Utilizing Leftover Spaces in Big Cities:

A Sustainable Tiny Housing Proposal for NYC

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Abstract:

As cities like New York continue to grow, they face an increasingly urgent housing crisis, with limited land and rising real estate prices, making affordable living nearly unattainable for many. At the same time, small, irregular, and neglected parcels of land—often deemed unsuitable for development—left empty, representing a missed opportunity in the urban fabric. This study explores how these leftover spaces can be repurposed into sustainable housing solutions, using 271 Bowery Street in Lower Manhattan, as a case study.

Developed for an international design competition, the Bio-Modular Housing Project presents a modular, flexible, and eco-friendly housing solution that transforms these underutilized urban voids into livable spaces. Designed with bioplastic masonry units (BMUs), a lightweight and sustainable material derived from recycled waste, the project emphasizes environmental responsibility, adaptability, and social equity. The design incorporates natural light, ventilation, and noise-reducing facades, creating comfortable and efficient micro-living units in a high-density setting.

By rethinking how cities use their forgotten spaces, this project demonstrates that innovative, sustainable, and socially inclusive housing is not only possible but essential for the future of urban living. The Bio-Modular Housing Project offers a replicable model that merges architectural ingenuity with ecological consciousness, proving that even the smallest urban spaces can make a significant impact.

Keywords: Urban Leftover Space, Sustainability, Modularity, Recycled Material, Housing Design.

1. Introduction

Planning plays an important role in controlling the density and efficiency of the cities. However, the pressure of unrestrained urbanization overcomes the future projections of these plans, causing exponentially increasing problems in the cities. Housing is one of the biggest problems in big cities, and New York City is one of them. It is the most populous city in the US and a symbol of the metropolis in the world. According to Jane Jacobs, the American-Canadian journalist, author, and activist known for her important works in the field of urban studies, especially on New York City, the dwellings for middle-income groups in NYC are like dull, monotonous wells that do not let the joy or vibrancy of city life (Jacobs, 1993). She was aware that the unplanned spread of the settlement would lead to chaos in cities. To prevent this, she opposed urban transformation programs and always defended the importance of streets and the contribution of walking by the citizens.

In big cities, where effortless gains in land values, also known as 'urban rent' cannot be avoided, some oddly sized and shaped empty parcels that are not preferred for investment, which occur because of different period development plans, stand out as a critical loss of potential.

In the international architectural project competition titled 'Pocket Home'[1], a modular and temporary housing design was opened to discussion through a design on a small and narrow parcel, left empty as not preferred for development in 271 Bowery in New York's Lower Manhattan district.

2. Theoretical Framework: Urban Leftover Spaces in Relation to Sustainability and Housing

In the ever-evolving urban landscape, residual spaces present both challenges and opportunities, particularly concerning sustainability and housing. As cities like New York expand rapidly, traditional planning often neglects urban growth's non-linear and fragmented nature, resulting in irregular parcels and underutilized areas. Usually deemed unsuitable for development due to their shape, size, or location, these urban residuals contribute to inefficiencies in land use and urban sprawl. However, with increasing awareness of sustainable urban practices, these spaces can be reimagined as potential assets within the ecological and social fabric of the city. They offer unique opportunities to infuse sustainability into the urban environment by providing spaces for innovative housing solutions in densely populated areas with limited traditional expansion. By reimagining these spaces through a sustainability lens, urban planners and designers can address the pressing issues of housing shortages while reducing the environmental impact of new developments. Theoretical research on the intersection of residual space, sustainability, and housing provides the foundation for resilient and inclusive urban futures by providing frameworks that prioritize adaptability, resource efficiency, and ecological harmony, setting the stage for a detailed exploration of transforming surplus urban spaces through sustainable and innovative housing strategies.

2.1. Leftover Spaces in the City

In today's cities, especially in megacities, uncontrolled urbanization pressures often lead to exponential problems. In big cities where effortless land income cannot be avoided, some small-sized and irregularly shaped empty parcels that are not preferred for investment and formed due to different period development plans stand out as a loss of potential. These plots create weaknesses in terms of safety, hygiene, and aesthetics, affecting environmental qualities negatively, and are called 'leftover spaces'. They may briefly be defined as a space that is not possessed by people (Alanyalı Aral, 2003).

[1] The competition titled 'Pocket Home' was organized by uni.xyz. For more information, please access; https://uni.xyz/competitions/pocket-home/info/about

Trancik describes these as ‘lost spaces,’ or ‘neglected urban areas’ that fail to contribute positively to their surroundings and are in need of redesign He highlights that vast amounts of unused land exist even in the downtown cores of major American cities (Trancik, 1986).
Over the past decades, rapid technological advancement and economic development have changed employment patterns, living arrangements, and industrial activities, further establishing lost spaces (Fernando, 2007). As cities expand, the effects of these neglected areas become more pronounced. They not only become more prevalent but also exacerbate social inequalities by reinforcing divisions. Inaccessible and unattractive, these redundant areas unintentionally create a psychological map of exclusion, where certain urban zones are mentally marked as off-limits or undesirable, further entrenching socioeconomic divisions.
Ni and Rahbarianyazd (2013) introduce methods in reclaiming lost spaces, suggesting that mixed use functions can significantly solve the problems of lost space enhancing urban inclusivity and coherence. Furthermore, Tharziansyah et al. (2023) argue that integrating these spaces into urban planning can alleviate challenges associated with irregular land arrangements, which often lead to urban slums.

Fig. 1 Leftover Spaces in the City (URL-1).

Here, different inputs come into play because, in areas where urban planning is systematic, spaces are deliberately selected and designated for specific uses. This deliberate selection helps to foster inclusive and vibrant communities and ensures that urban spaces fulfill their potential as centers of social interaction and participation. In contrast, the gaps and voids resulting from unplanned urbanization are often neglected, abandoned, polluted and largely dysfunctional for city dwellers.

These remaining spaces highlight the need to define and thoughtfully redesign urban spaces. By doing so, cities can address these shortcomings and disrupt the invisible social hierarchies that such neglected spaces perpetuate. The meaningful presence of people is essential to transform spaces into vibrant and engaging environments. Therefore, the use of space depends on its quality, and the ability to achieve this quality aligns with the fundamental goals of architecture and urbanism. Based on the principles of urban design, it can be inferred that achieving high-quality urban spaces is crucial for encouraging public participation and active use.

Memarian and Niazkar (2014) propose a set of criteria for reclaiming lost spaces, emphasizing human interaction and participation as key to reintegration. These criteria provide urban designers with a guide for transforming these neglected spaces into dynamic hubs of activity. Case studies in Turkey further highlight that revitalizing such spaces can foster inclusive community engagement, reduce social inequalities, and improve the urban fabric (Ni & Rahbarianyazd, 2013; Ünal & Topçu, 2022). Through intentional design and planning, urban spaces can be revitalized to reflect residents' physical presence and social aspirations (**Fig. 1**).

2.2. Sustainability and the City

As cities confront the challenges posed by residual land, sustainability principles are emerging as important tools to address these urban gaps. Integrating sustainable design provides solutions to reuse and revitalize neglected areas and supports broader environmental, social, and economic goals in urban environments. By transforming residual areas with sustainable strategies, cities can become more flexible and resilient in adapting to rapid urban growth.

Historically, the evolution towards sustainability gained momentum as a rection to the environmental and socioeconomic disruptions caused by the Industrial Revolution. While this era of industrial and technological progress revolutionized production and consumption, it also left behind a lasting impact, resulting in extensive ecological damage and tremendous risks to social and economic stability. Recognizing these challenges, the 21st century has brought sustainability and environmental awareness to the forefront of global discourse (Ekim, 2004).

The concept of sustainability, articulated in the Brundtland Report of the World Commission on Environment and Development in 1987, emphasizes development that meets present needs without compromising the ability of future generations to meet their own needs (Chan & Lee, 2008). This principle has profound implications for urban planning and design, especially given the extreme energy demands of metropolitan areas, which consume approximately 75% of the world's energy despite covering only 2% of the Earth's surface (Uygun, 2012).

Lee et al. (2015) point out that urban voids—often dismissed as wasted space—hold great potential for improving the environment. By adopting adaptive design strategies, these spaces can be turned into green corridors or communal areas, contributing to urban resilience. Covatta and Ikalović (2022) expand on this idea, emphasizing the role of leftover spaces on urban adaptability, suggesting that such transformations not only improve environmental quality but also enhance social well-being.

Sustainable architecture plays a vital role in achieving these urban sustainability goals. It focuses on designing and constructing buildings that reduce ecological impact while meeting people's spatial and functional needs (Karaaslan, 2011). By integrating human activities with natural systems, sustainable architecture provides solutions to pressing urban challenges and supports the long-term health of urban ecosystems.

The relationship between underutilized urban land and sustainability is a key aspect of the theoretical framework addressing current urban challenges. Unplanned and underused spaces are common in many cities, representing missed opportunities for environmental, social, and economic progress. They also worsen existing urban problems such as socioeconomic inequality and inefficient land use. However, when approached with sustainable design principles, these

spaces can be transformed from liabilities into valuable assets. Sustainable urban interventions can turn abandoned lots into functional, inclusive, and environmentally friendly spaces that enhance urban resilience and livability.
De Jongh (2022) highlights the need to prioritize transient populations in urban redevelopment, advocating for designs that improve mobility and accessibility. Similarly, Ünal and Topçu (2022) demonstrate that sustainable housing projects in revitalized spaces can provide long-term solutions to urban density challenges, ensuring that cities grow in a manner that meets the needs of both current and future residents. This shift is about more than just aesthetics or functionality_it reflects a strategic transformation in urban development, prioritizing long-term sustainability over short-term gains.
Moreover, integrating sustainability into housing development is particularly important in addressing the dual challenges of rapid urban population growth and reducing environmental harm. Sustainable housing design offers practical solutions to ensure cities can meet accommodate their residents while preserving resources for future generations. As cities continue to evolve, integrating urban planning with sustainability principles will be important for navigating the complexities of urban development. By identifying and reclaiming neglected spaces through sustainable approaches, cities can create more inclusive, vibrant, and resilient environments. This theoretical framework underscores the importance of a comprehensive approach that prioritizes innovation, community involvement, and environmental responsibility as core elements of urban development.

3. Case of New York and 271 Bowery Street in Lower Manhattan

New York is a prime example of modern urbanization, with its dynamic and constantly developing landscape. This ongoing transformation is evident in various parts of the city, including Bowery Street, one of Manhattan's oldest and most historically significant streets. Artists, immigrants, and workers preferred the Bowery area in the 19th and 20th centuries. However, by the mid-20th century, he neighborhood experienced significant decline, becoming a shelter for the homeless and the lower segments of society (Burrows and Wallace, 1998). However, in the 21st century, the region has undergone substantial changes, now home to cultural centers, art galleries, and boutique hotels (DeVillo, 2017).
The projects to be carried out in this part of the city are critical in building a bridge between the city's historical texture and its modern architectural approach to create a model for future living spaces.

3.1. History of Bowery Street

The historic 1.5-mile Bowery is the oldest street on Manhattan Island. Long before Broadway became Manhattan's signature road, the lane that would become the Bowery wound to the island's upper reaches. Originally, it was a dirt trail etched by the bare feet and moccasins of the Native Americans before the Dutch arrived and established their farms along the route. The Bowery's first residents were ten families of formerly enslaved people in 1645. Then, when the Dutch colonized Manhattan Island in the late 17th century, they named the path Bouwerij Road, derived from the Dutch word ‘bouwerij’ meaning ‘farm,’ as it linked the farmlands and estates on the city’s outskirts to the heart of the city like Wall Street and Battery Park (De Villo, 2017). By the late 18^{th} century, the Bowery became New York's most elegant street, lined with grand theaters, soaring banks, mansions of prosperous residents, and upscale shops. Today, Bowery Street in Lower Manhattan remains a bustling area with diverse uses. It primarily hosts commercial activities on the ground floors, while the upper floors serve as residential spaces for both high- and low-income residents in the surrounding area (Burrows & Wallace, 1998) (**Fig. 2**).

Fig. 2 The Bowery in the early 1900s (URL-2)

3.2. 'Pocket Home' International Competition

The international architecture competition titled 'Pocket Home,' organized by uni.xyz, sought innovative designs for a modular tiny multi-housing unit in a void plot left in New York City's dense urban fabric. Based on the modular and temporary housing project proposal named 'Bio-Modular House,' a set of multi-scale designs developed for this competition will be examined in this article. The bio-modular house is planned in New York, the most populous city in America, which suffers from irregular urbanization. The project focuses on utilizing small, often neglected plots that are typically too small to be considered for development.

A key design approach was how to give back to the environment due to this unplanned urban sprawl that is experienced all over the world, especially in New York City, and the resources that start to run out as a result of the wasteful behavior of people under current conditions. The project aimed to address two primary challenges. First, it sought to meet the competition's requirement for the number of residential units within a limited area, maximizing space efficiency. Second, it focused on using eco-friendly materials to avoid further strain on already scarce resources. In response to all these questions, the project aimed at a modular, sustainable, flexible, and temporary housing design, using optimum space for maximum comfort conditions, having natural light and ventilation, and being contextually harmonious, contributing to its vacant position physically and socially.

4. Definition of the Problem and the Project Area

4.1 Problem Statement

Urban plans are pivotal for managing city density and optimizing land efficiency. However, rapid urbanization often surpasses the predictive capabilities of these plans, giving rise to a multitude of challenges. Among these, housing stands as a critical and persistent issue, particularly in megacities such as New York City. With its status as a global urban hub, NYC faces a severe housing crisis worsened by limited land and a constantly shifting population. This crisis intensified in the wake of the COVID-19 pandemic, revealing and deepening the vulnerabilities in the city's housing landscape.

In NYC, where housing costs dominate household budgets, affordable and adequate living conditions remains a challenge. Real estate values are extraordinarily high, yet numerous vacant parcels of land—often irregularly shaped or disproportionately small—are left undeveloped. These "leftover spaces" represent a significant loss of urban potential, negatively impacting the environment, aesthetics, and safety. Their neglect caweakens the urban fabric, diminishing community well-being and perpetuating inefficient land use.
These conditions are not limited to NYC but extends globally, calling for innovative solutions to transform these neglected urban voids into thriving, sustainable assets. The challenge lies in creatively repurposing these spaces to meet the housing needs, often with minimal financial resources.

Addressing this multifaceted problem, defined in the brief of the competition, the Bio-Modular Housing Project proposes a modular, sustainable, flexible, and temporary housing solution designed to maximize spatial efficiency and comfort, having natural light and ventilation, contextually compatible, and contributing physically and socially to its location in the vacant plot determined (**Fig. 3**). Within the project scope, it was required to design modular, temporary (for a maximum of 6 months), twelve separate units on the empty lot at 271 Bowery in New York's Lower Manhattan region, which fits the definition of 'leftover space' in the city. The housing design is modular, flexible beyond temporality, uses optimal space for maximum comfort conditions, has natural light and ventilation, is contextually harmonious, contributes to its environment, and emphasizes physical and social sustainability as a solution to identified problems and required criteria within the project brief. In this context, using an innovative lightweight construction block made of bioplastic from recycled waste[2], the building will be essentially modular and sustainable, starting from the smallest unit.

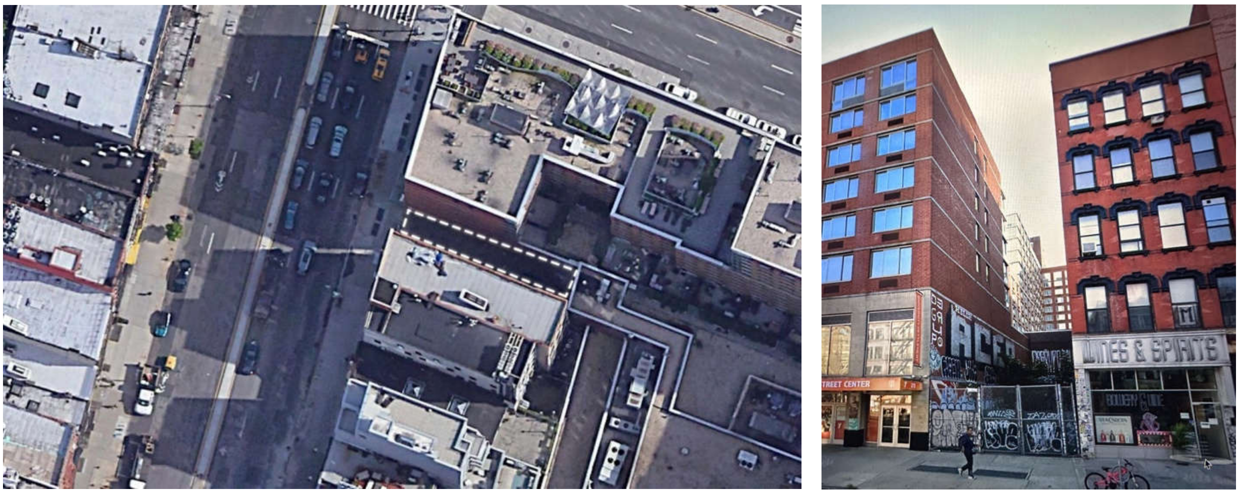

Fig. 3 (left) Aerial photo (URL-3), and (right) street view of the study area (URL-4).

4.2 Analyses of the Project Area and its Vicinity

A thorough analysis of the project site and its surrounding environment yielded essential insights that shaped the design approach, ensuring a contextually appropriate and sustainable housing solution. The analyses began with a ground-floor usage, which assessed the interaction between adjacent buildings and the street, offering critical data for defining the project's spatial organization and street-level engagement. Additional factors, such as the layout of key routes in the vicinity, pedestrian and traffic densities during peak and off-peak hours, and access to major public transportation nodes _including subway lines, stops, and bus terminals_ provided a deeper understanding of the site's connectivity and

[2] The bioplastic, modular, lightweight masonry unit with interlocking qualities is designed by the two of the team members; E. Baz (BSc in Mech. Eng.) and (BArch, MSc, PhD) and is applied for a patent in July 2021.

accessibility. Noise pollution from emergency vehicles and pedestrian activity further informed spatial planning, façade treatments, and material selection, ensuring the proposed design effectively responds to the multifaceted contextual challenges of the project site.

The project plot, like others in the vicinity and the city, is enclosed on three sides by adjacent buildings, completely obstructed by taller buildings on two sides, while the rear side is enclosed by a two-story high building. Consequently, the northwest-facing entrance facade provides the main opportunity for visual and functional engagement with the street. On the upper floors, residential spaces are more prominent.

Fig. 4 Analyses of the features of the project area (by the authors)
(1) Ground-floor functional analysis, (2) Public transportation analysis, (3) Pedetrian density, (4) Route for emergency vehicles, (5) Traffic density between 12.00 pm- 8.00 pm, (6) Traffic density between 8 pm- 2 am.

When the immediate surroundings of the project site are analyzed in terms of functional analysis, it reveals a predominance of various commercial services at the ground floor, such as daily shopping stores, restaurants, and cafés, which supports the vibrant and dynamic character of the area. Additionally, the service areas, shown in yellow on the map, such as banks, cinemas, theaters, and hotels, contribute to the social and economic diversity of the area. Moreover, educational and healthcare facilities, shown in purple and blue tones, also play an important role in meeting the daily needs of users. The dominant residential use on the upper floors, contribute to a mixed-use environment by integrating with the commercial functions on the ground floor, providing a day-long, balanced living environment for both local residents and visitors, as shown **Fig. 4-1**.

From the point of traffic circulation, 271 Bowery is a dense street on the routes of police and ambulance, next to an even denser avenue, East Houston Street, on the routes of police, ambulance, and fire trucks, with a lot of noise pollution due to sirens (**Fig. 4-4**). Strategically located near several popular tourist destinations and equipped with various amenities catering to both locals and visitors, the site benefits from its close access to a nearby park, enhancing its appeal as a transit-friendly and versatile urban space.

The area experiences high pedestrian traffic throughout the day, particularly on side streets and around key transit stops, as illustrated in **Fig. 4-2**. The subway stops and bus stops contribute to this concentration of people, making it a densely populated zone. Additionally, people waiting at these stops and the short, direct routes from Bowery Street to nearby tourist attractions further increase pedestrian activity. As depicted in **Fig. 4-3**, this influx of people amplifies noise pollution and intensifies the area's overall soundscape. High pedestrian density naturally leads to increased vehicle congestion, compounding the noise levels and creating a challenging environment that requires careful consideration in urban planning and design.

Google Maps was utilized to analyze vehicle traffic patterns in the area and the locations of the nearby emergency routes toward the hospital, police station, or fire department to estimate the amount of general noise produced by people and emergency vehicles. An analysis of the traffic conditions indicates a fluctuation between moderate and heavy congestion on side streets, leading to significant noise pollution from vehicle sounds and frequent horn use. As illustrated in **Fig. 4-5** and **4-6**, the Bowery and its surrounding streets experience exceptionally heavy traffic between 12 pm and 8 pm. This congestion persists into the night, with varying levels of intensity observed between 8 pm and 2 am, as represented in **Fig. 4-6**. Consequently, the soundscape of nightlife in a bustling metropolis like New York is anticipated to reflect elevated noise levels. The analysis of pedestrian and vehicle density near the site played a pivotal role in the design approach for the project. The Sounds of New York City (SONYC) initiative, which involves deploying sensors throughout the city to capture 10-second audio samples, serves as an inspiration for addressing noise pollution. These recordings are uploaded onto a platform where citizen scientists assist in identifying sounds, while artificial intelligence increasingly automates the classification process. SONYC also relies on artificial intelligence as computers get better and better at identifying the sounds independently. The goal is to help the city's Department of Environmental Protection mitigate against noise pollution (Young & Medzen, 2019). The ultimate aim is to support the city's Department of Environmental Protection in reducing noise pollution.

The Bowery area, characterized by its historical residential apartment buildings, experiences significant noise pollution. Many old buildings in the vicinity lack contemporary insulation technologies due to the use of old materials, allowing external disturbances to permeate interior spaces. By addressing these challenges proactively, the project aims to enhance both the livability of the proposed housing units and their integration into the surrounding urban environment.

5. Main Approach and Decisions

In the 21st century, sustainability has become a defining concern for megacities, encompassing environmental, social, and economic dimensions. In that sense, social sustainability and equity concepts emerge as the essence of the solution and the proposals developed in this study. Social sustainability is a favorable situation characterized by strong social cohesion and equal access to basic health, education, transportation, housing, and recreation. It occurs when both formal and informal mechanisms, systems, structures, and relationships actively enhance the capacity of present and future generations to build healthy and livable communities. Socially sustainable communities are marked by equity, diversity, connectedness, democracy, and a high quality of life (McKenzie, 2004).

However, when examining New York City, it is clear that only some members of society experience equity or access to a socially sustainable living environment. In this context, homelessness is one of the most pressing issues facing New York City. Often described as a ‘revolving door’ crisis, it is a problem where a significant number of people exit rapidly, but new people join this homeless population quickly. In a year, four to five times more people experience homelessness than are homeless on any given day (Burt, 2001).

The Bio-Modular Housing project was conceived in response to this critical issue, presenting a model that reimagines how cities can address homelessness and underutilized urban spaces simultaneously. This innovative project is designed to provide a short-term housing solution, as a model for other big cities in the world. By offering temporary accommodations with a maximum stay of six months, the project aims to serve as a transitional solution, providing individuals with the stability necessary to rebuild their lives. The project's incorporation of sustainable materials and community-focused design further emphasizes its commitment to increasing social sustainability.

The initiative aims to provide immediate relief and inspire broader systemic approaches to urban challenges. By transforming neglected and underused urban spaces into vibrant, temporary housing environments, the project aligns with the broader goals of creating a socially equitable and sustainable urban environment where all citizens have access to basic needs and are empowered to contribute to the city's ecosystem (**Fig. 5**).

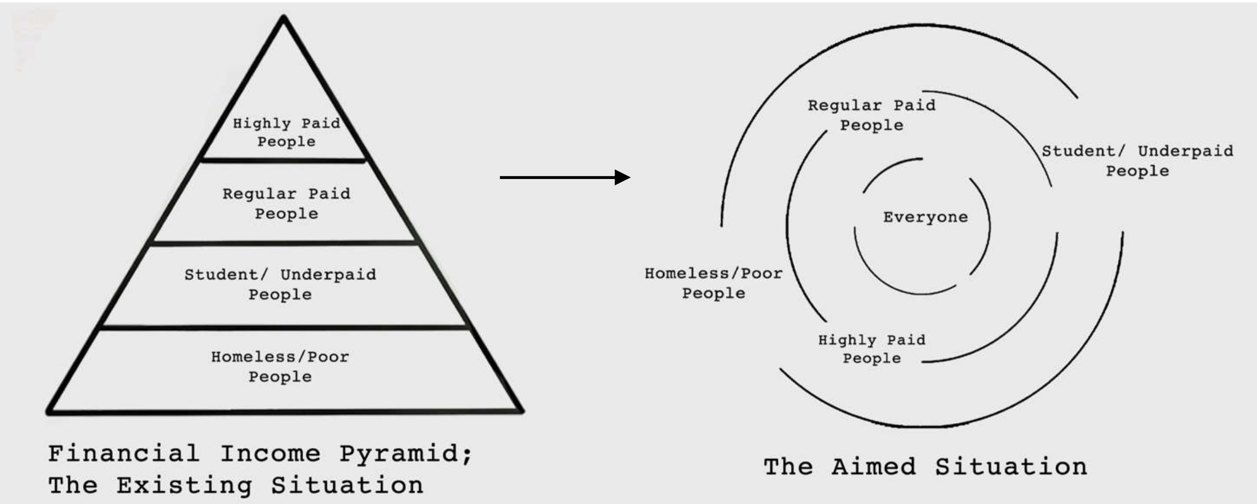

Fig. 5. Financial Income Pyramid: The Existing Situation and the Aimed Situation (by authors)

Consequently, the pressing challenges faced by New York City have become foundational design principles for the Bio-Modular Housing project, conceptualized for the Pocket Home Competition. The design aspires to accommodate individuals across all socio-economic strata, guided by the principle, *"If you want to change the world, first change your world."* By challenging the conventional norms that prevail globally, the project espouses the belief that everyone deserves equal living conditions when they contribute under equal circumstances. As such, the housing initiative is crafted to provide equitable opportunities for individuals with limited or no financial means.

5.1 Proposals

The Bio-Modular Housing project addresses New York City’s critical housing challenges by repurposing underutilized urban spaces into sustainable and dynamic living environments, while also aiming to alleviate the effects of homelessness in New York City. The main design idea of the Bio-Modular Housing project revolves around creating modular, adaptable housing units, harmonizing with the existing urban landscape, built with an inherently parallel material: an innovative, lightweight building block made of recycled bioplastic, that optimizes comfort by leveraging natural light and ventilation.

5.1.1 Building Integration and Urban Context

A key design consideration is to seamlessly integrate the ground floor with the street to invigorate street life and foster community engagement. Based on environmental analyses, the residential building is designed according to the program requirements, and its facades are designed to mitigate noise pollution from nearby emergency routes. The solution ensures the sustainable development, enhancing its immediate physical and social context, as well as providing a comfortable and livable environment for its residents.

5.1.2 Social Sustainability and Equity

The design facilitates those unable to afford housing costs by offering the option to work part-time or full-time in the workshop, thereby integrating economic empowerment with shelter. In the demanding environment of New York City, Bio-Modular Housing project aspires to be a refuge accessible to all, embodying a commitment to social equity and sustainability. This endeavor addresses immediate housing needs and fosters inclusive participation and community support, illustrating how architecture can transform urban society.

Envisioned to create "a building that lives with its street," a small deli has been proposed on the ground floor, reflecting the commercial nature of the surrounding area. This space is designed to serve both the building's occupants and passersby, contributing to the vibrancy of the street. On the ground floor, the entrance of the building is set back, allowing room to arrange seating areas in front of the proposed commercial space, encouraging social interaction and providing a welcoming atmosphere (**Fig. 6**). This approach aims to transform this urban leftover area into a dynamic, inviting space, aligning with the objectives of the competition to enhance street-level activity and connectivity.

5.1.3 Flexibility and Living Units

As defined in the project requirements, the design accommodates twelve compact living units across three upper floors, with each unit ranging from 14.5 sqm to 22.5 sqm. Designed for individuals, couples, or small households, the units prioritize comfort by incorporating natural light and ventilation. Living units share the amenities, including a central circulation space with an elevator, staircase, bike racks, and peripheral balcony-like spaces. These semi-open areas became essential especially during the COVID-19 pandemic, emphasizing the need for natural ventilation.

The Bio-Modular Housing draws on the principles of modular architecture, inspired by pioneering examples in the field. Its contemporary design transcends the concept of simply assembling buildings like legos, embracing an innovative approach that redefines architectural fundamentals. The project embodies this philosophy by utilizing recycled bioplastic material even in its basic units, creating a structure that naturally adapts and evolves (**Fig. 7**).

This housing concept emphasizes the functional advantages of modular architecture while extending its application to the design of interior spaces within each module. This flexibility enables the building to be reconfigured to meet the changing needs, temporal demands, and conditions of its occupants, addressing any deficiencies over time.

For instance, a single-room configuration built entirely from Bioplastic Masonry Units (BMU) integrates bathroom, kitchen, and bedroom elements into a unified space. The staircase elements are creatively adapted to serve as storage solutions. In a two-room configuration (**Fig. 8**), the same units are reimagined to accommodate two occupants, with the staircase components extended to function as closets, showcasing the system's versatility.

Fig. 6 Ground, first and second-floor plans, 3-d images from the common areas (by the authors).

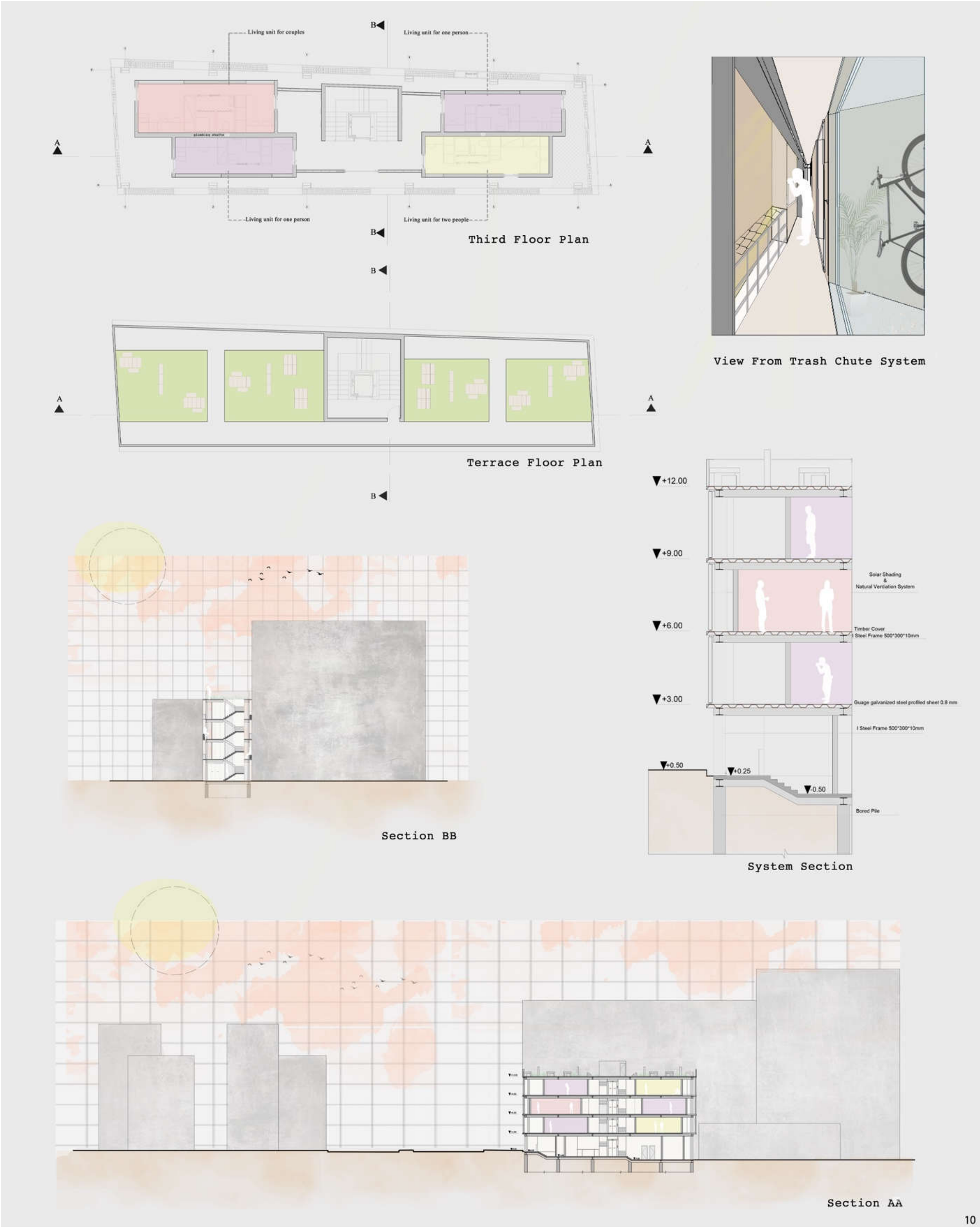

Fig. 7. Third-floor, Terrace-floor plans, building sections, system detail, and view from trash chute system (by the authors).

Through these examples, the project sets a new benchmark in architectural design, illustrating a commitment to modularity from material production to building completion. This innovative application of modular systems optimizes spatial efficiency and establishes a sustainable framework for urban living.

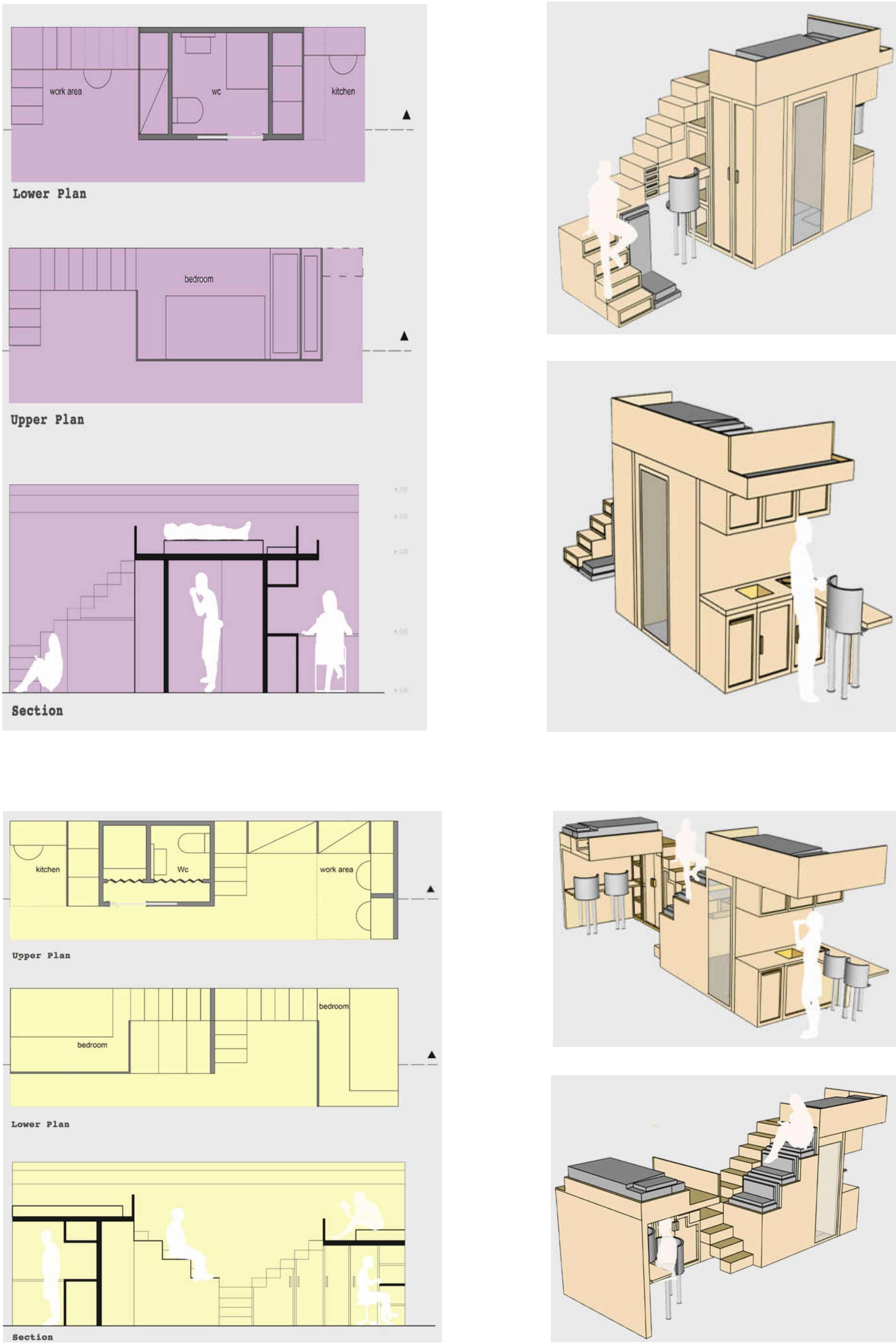

Fig. 8. (upper) Living Unit For One Person, 14.50 m2, (lower) Living Unit For Two People, 15.66 m2 (by the authors).

5.1.4 Material Innovation and Modular Design

Modularity has been an key element of architectural design, enabling adaptable, flexible, and dynamic spaces. This concept gained prominence in the 1960s with Japan's Metabolism Movement, which aimed to reshape urban planning that encouraged both personal freedom and societal reorganization (Schalk, 2014). Visionary architects like Kenzo Tange envisioned modular cities that could dynamically respond to evolving needs—a forward-looking concept that remains relevant today.

Notable historical examples underscore the transformative potential of modular architecture. The Nakagin Capsule Tower, designed by Kisho Kurokawa in 1972, intorduced prefabricated modules with a plug-in/plug-out concept, offering sustainability and construction innovation through the use of concrete (Ishida, 2017). Similarly, Moshe Safdie’s Habitat '67 demonstrated how modular design provide a perfect balance communal living and individual privacy. Its reinforced steel cage system converted modular boxes into fully functional living spaces, highlighting how modularity could optimize cohabitation while preserving space and views (Safdie, 2009).

The essence of modularity lies in its capacity for adaptation and evolution, aligning with the objectives of the Pocket Home project. The Bio-Modular Housing draws from these principles, leveraging modularity to maximize the use of limited space with flexible and temporary solutions tailored to urban constraints.

Achieving modularity in contemporary architecture depends heavily on material innovation. The Bio-Modular Housing project focuses on Bioplastic Masonry Units (BMUs), which epitomize sustainability and functionality. These BMUs are synthesized from recycled bioplastic materials and feature a unique locking system that eliminates the need for traditional mortar elements (**Fig. 8**). This design reduces construction weight and simplifies assembly, resulting in lighter, modular walls adaptable to various urban conditions.

The sustainability of BMUs is enhanced by their production from renewable biomass resources, reinforcing their alignment with ecological goals. This material choice enables the housing units to adapt to the specific needs of different urban plots, making them particularly suitable for temporary, flexible applications in densely populated environments like New York City. The project bridges historical modularity concepts with sustainable innovations, realizing untapped potential through materials that meet both structural requirements and environmental objectives (**Fig.9**).

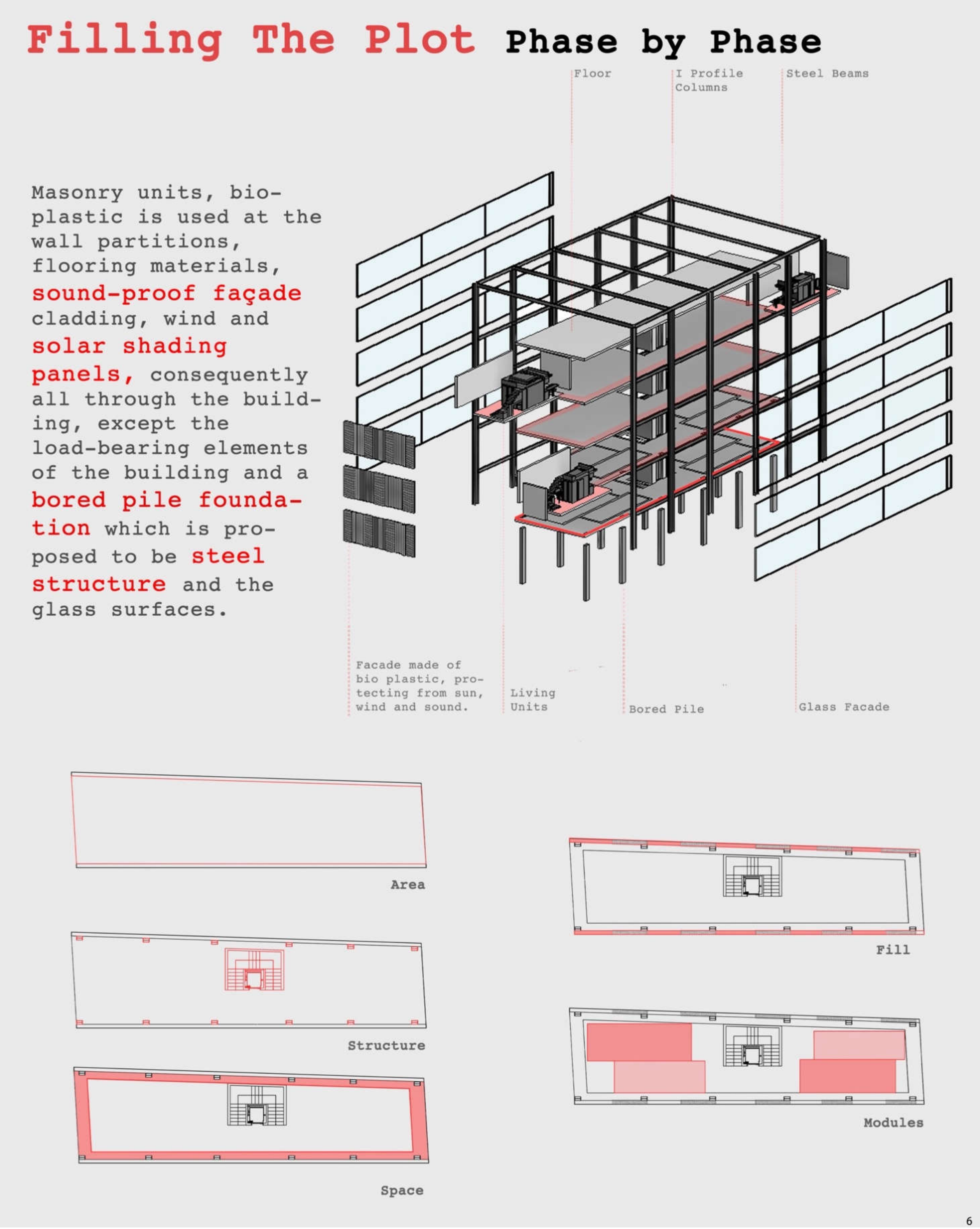

Fig. 9 Construction phases of the modular building on the plot (by the authors).

5.1.5 Sustainability and Bioplastic Material

The imperative for sustainable design has intensified, emphasizing the need for approaches that reduce energy consumption, mitigate environmental impacts, and enable future generations to meet their needs. Using cutting-edge technology, the Bio-Modular Housing project aims to offer viable solutions to the sustainability challenges faced by today's megacities and developed within the scope of the Pocket Home Competition. The project uses a new and innovative lightweight building block, developed and applied for a patent by Xx and Author 1[3], synthesized from bioplastic biodegradable material obtained from renewable biomass resources (for further information about the bioplastic material, see Fras et al., 2014).

In this design, the primary material is produced by recycling waste materials such as plastics, glass, metals, and paper, which are transformed into various non-structural building components. This approach not only supports the reduction of environmental pollution but also facilitates the comprehensive application of bioplastic materials in partition walls, floors, acoustic and thermally insulating facade cladding, and wind and sun shading panels. Apart from the modular load-bearing steel structure and pile foundation, these components contribute significantly to the sustainability of the building.

To complete the building's temporary, modular, and portable design, it is proposed to include a waste collection room and a workshop on the ground floor. This feature provides a self-sufficient system for continuously producing and replacing bioplastic materials, reinforcing the project's unwavering commitment to sustainability and innovative resource management.

In addition, this approach reduces the carbon footprint associated with traditional building materials and construction practices. By adopting pioneering methods in waste recycling, the project exemplifies ecological responsibility and demonstrates the potential for scalable application in other urban environments. As a result, integrating bioplastic materials is crucial to increasing lifecycle sustainability and offers a compelling model for future urban housing developments.

5.1.6 Innovative Sustainable Bioplastic Construction Block

Traditional concrete masonry units, such as Autoclaved Aerated Concrete (AAC) and pumice blocks, are primarily derived from sand-based materials, which are not conducive to recycling. Once buildings made from these materials are demolished, the resultant debris is often transported to remote locations, posing significant environmental hazards as these materials do not biodegrade. This is exacerbated by cement additives, which render the debris non-recyclable. In contrast, bioplastics are biodegradable and synthesized from renewable biomass resources such as vegetable oils, animal fats, corn starch, straw bales, wood chips, and food scraps. The bioplastic construction block offers several advantages over conventional masonry units. It is notably lighter, coupled with its interlocking design, enhances modularity and yields substantial logistical and financial benefits[4]. Including graphene oxide as a primary additive enhances the mechanical properties of the bioplastic, resulting in a robust and durable material comparable to standard cement-based blocks.

[3] National Patent no.2021/011994

[4] For 1 sqm of wall, the number of masonry units to be used is the same as the others. So, with a truckload of standard masonry units can build about 36 sqm of wall. We can imply that 4 times more can be built with the same volume of specially designed modular bioplastic masonry units, composed of 6 modular surfaces that can be flat packed and can be packed on top of each other requirng less space. On the other hand, as mentioned above, when a pumice concrete block unit weighs about 8 kg and an AAC unit about 5 kg, the proposed bioplastic unit weighs about 3 kg.

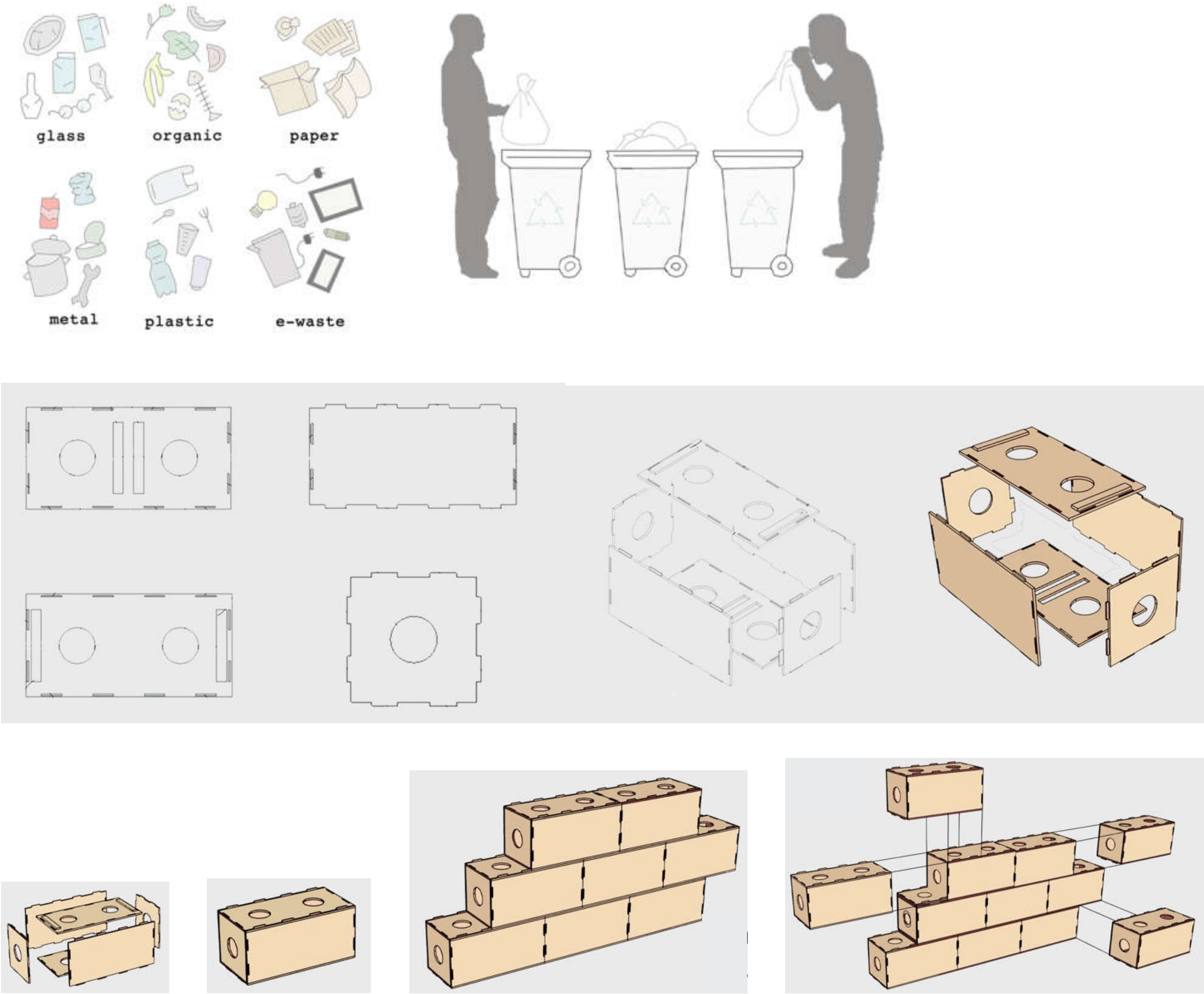

Fig. 10 (top) Bioplastic resources and collection of human waste (prepared by the authors),
(bottom) Construction Unit and their Practical Assembly/Disassembly Possibilities (Baz, 2023).

The production of AAC involves the generation of byproducts such as aluminum, silicate, and radon, which are detrimental to the human respiratory system and have been linked to severe lung damage and cancer. Conversely, the manufacturing process of bioplastic masonry units significantly mitigates environmental pollution by reducing emissions and utilizing waste materials, thus fostering a cleaner and healthier environment. This 'eco-friendly' or 'eco-supportive' production method transforms human-generated waste into viable construction materials and reduces pollution. Beyond masonry units, bioplastic is also employed in various building applications, including wall partitions, flooring materials, soundproof facade cladding, and wind and solar shading panels, permeating throughout the structure—except for load-bearing elements and a bored pile foundation designed for minimal intervention on multi-story building sites, which employ steel frameworks and glass surfaces. The manual molding process of bioplastic masonry units allows for efficient and rapid production, making it an ideal choice for sustainable construction practices (**Fig. 10** and **Fig.11**).

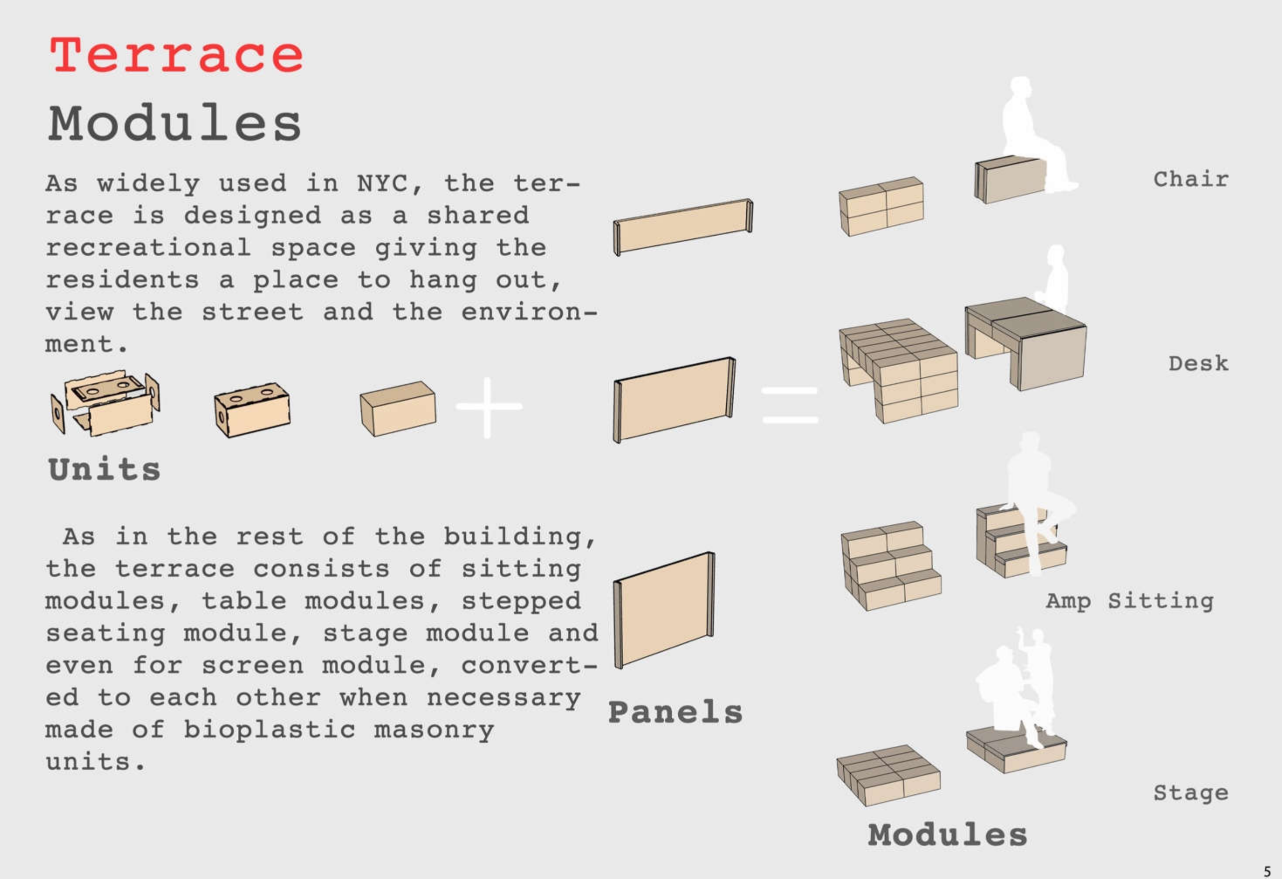

Fig. 11 Bioplastic masonry modules designed for recreation at the terrace (by the authors).

5.1.7 Proposed Façade Qualities

Movable façade panels represent an innovative approach to sustainable architectural design, enabling enhanced energy efficiency and occupant comfort. These adaptive systems are particularly effective in managing climatic variations, as they dynamically respond to environmental conditions to optimize ventilation, daylighting, and thermal comfort.

Key Features of Movable Façade Panels:

1. Enhanced Ventilation and Daylighting:
   - Panels can be adjusted to increase or decrease airflow, creating a well-ventilated indoor environment.
   - Natural light penetration is maximized while reducing glare and overheating, contributing to energy savings.
2. Dynamic Shading:
   - Vertical shading devices integrated into the façade system can mitigate harsh sunlight, reducing cooling loads.
   - Adjustable features ensure protection against excessive wind and sunlight, maintaining comfortable interior temperatures.

According to Kassim (2017), sound diffusers work by scattering sound waves evenly throughout a space rather than reflecting them back or absorbing them entirely. This reduces echoes and reverberation, enhancing sound clarity. Diffusers are often favored as an alternative or complementary solution to sound absorption. Meanwhile, acoustic egg sponge panels, commonly used in settings such as recording studios, home theaters, broadcasting studios, many other industrial and commercial applications, are highly effective at controlling noise by absorbing sound and reducing reverberation.

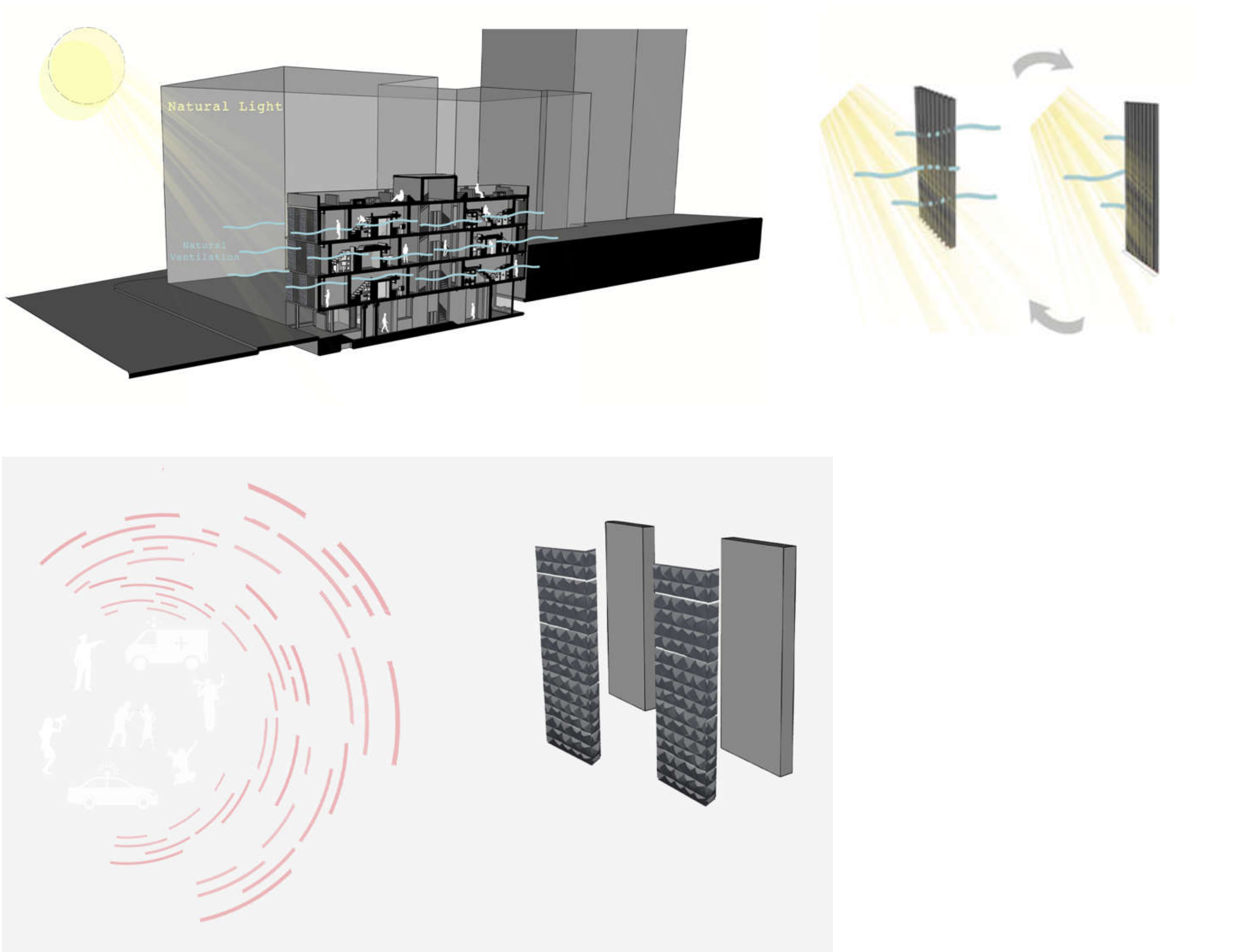

Fig. 12 Designs related to facade elements (by the authors);
(1) Natural Light and Ventilation System (2) Wind and Solar Shading Panel System, (3) Acoustic Egg Sponge Panels.

Based on this information, the building's facades incorporate a combination of soundproof cladding materials designed to mitigate noise pollution. Specifically, the facade facing Bowery Street employs soundproof egg sponge material to reduce noise intrusion effectively (Figure 10). Acoustic foam, a key component of this design, is an easily installable sound-dampening insulation that absorbs noise across multiple frequencies. It minimizes reverberation, enhances acoustic performance, and prevents sound from escaping the enclosed spaces it lines. This solution significantly improves the building's acoustic environment, contributing to both interior comfort and noise pollution control (**Fig. 12**).

As the old buildings in the vicinity lack contemporary insulation technologies due to the use of old materials, the proposed project incorporates a new facade design featuring acoustic egg sponge panels and a sound diffuser known as ravioli, as explained by Ghilahare and Pandey (2017).

6. Conclusion

In dense urban centers like New York, housing emerges as one of the most critical challenges, as increasing human density and the expansion of built environments strain urban infrastructure. The problem of multi-dimensional accommodation is further complicated by the emergence of leftover spaces, resulting from different planning practices at different periods. These spaces contribute to inefficiencies, affecting the safety, hygiene, and aesthetics of the city, while also negatively diminishing its environmental qualities. Nevertheless, these neglected areas have significant potential as valuable sites for innovative urban design that meet various urban needs.

The case study of New York City's Bowery Street, highlights these challenges and opportunities. The 'Bio-Modular Housing' project, conceptualized as part of the 'Pocket House' international architectural design competition organized by uni.xyz, explores design solutions to address these issues. This project exemplifies an innovative approach to housing that utilizes sustainable living principles by demonstrating how modular structures can be effectively integrated into densely populated urban environments.

Bio-Modular Housing project uses environmentally friendly materials and energy-efficient technologies to create a living space harmonious with its surroundings. The project aims to create a self-renewing system that complies with sustainable housing design principles and ensures social equity in using otherwise neglected urban areas.

Bio-Modular Housing Project stands out for its adaptability and modularity, which enable it to integrate seamlessly into existing urban areas and adapt flexibly to future growth. This adaptability empowers residents to change their living arrangements in response to changing needs, significantly enhancing their quality of life. By proposing a sustainable, modular, and flexible living solution, the project effectively addresses contemporary housing needs and the environmental concerns of urban life.

The Bio-Modular Housing, with its innovative use of bioplastic materials at its core, not only meets the urgent needs of urban residents but also sets a new standard for sustainable development. This project advances a transformative vision for urban living, embodying a sustainable ethos that combines equity with environmental awareness in the modern metropolis, particularly through the lens of New York City.

Ultimately, the Bio-Modular Housing combines the dynamic energy of Bowery Street with the principles of sustainable architecture to offer a transformative model for urban living. It represents a pioneering example of how urban design can create vibrant and inclusive living environments while preserving ecological balance, setting a benchmark for future housing projects, and redefining the possibilities for sustainable urban development.

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