A New Prosthetic Ecosystem of the Future: Comprehensive Review of a Contextual Example 'Green Field Factory of Karupannya Rangpur Limited'

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Abstract
Creating a sustainable foundation for the future is crucial in today's world, especially when it comes to socioeconomic sustainability and resilience in nations like Bangladesh. The country's economy revolves around three main sectors: agriculture, garments, and remittances. Being a developing country, industrial development is growing rapidly with the establishment of large numbers of industrial buildings, which also impacts the environment and ecosystem, natural resources and elements as well as the socioeconomic structure of society to the overall working environment. In this context, the Green Field of Karupannya Rangpur Factory was established with the notion to set an example of a sustainable factory that has a minimum impact on the environment and ecosystem, implying innovative natural resources consumption and management system and bringing in positive changes in socioeconomic structure. This paper aims to conduct a comprehensive review of the factory by understanding the design strategies and operation process of the factory, evaluating the performance of the factory based on the GBRS (LEED) rating system, and compliance with the Sustainable Development Goals (SDG). Finally, the paper develops a conceptual strategic framework for a sustainable factory ecosystem of the future.

Keywords: Eco-system, natural elements, workplace, SDG.

1. Introduction

In today's rapidly evolving world, the need to establish a sustainable foundation for the future is of utmost importance. This is particularly crucial in developing nations such as Bangladesh, where the pursuit of socioeconomic sustainability and resilience is essential. Bangladesh's economy heavily relies on three main sectors: agriculture, garments, and remittances. While these sectors have significantly contributed to the country's growth, the rapid pace of industrial development has posed significant challenges to the environment, natural resources, and the socioeconomic structure of society. To address these challenges, the concept of sustainable development has gained traction, emphasizing the need for environmentally friendly and socially responsible practices. One notable example of such an endeavor is the Karupannya Rangpur Factory, a greenfield project aimed at setting a benchmark for sustainable factories. This factory strives to minimize its impact on the environment and ecosystem, employing innovative approaches to natural resource consumption and management while bringing positive changes to the socioeconomic fabric of the region. The primary objective of this paper is to conduct a comprehensive review of the Karupannya Rangpur Factory. The review will delve into the factory's design strategies and operational processes, evaluating its performance based on the GBRS

(LEED) rating system. Additionally, the paper will assess the factory's compliance with the Sustainable Development Goals (SDGs) set forth by the United Nations, which serve as a global framework for sustainable development. By examining the Karupannya Rangpur Factory as a case study, we aim to gain insights into the strategies and practices employed to establish a sustainable factory ecosystem. Moreover, this paper aims to develop a conceptual strategic framework that can serve as a guiding model for future sustainable factory ecosystems. The implications of this research extend beyond the Karupannya Rangpur Factory and Bangladesh. By contributing to ongoing efforts to build sustainable economies and resilient societies, this study aims to inspire similar initiatives globally. The knowledge gained from understanding the design strategies, operational processes, performance evaluation, and SDG compliance of the Karupannya Rangpur Factory will be instrumental in shaping the future of sustainable industrial development, ensuring a better and more sustainable future for all.

2. Methodology

2.1 GBRS

A green building rating system is a tool that evaluates the environmental performance of a building based on a set of criteria and standards. It usually involves a certification process that verifies the level of sustainability achieved by the building. For this study work the framework of LEED (Leadership in Energy and Environmental Design) has been adopted to evaluate building performance.

In 2000, the U.S. Green Building Council (USGBC) developed and released guidelines for implementing practical green building solutions through its Leadership in Energy and Environment Design (LEED) rating system for new buildings. LEED helps buildings to focus on efficiency and leadership to deliver the triple bottom line of people, planet, and profit. LEED v4.1 raises the bar on building standards to address energy efficiency, water conservation, site selection, material selection, daylighting, and waste reduction. LEED v4.1 consists of a rating system of existing buildings that are fully operational and occupied for at least one year.

The evaluation system of LEED v4.1 Certification involves the parameters listed below:

Table 1: LEED Certification Evaluation Criteria

Impact Category	Evaluation Parameters	Points
Location and Transportation	Sensitive land protection, High priority site, and equitable development, Surrounding density and diverse uses, Access to quality transit, Bicycle facilities, Reduced parking footprint, Electric vehicles	16
Sustainable Sites	Site assessment, Protect or restore habitat, Open space, Rainwater management, Heat Island reduction, Light pollution reduction	10
Water Efficiency	Outdoor water use reduction, Indoor water use reduction, Optimize process water, Water metering	11
Energy and Atmosphere	Enhanced commissioning, Optimize energy performance, Advanced energy metering, Grid harmonization, Renewable energy, Enhanced refrigerant management	33
Materials and Resources	Building life-cycle impact reduction, Environment product declarations, Sourcing of raw materials, Material ingredients, Construction, and demolition waste management	13
Indoor Environment Quality	Enhance indoor air quality strategies, Low-emitting materials, Construction indoor air quality management plan, Indoor air quality	16

	assessment, Thermal comfort, Interior lighting, Daylight, Quality views, Acoustic performance	
Integrative Process	Integrative process	1
Innovation	Innovation, LEED accredited professional	6
Regional Priority	Regional priority-specific credits	4

Source: https://www.usgbc.org/leed-tools/scorecard

To achieve LEED certification, a project earns points based on the particular prerequisites and credits that address carbon, energy, water, waste, transportation, materials, health, and indoor environmental quality. The project goes through a verification and review process by GBCI and is awarded points that correspond to a level of LEED certification: Certified (40-49 points), Silver (50-59 points), Gold (60-79 points), and Platinum (80+ points).

LEED-certified buildings save money, improve efficiency, lower carbon emissions, and create healthier places for people. They are critical to addressing climate change and meeting ESG Goals, enhancing resilience, and supporting more equitable communities that contribute towards meeting the Sustainable Development Goals.

2.2 SDG Compliance

The 2030 Agenda for Sustainable Development, adopted by all United Nations Member States in 2015, provides a shared blueprint for peace and prosperity for people and the planet, now and into the future. At its heart are the 17 Sustainable Development Goals (SDGs), which are an urgent call for action by all countries- developed and developing – in a global partnership. They recognize that ending poverty and other deprivations must go hand-in-hand with strategies that improve health and education, reduce inequality, and spur economic growth – all while tackling climate change and working to preserve our oceans and forests. The SDGs emphasize the interconnected environmental, social, and economic aspects of sustainable development by putting sustainability at their center.

Table 2: The 17 Sustainable Development Goals

Goals	Intent	Architectural Implications
No Poverty	End poverty in all its forms everywhere	Use of affordable and environment-friendly building materials Architecture, landscape, and planning must adapt the built environment to climatic, geographical, and cultural contexts Increase the quality of life while reducing energy consumption [1,2]
Zero Hunger	End hunger, achieve food security and improve nutrition and promote sustainable agriculture	Design favoring land use for food production on various scales Maintenance and rebuilding of species diversity in landscapes, settlements, and urban areas Use of locally adapted vegetation for landscape and plantation [1-3]
Good Health and Well-being	Ensure healthy lives and promote well-being for all at all ages	Building design must enable a healthier indoor climate concerning light, acoustics, air quality, and exposure to radiation Avoid the use of environmentally hazardous building materials Building design and planning must encourage physical activity [1,2]

Quality Education	Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all	Building design and planning should facilitate access to education The built environment can provide training opportunities regarding the sustainable performance of buildings, settlements, and urban areas [1,2]
Gender Equality	Achieve gender equality and empower all women and girls	Buildings, settlements, and urban areas must be inclusive to all citizens regardless of gender Design must offer girls and women equal access to leisure and activities and create conditions that encourage use by all The organization of public spaces, institutions, and security of women [1,2]
Clean water and sanitation	Ensure available and sustainable management of water and sanitation for all	Collection, preservation, and use of rainwater Reduce hard surface in design to ensure maximum rainwater infiltration to the ground with our being contaminated [1,2]
Affordable and Clean Energy	Ensure access to affordable, reliable, sustainable, and modern energy for all	Buildings must be designed to limit energy consumption and to produce and recycle energy Ensure maximum use of daylight and natural ventilation. Design solutions can employ innovative sources of renewable energy. [1,2, 4,5]
Decent Work and Economic Growth	Promote sustained, inclusive, and sustainable economic growth, full and productive employment, and decent work for all	The workplace must be designed to support a healthy and productive work environment. The ability to move from home to the workplace, time spent in transit, and affordable transport play a vital role in citizens' access to work. [1,2]
Industry, Innovation, and Infrastructure	Build resilient infrastructure, promote inclusive and sustainable industries, and foster innovation	Industry, its services, products, and transportation systems should pollute less, tie up less energy, produce less waste, and provide solutions that are safer and healthier than current standards. The building industry can be site-specific, produce sustainable product locally, uses local materials and resources, and focuses on no waste from a lifecycle perspective. [1,2, 4,5]
Reduce Inequalities	Reduce inequality within and among countries	Architecture must be designed and executed so that it is socially responsible, inclusive, and consider the needs of all members of society. Buildings must be designed with accessibility as core functionality, ensuring even surfaces, lifts, ramps, and way-finding features. [1,2]
Sustainable Cities and Communities	Make cities and human settlements inclusive, safe, resilient, and sustainable	Buildings and settlements should be inclusive, safe, robust, resilient, and environmentally sustainable. Building complexes and settlements must be developed to increase resilience and robustness in the face of climate change and include vegetation and green areas to help counteract the loss of vegetation and biodiversity caused by urban growth. [1,2]
Responsible Consumption and Production	Ensure sustainable consumption and production patterns	Designing for a long lifetime, steady maintenance and careful adaptation of existing buildings are key

		to sustainable consumption in the built environment. [1,2]
Climate Action	Take urgent action to combat climate change and its impacts	The CO2 impact of buildings and settlements must be reduced through energy renovations, integrating renewable energy production in buildings, reducing the transport of building materials, and use of local and renewable materials. Consideration of the local climate, design with natural light and ventilation should be incorporated in the building design process. Building design solutions should be resilient to changing climatic conditions. [1,2,4]
Life Below Water	Conserve and sustainably use the oceans, seas, and marine resources for sustainable development	Design and planning must ensure that pollutants like pesticides, nitrogen, and human waste are handled on-site and do not reach the groundwater or the oceans. Through architecture, planning, and design, develop solutions that reduce cost and add co-benefits to water-managing infrastructure. [1,2]
Life on Land	Protect, restore, and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification and halt and reverse land degradation and halt biodiversity loss	To protect, restore and support ecosystems and biodiversity, buildings, and settlements must include habitats for plants, insects, and animals. Planning and development of all new settlements must ensure sustainable conditions for the local ecosystem, flora, and fauna. Local flora and fauna must form the basis of landscape design in buildings and settlements, including lawns and interior greenery so that plants will interact with and support local ecosystems. [1,2,4,5]
Peace, Justice, and Strong Institutions	Promote peaceful and inclusive societies for sustainable development, provide access to justice for all, and build effective, accountable, and inclusive institutions at all levels	Architecture and planning must ensure that public spaces and institutions are inclusive, welcoming, secure, and non-discriminatory. [1,2]
Partnerships for the Goals	Strengthen the means of implementation and revitalize the Global Partnership for Sustainable Development	Architects, designers, and planners can contribute by sharing knowledge, promoting sustainable solutions, and engaging in collaboration with research and institutional partners, to develop and implement sustainable solutions. Key to partnership is a willingness to include new knowledge, test new practices, engage with local climate and resources, and work with end-users [1,2]

Source: AN ARCHITECTURE GUIDE to the UN 17 Sustainable Development Goals

The Sustainable Development Goals (SDGs) are a reference framework recognized worldwide. The 17 objectives are interlinked so that the success of one directly affects the rest. The SDGs convey a spirit of collaboration and pragmatism for choosing the best options to improve life sustainably, for future generations. Adaptation and alignment with the SDGs of Architecture signifies its role in achieving a positive change for the benefit of the world and its habitants.

2.3 Measures and Techniques

To conduct a comprehensive review of the factory building and its performance, an extensive study of the building context and design strategies, architectural attributes, construction techniques, materials, and the factory operation process is carried out. Each finding of the study is then evaluated based on the particular LEED v4.1 evaluation categories and achieved points have been calculated. These points have been compared with the LEED certification benchmarks to assess the performance of the building and accountability of the design strategies. A comparative analysis is being carried out to verify compliance with the 17 Sustainable Development Goals (SDGs). The synergies between LEED and SDGs are used to establish the hypothesis.

3. Comprehensive study of the project

3.1 Context and design strategies analysis of the project

Architectural design strategies are the methods used to design buildings and spaces that are responsive to the context around the site, the climate advantages and challenges, the socio-cultural factors, the functions, and the users of the project. Design strategies can be identified by analyzing the objectives and purposes that are adopted throughout the whole project; the effectiveness of the strategies can also be measured by following the coherence of the project.

3.1.1 Context and background study

Greenfield Factory of Karupannya Rangpur Limited is located in Robertsongonj, Rangpur, Bangladesh. This greenfield factory is located in Rangpur which is in Tropical Monsoon Climatic zone according to Köppen-Geiger climate classification. This Greenfield factory started its journey in 1991 in Rangpur and presently manufactures carpets and other woven floor coverings, the most majority of which are shipped to the European Union, the United States, and Asia. The site location of the project is adjacent to a secondary road, which allows heavy vehicles to access it easily from the primary road as well as the rural roads used by workers.

Fig 1: Project Location according to climate and Site Location (Source: Author)

Bangladesh has a tropical climate with moderate winters from November to March and hot, humid summers from March to June. As being located in a monsoon climatic zone the monthly mean temperature of the project site is over 18 °C and Humidity remains high throughout the year. Climate responsive design of the green field factory building for Karupannya Rangpur Ltd. is a pioneering example for Industries in this region.

3.1.2 Built Environment and Ecosystem

The Industrial Unit frequently disrupts the relationship between humans and nature, as well as the surrounding eco-system. The entire site area of the project is 14170 square meters, and the overall built-up area is 24850 square meters. Their main factory building is a seven-story structure with a footprint of 3820 square meters. Design of the main factory building was successful to establish a close bonding between human and nature while supporting the eco-system of the building surroundings. The idea was implemented to support the climatic scopes as well. Overall design emphasizes on the rural contextual archetype like using courtyards, gardens, water bodies, and traditional climatic solutions as well as preserving rural vibes. Moreover, there is an attractively constructed "Nandini Park" on the roof top of the day-care facility where many workers eat their lunch daily. A beautiful front yard garden design in the front zone of the site is an eye treat to everyone while entering the compound. Along with the working area, the factory comprises of medical center, grocery shop for employees, food canteen, prayer room, ATM Booth etc.

Fig 2: Aerial View of Greenfield Unit of Karupannya Rangpur Ltd. (Source: Author)

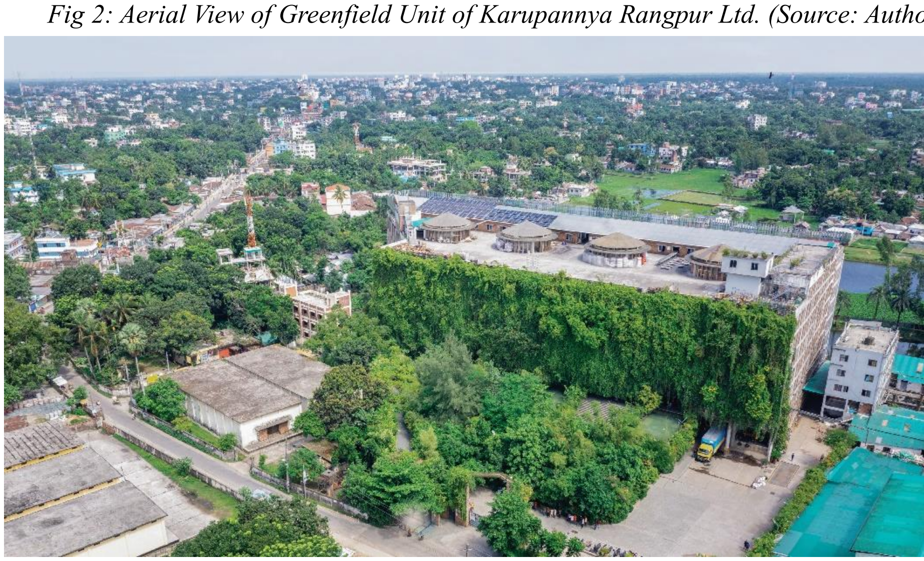

Fig 3: Frontal view of Greenfield Unit of Karupannya Rangpur Ltd. (Source: Author)

The factory building was designed with and enormous entry, leading towards the first floor. The ground floor needed to accommodate some heavy machinery as those machineries create vibrations. On the other hand, rest of the floor was designed focusing the accessibility of the coworkers and users. The works spaces were organized beside the central atriums in order to ensure more human friendly spaces.

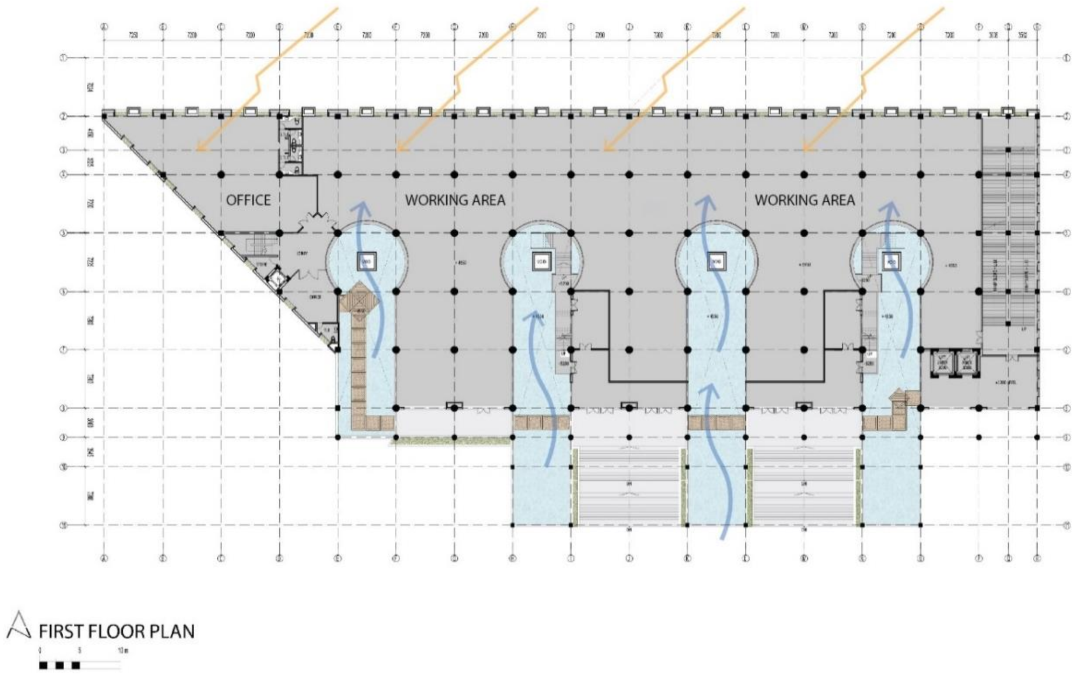

Fig 4: First floor plan of Greenfield Unit of Karupannya Rangpur Ltd. (Source: Author)

The implementation of a vertical green screen serves the purpose of reducing direct sunlight exposure while allowing ambient sunlight to reach the working area. This is made possible as sunlight passes through the light well, providing a pleasant influx of natural daylight to the interior space. Additionally, air passing over the water sheets undergoes a cooling process, subsequently flowing towards the workspace, contributing to a more comfortable environment. To facilitate effective ventilation, vertical voids are incorporated, which exhaust warm air upwards, creating room for cooler air to circulate.

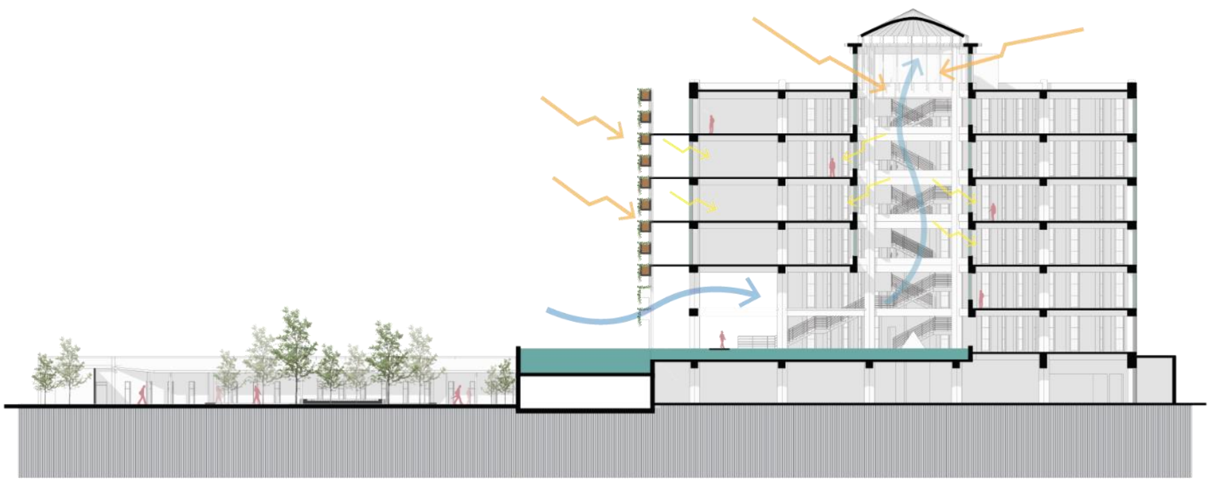

Fig 5: Sectional View of Greenfield Unit of Karupannya Rangpur Ltd. (Source: Author)

3.1.3 Design Strategies and considerations

The Greenfield Factory of Karupannya Rangpur Limited establishes various dimensions to the working environment based on many parameters for the working environment based on the natural resources it has and the difficulties it must overcome.

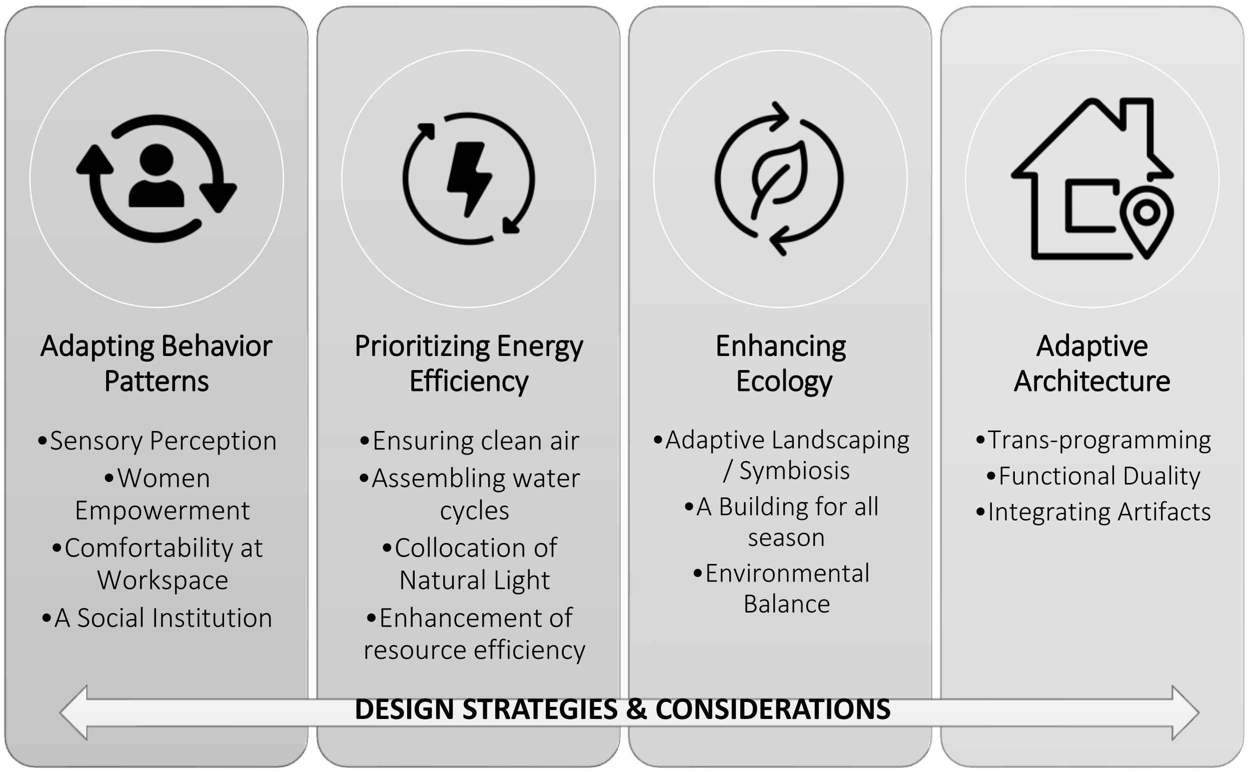

Fig 6: Key points followed to generate Design Strategies (Source: Author)

3.1.3.1 Adapting behavior patterns

Adapting behavior patterns for architecture is a design approach that aims to create built environments that are compatible with human needs, preferences, and sensibilities. To adopt human needs, preferences, and sensibilities in architecture, we need to use a human-centered design approach to optimize the relationship between people and buildings. We also need to consider the impact of the various senses, not just sight, on the well-being of the building's inhabitants and be aware of the way in which sensory cues interact. By doing so, we can create solutions that attend to the community's needs and promote health, happiness, and social development. To adapt the behavior patterns of the users to this project, the following strategies were assessed:

Sensory Perception:

Humans are connected to the environment through five sensory perceptions: eyes, nose, ears, tongue, and skin. In 10,000 years of known civilization, only in the last century have humans tried to create a preferable environment by mechanically controlling light, temperature, and humidity.

That costs energy and harms the natural environment. It is always preferable and healthy that men are connected to the natural environment with their sensory perceptions as much as possible. This Greenfield factory maximizes the environmental connection with the users. It creates a vertical ground that gives the user the impression that they are connected to the ground with the greenery.

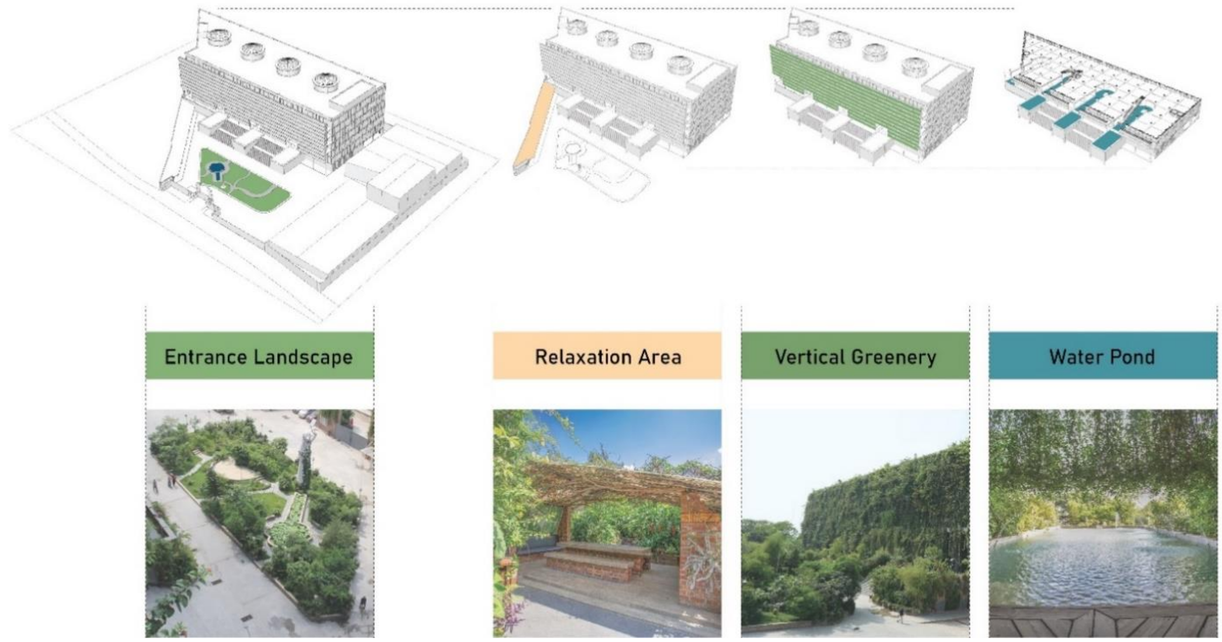

Fig 7: Natural Environment adapted on Multiple Levels (Source: Author)

Women empowerment:

95% of the workers in the factory are women. Over 5000 women workers create 30 million USD in revenue from this factory and earn their livelihood there. A respectable job with decent earnings gives them the power to influence and make decisions. This factory enables them to influence their lives, families, and society. The greenfield factory has provided a sense of freedom to the local women. Acknowledge that the factory has a sculpture that holds a spindle in one hand and raises that hand, symbolizing women with a spindle in hand, shaping the economy of this country.

Fig 8: Women-centric Co-working Spaces (Source: Author)

Comfortability at Workspace:

Providing a better working environment and as well as a comfortable workplace is a major success of the building. The factory building provides facilities for groceries, day care services, restaurants, playgrounds and most importantly healthcare. All the 5000 workers and their families get basic healthcare from factory for free. Even the furniture of the relaxing areas was designed in a way that they can relate to the local tea stalls. Overall, this place sets a local standard for how an industrial workplace should be.

Fig 9: Amenities around the Co-working Spaces (Source: Author)

A social institution:

Bangladesh has seen industrial development, especially in the garment industry, in the last few decades. Where workers come to the industrial areas and shape their lives the way their work needs to shape them. Even so, they live with great difficulties with no proper living facilities. It has great similarities with the book ‘A Tale of Two Cities by Charles Dickens, where he portrayed the story of London. The Greenfield factory is the only example where the workers were not uprooted. So, the worker lives in their own house and earns comparatively well, which puts them in a better social position. The factory provided freedom, better earnings, and healthcare. That gives the factory social stability and makes it a social institution.

Fig 10: Social Activities (Source: Author)

3.1.3.2 Prioritizing energy efficiency

Prioritizing energy efficiency in architecture means designing buildings that use less energy and produce fewer carbon emissions, both during construction and operation. These strategies stand alongside the climate crisis and reduce the environmental impact of the building sector, which is responsible for a large share of global energy consumption and carbon emissions. Following segments were assessed to prioritize the energy efficiency:

Ensuring clean air:

By keeping the south, north, and east sides open, the building's naturally advantageous working environment is maintained. The front face also has verandahs and four-foot-deep openings, both of which are equally covered in plant layers. Four circular openings allow the northerly air that is flowing through the vegetation and water reservoirs to enter the structure, keeping the interior five degrees cooler than the outside. The facility actually only has a few electric fans for cooling purposes. In addition to improving air quality, a well-designed vertical garden helps lower solar heat gain. The majority of the spaces around the property are adequately functional with natural air flow; only a small number of the rooms in this compound are artificially ventilated to fulfill functional need.

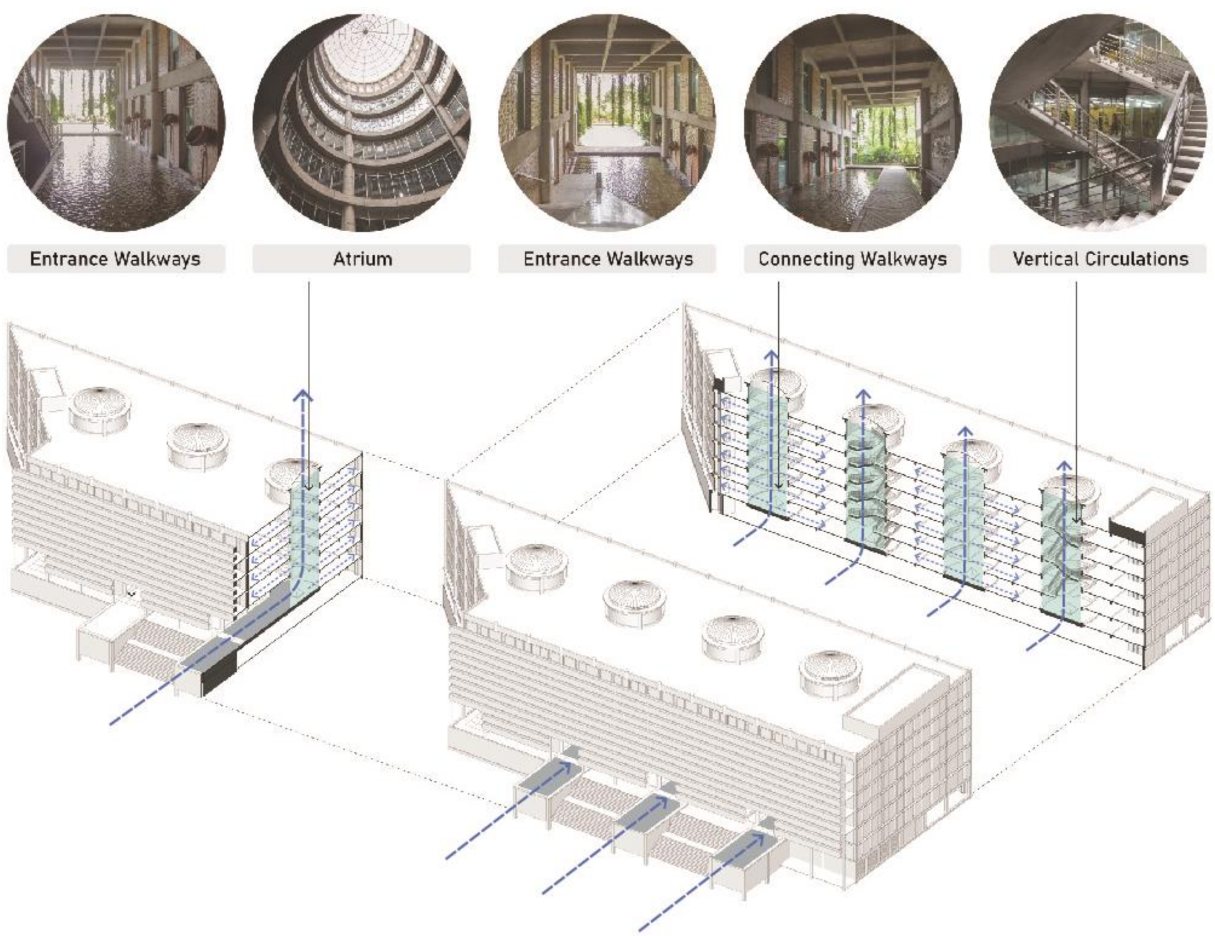

Fig 11: Amenities around the Co-working Spaces (Source: Author)

Assembling water cycles:

To cut down on the consumption of ground water, four enormous reservoirs at podium level have been built, each holding 5 lakh liters of water. In addition to being utilized in the dying process, this water is put aside for fire safety. Following death, spent water is recycled in a Zero Discharge ETP before being poured back into the reservoir to undergo natural oxidation. Up to 80% to 90% of the groundwater needed for the entire process is saved. Rainwater collection has also been done using these water tanks.

Collocation of natural light:

Designing a large building always brings the challenge of providing enough air and light at the center of the building. Greenfield factory is a large building by its function. The significant width of the building creates a larger challenge to make the center of the building naturally well-illuminated and ventilated. To face this challenge nine-grid concept was used in which the central grid was left as an atrium that can bring light to the core of the building, and the front grid was also left void to bring air within the building. Then this nine-grid module was repeated three times sidewise to form the functional requirement, and another line of the grid was added at the front and back for circulation function. By doing this, the center of the building is similarly well-illuminated and ventilated as the sides of the building.

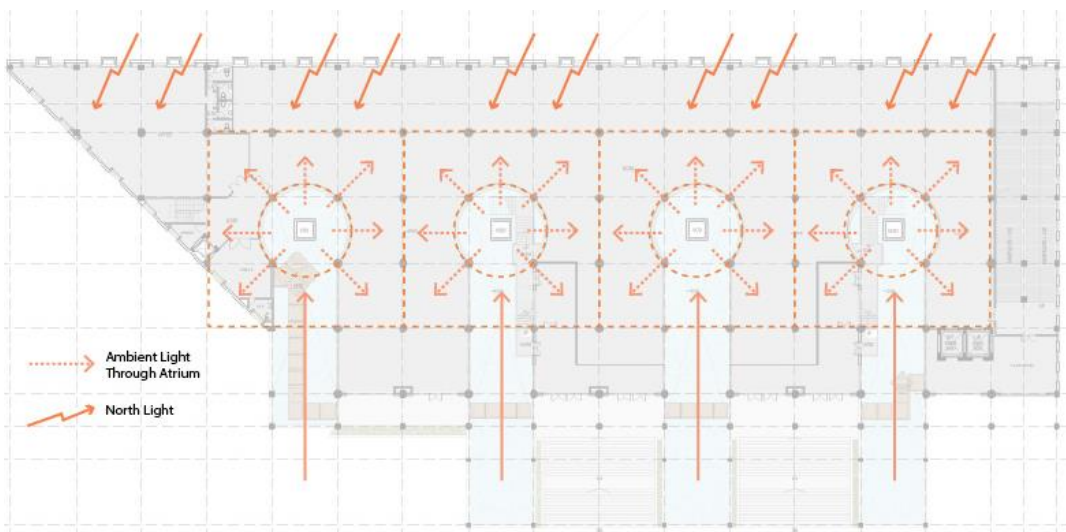

Fig 12: Modular grids for maximizing usage of natural lights (Source: Author)

Enhancement of resource efficiency:

100% Polyester and chemical free materials are used annually in this factory. As for example, Jute, expelled waste, Sea grass, Water Hyacinth, Wool, Recycled yarn and Recycled Pet fiber. Product processing is mostly done manually, in order to utilize maximum man power. Manual labor force equals to no mechanical power, thus ensures less energy consumption. All the wastage are collected and sold as raw material to other industries. The sludge stored in biological ETP of the factory is sent to cement factories to make adhesive for cement. Polythene wastages are sold to polythene recycle companies, Jute wastages are sold to jute spinners, Cotton wastages are sold to Cotton recycling industries. Food waste is given to animal feed industry. Solid wastes are given to local municipality. The factory has a designated team that handles Hazardous wastes which is only sold to licensed companies. Furthermore, renewable energy from the solar panels meets up to 5% of total energy requirements of the factory.

3.1.3.3 Enhancing ecology:

To enhance ecology through architecture, we need to design buildings that respect and restore the natural environment, support biodiversity, and treat ecosystems as our greatest resource. Strategies followed to enhance ecological scopes of this project is described below:

Adaptive Landscaping / Symbiosis:

Being native plants, these plants need very little maintenance and irrigation. The concept was to create a vertical jungle instead of a vertical garden. The plants collect their food from the surrounding created by themselves. Natural symbiosis keeps the cycle ongoing by providing food for each other. The natural takeover turned into a jungle once it was created as a garden. Even though these vertical gardens may appear dense from the outside, they do not limit the penetration of daylight and potentially of natural light among interior space. However, careful selection and maintenance of the plants ensure that sufficient daylight to illuminate the interior space.

Fig 13: Adaptation of Green Screen (Source: Author)

A Building for all season:

Nature took over the greenfield factory building's vertical garden as it transformed seasonally with the change in nature. Contextually, Bangladesh has six seasons, and nature has its way of expressing itself. From the warm summer to the wet rainy season to the brown winter. The building changes its appearance with the surroundings. That makes the building a living bio element that nature has taken over—a building for all seasons.

Fig 14: Adaptation of Green Screen (Source: Author)

Environmental Balance:

The total building footprint of the greenfield factory is 40,000 sq. ft. The structure has given back 14,000 sq. ft of green to the environment with the vertical jungle, rooftop garden, and landscaping. It accumulates about 33% of the total green eliminated while constructing the building. Also, through productive landscaping, this surface enables the workers to grow vegetables used in the food given to them as a midday meal.

3.1.3.4 Adaptive architecture:

Adaptive architecture is presented as an alternative modus operandi for architects to create buildings which are flexible, sustainable, future-proof systems, rather than fixed, immovable objects trapped in a particular context and time. The following strategies were assessed to design this project in more adaptive manner:

Trans-programming:

Cross-programming is the intentional combination of building programs or architypes, especially those that seem inextricably incompatible. A sustainable approach requires devising functional uses and maximizing user interaction with a structure. Considering that the Greenfield factory was designed to build a user-friendly structure, for social inclusion, the building has a rooftop garden, dining areas, and shopping areas. This idea of social inclusion in a factory building through cross-programing made the Greenfield factory the world's first factory building that is visited by its workers on off days. (Porter, 2004)

Functional duality:

The factory building has an enormous entry with a grand stair leading to the first floor. The first floor had to be the landing floor for the entry because the ground floor needed to accommodate some heavy machinery. As those machineries create high vibrations which would be bad for the building structure if located at a higher floor level. This grand stair makes the entry of the building very accessible and aesthetically viable while meeting the functional requirement. The stairs also have alternative use as an amphitheater; a performing stage was designed to opposite to the stair. During a function the stairs can accommodate 1500 people.

Fig 15: Adaptation of Green Screen (Source: Author)

Integrating artifacts

The interior and the articulative elements were designed to focus on the user group along with the exterior and the environment. The overall design corporates contextual materials along with artifacts showing rural context. The window, wall ceiling surfaces, everything was designed considering the worker group, as they would be users of those spaces. Even the wall tiles contain the faces of the workers, which helps the workers to connect with the place and make them feel comfortable. That always gives a psychological benefit for the workers and enhances productivity.

Fig 16: Incorporating rural motives (Source: Author)

Fig 17: Incorporating rural materials into interior space (Source: Author)

Fig 18: Artifacts around the compound (Source: Author)

3.2 GBRS analysis of the building

GBRS measures the level of sustainability of a building through a multi-criteria assessment, promoting the adoption of environmentally, socially, and economically sustainable practices in the design, construction, and operation of buildings. GBRS evaluates a building based on its design strategy, architectural features, building performance, and its impact on the surrounding socio-economic conditions and the environment. The primary focus lies on a building's architectural attributes and its functional performance.

Table 3: Building Design & Performance Evaluation based on LEED Certification Rating System

Impact Category	Attributes of the Building Design & Performance	Achieved Points
Location and Transportation	The majority of the workers do not need to use transportation due to the location of the factory. Those who need transportation use electric-charged vehicles and bicycles.	14
Sustainable Sites	Rainwater harvesting contributes 18% of the total freshwater uses which is stored at reservoirs of atrium. 33% Greenery of the total site area helps keep the environment cool reducing the heat island effect. High SRI (Solar Reflective Index) paint is also applied on the rooftop, which bounces sun radiation and keeps the top floor cool. Unique and innovative waste management and cycling systems helped to reduce waste discharge to almost 0% because waste is used as raw materials in relative industries.	4
Water Efficiency	Karupannya reduces water consumption by using recycled water. The water is recycled through a biological ETP. Also, rainwater harvesting reduces underground water use. For diverse water consumption, such as irrigation, flushing toilets, process water, and domestic use, separate water sub-meters are installed, which helps track water consumption and possible area of improvement. Installing high-performance water fixtures reduces water wastage. The landscaping contains 100% native and adaptive plants, which need little or no irrigation water.	11
Energy and Atmosphere	In Karupannya, a separate energy meter is installed for different energy uses such as REB line, Generator, Solar, etc. The diesel Flow meter is installed in the generator to keep track of Diesel use. The rooftop solar system generates 89kw of renewable energy. An incineration boiler operated by a rise husk adds a positive node.	31
Materials and Resources	To reduce waste at Karupannya, waste bins are placed on each floor. A central waste yard facilitates the segregation of production waste, which is then given to a waste hauler for recycling or proper disposal. A waste policy is implemented, and waste inventory data, including generation, reuse, and external disposal, is maintained for one year. Organic waste is converted into food waste in biogas plants.	7
Indoor Environment Quality	Karupannya underwent air quality tests (indoor and ambient) for PM_{10}, $PM_{2.5}$, CO_2, and O_3, taking necessary initiatives for improved indoor air quality. An updated basement machine floor exhaust system maintains fresh air and CO_2 balance. A 10ft long mat was installed at the entrance to prevent dust from entering the production floor. There is no smoking signage within 25ft of any air intake point. A green cleaning policy is followed to maintain the facility.	16
Innovation	Green education and awareness programs among the employee	1

Source: https://www.usgbc.org/leed-tools/scorecard, Author's analysis

3.3 Compliance with SDG: Initial findings

The Sustainable Development Goals (SDGs) provide a more comprehensive understanding of a building's sustainability when used to evaluate building performance. SDG evaluates environmental, social, and economic aspects along with architectural attributes. This evaluation framework examines how a building's design, construction, and operation align with SDG targets. The utilization of the SDGs as a benchmark enables the measurement of sustainability and the positive impact of buildings on global development objectives.

Table 4: Comparative analysis of building attributes based on The Sustainable Development Goals

Goals	Impact Categories	Attributes of the Factory Building
No Poverty	Affordable and environment-friendly building materials Energy efficiency Job Opportunity	The factory's establishment has resulted in job opportunities at the regional level and employs 5000 people in two shifts. Local building materials and construction techniques along with contextual interior solutions used to reduce building costs.
Zero Hunger	Productive farming Adaptive vegetation	For landscaping and plantation local adaptive plants are used that require minimum maintenance resulting in natural symbiosis. The landscaping includes productive farming that grows vegetables and is used as a mid-day meal.
Good Health and Well-being	Healthier indoor climate- lighting, acoustics, ventilation, sun radiation Eco-friendly building materials Provision of physical activity	The strategic design of the factory building ensures maximum use of daylight through surface openings and three atriums that also help to use natural ventilation and evaporative cooling. The indoor temperature remains 5 degrees cooler than outside. Workers in this factory feel highly enthusiastic and motivated to work in such a beautiful and environmentally friendly workplace. The garden at the rooftop of the daycare creates the opportunity for the workers to walk around, take a rest, and have a brief respite amid hectic working hours that fill the workers with delight.
Quality Education	Training opportunities regarding the sustainable performance of buildings	The factory conducts seminars for the workers to grow environmental and social awareness.
Gender Equality	Inclusiveness- building for all Equal access for women Safety & security of women	Eighty percent of the factory's 5000 employees are women. The job opportunity of such permanent infrastructure has given the local women a sense of security and unleashed freedom. Thus, women's importance in the family has been escalating. The working environment of the factory is inclusive and gender-neutral.
Clean water and sanitation	Water efficiency Rainwater harvesting Minimum hard surface	The factory used Zero Liquid Discharge (ZLD) ETP which saves up to 80% ground water use. The water of ETP goes through natural oxidation and is then used for dying. Rainwater harvesting produces 18% required fresh water.

		33% of the factory is kept for landscaping which ensures fresh and uncontaminated water can infiltrate into the ground.
Affordable and Clean Energy	Reduce energy consumption Use of renewable energy Maximum use of daylight and natural ventilation.	The factory is designed as an energy-efficient and climate-responsive structure that can save up to 40% on energy consumption. Also, energy efficiency, water efficiency, optimal use of daylight, plantation, and eco-system preservation are all sustainable design elements. The south, north, and east facades are kept open to let the air circulate through the structure, keeping the working climate naturally beneficial. Moreover, the front face includes four-foot-deep apertures and verandahs, which are similarly covered with layers of plants. The northward breeze blowing through the plants and water reservoirs enters the building through four circular gaps, keeping the internal spaces 5 degrees cooler than the outside. The factory uses solar energy and bio-gas plant to ensure the use of renewable energy.
Decent Work and Economic Growth	Indoor space quality & work environment Accessibility to workplace	Established in the regional territory, the factory has reasonably reduced labor migration. The location of the factory enables workers to come to work by walk or bicycle. The factory has also given social and micro enterprises to work including retired and elderly citizens of the community.
Industry, Innovation, and Infrastructure	Waste management system Use of local and sustainable raw materials for production Industrial waste cycling	Petrochemical and Polyester free materials like-Jute, expelled waste, Seagrass, Water Hyacinth, Wool, Recycled yarn, and Recycled Pet fiber are used as raw materials for production. All the wastage is collected and sold as raw material to other industries, the sludge stored in the biological ETP of the factory is sent to *Lafarge*, which they use to make adhesive for cement, and polythene wastages are sold to polythene recycling companies, Jute wastages are sold to jute spinners, and Cotton wastages are sold to the Cotton recycling industries, food waste is given to the animal feed industry and Solid wastes are given to the local municipality. This unique waste management cycle has created a circular economy.
Reduce Inequalities	Universal accessibility Socially responsive and inclusive space design and permeability	Greenfield factory was designed to build a user-friendly structure. The building has a rooftop garden, fathering, and shopping areas for social inclusion. This idea of social inclusion in a factory building through cross-programming made the Greenfield factory as world's first factory building that is visited by its workers on off days.

Sustainable Cities and Communities	Inclusive, resilient to climate change, and environment-friendly design Counteract loss of vegetation and biodiversity	The establishment of the factory has brought a significant change in the context of the locality both environmentally and economically. Being an energy-efficient local craft-based production unit, the factory helps preserve the traditional craft industry and enhance the capacity building of the associated people. A huge amount of people who used to migrate to industrial cities and abroad now get the opportunity to work based on their skills locally.
Responsible Consumption and Production	Building lifecycle planning Use of recyclable building materials	As construction material-Shingles, a semi wastage low profile building material has been used to reduce the overall construction cost which is also reusable. No Paint has been used anywhere in the building's façade to reduce the use of hazardous chemical compounds. Wood and bamboo are the primary interior decoration materials along with handmade clay motifs, that are recyclable building materials sourced locally. Considering that Greenfield factory is designed in a way that if needed can transform or cater to other functions very easily. The fluid spatial design and functional flow make the building useable for other purposes. It increases the life span of the building and promotes sustainability.
Climate Action	A contextual building design approach Use of natural light and ventilation Reduce energy consumption for air-conditioning and lighting	To reduce the CO2 footprint of the building's traditional construction techniques, local building materials have been used. No paintwork has been done to get rid of the chemical-based finishing materials. Wood and bamboo are the primary interior decoration materials along with handmade clay motifs. Furthermore, renewable energy from solar panels meets up to 5% of the total energy requirements of the factory.
Life Below Water	Wastewater management system Groundwater infiltration Reduce water contamination	To reduce freshwater use and contamination of natural waterbodies the factory uses ZLD ETP that saves 80% use of fresh water by reusing the treated water repeatedly.
Life on Land	Protect and restore ecosystem and biodiversity Adaptation of local flora and fauna in landscaping	Gardening and landscaping have taken up 30% of the entire land area, preserving the native flora and animals. Vertical zoning has also been used to keep the footprint of an energy-efficient factory small to prevent land damage. The building landscape has merged with the local ecosystem that responds to the season change, adapts, and reforms according to the seasonal climatic conditions accommodating macro and micro level members of the ecosystem and biodiversity.
Peace, Justice, and Strong Institutions	Incorporation of healthcare facilities, fair economic policies, and inclusive environmental protection	The establishment of the factory has brought a significant change in the context of the locality both environmentally and economically. Being an energy-efficient local craft-based production

	unit, the factory helps preserve the traditional craft industry and enhance the capacity building of the associated people. A huge amount of people who used to migrate to industrial cities and abroad now get the opportunity to work based on their skills locally.

Source: AN ARCHITECTURE GUIDE to the UN 17 Sustainable Development Goals, Author's analysis

4. Results and Discussion

The Greenfield of Karupannya Rangpur Factory achieved 84 points in the LEED v4.1 model which earned the factory building LEED Platinum Certificate. This signifies the level of sustainability achieved by the building through design strategies & innovative design solutions, building operations, and socioeconomic impacts. The building has successfully impacted the environment & ecosystem, society, and economy to a positive extent ensuring energy efficiency, optimized water consumption, efficient resource management, innovative design solutions & material use, social stability, and sustainable economic growth.

The Sustainable Development Goals are the most structured guidelines for sustainable and resilient development initiatives of the future. The model provides a holistic approach to development which involves the upgradation of people, economy, society, environment, ecosystem, and biodiversity and the fight against poverty, social injustice, gender discrimination, adverse effect of climate change, and ecological imbalance. The Greenfield factory successfully aligns with the objectives of SDGs. This significantly establishes that the design strategies, innovative solutions, operation processes, and socioeconomic policies of the Greenfield factory are successful initiatives of the climate-responsive and resilient development model.

This study has investigated the significance of architectural attributes, policy interventions, and physical impacts of creating a sustainable foundation for the future. The study outcome is twofold- firstly, a comprehensive study of the Greenfield factory outlines the features in the context of factory design. Secondly, GBRS analysis results and alignment with the 17 SDGs establish the Greenfield of Karupannya Rangpur Factory can be a contextual example in the path of laying the sustainable foundation of the future. The findings and their implications can be summarized in the following brief inference.

- A sustainable building must adapt to its context in terms of design solutions, built environment, and material resourcing.
- The building must be efficient from the perspective of design, energy consumption, resource use, functional use, space arrangement, and waste management.
- The building must have a positive social, economic, and environmental impact along with sustainability in the built environment and architectural attributes.
- Surrounding ecology and ecosystem, biodiversity, natural preservation, and climate change should be considered when designing a sustainable building.

Successful integration of these considerations in a design solution should lead to sustainable and resilient designs for the future.

5. Conclusion

The dynamic economy of Bangladesh has escalated rapid industrial development which also amplifies the environmental, social, and economic risk factors in the context of achieving a sustainable and resilient foundation for the future. The building industry has a major role to play in mitigating the challenges of climate change and achieving sustainability. In light of the study outcomes, strategic design guidelines can be drawn for establishing a sustainable industry. The comprehensive review of the Greenfield of Karupannya Rangpur Factory shows how the factory performs in terms of achieving sustainability through the successful integration of architectural attributes, policy interventions, and physical impacts. The Greenfield of Karupannya Rangpur Factory sets the contextual example of the Ecosystem for a sustainable and resilient foundation for the future.

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