可塑城市：
基于塑料的基础设施
与气候适应性沿海社区构建

PLASTICITY:
PLASTIC-BASED
INFRASTRUCTURE FOR
CLIMATE-RESILIENT
COASTAL COMMUNITIES

1 背景与问题

要设计一个能回收利用那些被丢弃至河流并最终排入海洋的塑料垃圾的流程，首要任务就是明确这些垃圾的来源。尽管全世界河流都面临塑料污染的问题，但在那些缺乏关键性垃圾处理基础设施的地区，这一问题尤显突出。例如，亚洲、非洲和南美大陆的很多城市都处于飞速发展阶段，它们在取得经济飞跃的同时也成为了海洋塑料垃圾的主要输出源头。若以受污染河道的线密度计算，发源于菲律宾马尼拉的帕西格河是目前世界上第二大污染严重的河流，本项目即以马尼拉为研究对象。据估计，每年经帕西格河流入海洋的塑料达63 700吨，并有研究数据显示，其中大部分塑料的排放都产生于季风季节，因为降雨形成的地表径流会将大量未经妥善处理的垃圾从周围城市和棚户区中冲入帕西格河及其支流^[1]。那么，能否在河流入海前就利用河流本身对其进行分类与截留？这会对周边社区带来怎样的效益？在本研究中，笔者不仅调查了马尼拉地区污染的起因和源头，也探究了气候变化对这座城市的影响，并借助开源的卫星地图进行了一系列地形分析，以预测2020年、2050年和2100年的洪水淹没范围。

通过分析菲律宾各省的人口密度，笔者预估到2100年将有160万人遭受海平面上升的影响，受影响最严重的恰好也是人口最密集且仍在稳步增长的地区。由于在20世纪70年代的城市劳动力迁移过程中缺乏城市规划指导和基础设施开发的保障，如今，马尼拉遍布低矮无序

周凯蓉
新加坡科技设计大学建筑与可持续设计系硕士研究生

费德列克·鲁伯特
北京临界工作室联合创始人；新加坡科技设计大学建筑与可持续设计系助教

CHOW Khoi Rong, Clara
Master Student of Faculty of Architecture and Sustainable Design, Singapore University of Technology and Design

Federico RUBERTO*
Co-founder of reMIX Studio; Adjunct of Faculty of Architecture and Sustainable Design, Singapore University of Technology and Design

*Corresponding Author
Address: 75 Meyer Road, 16-02, 437901, Singapore
Email: federico.ruberto@egs.edu

摘要

目前，世界上人口超过百万的城市中有五分之一位于沿海地区，而这些地区的城市化程度正在持续增高。尽管面临洪水、台风和海啸等诸多威胁，因其可为各类产业的发展提供重要资源，沿海居民点始终是投资热点区域。东南亚市场更是有望在2020年成为全球第五大经济体，届时必将有更多农村人口移居至城市地区，这无疑会给东南亚发展中国家现有用于固体垃圾处理与回收等的城市基础设施带来巨大压力。

显然，在当今的人类世时代，人类一直掌控着自然，极大地改变了地球样貌。为了生存，人们创造出垃圾填埋场、矿山和支离破碎的农田，任由有毒物质和塑料垃圾充斥大气、堵塞海洋。不当的垃圾处置措施导致垃圾填埋场管理不善，垃圾被雨水携卷入河，威胁着当地环境和依靠这些河流生活的社区居民（他们通常都是弱势群体）。此项目希望通过研究塑料特征，在构想一个可以缓解河流塑料垃圾堆积的“机械景观”的同时，创建出可适应全球变暖、海平面上升等环境条件变化的探索性基础设施网络。

关键词

城市基础设施；海平面上升；国土；塑料；社区；马尼拉

ABSTRACT

Many of the world’s coasts are becoming increasingly urbanized, with two-fifths of cities with populations of millions located near coastlines. Coastal settlements have always been attractive due to the provision of critical inputs to industries, despite the many threats — floods, typhoons, tsunamis, etc. With the Southeast Asian market expected to become the fifth largest economy by 2020, migration from rural to urban areas is set to increase, putting a strain on existing infrastructures within the cities, one of which is the solid waste disposal and recycling infrastructure within the developing nations in Southeast Asia.

Currently in the age of the Anthropocene, it is clear that human has greatly reshaped the Earth, bending nature into the course of human wishes, terraforming the land with landfills, mines, and patchwork agriculture fields, choking the atmosphere with toxic emissions, and clogging the seas with plastic waste. Inadequate waste disposal management has resulted in poorly managed landfills with waste being washed into water during rainy seasons, jeopardizing the environment and local communities (typically the most vulnerable ones) that depend on it. This project hopes to explore the nature of plastics, by envisioning a “mechanic landscape” that manages waste input within rivers whilst creating a speculative infrastructural network that varies with environmental conditions (such as global warming and sea-level rise).

KEYWORDS

City Infrastructure; Sea-Level Rise; Territory; Plastic; Community; Manila

的建筑，许多城市流动人口居住的棚户区侵占了河道，而这类人群本就严重缺乏应对灾难的能力，因此也更易遭受气候变化的不利影响。那么，本项目如何才能为周边社区的居民提供能够抵御季节性洪水的住所、体面的工作和稳定的收入？目前，这些棚户区中的许多居民都依靠捡拾废品来维持生计，但这项工作不仅条件恶劣，且由于原材料和回收品价格的波动，长时间的辛苦工作往往只能换取微薄的收入。因此，项目期望提出一个以棚户区居民为主体的概念构想，帮助他们建造一种可以收集和分拣塑料的机械景观。这一构想的时间跨度约80年，期间居民们将清理帕西格河的塑料垃圾，以获得建立必要基础设施所需的材料，进而构建韧性社区。

2 设计过程

2.1 分析阶段

为了揭示人、塑料和环境之间盘根错节的关系，项目进行了“千

层饼”分析。首先，针对人与环境的关系，笔者通过对马尼拉大都会区景观的地形分析，得出了可能对菲律宾人口造成威胁的洪水淹没范围。项目预测了2020年、2050年和2100年的海平面上升情况，并明确了当前弱势群体的居住地及生活条件，以及对应年份洪水退却后是否需要重建基础设施。

其次，针对人与塑料之间的关系，笔者发现非正规居民区和垃圾填埋场最可能存在垃圾管理不善的状况。通过研究“2003年马尼拉大都会区固体垃圾管理项目”^[2]，笔者进一步了解到，马尼拉的许多垃圾填埋场都存在毒害风险，而且即将到达使用年限。其中少数填埋场的垃圾处理设施也存在缺陷，例如一些作业区的垃圾填埋不够严密，甚至被大量暴露在外，加之边界管控不严，无法有效限制废品捡拾者进入这些充满危险而崎岖不平的填埋场。因此可以推测，在3~10月季风期间，地表径流会将大量塑料从非正规规定居点和垃圾填埋场冲入附近支流并最终流入帕西格河——帕西格河塑料排放量监测数据也印证了这一推测。

第三，针对塑料与环境的关系，笔者分析了马尼拉大都会区的河流系统，以了解塑料垃圾最有可能聚集和堵塞的区域：首先根据之前对马尼拉的地形分析，将所有河流按照层级和流速分类，并通过基于地形的地表径流分析，找出垃圾堆积的主要地区——即地表径流流经非正规居民区和垃圾填埋场，最终所汇入的流速缓慢或水深较浅的河道。笔者将这些地区确定为潜在的塑料收集点，以便为易受海平面上升影响的社区建造水陆两用的住所提供原材料。

2.2 设计第一阶段——河流改造

第一阶段的设计旨在探究切实可行的河流改造方法，使帕西格河转变成为一种可以被动分类和收集塑料的机械景观，以提高毗邻垃圾填埋场的沿岸非正规居民区居民的生活品质。因此，关键是要了解当前不同类型塑料的处理与分类方法。在现有的垃圾流处理技术中，利用“浮沉分离法”，未经分类的塑料颗粒可在不同密度的液体中运动，

从而实现对不同浮力的塑料的分离。那么，是否可以通过在河流中加入某些物质来改变不同点位水体的密度？这一想法显然并不现实，却启发笔者通过改变河流形态来影响不同支流中物质的流动方式——例如，中国的都江堰灌溉系统即通过设置宽度、深度不同的“内江”与“外江”来应对成都平原雨季的洪水和河道淤塞问题。以此为参考，本项目尝试改变河流的分叉角度和深度，来减缓湍流、改变水体流速。这就需要重新设计河流形态，塑造辫状河道——河水将一直沿其中深而窄的河道流淌，而宽而浅的河道则可用于雨季蓄水，并收纳由地表径流带来的、散落在附近棚户区和社区地面上的塑料垃圾，使之聚积并被自动分类：密度较大的塑料，如聚对苯二甲酸乙二醇酯（PET）、聚氯乙烯（PVC）和聚苯乙烯（PS），会聚积在沙堤外缘；而密度较轻的塑料，如聚乙烯[高密度聚乙烯（HDPE）和低密度聚乙烯（LDPE）]和聚丙烯（PP），则会受离心力作用而聚积在沙堤内缘。因此，沙堤将兼具分流河道和引流、回收和分拣塑料垃圾的作用。由

- 2. 马尼拉大都会地区的“干层饼”分析图
- 3. 马尼拉地形分析。紫色与粉色区域分别代表2050年和2100年的洪涝风险区，圆圈代表可能受海平面上升影响的人口密集区。
- 2. Indexical layers of Metropolitan Manila
- 3. Topographic analysis of Manila, with flood risks indicated in purple and pink for 2050 and 2100 respectively, and bubbles indicating the population affected by sea level rise.

4. 马尼拉大都会区的塑料垃圾堆积分析
4. Analysis of accumulation of plastics in Metropolitan Manila

此，社区居民可获取用于建造新基础设施的材料，从而实现建造一个可在季风季节适当抬高和扩展的水陆两用社区的构想。

2.3 设计第二阶段——模块嵌合

待河流和社区居民完成塑料收集后，就可以开始建造新的基础设施，以使社区适应不断变化的环境。笔者研究了当前的各种塑料成型技术，并选取了“挤压成型”和“旋转成型”两种技术来制造社区构建元件。其中，挤压成型技术将用于制造结构元件，而旋转成型技术则适用于生产大型的可居住模块，这些模块可一次成型，且中空的结构有利于建构水上空间。下一步是确定社区居民生存所需的功能空间，以找出可能的模块嵌合方法。最终笔者明确了四大功能组块，各种功能节点可由不同的结构元件或模块组合而成。作为最重要的功能空间之一，生产节点可服务于基础设施建设、物质储存、热解能源开发，以及塑料收集机械生产等。社交空间节点是另一大核心功能组

块，包含生活区、市场、用于规划改造和其他战略部署的市政大厅、作为劳动力培养和未来人才的学习空间等系列模块。农业和水产养殖节点则旨在保障社区食物自给。不同的模块经过某种排列与组合后即可形成具备特定功能的节点。为方便不同模块间的衔接，笔者又创建了一组具有不同空间特性的模块，如竖向衔接的斜坡、组装时可以改变嵌合方向的螺旋体，以及供社交集会使用的双层空间等。而后，笔者进行了三维嵌合模拟，以了解如何运用这些简单的模块建造复杂的空间形态，再根据其特性进行节点分类——假若某地需要配置可向内缩进或向外延伸的阶梯式空间，或当需要运作生产机械时，则节点需要创造充足空间。如此，不同的模块嵌合方式将构建出多种功能节点，以使各类节点的空间特性和模块功能形成最佳匹配。

社区在生产第一批模块时，会同时将沙堤作为功能节点的临时锚地。到2090年前后——即设计构想的最终阶段，海平面上升将威胁到居住在低洼地带的社区居民，此时的社区也已做好应对准备，随着气候条件如预期发展，这些节点将会沿沙堤逐步建立起相对稳定的生产、社交和农业集群。每逢雨季发生洪水时，沙堤上将会形成小水渠和池塘，将水输送至节点集群的下部，使其漂浮于洪水之上，并且借助结构性桩柱防止节点集群随洪水漂走。而在旱季，在这些节点下部将构筑起一层新的模块，以将社区基面抬高。直到临近2090年的最后阶段，当海平面上升至可能永远淹没这片人们赖以生存的土地时，这些发展成熟的节点集群将开始随着海潮上升，最终和沙堤（锚地）分离，沿河道顺流而下去飘向入海口。

2.4 设计第三阶段——战略性生长

在这一阶段，节点集群将开始离开陆地，沿着马里基纳河（及其他河流）进入海洋。此时的关键点在于了解随着社区由陆地转向海洋，人们的生活将发生怎样的变化。一个个集群在从河流漂入大海的过程中会彼此靠拢，并相互插接构成更大的集群。这些更庞大的集群继续顺着洋流在海洋环流周围聚集，最终形成一种新的城市形态——“可塑城市”，并发挥环境服务功能。

可塑城市的构建元素分为三个层级，即建筑模块、由模块嵌合而成的节点，以及最终由节点嵌合而成的具备不同功能的集群。各模块的连接点被设置于上部，居民可通过位于中央的楼梯上行，去往其他节点甚至集群。此外，可塑城市中还将环绕各集群设置一条专用的“高速路”，以连接起其中的重要节点。曾经在陆地上依托沙堤进行的生产集群间的运输改由划艇交通系统完成，其可以将材料运输到下游的生产节点，并将制成的产品带回上游的生活区。同时，在这种海洋社区中，更多发挥连通功能的“高速路”将开始形成。当来自两个集群的节点在海洋里相遇时，就会打开各自外部“高速路”的连接点，使两大集群相互连通。如此一来，越来越多的集群将聚集到一起，不相邻的节点间也将间接地建立起更多的“高速路”连接。在海洋环境中，社交空间集群和农业生产集群将会链接到一起，并且随着社区的成熟，越来越多的模块将会在不同节点间实现有机连接。但与

1 Background and Problems

In order to design a process to allow the reuse of plastics that have been thrown away into rivers and eventually to the sea, it is crucial to find out about where most of the waste that ends up in oceans comes from. Plastic pollution exists throughout the rivers worldwide, but the problem becomes pronounced in areas short of critical waste management infrastructure. Hence Asia, Africa, and the South American continents ended up being huge contributors of plastics in oceans due to the presence of many developing cities, with growing economies and affluence in the region. The project grounds itself in Manila, home to the Pasig River, the second most polluted river in the world based on linear density. Each year, it is estimated that 63,700 tons of plastic flows from the Pasig River into the ocean. However, through research and data collected, most of the waste is dumped during the monsoon season^[1]. This occurs when surface runoff carries the mismanaged waste from the urban and slum areas surrounding the river and its tributaries into the river itself. Would it be possible then, if the river can be employed to sort and withhold the plastics before it flows to the sea? And how could this possibility benefit communities surrounding the river? Besides researching into the causes and sources of pollution in Manila, the project also looked into how the changing climate could affect the city. The authors did a series of topographic analyses using satellite scans of the land available online, and predicted how much land would be covered by flooding in the next 30 to 80 years from now.

By analyzing the population density in different provinces, the authors estimated that 1.6 million people may be affected by sea level rise by 2100. Unfortunately, the regions most direly affected by rising sea level are the most densely populated, with their population size steadily growing. Due to a lack of urban planning and infrastructural development during the urban migration in the 1970s, Manila is now covered by a low-lying sprawl of buildings. Many of these urban migrants have to inhabit slums that encroach on the rivers, making the poor exceptionally susceptible to climate change, yet being the least equipped to survive this impending doom. How then could the project give back to the communities surrounding it by providing them with homes that could survive seasonal flooding, the people a stable job and income in a dignified manner? Currently many of these slum dwellers partake in waste picking as their choice to a source of income. While it allows them to make ends meet for themselves and their family, the conditions of work are non-ideal, with long laborious hours being returned with meager income, subjected to the fluctuating price of raw materials and

8. 通过图示的形态改造，马里基纳河可对塑料垃圾进行被动分类，并为当地的社区居民提供更多谋生途径。
8. The Marikina River will be terraformed to passively sort out plastics and act as a host to various livelihood.

surface runoff was also topographically analyzed to locate the accumulation hotspots of rubbish — the areas where surface runoff will pass through informal settlements and landfills and end up at river channels with low velocity or low depth. The project initially identified these areas as potential starting points for the intervention of collecting plastics for the building of amphibious housing for the communities vulnerable to rising sea levels.

2.2 First Design Phase — River Terraforming

The first stage of the design process was to figure out an effective way of terraforming the river into a mechanic landscape that would sort and collect plastics passively, improving the quality of life for the informal settlers staying near rivers next to landfills. To that end, it was crucial to understand what the current methods of processing and sorting different types of plastics are. Interestingly, the current technology of waste stream is the use of the sink-float technique that allows an unsorted collection of plastic pellets to be moved through liquids of different densities and sorted into different categories depending on their floatability. This gave us the idea to check if there were

compounds in the river that could vary the density of water at different points. Unable to have water of varying densities throughout the river, the project instead looked into ways through which the river morphology could affect how contents in the river flow between different distributaries. The authors studied the Dujiangyan Irrigation System in Chengdu, China, which varied depth and width between two channels to control the flooding and silting problem within the crop valley by diverting silt and water away during the monsoon months. In a similar fashion, the project varied the angle of bifurcation and depth of the river to change the turbulence and velocity of flows. This required redesigning the river morphology into a braided river, where freshwater remains in a system of deep but narrow canals that flow throughout the landscape all year round, whereas a separate system of wider and shallower canals would get filled during the monsoon months to collect and sort the plastics. Furthermore, during the monsoon months surface runoff carries the plastics strewn on the ground of nearby slums and communities. Plastics of a higher density — Polyethylene terephthalate (PET), Polyvinylchloride (PVC), and Polystyrene (PS) will flow along the outer edge of the sandbars,

while plastics with a lower density — Polyethylene (HDPE and LDPE) and Polypropylene (PP) will float along the inner edge, by virtue of centrifugal force. Thus, the river will end up having sandbars that split the river course and channels various kinds of plastics to be sorted and collected within its depths. This sort of terraforming would allow the community to sort and collect plastics that could be used for new infrastructure construction, allowing for the speculative proposal of building an amphibious community that would rise and grow with each monsoon season.

2.3 Second Design Phase — Module Aggregation

As soon as plastics have been gathered and collected by the river and the community, a new infrastructure can be created that would allow the community to adapt to the changing environment. The project looked into various techniques that are currently used to form plastic products and adapted two of them, extrusion molding and rotational molding, for the casting of elements of the building blocks. Extrusion molding might be used for the manufacture of structural elements while the rotational molding method was chosen for the casting of modules that would be inhabited because of its ability to cast large objects in a single go yet remain hollow encouraging floatability. Before looking into possible ways of agglomerating the objects, it was necessary to first identify programs of spaces necessary for the survival of the

community. The project proposed 4 families of function with a few of elements or modules within its umbrella. Production nodes were seen as one of the core families, built for programs such as production of infrastructure, material storage, energy production using pyrolysis as well as the machines used for the collection of plastics. Social Spaces nodes were seen as another important pillar and include functions such as living quarters,

9. 节点集群依托沙堤逐步生长，并分化出适宜不同活动的功能形态。
 10. 海上“可塑城市”剖面图，展示了建筑材料及产品从生产节点运送到生活区的过程。
 11. 模块类型及组合方式
 12. 与不同活动功能对应的模块设计
9. Growing phases of clusters on the sandbars, based on different programs envisioned.
 10. A section of the Plasticity in the sea. It shows how building materials and goods will be sent from the production nodes to the living quarters.
 11. Catalogue of modules and their accumulation
 12. Concepts of modules designed for various programs envisioned

marketplace, town hall for the planning of terraforming and other strategic activities, and learning space for the education of more manpower and the future generations to come. Agriculture and Aquaculture nodes are also considered as a means for protecting the food sovereignty of the community. Single generic plastic modules may come together to form nodes of particular functions through certain arrangements and organizations. With these programs' connection in mind, a family of modules were created for different qualities of spaces needed, such as slopes to connect vertically, twists to change direction during circulation, double-height spaces, and a meeting for social gathering and cohesion. 3D tessellation studies were conducted to understand how one could generate complexity from the repetition of this reduced family of modules, and the resulting nodes were classified based on the quality of space it could provide: there might be more modules needed to meet at a single point, if they are terracing in or out, or when a large central space could be

left void for the machines used for production. With that, the different types of agglomeration of modules were assigned to specific programs, forming nodes with qualities that best suit the function of the program.

As the community begins to produce its modules, they will agglomerate these modules into nodes atop the sandbars that act as hosting sites to the community's nodes. Until climate conditions are right, these nodes will then intensify and create production, social or agricultural intense clusters along the sandbars, as the community prepares itself for the last stage of the narrative, happening around the year of 2090, when the sea-level rise threatens communities living on low-lying terrains. Every year as monsoon season brings in floods, there will be small channels and pools in the sandbars that allow water to fill up beneath the node and to float on the surface of the flood water whilst being railed in by structural columns. During the dry season, a new layer of modules will be built

underneath allowing for the building up of the community. Towards the final stage closed to the year of 2090, as the sea-level rise threatens to inundate the piece of land they would live on forever, the matured clusters will begin to lift together with the tides and eventually detach itself from the host sandbar, following the course downstream and towards the exit point into the sea.

2.4 Third Design Phase — Strategic Growth

At this stage the clusters will start flowing along the Marikina River (among others) to exit land and move into the sea. It would be important to understand how their livelihood would change as they move from a land-based community to one within the oceans. The individual clusters will float out from the rivers to sea, finding each other then building bigger clusters, plugging in and building connections. They would follow the

currents of the seas, grouping around ocean gyres to perform the environmental functions of “Plasticity,” a new form of city.

There are three hierarchies of building elements, building modules, and aggregated nodes that eventually gather to form different function clusters. The connectivity between modules occurs in the higher parts of module, where inhabitants would climb through the central stairs and exit the modules, allowing habitants to connect through the node and eventually the cluster as well. Additionally, there would also be a dedicated circulation “highway” that envelopes the cluster and would connect between important points within it. Once on the sandbars, connections within the productive cluster are left to the gondola lift systems that would bring the materials downstream to production nodes and harvest good upstream to living quarters. Meanwhile, it is within the sea-based community that further connective “highways” will begin to grow. When a node meets another in the sea, it opens the intersecting segment of the exterior enveloping “highway,” allowing nodes to be made between two clusters. This will continue to propagate as more clusters begin to join together, where more connected “highways” will be built between the non-adjacent nodes. Social Spaces clusters and Agriculture Production clusters will begin to calcify together within the sea, as communities grow and begin to connect their modules more organically between nodes. However, Energy and Material Production clusters will remain discrete and separate in order to allow them to unplug and move to parts of the sea wherever conditions are favorable (i.e., wherever is closest to the ocean gyres); as well as to allow them to attach to parts of Social Spaces clusters that require more energy.

3 Discussion and Review

The current status of the project remains very much in the massing stages within a speculative environment, a further push in the project could be in the direction of defining the architectural design. Firstly, with the river starting to sort between different types of plastics, there is an opportunity to use different plastics for different architecture elements. This would also be possible with greater understanding on the material properties of various types of plastics. With this there could be a refinement on the types of connections between modules, nodes, and clusters, where the connections could also double as central-facing podiums for residents in the community to gather and discuss issues pertinent to their existence in the sea and the constantly changing environment that the authors can only fathom and begin to imagine. This

13. 一系列沙堤界定了河道曲折有致的形态，材料生产节点及生活节点也将建立。
13. Nodes for material production and living quarters to be built on the sandbars that divert river channels.

14. “可塑城市”将对收集至海洋环流附近的塑料垃圾加以利用，使其逐步生长为节点集群并固定为一座“浮岛”。
14. The Plasticity benefits from plastics found in ocean gyre garbage patches. The clusters were drawn in various degrees of maturity, with the mature clusters beginning to calcify the nodal clusters into an entire floating island.

interweaving of connection could also bring a second wave of aggregation along the connective pathways that snake through the clusters, creating a cloud of aggregation of modules above the surface of water. Although the current project remains atop the surface of the oceans, refining the openings of the modules and allowing it to be a water-tight system with ventilation tanks will allow the community an opportunity to live within the depths of the oceans. There they could learn about the health of the seas and co-exist with marine creatures within — adapting within the constantly changing environment. Lastly, as the environment changes from being land-based to water-based, there would be a change in emphasis from land-based agriculture to aquaculture, not just in terms of rearing crustaceans and fishes but also with sea-based agriculture like seaweed and mangroves that further solidifies the community against the harsh ocean environment. Aquaculture pods and nets can be attached to voids between the nodes to cultivate fingerlings and fishes. Existing Agriculture nodes can be lowered into the water onto connective twines between Floating nodes and Habitation nodes, calcifying and strengthening the structure of the floating communities. **LAF**

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