 mm
2	Width	235 mm
3	Thickness	18 mm
4	Area	0.105 m^2
5	Volume	0.002m^3

Source: Field data (2024) based on ASTM D618

Workshop procedures for preparing the formwork (metal tray)

Steel was chosen for the construction of the metal tray. Steel was chosen for the formwork construction based on the work of Zeng et al. (2025), where steel formwork was used in a novel way in an experimental study. Steel was also adopted because it has a high tensile strength, is hard, durable, and can withstand deformations. A sample of the formwork is presented in Plate 1.

The metal tray was constructed by following these processes:

1. First, the 6 mm thick soffit plate of the metal tray was checked for serviceability. The measurements were marked on the surface of the soffit plate. It was then cut to the correct size (486 mm × 636 mm) as required by the metal tray design, which was in line with the experimental cladding unit size.
2. The square pipes used as the side and middle pipes were checked for serviceability and measurement markings. The side pipes were then cut to the required length and width of 450 mm and 636 mm, respectively. The middle pipes were also cut to a length of 450 mm.
3. After the soffit plate and side pipes were cut to the correct sizes and lengths, a trial assembly of the metal tray parts was conducted to determine the shape and function of the metal tray.
4. Furthermore, the final assembly of the metal tray was performed by welding the various parts of the metal tray.
5. Pins of approximately 3 mm diameter (solid) were also welded on the edges of the soffit plate to create holes to aid in the jointing of the cladding unit to the background for which it was to be used.
6. Round pipes of approximately 4 mm diameter were measured and cut to the required sizes, which were inserted around the pins before the unit was cast.
7. A top plate with the exact dimensions of the metal tray was also checked for serviceability and cut to the required size. Holes were drilled on the top plate at the positions where the 3 mm pins were welded on the soffit plate.
8. Locker pins were required to provide locker joints with 4 mm pipes on the top plate to lift the top plate together with the hollow pipes. Tables 4 and 5 show the power machines, tools and equipment list, and the cutting list of materials, respectively.

Plate 1: The metal tray (formwork)

Source: Authors' own work (2024)

Table 4: Power machines, tools, and equipment list for the construction of the experimental cladding unit metal tray

S/NO	TOOL NAME	TYPE	QUANTITY	REMARKS
1	Welding machine	Electric	1	Serviceable
2	Cutting machine	Electric	1	Serviceable
3	Drilling machine	Electric	1	Serviceable
4	Square	Try-square	1	Serviceable
5	Tape measure	Steel – 5m length	1	Serviceable
6	Marker	Temporal	1	Serviceable

Source: Field data (2024) based on ASTM D618

Table 5: Cutting list for the experimental cladding unit formwork

S/NO	ITEM	QUANTITY	SIZE	REMARKS
1	Soffit plate	1	486mmx636mmx6mm	Serviceable
2	Side pipe (length)	2	450mmx18mmx18mm	Serviceable
3	Side pipe (width)	2	636mmx18mmx18mm	Serviceable
4	Top plate	1	486mmx636mmx2mm	Serviceable
5	Pins	12	3mm x18mm	Serviceable
6	Round pipes	12	4mmx22mm	Serviceable

Source: Field data (2024) based on ASTM D618

3.4 Production of the cladding unit

Workshop procedures for forming the cladding unit

1. The raw plastic material was heated at a temperature range of 127 °C to 177 °C (Boydston et al., 2018) to obtain a paste state.
2. The inside of the metal tray (formwork) prepared for casting the cladding unit was oiled for easy removal of the unit
3. The paste was poured into a metal tray.
4. The unit was allowed to set and cool at room temperature before being removed from the metal tray by carefully dismantling the metal tray.
5. The unit was cured with water for 24 h.

4.0 RESULTS

4.1 The weather elements that affect cladding units

Of 120 questionnaires administered to professionals, 102 were retrieved. This represents an 85 % response rate, which is acceptable for this study (Yu and Qian, 2018). From Table 2, Forty-two (42) out of the One hundred and two (102) site professionals were site engineers. This represented 41.18 % of the total responses, and 14 of them had 5-10 working experience and 17 of them had 11-15 years of working experience in the construction industry. Nineteen professionals (18.63 %) were site foremen, with three of them having 5-10 years of working experience and 16 of them having 11-15 years of working experience in the construction industry. This means that the majority (59.81

%) of the total respondents were directly involved in site activities, which gives credibility to the data obtained and shows the knowledge and experience of the site professionals and their level of exposure to the use of cladding units. Thirteen (12.75 %) of the professionals were contractors, quantity surveyors, and project managers had 7 (6.86 %) number each, and architects and civil engineers each numbered five (5.90 %), while there were four (3.92 %) structural engineers who took part in the survey.

Table 6: Weather elements that cause defects to cladding units

S/N	WEATHER ELEMENTS THAT CAUSE DEFECTS TO CLADDING UNITS	MEAN RATING	RANKING
1	Wind	3.84	4TH
2	Rain	1.18	1ST
3	Sunlight	2.58	3RD
4	Temperature	2.27	2ND

(
Source: Field survey, 2024) *(Key: ratings are from 1-4, with 1 as the highest and 4 as the lowest.*

As shown in Table 6, the researchers needed to determine which weather element caused serious defects to the cladding units, with each weather element assigned a rating based on its perceived impact on the cladding units. The key indicates that lower mean ratings represent a higher severity. Rain with a mean rating of 1.18 was the most important weather element identified in the research. Temperature, with a mean rating of 2.27, ranked second in terms of its impact on the cladding units, according to the knowledge and experience of the site professionals. Again, sunlight, with a mean rating of 2.58, ranked third in impact by the site professionals based on their experience and knowledge of cladding construction. Finally, wind, with a mean rating of 4.84, was ranked last by the site professionals.

After applying ASTM D618 (Standard Practice for Conditioning Plastics for Testing), the final product, as presented in Plate 2, was achieved. The allowable temperature range for heating that allowed for formation into the steel form shape, settling, and cooling without cracks in the final product was 127 °C to 177 °C.

Plate '2': Sample of the produced cladding unit

Source: Field data (2024)

4.3 Temperature deformation tests on the cladding unit

Based on ASTM D618 (Standard Practice for Conditioning Plastics for Testing) and ASTM D6954 (Standard Guide for Exposing and Testing Plastics), a temperature deformation test was conducted on the cladding unit to ascertain its thermal resistance. High temperatures are commonly employed in controlled laboratory settings to accelerate thermal effects and assess the material stability, deformation potential, and mass change (ASTM, 2013). Owing to solar radiation, façade and cladding surface temperatures are often reported to be higher than ambient air temperatures in tropical locations. External wall surfaces can reach 50–70 °C during peak insolation, especially for dark or poorly ventilated façades. To assess the material robustness, dimensional stability, and resistance to thermal softening beyond typical service conditions, 100 °C was chosen as an accelerated thermal exposure level, whereas 50 °C is a realistic upper-bound surface temperature for cladding in tropical climates. These high conditioning temperatures are consistent with standard polymer testing procedures for determining compatibility for screening in high-temperature service settings.

Table 7: Temperature deformation test results

	50°C		**100°C**	
TIME	30 min	60 min	30 min	60 min
Initial weight (g)	34.5	52.9	26.7	33.4
Final weight (g)	34.5	52.9	26.7	33.4
Weight change	0	0	0	0

Source: Field data (2024) based on ASTM D618 and D6954

Table 7 shows that the percentage change in weight due to the thermal effect was negligible at 50 °C and 100 °C. This indicates that the cladding unit has strong thermal resistance and is appropriate for settings with moderate heat exposure, as it did not lose moisture, deteriorate, or exhibit thermal decomposition at these temperatures. As a result, with mild heating, the material maintained its chemical and dimensional stabilities.

5.0 DISCUSSION OF RESULTS

The field survey revealed that failures in cladding units are primarily caused by rain (moisture). Therefore, it was ensured that the unit produced did not allow water to find its way into the content and background of the cladding unit; thus, the unit produced was rain-resistant and, to a great extent, free from production errors. To ensure that the unit produced was rain-resistant, a water-resistant material was selected to form the cladding unit. Thermosetting plastics were chosen as the appropriate material for the formation of the cladding unit. Plastics are extracted from crude oil and are strong and resistant to weather elements. Their temperature can be raised for it to become soft, but it becomes hard again after the temperature is reduced (Kehinde et al., 2020). Plastic is becoming increasingly important in the construction industry because of its easy bonding system (polymerisation). Polymerisation is the process of taking a few (micro) molecules of plastic and converting them into a macro molecule (Schyns and Shaver, 2021). Polymerisation occurs in the presence of monomers, which are molecules of plastic. Monomers must combine to produce polymers (chains) (Balla et al., 2021). Polymers form a particular plastic depending on the nature of their chains.

The analysis of the field data revealed that the failure of cladding units by weather elements is greatly caused by rain (moisture) and temperature fluctuations. To overcome the effects of rain on the cladding unit, a rain-resistant material (waste plastic) was used to form the sample wall cladding unit. This ensured that the unit produced did not allow water to find its way into the content and background of the cladding unit; thus, the unit produced was rain-resistant. Despite its lightweight nature, plastic shields buildings from rain, sun, snow, wind, and temperature fluctuations when used as exterior materials (Cousins, 2022). Chemical deformation tests (acidic and alkaline) and temperature deformation tests were conducted on the finished product to show the product's resistance to these chemicals and extreme temperatures, as the product is going to be applied in warm climate conditions. While the developed cladding unit demonstrated favourable resistance to moisture ingress and maintained surface integrity under elevated temperature exposure, its performance under acidic and alkaline environments should be interpreted as preliminary. Comprehensive chemical resistance testing in accordance with relevant standards is required to fully characterise the long-term durability under aggressive environmental conditions. There were no effects of acid and alkaline on the cladding product, even at higher concentrations. The unit also exhibited resilience to higher temperatures of up to 100 °C.

The knowledge and experience of the site professionals with cladding units indicate that rain contributes to more serious defects in cladding units than any other weather element identified in the research. Moisture penetration into cladding units as a result of leakage in the roof, dampness, and rain affects cladding units the most. Extreme temperatures can cause cladding systems to expand and contract, leading to cracking and other forms of damage. Heavy sunlight can cause the cladding unit to fade and discolour over time. Sunlight can also cause the cladding material to become brittle and crack, leading to further damage. This can affect the appearance of buildings and reduce their value. In summary, respondents ranked the weather elements that affect cladding units in the order of higher severity as rain, temperature, sunlight, and wind, respectively. Addressing these factors during the design, manufacturing, and installation processes is crucial to prevent the effects of these weather elements on cladding units.

An important development in sustainable façade technology for tropical regions is the creation of novel weather-resistant cladding units from recycled plastic waste. The fabrication method, which includes controlled melting, moulding into a 450 mm × 235 mm × 18 mm design, and performance verification against thermal exposure and rain penetration, is in line with new research supporting low-carbon, robust, and versatile façade solutions. The results support the larger body of research that argues that sustainable building envelopes in poor economies can only be achieved through material innovation, circularity, and climate-responsive façade engineering design.

The results indicate that, in terms of moisture resistance, dimensional stability, and environmental sustainability, the developed recycled plastic cladding unit may serve as an alternative external wall finishing solution to traditional cement-sand plaster. However, because thorough evaluations of mechanical strength, fire performance, impact resistance, and long-term weathering were outside the purview of this study, it cannot yet be claimed to be a straight one-to-one replacement. The results indicate that recycled plastic trash can be designed as a structurally sound exterior cladding unit that can replace the conventional cement-sand plaster used on building façades. This is a significant innovative outcome of this study. This result validates the proposal made by Cascione et al. (2024) for scalable circular-material solutions in façade design, in which high-performance panels are created by reconfiguring waste-derived and biobased materials. Two sustainability imperatives are addressed by the successful conversion of plastic waste into a useful cladding product: removing significant amounts of plastic from the waste stream and lowering the embodied carbon and lifecycle emissions related to cement and sand plaster, the production processes of which are well known to be carbon-intensive.

The performance characteristics noted, especially the ability to tolerate warm, humid weather and resistance to rain penetration, highlight the applicability of the unit in tropical climatic environments. These features align with the climatic design concepts outlined by Fadhila (2024), who stressed the significance of façade systems that reduce cooling loads and improve material longevity by moderating solar heat gain and preventing moisture penetration into the building. When produced appropriately, plastic has great impermeability and low water absorption, which directly contribute to its weather resistance. This characteristic makes the recently created cladding unit an appropriate barrier layer in areas that experience heavy rainfall and prolonged wet seasons.

Additionally, the use of a bespoke metal mould during the moulding process guaranteed dimensional precision and decreased production errors. This is consistent with the platform promoted by Atashbar and Noorzai (2023) in terms of optimisation and manufacturing efficiency, where controlled production and precise design significantly improve façade performance and reduce long-term maintenance concerns. Additionally, a robust and consistent cladding unit enhances constructability, uniformity in installation, and compatibility with various wall substrates, all of which are essential for acceptance in actual construction practice.

The results also corroborate the viewpoints on whole-life sustainability that have been discussed in previous research. When recycled into long-lasting façade components with lower maintenance profiles, plastics' durability and non-biodegradable nature—which present environmental problems in landfills—become favourable. Ansah et al. (2020) showed that façade alternatives with longer service lives and lower end-of-life burdens significantly reduce life-cycle energy consumption and environmental effect, which is consistent with this observation. The circular value chain is further improved by the plastic cladding unit, which is potentially recyclable at the end of its useful life.

Crucially, the successful manufacturing of the cladding unit shows great potential for technological localisation and scalability. Technical universities, regional businesses, and small-scale manufacturing companies can adopt the invention without depending on expensive, energy-intensive equipment, owing to the implementation of standard workshop and laboratory procedures. This localisation is in line with the larger policy orientation in many developing economies, which aims to strengthen the local industry through the transfer of green technologies and innovative materials.

Overall, the results show that the created plastic waste cladding unit meets critical climatic, functional, and sustainability requirements and has great potential as a substitute façade finish in tropical areas. The results support the claims made in the literature that innovation in cladding must be based on precision design, material circularity, and environmental responsiveness. By putting these ideas into practice, this study adds a useful prototype to the expanding corpus of research on sustainable building envelopes and provides a viable remedy for the environmental effects of the construction industry as well as the world's plastic waste problem.

6.0 CONCLUSION

The goal of this study was to repurpose plastic trash through controlled melting and mould-based fabrication to create a novel, sustainable, and weather-resistant cladding unit appropriate for buildings in tropical areas. The findings show that recycled plastic can be designed as a long-lasting, dimensionally uniform, and climate-resistant façade element that can replace traditional cement-sand plaster on external walls. The proposed unit satisfies the functional, environmental, and service life requirements for tropical building envelopes by attaining resistance to rain penetration, stability in warm climates, and reduced production faults. By demonstrating how circular material principles (typically investigated in conceptual or laboratory contexts) can be operationalised into a functioning cladding prototype, this study adds to the theoretical debate on sustainable façade systems. By proving the feasibility of high-performance cladding units made completely from waste streams, it expands façade sustainability theory and advances models that view materials as strategic agents of environmental restoration and carbon reduction, in addition to thermal and aesthetic building components. Furthermore, the results support the theoretical claims regarding the incorporation of climate-responsive features into façade assemblies, particularly in hot and humid regions, where the building envelope performance is determined by thermal loading and moisture control.

In practical terms, the created recycled plastic cladding unit provides an inexpensive, low-maintenance, and locally produced substitute for conventional plaster finishes. It provides building professionals with a façade solution that lowers embodied carbon, expedites installation, and improves durability in regions with heavy rains and extended heat exposure. The innovation is positioned for adoption by local artisans, technical universities, and small-scale manufacturers, owing to the simple production process, which makes use of widely accessible workshop technologies. This promotes green building practices and the localisation of sustainable building materials in economies with limited resources, such as Indonesia.

These results have significant social implications. This study offers a means to solve urban waste management issues and promote green entrepreneurship by turning plastic waste into a useful building material. By keeping non-biodegradable plastic out of landfills and waterways, the product promotes national sustainability objectives, creates jobs in the building and recycling sectors, and improves the urban landscape. It is an egalitarian alternative for low- and middle-class households that require long-lasting and climate-resilient housing finishes owing to its affordability and durability.

The integration of recovered plastic waste into a logically designed cladding unit that is especially suited to the needs of a tropical climate makes this research unique. This study presents a novel method that repurposes post-consumer plastics into structurally sound and weather-resistant façade elements, in contrast to previous research that focuses on bio-based or composite materials. Together, the customised mould design, regulated heat processing, and favourable performance results demonstrate an innovative manufacturing process that is both scalable and context-specific.

The lack of extensive mechanical, fire resistance, and long-term durability testing necessary for complete certification as a façade system is a significant study constraint. To determine the complete replacement capability of the designed cladding unit compared with cement-sand plaster systems, future research should include standardised fire behaviour tests, cyclic weathering, impact resistance, and load-bearing evaluations. Thorough performance testing of the cladding unit, including thermal conductivity, UV resistance, fire behaviour, mechanical strength, and long-term durability under dynamic weathering conditions, should be conducted in future research. The environmental benefits of this approach should be further evaluated through comparative life cycle assessment (LCA) studies utilising various cladding materials. To enhance fire safety and structural performance, research could also investigate design optimisation using parametric modelling, integration with insulating materials, aesthetic surface texturing, and possible hybridisation with bio-based or mineral additions. To verify constructability, user experience, and field performance under real-world circumstances, pilot deployment on full-scale buildings is advised.

AUTHORS' CONTRIBUTIONS:

Sarfo Mensah: Conceptualisation; Writing – Review & Editing; Project Administration; Validation; Resources

Mark Osae Afful: Data Curation; Methodology, Formal Analysis, Writing – Original Draft Preparation

Collins Ameyaw: Resources, Writing – Review & Editing,

Nanyin Kobina Orgen: Supervision

Addo Koranteng: Writing – Review & Editing,

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