Reinventing the Freshwater Shelter: An Experimental Planning Project for the To Kwa Wan Area in Hong Kong

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After an era of rapid development, Hong Kong has reached a critical juncture at which urbanisation is saturated and in urgent need of transition. Hong Kong's freshwater resources are in a state of scarcity due to its small geographical size, limited surface watersheds, ageing building services and extensive reclamation. Under the guidance of the Sustainable Development Goals, planning for the utilisation of Hong Kong's existing resources and the introduction of emerging technological tools provide development opportunities for the experimental remodelling of Hong Kong's freshwater system. The concept for a shelter is based on the ageing infrastructure and impending collapse of the freshwater system in the To Kwa Wan area of Hong Kong. The objective of this paper is to experimentally reconfigure a freshwater system in a densely populated area through novel bio-building materials, modular design systems and computational modelling. Moreover, this paper provides design concepts for future cities to cope with the complexities of climate change and sudden-onset disasters. The validity of the design results is assessed through experimental modelling and scenario simulations.

#modular design

#bio-building materials

#bio-purification of water

#design computation

#future urban renewal

Introduction

Hong Kong, as an important economic centre in the Asia-Pacific region, has entered a stable stage of urbanisation after prosperous development. It has a large number of old urban areas, which are often characterised by ageing buildings, poor community hygiene and inadequate transportation and public infrastructure.

For a number of years, Hong Kong has relied mainly on the diversion of water from Dongjiang on the Mainland for the importation of fresh water resources (Water Supplies Department n.d.-c.). Hong Kong relies on mainland China for importing 52% of its fresh water, while the local rainwater harvesting system contributes only 26% (Wikipedia n.d.). Desalination can meet approximately 5%–10% of its overall freshwater demand (Water Supplies Department. n.d.-b.). Due to the ageing of water harvesting and supply equipment, localised water harvesting is not fully utilised, resulting in a poor urban water storage capacity. Desalination in Hong Kong also has drawbacks, such as high carbon emissions, high costs and saline pollution (Wang 2021). The hilly terrain, small land area, subtropical climate and uncontrolled urban expansion are all major problems leading to the shortage of freshwater resources. After the industrialisation of the To Kwa Wan area in Hong Kong, the problem of freshwater shortages has become increasingly serious due to irrational planning.

First, sparse greenery and dense construction in To Kwa Wan have led to a severe urban heat island effect. Second, the large-scale reclamation in the area has led to seawater intrusion into the groundwater. Third, To Kwa Wan lacks surface runoff and has scarce freshwater resources that can be utilised directly. Fourth, the water supply facilities in To Kwa Wan are ageing, and breakages in the water mains have caused serious water shortages. Finally, the over-pumping of groundwater for MTR (The Mass Transit Railway of Hong Kong) construction has led to ground subsidence, affecting the safety of residents.

To Kwa Wan has a large population; approximately 82% of the buildings are for residential use, and only 6% of the area is green space. In 2018, public transport construction in the area caused over-pumping of groundwater, leading to excessive ground subsidence and building cracks and leaving residents dealing with housing safety problems (Lin 2018). In 2023, a large-scale acute water shortage problem occurred in the Ma Tau Wai Road area of To Kwa Wan due to the rupture of water supply pipes caused by ageing water mains. Due to this, the water supply system was unable to function properly, thus seriously affecting residents' livelihoods (Deng and Huang 2023).

When it comes to disaster management, temporary shelters are the main requirement in the face of emergency situations (Nekooie and Tofighi 2020). Urban ageing and the need for fresh water necessitate urban regeneration in the To Kwa Wan area to cope with disasters. The concept of freshwater shelters has arisen from this. How to gradually relocate people to freshwater-orientated shelters in densely populated areas is the focus of this essay.

In the event of a disaster, prefabricated modular buildings allow for an emergency response and increase the efficiency of temporary housing construction (Farrokhsiar et al. 2024). Emergency modular system design allows for the rapid formation of dynamic and manageable shelters in densely populated areas of Hong Kong. Influenced by the Sustainable Development Goals, the human-centred design perspective is gradually shifting towards a biocentric model. Ghomi et al. (2023) mentioned that biomaterials create resilient features for shelters by virtue of their self-adaptive, self-healing and progressive growth characteristics. The use of biomaterials for water purification is in line with the goal of sustainable resource utilisation. How to improve the efficiency of biomaterials for water purification and apply them to modular systems needs to be simulated by means of computational modelling to obtain optimal solutions.

Parametric design provides ideas through algorithms, and the balance between humanism and ecosystems should be emphasised. According to Andriasyan (2020), computational modelling allows for an improved analysis of shelter designs and real-time feedback on design results through visualisation charts. The current study uses Grasshopper, a powerful urban design analysis tool, to introduce generative design into an urban design system for simulating urban regeneration pathways and optimising the application of biomaterials for water conservation. Design computation drives the formation of a design system through its immense real-time feedback and dynamic simulation capabilities. Meanwhile, the design system guides the parameterisation of design computation while taking into account various stakeholders. This essay explores the potential of combining digital technologies and systems design thinking in future urban design projects by integrating computational design with humanistic concerns. Furthermore, the limitations of computer-aided design in urban planning projects guided by systems thinking are discussed during the design process.

Algorithms and Case Studies

Wallacei – Evolutionary Simulation. Wallacei is a Grasshopper plugin for result-optimisation calculations developed by Mohammed Makki (Wallacei n.d.). As an analytical tool, it can be simulated by adjusting parameters to obtain the desired results after evolution. Wallacei can be used for evolutionary selection in urban design.

Physarum – Biomimicry and Shortest Paths. Physarum is a Grasshopper algorithm that quickly generates the shortest paths by setting up a starting point and a food point based on terrain with obstacles (Ma and Xu 2017). The research on this algorithm originated through the consideration of biomimicry to obtain new ideas of urban path planning from the perspective of natural growth and to break irrational planning caused by the process of rapid urbanisation. Lee and Lee (2018) noted that Physarum is a self-organising system that can be used to inspire undiscovered urban paths. Physarum can help make new connections based on the consideration of the original urban layout and can provide ideas about the shortest paths for the transmission of freshwater resources.

Computational Seeding. Using Buildings as Bark: Bio-receptivity refers to a new kind of building material that can reduce the urban heat island effect and maintenance costs (UCL Bartlett School of Architecture 2019). Planting mosses on building façade materials with special grooves allows for water purification, water storage and the regulation of localised urban microclimates through plants. Instead of being installed on the surface of a building by means of brackets, as in the past with green walls, the plants grow on the surface to reduce maintenance and irrigation costs (Figure 1).

Green Moss Solar Steam Generator – Improving the Efficiency of Water Purification. According to Khajevand et al. (2021), natural moss materials combined with solar collectors can improve the efficiency of purifying natural water and enable desalination and water purification under sustainable conditions. Green moss is environmentally friendly, low-cost and easy to grow. The heat absorption of moss during water evaporation can effectively mitigate the urban heat island effect. How moss water purifiers should be installed to maximise the efficiency of water purification in shelters is a question worth considering.

Foramanifera Architecture – Desalination of Seawater Using Solar Energy. According to Chatel (2016), offshore floating platforms (Figure 2) have been built to desalinate seawater and improve freshwater supply structures. Seawater is pumped into a solar pool on the roof, and fresh water is piped into all parts of the building. The cooling effect of the pool promotes the natural ventilation of the building.

Design Theoretical Framework

Two Loops Model. Under the Sustainable Development Goals, a shift in the design perspective from human centred to eco-centred is needed to address the complexities of future climate change. The Berkana two loops model suggests that when a dominant system reaches its peak and faces decline, an emergent system full of possibilities should be created to repair the complex system (Berkana Institute 2024).

Hong Kong relies heavily on the import of fresh water. The acute water shortages that have occurred frequently in the To Kwa Wan area in recent years suggest a freshwater system that is about to collapse (Figure 3). To Kwa Wan is currently in a transitional phase of urban transformation, and to create a more comprehensive emergency system, a deep analysis of the existing system is required to understand the needs of all aspects and to highlight humanistic and ecological adaptations.

Summarising the current freshwater system in the To Kwa Wan area of Hong Kong from the macro, meso and micro perspectives (Figure 4) allows for a clearer identification of the systemic issues. From a macro perspective, the impacts of global warming and urbanisation have resulted in a significant heat island effect in Hong Kong, with a consequent decrease in precipitation. This will lead to an increase in overall drought in Hong Kong and an increase in the demand for fresh water. At the meso-community level, To Kwa Wan's water reuse is inefficient, and ageing water supply equipment is leading to a higher rate of freshwater loss. In the micro emergency response system, over-exploitation of groundwater has led to ground subsidence and increased problems with the safe use of buildings, while adding to the risk of freshwater pipeline leaks.

Complex Adaptive Systems. The theory of complex adaptive systems (CASs) was proposed by Holland (1992). According to the theory, parallelism, competition and recombination are three necessary mechanisms for CASs. These sytems focus on the complexity of internal structures and have their own evolutionary capabilities and feedback mechanisms, and an internal model can respond positively in times of transition. Nair and Reed-Tsochas (2019) mentioned that the elements of a CAS should be in a competitive and cooperative relationship that is interconnected and co-evolves to form a whole what is stable and adaptable to various changes. A city is also a complex dissipative system, and only by combining urban development with the environment can the output entropy be kept stable. The stabilisation of entropy requires a balance of urban metabolism (Gallopín 2020). As a complex adaptive system, a city should respond quickly and positively to changes in the environment.

Under the guidance of CAS theory, systemic innovations need to simultaneously incorporate synergies among elements. A complex system should be able to respond to changes in the external environment, receive feedback from any environmental change and react in a timely manner to achieve positive outcomes. Complex freshwater adaptive systems are necessary to reconcile growing water demands with serious climate change.

Stakeholder Network. At the micro-construction level, stakeholders consider how designers select materials and whether this will affect worker employment and the suitability of water purification equipment for specific locations. At the mid-community level, attention should be paid to how to coordinate residents, the local economy and community organisations to promote the regenerative water recycling model. At the macro-societal level, how the government implements policies and financial support, how social media work, how the educational value of recycling fresh water should be promoted and how sustainable partnerships with businesses should be built are all synergies that need to be considered in the creation of a CAS (Figure 5).

Methodology

To achieve the United Nations' Sustainable Development Goals, promote the use of clean energy, achieve equity in the distribution of freshwater resources and respond positively to climate change, the following six coping strategies have been proposed (Figure 6): (1) improving water purification efficiency and reducing import dependency; (2) increasing the efficiency of water recycling and reducing waste; (3) switching to biological materials for seawater purification to reduce carbon emissions and mitigate the heat island effect; (4) establishing residential autonomous water purification systems to reduce transportation costs; (5) restoring ecological habitats and increasing groundwater recharge; and (6) resolving the ageing of water pipes due to ground settlement and relocating residents to a safe environment.

To solve the problem of freshwater shortages in the To Kwa Wan area, the freshwater system should be reconfigured and the construction of an urban refuge completed. It is necessary to develop design strategies from both horizontal and vertical perspectives.

Horizontal Design Strategy. Horizontally, older buildings that jeopardise the safety of residents will be demolished, and people should be relocated to new shelters. Meanwhile, it is necessary to replan road construction and increase the ventilation corridors in the city. Physarum is used to simulate new roads in the city.

The buildings in To Kwa Wan are old, with construction concentrated in the 1950s to 1980s. The older buildings are centred on Ma Tau Wai Road (orange dashed area), with ages decreasing in the surrounding area (Figure 7). The To Kwa Wan MTR Station was built on Ma Tau Wai Road. In this area, there was a ground collapse with burst water mains due to over-pumping of groundwater. Therefore, Ma Tau Wai Road is used as a priority area for the emergency planning of shelters.

Since the collapsed area (in black in Figure 11) is uninhabitable, the buildings will be returned to urban green space to promote rainwater infiltration and groundwater recharge. In the horizontal design, the launching point of Physarum is the traffic centre of Ma Tau Wai Road, which serves as an intersection between the To Kwa Wan area and external traffic. Food points will be located in places such as schools, commercial areas, hospitals and fire stations and will be connected to shelter locations for easy access. Due to the severe heat island effect in the To Kwa Wan area caused by the original high urban density, the existing road plan will be elevated to increase urban ventilation corridors.

The area's boundaries will not be strictly limited when the path is optimised so as not to affect the way Physarum moves. As visualised in Figure 8, the most efficient paths planned by Physarum are significantly different from the original urban planning. Areas with dense paths can be constructed as transportation hub facilities, thus reducing traffic congestion and improving efficiency. As a result, the urban heat island effect can be controlled. In addition, the optimised paths provide effective suggestions for the location of shelters.

The next step of the horizontal design strategy is the gradual relocation of people who encounter severe water scarcity problems and hazardous living spaces to new urban shelters. As slime mould grows, new urban staging areas will be identified. The demolition of existing housing units, which are at risk of habitation and freshwater scarcity, is necessary. The rapid relocation of the population to the new shelters has become a design priority.

As shown in Figure 9 (1) and (2), the collapsed area through which Physarum passes will be restored to an urban green landscape area. The To Kwa Wan area is sparsely vegetated, with poor evaporation and heat absorption for groundwater recharge. Green space planning can help mitigate the urban heat island effect. Meanwhile, path optimisation means that this area can be set up as a comfortable walking space that preserves green space performance while taking into account traffic accessibility. As shown in Figure 12 (3), areas with dense Physarum can serve as important transportation hubs. However, Physarum's path optimisation traverses currently preservable built-up areas, proving that it can be used as a secondary transportation node and that such areas can be gradually upgraded during the urbanisation process. To ensure residential performance and combine the TOD concept of transportation-orientated urban design, a vertical living space that integrates transportation, commerce and housing can be established in the planning of such areas. As shown in Figure 12 (4), the blue areas are reserved buildings in the non-collapse zone at this stage and are not affected by the road plan. These areas will be used as progressive relocation zones for shelters, and the ageing buildings will be gradually demolished according to their condition.

Vertical Design Strategy. The vertical design strategy focuses on three perspectives: reserved buildings, dying buildings and additional shelters. The green moss solar steam generator and bio-receptivity building materials mentioned in the case study will be appropriately integrated into urban life. The shelter design uses a modular design approach with simulation to promote equal water allocation.

Micro-Scale: For Reserved Buildings. At the micro scale, buildings not affected by ground collapse or reserved will be fitted with moss water purification devices on their roofs for rainwater harvesting and storage (Figure 10). According to Khajevand et al. (2021), these moss evaporation water purification devices were designed as moss tables that can be placed on the roof to collect and purify rainwater. The evaporation rate of the mentioned biomass solar steam generator (moss) (Khajevand et al. 2021) is as follows:

2.61 kg m-2 h-1.

According to the Census and Statistics Department (n.d.), the average domestic household size in Hong Kong (number of persons) is 2.7. Research by the Hong Kong Water Supplies Department (n.d.-a.) mentioned that daily water consumption per capita is approximately 150 litres. Based on this, the total water requirement of one family is 2.7 × 150 = 405 L (405 kg). Therefore, the hourly water requirement per household is 405kg / 24h = 16.875 kg/h. The required moss filter area is 16.875 kg/h ÷ 2.61 kg/m^2/h = 6.47 m^2.

Micro-Scale: For Dying Buildings (Subsidence Area Construction). The design strategy for collapsed areas is to demolish buildings and restore green spaces while recycling building materials. Useful building structures can be used to grow moss and create a characteristic urban landscape, since the moss gradually erodes. In addition, open spaces can be used for installing moss water purification devices to collect rainwater and create an urban landscape reservoir (Figure 11).

As shown in Figure 12, planting the collapsed area with moss can increase the green area and improve evaporation and heat absorption. Buildings will gradually be restored into a green landscape through moss erosion. Urban green landscapes can increase soil activity, increase rainwater infiltration, recharge groundwater and stabilise building foundations. In addition, the vacant land where buildings have been demolished can be used to install moss water purification units for water recharge.

Meso-Scale: For New Living Modules (Modular Shelters). Populations affected by water shortages and building safety issues will be moved from the collapse zone to new modular shelters and optimised using Wallacei. The shelter design should therefore follow regenerative, dynamic and adaptive design principles. The material selection for the shelter will utilise porous MPC concrete (moss) building materials (Figure 13). After this, the shelter will realise water purification and storage functions and regulate the local microclimate through moss materials. The number of shelters will gradually increase as the population migrates. In parallel, the regulatory function of the moss will increase and eventually complete urban renewal.

Computational design can be used to adjust design schemes in real time according to reality, thus breaking the hierarchy of traditional buildings and promoting the equal distribution of resources. Evolution produces offspring, with rules for the optimal recombination of useful genes belonging to genetic algorithms compatible with the evolutionary mechanisms of complex adaptive systems (Holland 1992). The purpose of using Wallacei optimisation is to obtain a comfortable living experience as well as to maximise the protection of freshwater resources by changing the shelter layout.

According to a report by the Hong Kong Legislative Council (2022), the per capita living space in Hong Kong is approximately 16 square metres (the per capita area of sub-divided units is only 6.6 square metres). The modular design of the shelter consists of a square block of 12 metres/side, with a living area of 100 square metres/unit (Figure 14).

Among architectural classics, Amsterdam Orphanage promotes community interaction and humanity by incorporating modules into the functional connections of the space (Fracalossi 2019). Besides, the successful promotion of MIT's 1K module house demonstrates the importance of modular design in maintaining spatial continuity and flexibility, and promoting optimal resource utilization (MIT n.d.). Therefore, this research incorporates the advantages of modular design in sustainable development, extends the community communication function, and innovates disaster response design.

A quarter of the area of each shelter module comprises a public corridor (Figure 15), which can maintain the public spaces continuously, no matter how the algorithms are combined or how subsequent shelter modules are added. In the process of block growth, the moss wall can be connected as a whole, guaranteeing the city’s self-growth (Figure 16).

As shown in Figure 17, there are three control variables in the optimisation of the results with Wallacei. The first is the height of the shelter building, and the footprint of the shelter can be changed at any time according to the actual site situation. Setting the height of the building as a controllable variable facilitates the determination of the budget required for the construction of shelters based on the migration status of the population. The second control variable is the number of shelters, where the combination of Physarum’s simulation and the age of the buildings can determine the number of people who need to be relocated at the current time. Consequently, the parameters can be adjusted for the appropriate number of shelters to generate a diversified form of settlement. The third gene is the frame structure, which aims to preserve the basic structure of the building with the same module size and improve the flexibility and stability of the building. As a result, suitable wind channels can evolve with a set range of gene pools. The selection of structures for heat island effect reduction is used for subsequent evaluation using wind simulation software.

It is worth noting that Wallacei optimisation can compute only datasets that converge with the optimal result under specified parameters. Therefore, simulation results need to be optimised and evaluated based on reality. Figure 18 shows the simulation results of the Ma Tau Wai Road area, with shelters integrated into the city and green spaces progressively connected.

Phoenics was used to simulate the wind environment of the site by inputting climatic data from the To Kwa Wan area for the previous 10 years. As shown in Figure 19, after using the new design strategy, the wind velocity in the To Kwa Wan area was significantly enhanced, and the passive cooling performance of the city was improved. A reduction in the heat island effect will lower urban temperatures while reducing evaporation and promoting rainwater harvesting and groundwater recharge.

Meso-Scale: Green Moss Solar Steam Generator for Seawater Desalination. In terms of desalination, combining moss with a floating island desalination unit designed and built by Bart//Bratke and studioDE, as mentioned by Chatel (2016), can reduce the cost of desalination. In addition, moss can reduce carbon emissions compared to traditional desalination methods. Meanwhile, the establishment of floating island desalination plants in seawater can create low-pressure zones that increase urban ventilation (Figure 20).

Macro-Scale: Macro System (Water Circularity in Multiple Layers). A plan for a freshwater urban shelter based on computational modelling was developed. The design is orientated towards fresh water, and moss is used as a biomaterial throughout the design. Buildings are categorised as dying buildings, reserved buildings and new shelters. Dying buildings are returned to urban green spaces, while reserved buildings are used for installing rainwater harvesting and purification devices. Additionally, new shelters collect rainwater and regulate the city's microclimate through moss. As buildings age, reserved buildings become dying buildings, and people are progressively relocated to new urban shelters.

Freshwater cities are designed to be systematic. As shown in Figure 21, the formation of urban green spaces recharges groundwater and contributes to soil biodiversity restoration and building foundation stabilisation. Rainwater is channelled through moss installations. Pathway simulation–inspired urban planning approaches target design concepts with regard to the impacts of the heat island effect on freshwater, and systematic design thinking promotes reflection on greywater reclamation and desalination. In addition, mosquito control takes into account government regulations.

The design of freshwater-orientated urban shelters is a gradual process. Therefore, after the design concept has been developed, the sequence in which the demolition of ageing buildings and the gradual construction of shelters will be carried out is the research point at this stage.

There are many ageing buildings in the To Kwa Wan area, except in areas of acute water shortages due to ground collapse and breakages in the water mains. Other buildings that are unfit for human habitation still exist. As shown in Figure 22, by overlaying the age distribution map of buildings in the To Kwa Wan area with the Physarum algorithm and combining factors such as construction conditions, water shortage problems, the heat island effect and traffic conditions, the path to urban renewal in upcoming decades can be determined step by step.

Results and Discussion

Figure 23 is the vision of To Kwa Wan after the application of design strategy. With the gradual migration of the population, To Kwa Wan will complete its freshwater-orientated urban renewal by 2070. Over time, green spaces will gradually connect to form new urban ventilation corridors. At this point, the city's water circulation system will be in relative balance. According to the calculations, we know that a 6.47 m² moss water generator can purify the fresh water needed for a family for a day. However, this fresh water is not potable. Nevertheless, biomaterial water purification devices are still an option that deserves thorough investigation.

Initially, the design strategy focused on the Ma Tau Wai Road area, where the water shortage is acute.

The area of wetlands restored at this point is 5%, and that of the rooftop rainwater harvesting device is 14%. During the 2030, 2050 and 2070 phases, wetland acreage will increase incrementally with the demolition of older structures and eventually reach approximately two-thirds of the city. People living in subsidence zones, where fresh water is scarce and the safety of their livelihoods is seriously compromised, will be gradually moved to shelters, where old and new buildings can coexist. As shown in Figure 28, in 2030, buildings will be fitted with moss water purification devices. Wetlands will gradually replace rooftop water purification spaces as the main water purification and storage spaces. Urban wetlands will be connected as a whole to create localised urban micro-climates.

The original intent of the project was to use computational modelling methods to explore new approaches to the design of future urban emergency shelters. Design modelling serves as the core to considering how system thinking can be accommodated in computational design. Computational modelling is inspiring for overall systematic design. Incorporating concepts such as humanism and eco-design into modelling can bring the designer's initiative fully into play.

Grasshopper has always taken a powerful role in the field of computational modelling. Physarum path simulations demonstrate the flexibility of biomimicry in urban design, with quick visual feedback assisting in design formation. Simultaneously, biomimicry provides ideas for biosphere-centred design. However, the design results of computational design are usually biased towards established logic. When placing simulation results in a real design scenario, designers should evaluate and optimise them based on specific situations.

Wallacei simulations provide a useful basis for shelter design. Designers can combine algorithm generation based on existing design logic to obtain logical and diverse design results. Furthermore, Wallacei's unique evolutionary capabilities rationalise and humanise results. Nevertheless, Wallacei is similar to Physarum in generating results that are usually simply sets of stage-optimal solutions with a defined number of evolutions. Active intervention and evaluation are required by the designer if a more rationalised design outcome is to be achieved.

In summary, design computation is a powerful aid to the entire design process. For example, Physarum's path simulation has inspired the optimisation of urban regeneration, enabling the construction of entire design systems towards sustainability, continuity and adaptability. Second, the simulation results of computational modelling can guide various problems in system design. By changing the parameters to obtain different results that fit the design logic, design computation helps make real-time feedback and predictions during the design process. Meanwhile, design computation will inspire the designer to supplement the design system with simulation and emulation results after the existing design solution has been formed, such as rethinking the desalination approach through the positive effect of pathway planning on the heat island effect or continuing to plan for potential environmentally friendly functional areas through simulation results. However, because systems design thinking in urban design is highly dependent on reality, there are technical limitations and different stakeholders involved. Allowing a high degree of accuracy and the simulation of design computation to serve the design process while taking into account cultural, historical and social complexities will enable true design sharing.

Nevertheless, the core of this research is still a voluntary study, and the challenge of funding support remains significant. Stakeholder research is highly relevant to financial issues, and searching for partner support can help enrich the design system. Seeking necessary financial support and partnerships will be considered in later research.

Talent training and resource integration are also the scope of research on urban regeneration design for subsequent practice input.

This research proposes a phased design programme spanning five decades, with preliminary simulations and projections of the results. Future work will further explore the detailed challenges of technology maintenance, integrate community resources based on practical realities and enhance the feasibility of design strategies. These design strategies will break down the region and develop targeted micro-solutions guided by the macro-system to make the research more grounded. The aim will continue to be to maintain the dynamic stability of the elements of the system to sustain a good urban metabolism system and promote the adaptive capacity of the city to cope with future environmental changes.

When this study is applied to real-world applications, issues such as financial support, technology maintenance and community conditions will be faced. Therefore, when carrying out the construction of freshwater shelters in a progressive manner, full consideration should be given to the building structure and composition and the difficulty of renovation in the region, and the equipment installation and water diversion construction should be combined with actual water demand. In addition, the current predictions are based on an idealised simulation carried out after the remodelling of the freshwater shelter has been completed. When performing the actual construction, each step should be clearly simulated and predicted based on computational modelling to strictly improve the practicality of the computation results.

Conclusion

This project is a shelter design study orientated to urban freshwater resource regeneration that aims to build a post-urbanisation emergency response system in the To Kwa Bay area by combining biomaterials, computational modelling and other aspects (Figure 24). During the research process, computational modelling played an important role in conceptual inspiration and contextual simulation. Based on the simulation results, design strategies that are more humanistic can be further identified.

There are three main ways to conserve freshwater resources in a dynamic design solution: improving purification efficiency, building water storage warehouses and reducing the evaporation of water resources. The use of moss evaporators is a new attempt to apply biomaterials to the design of future cities, and calculations have shown positive purification results. The use of Physarum for path optimisation and the gradual relocation of people affected by water scarcity to new shelters can gradually restore urban green spaces. The creation of urban green spaces and rooftop reservoirs creates positive conditions for water storage and groundwater recharge. The main method of reducing water evaporation is to mitigate the urban heat island effect. The simulation of urban ventilation in software and the creation of desalination ponds yielded positive results.

However, current design strategies focus on non-potable freshwater, and the sustainable use of potable water needs to be emphasised. Shelter forms are also designed in basic blocks, and details that are more suitable for human habitation need to be further considered. Furthermore, the rational allocation of water resources requires a highly developed management system in the city. Currently, many simulations of urban details cannot be accomplished because of regional imbalances in data systems. Perhaps in the future, when big data excludes the problem of missing data due to geographic differences, reinforcement learning can be better combined with computational modelling approaches to facilitate urban freshwater resource management.

Figure 1. Computational seeding – Porpus MPC concrete for moss plants. *Source: UCL Bartlett School of Architecture (2019). Photograph downloaded from the UCL Bartlett School of Architecture's official website.*

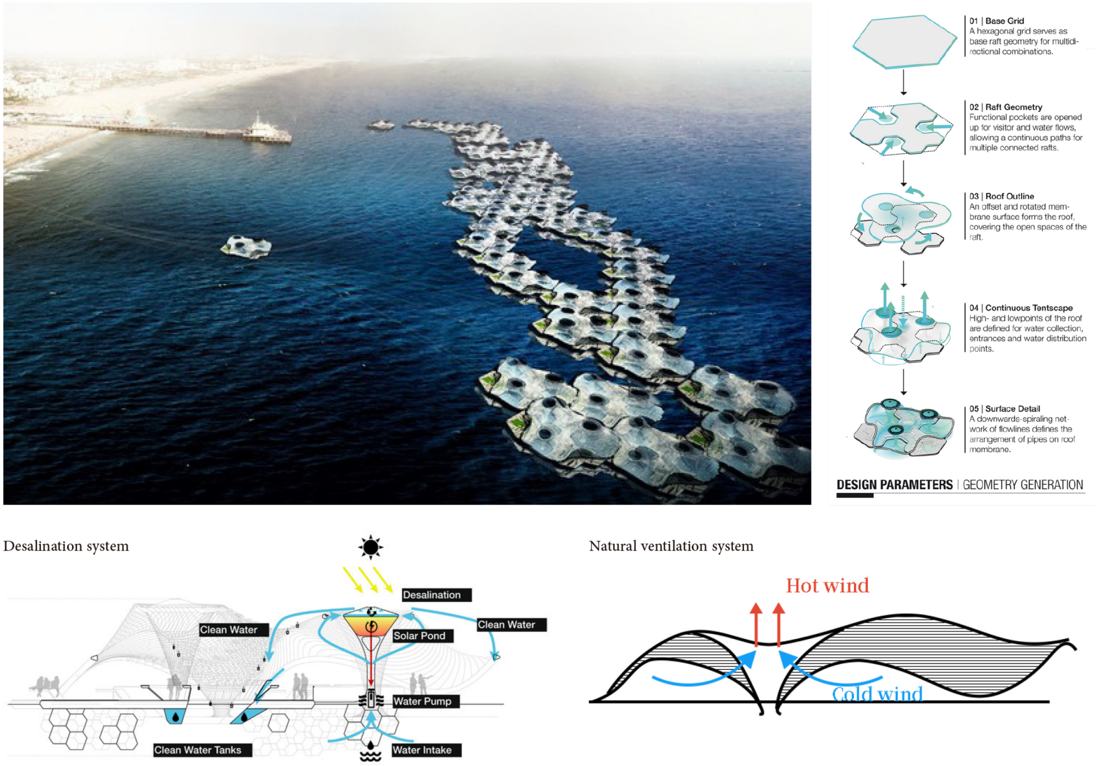


Figure 2. Offshore floating platforms for seawater desalination.
Source: Chatel (2016).

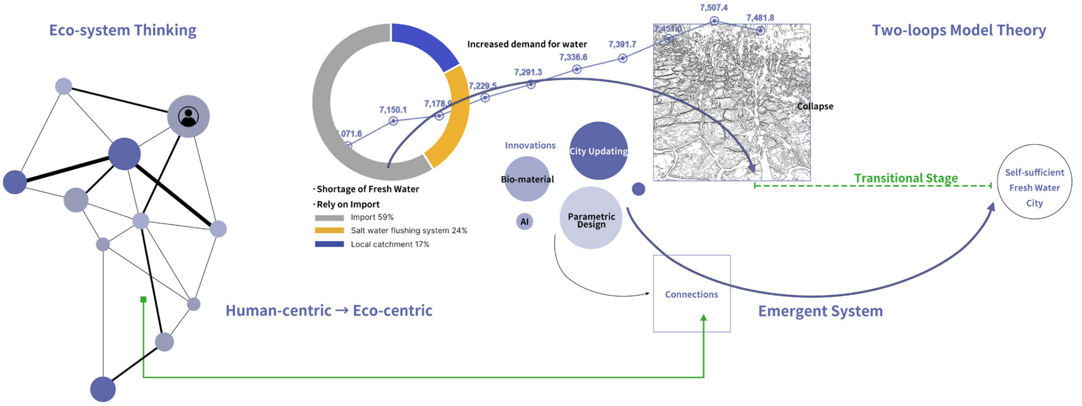


Figure 3. Two loops model: Hong Kong's freshwater crisis.
Source: Author.

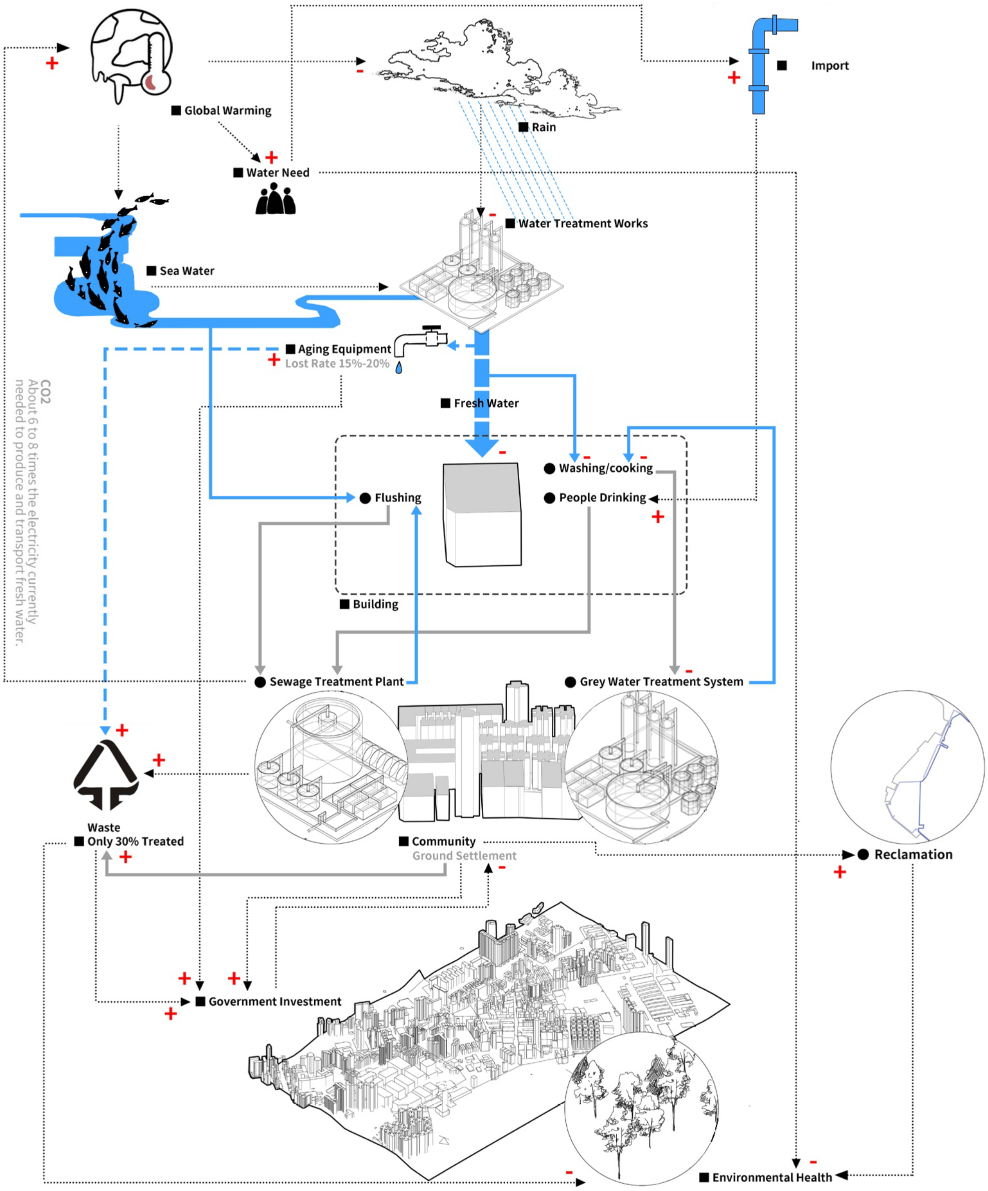


Figure 4. Causal mapping: Summary of data analysis – imbalance metabolism (input and output). *Source: Author.*

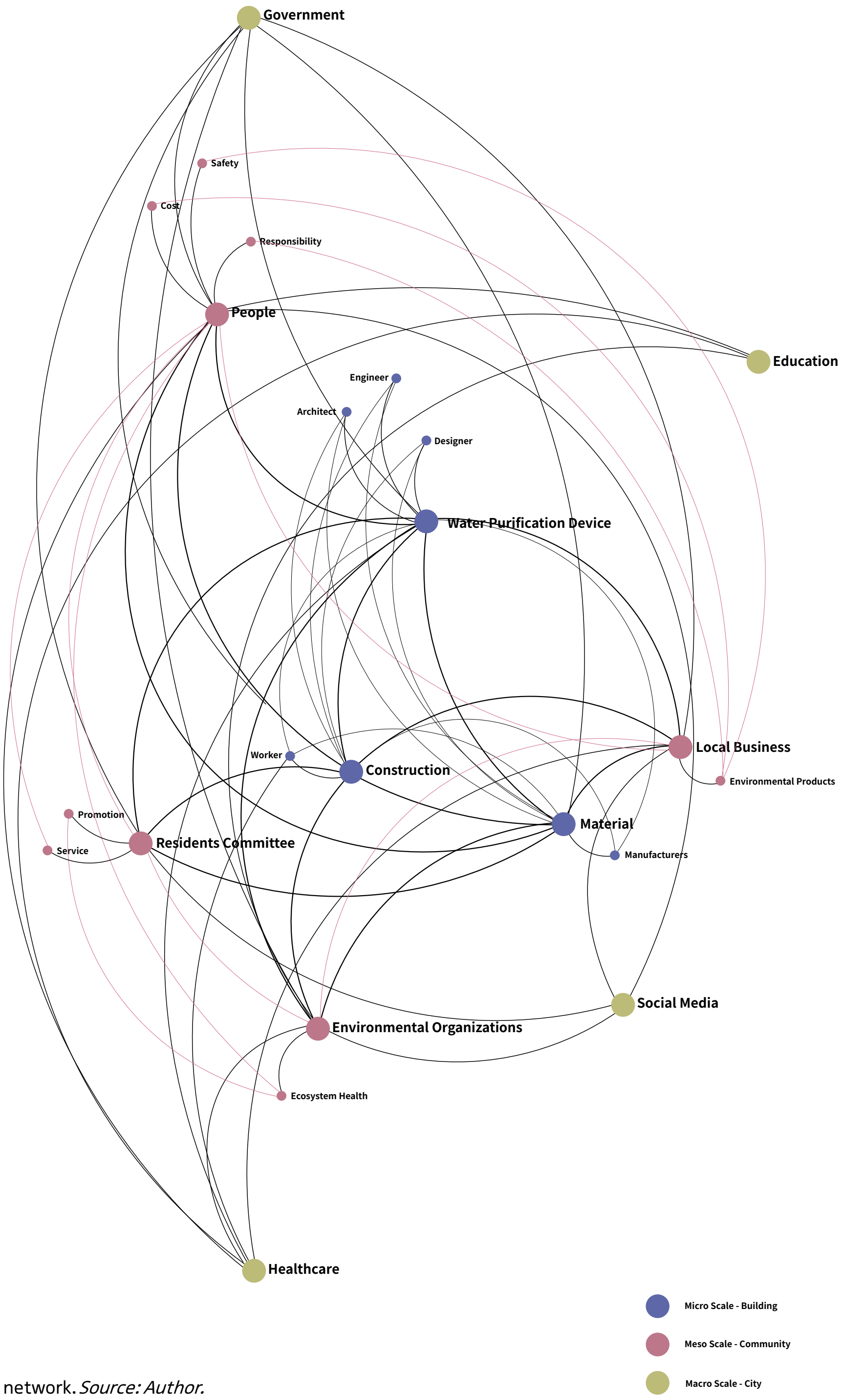


Figure 5. Stakeholder network. *Source: Author.*

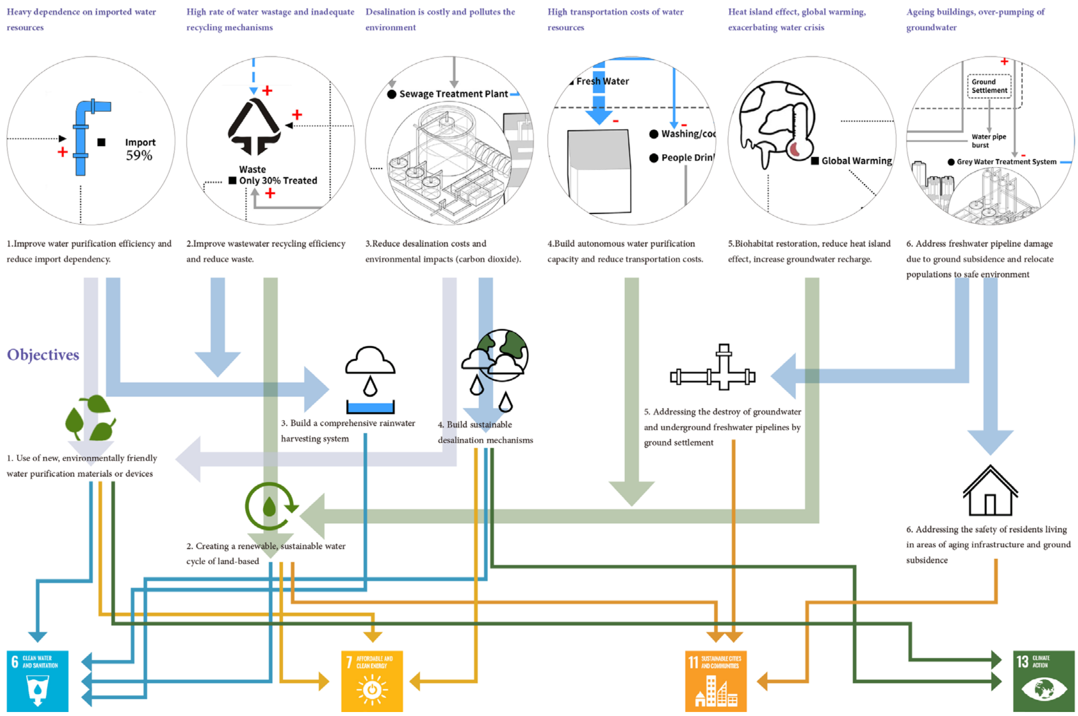


Figure 6. Initial design concepts (United Nations n.d.). *Source: Author.*

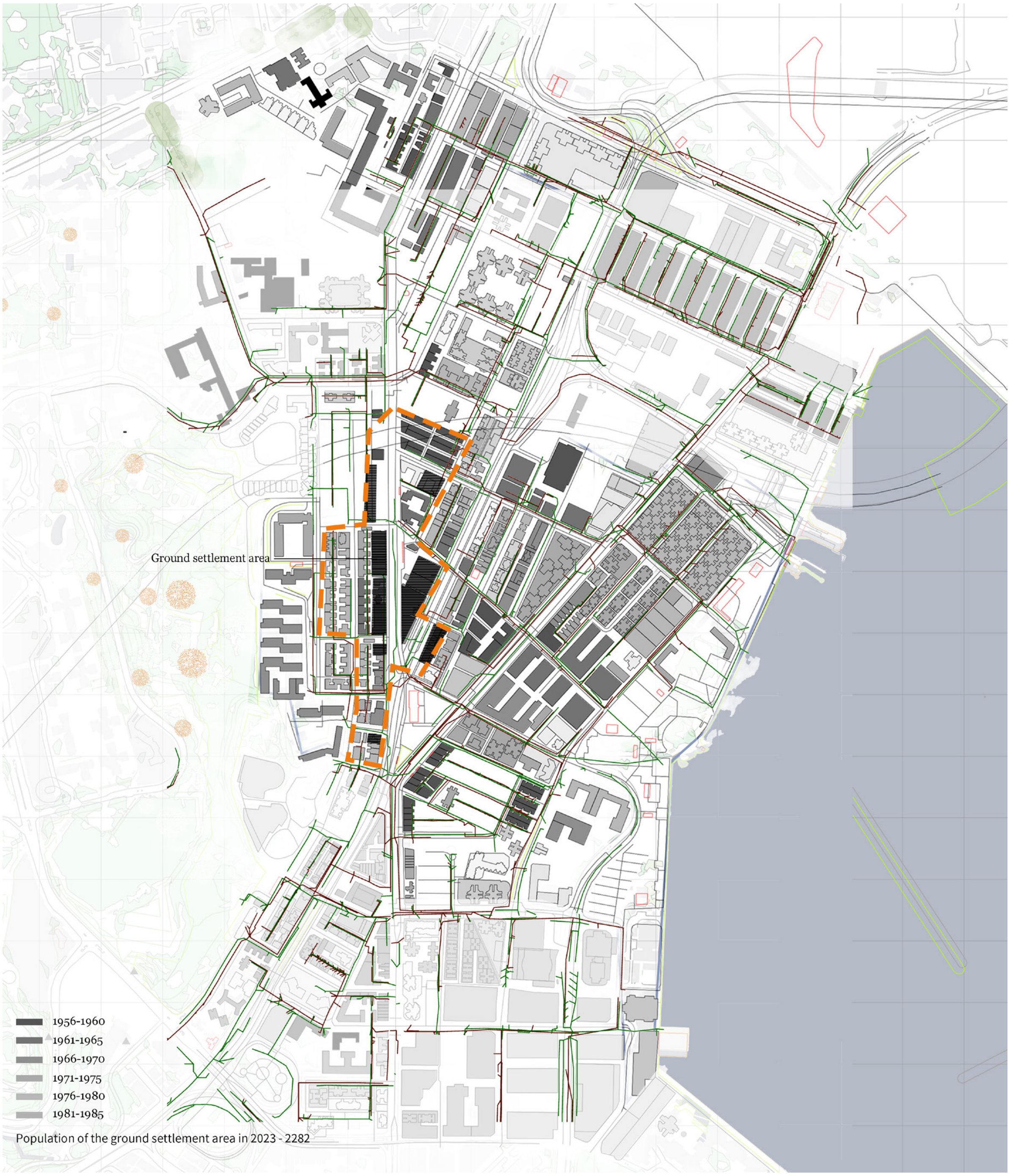


Figure 7. Map of the age distribution of buildings in To Kwa Wan. *Source: Author. Map GIS source: Common Spatial Data Infrastructure (2023).*

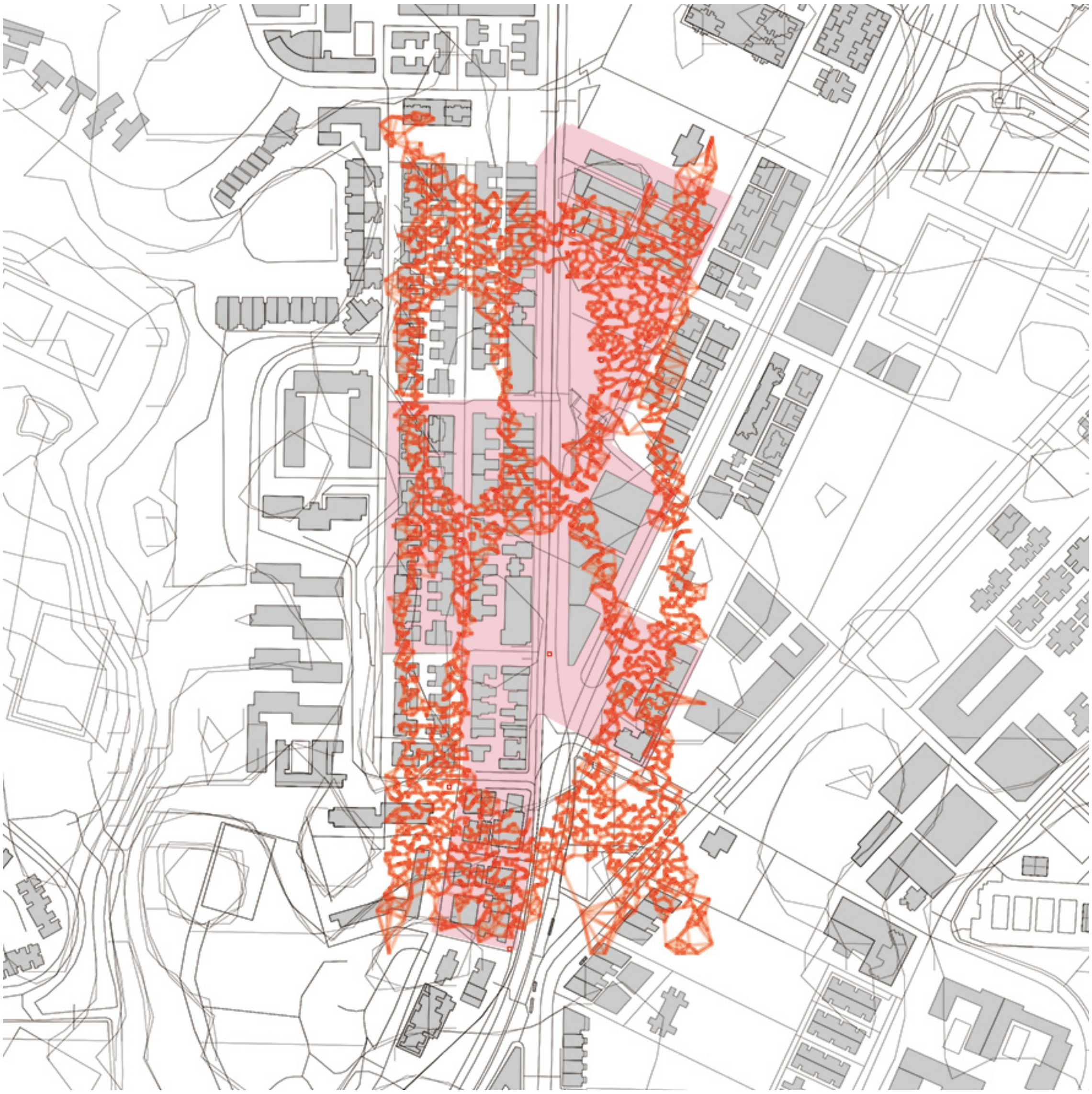
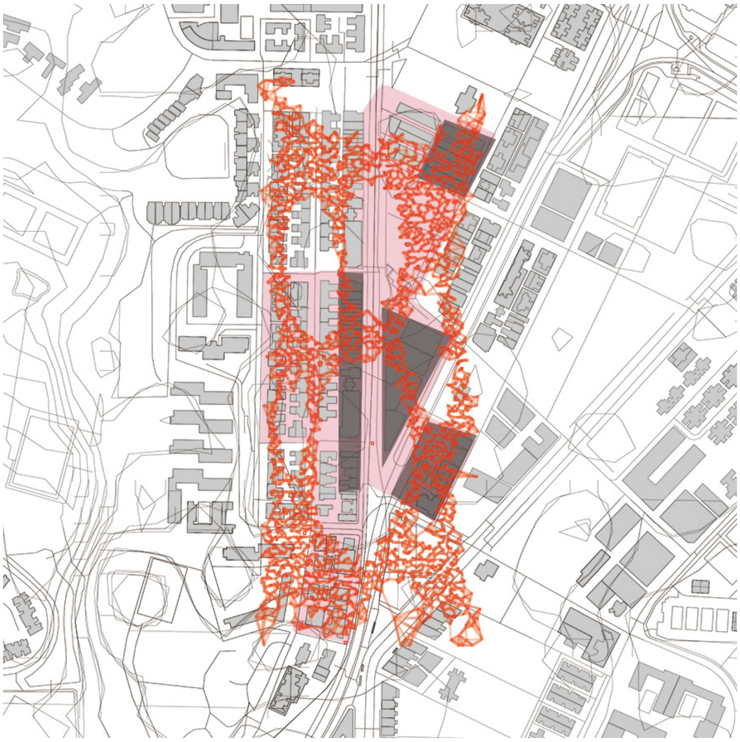
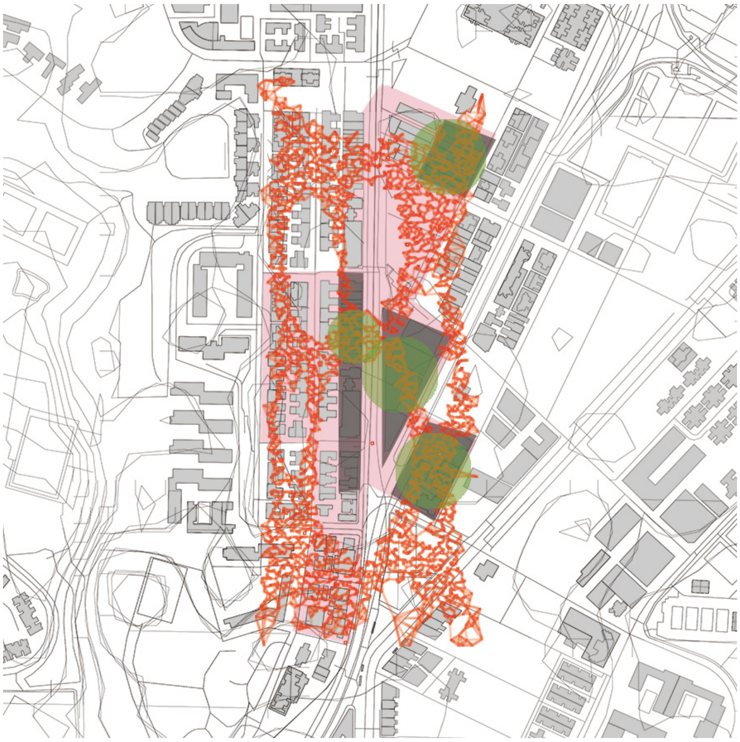


Figure 8. Path debugging using Physarum in the Ma Tau Wai Road area. *Source: Author. Map GIS source: Common Spatial Data Infrastructure (2023).*

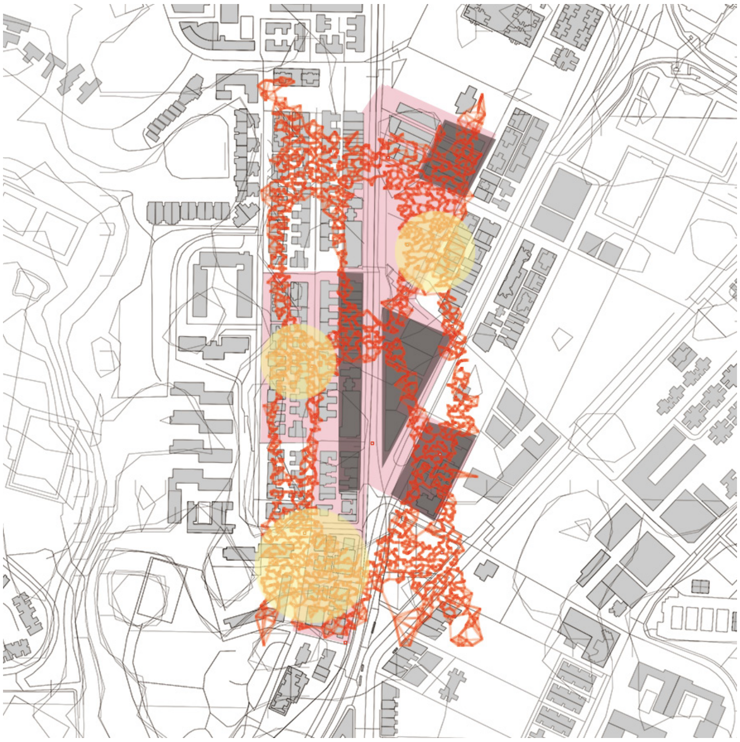


1. Black: Subsidence area

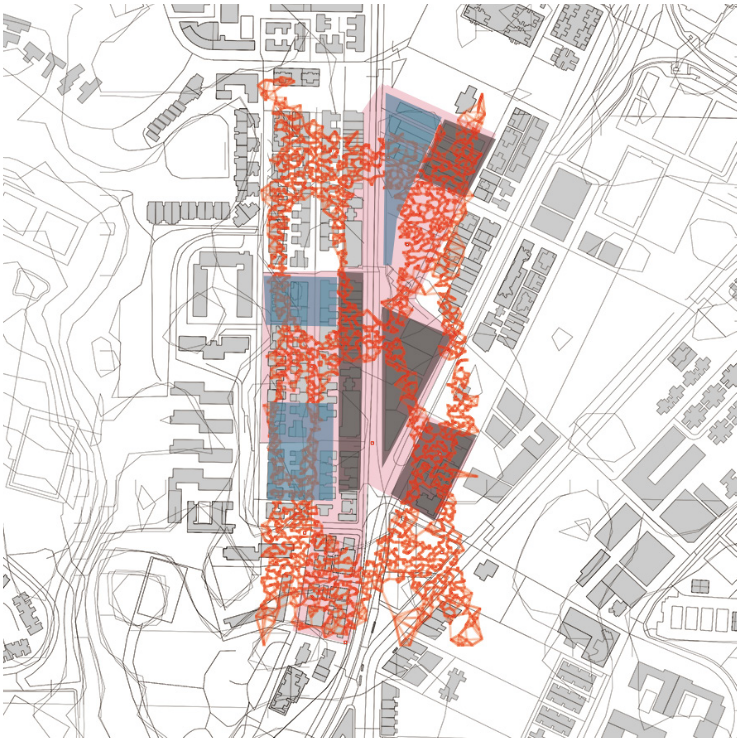


2. Green: Greenfield restoration area

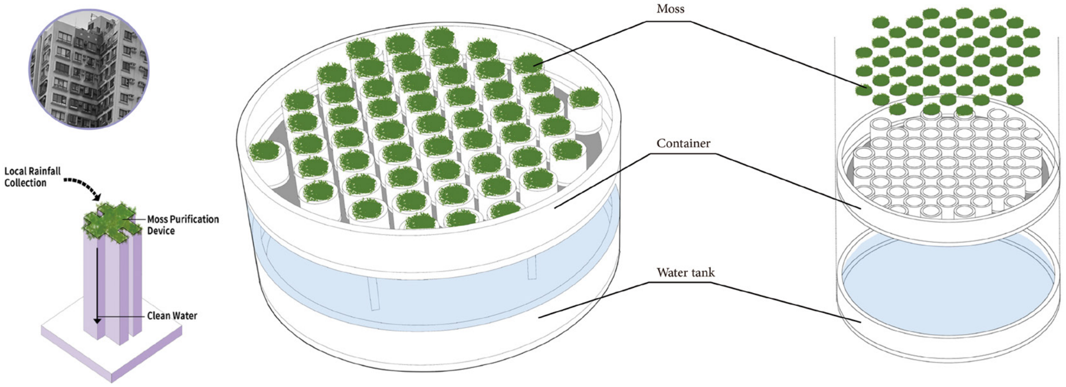
Figure 9 (this page and next). Path idea by Physarum. *Source: Author.*
Map GIS source: Common Spatial Data Infrastructure (2023).



3. Yellow: Transportation junction

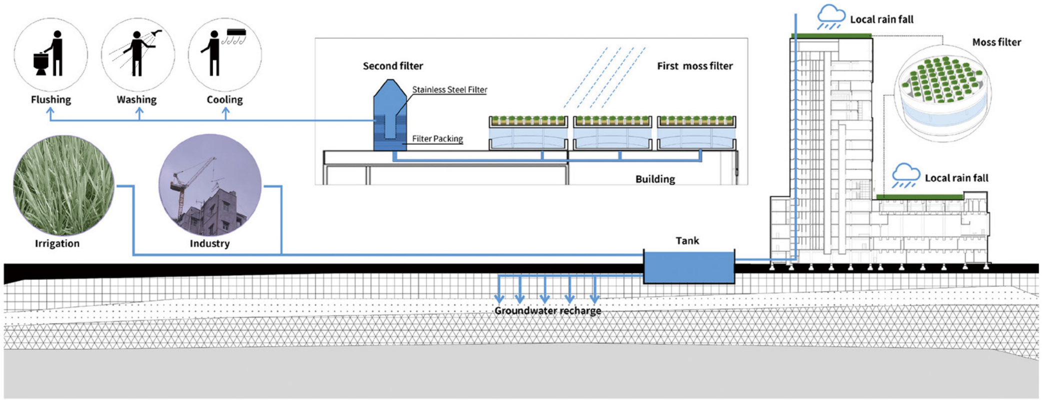


4. Blue: Reserved area



Put the moss purifier on the roof

Moss table for water purification



Rainwater harvesting systems for buildings

Figure 10. Reserved building with a green moss solar steam generator. *Source: Author.*

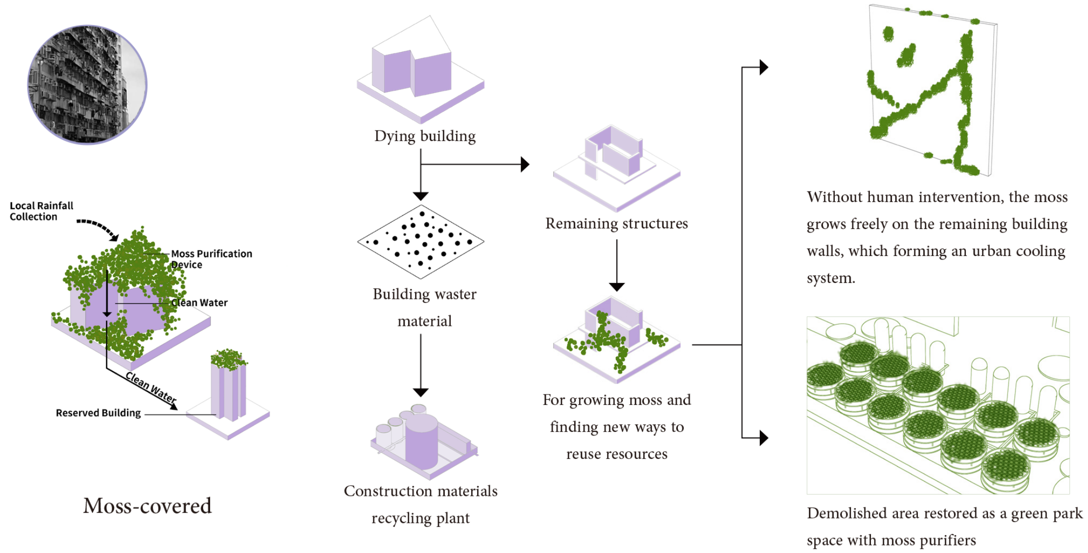


Figure 11. Design strategy and reuse method for buildings in subsidence areas. *Source: Author.*

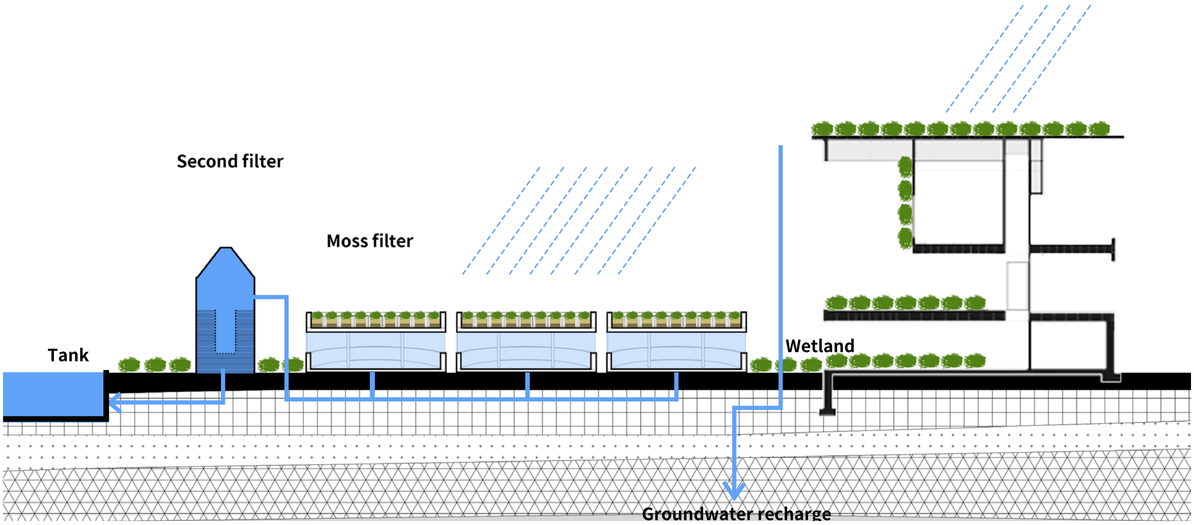
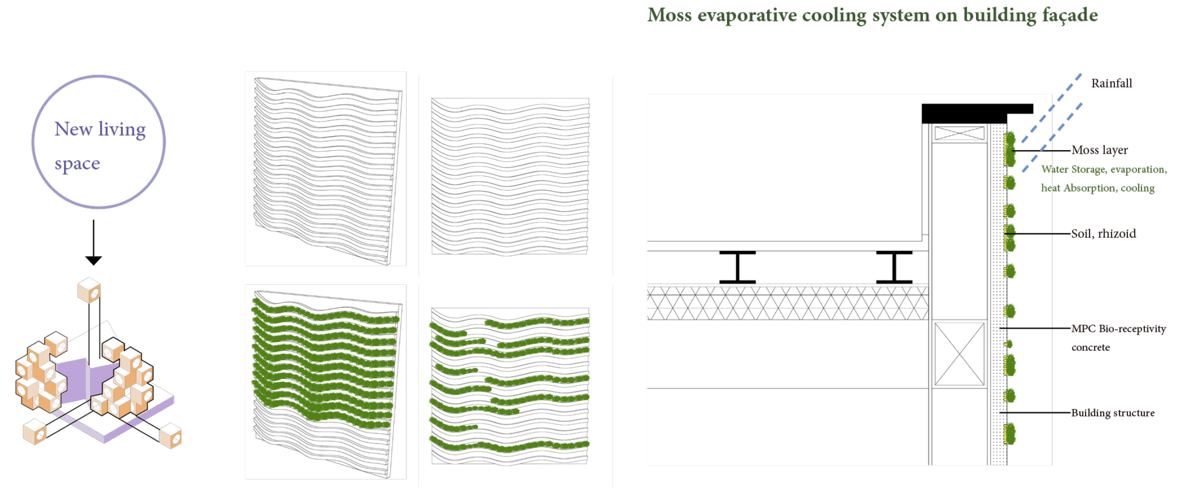


Figure 12. Dying building and green park water collection system. *Source: Author.*

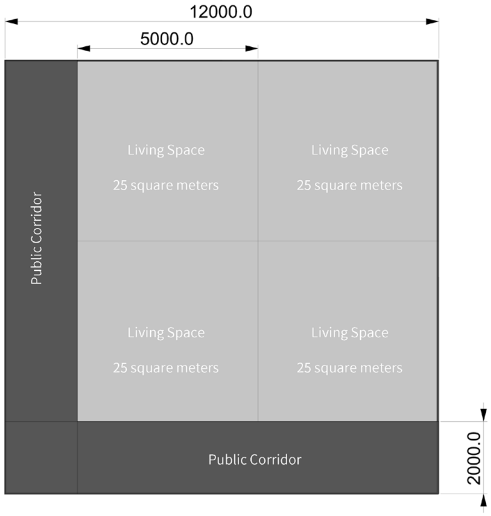


Moving populations to safe, self-growing spaces

Porous MPC concrete for moss plant
Learn from case study

Porous MPC concrete for moss plant

Figure 13. Modular design strategy and porous MPC concrete (moss). *Source: Author.*



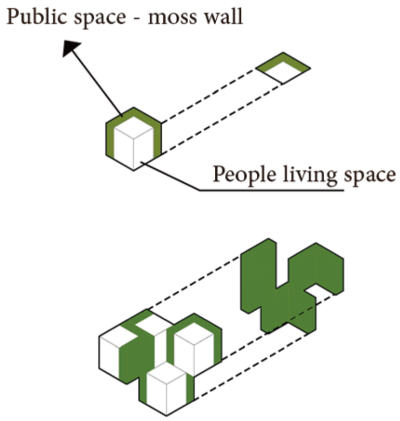


Figure 14. Plan of a single unit in modular design. *Source: Author.*

Figure 15. Building blocks that grows naturally as the population continues to move. *Source: Author.*

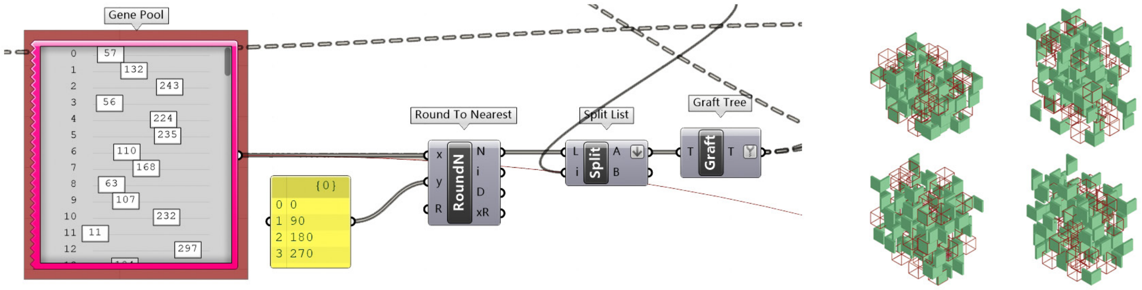


Figure 16. Modules that can be rotated at any angle with continuous public corridors. *Source: Author.*

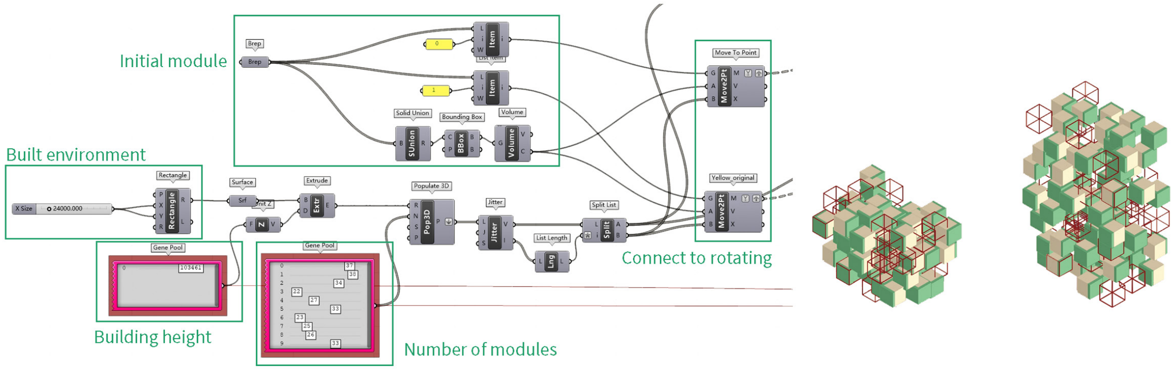


Figure 17. Freely adjust the building height and generate different heights. Source: Author.

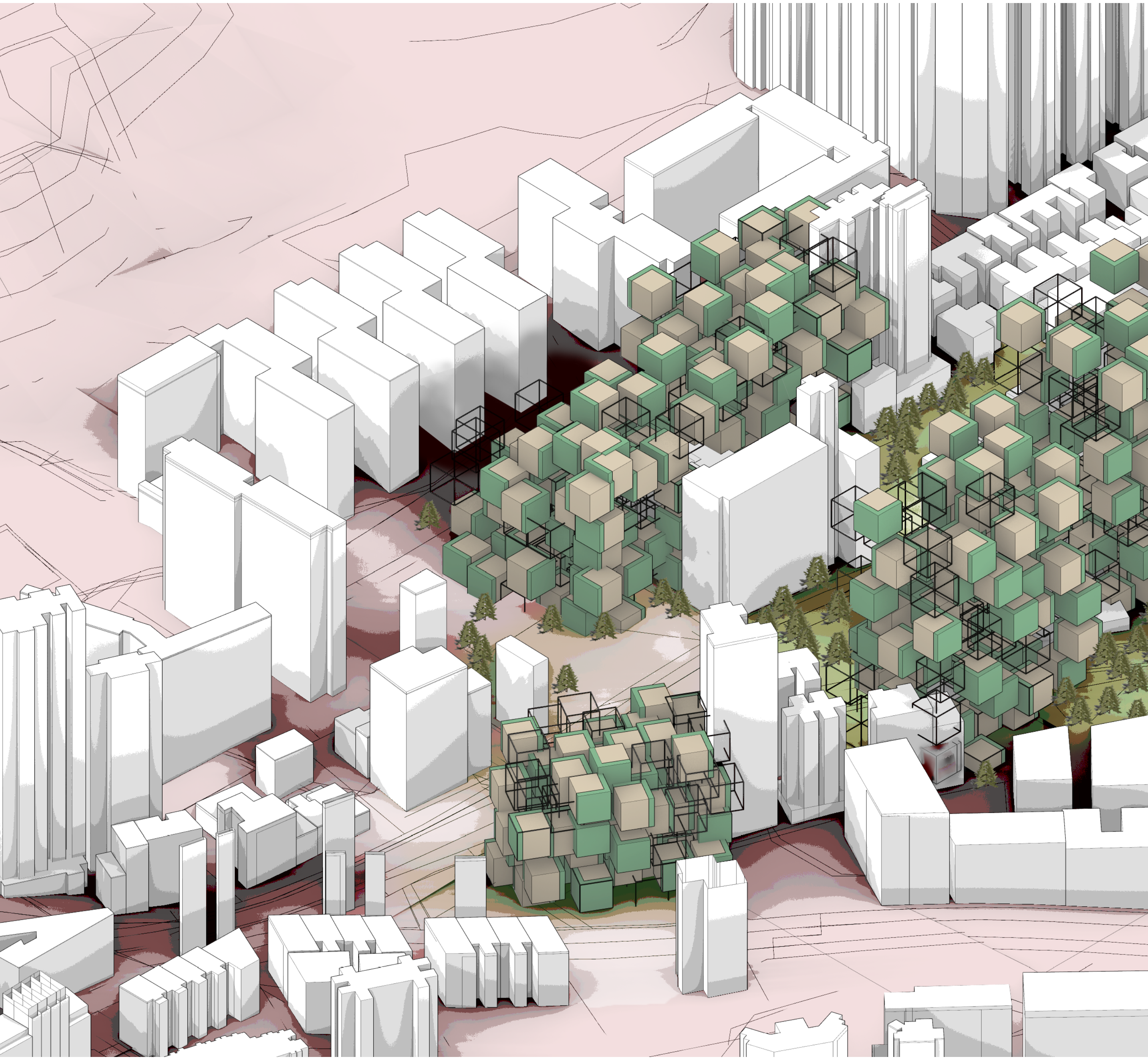
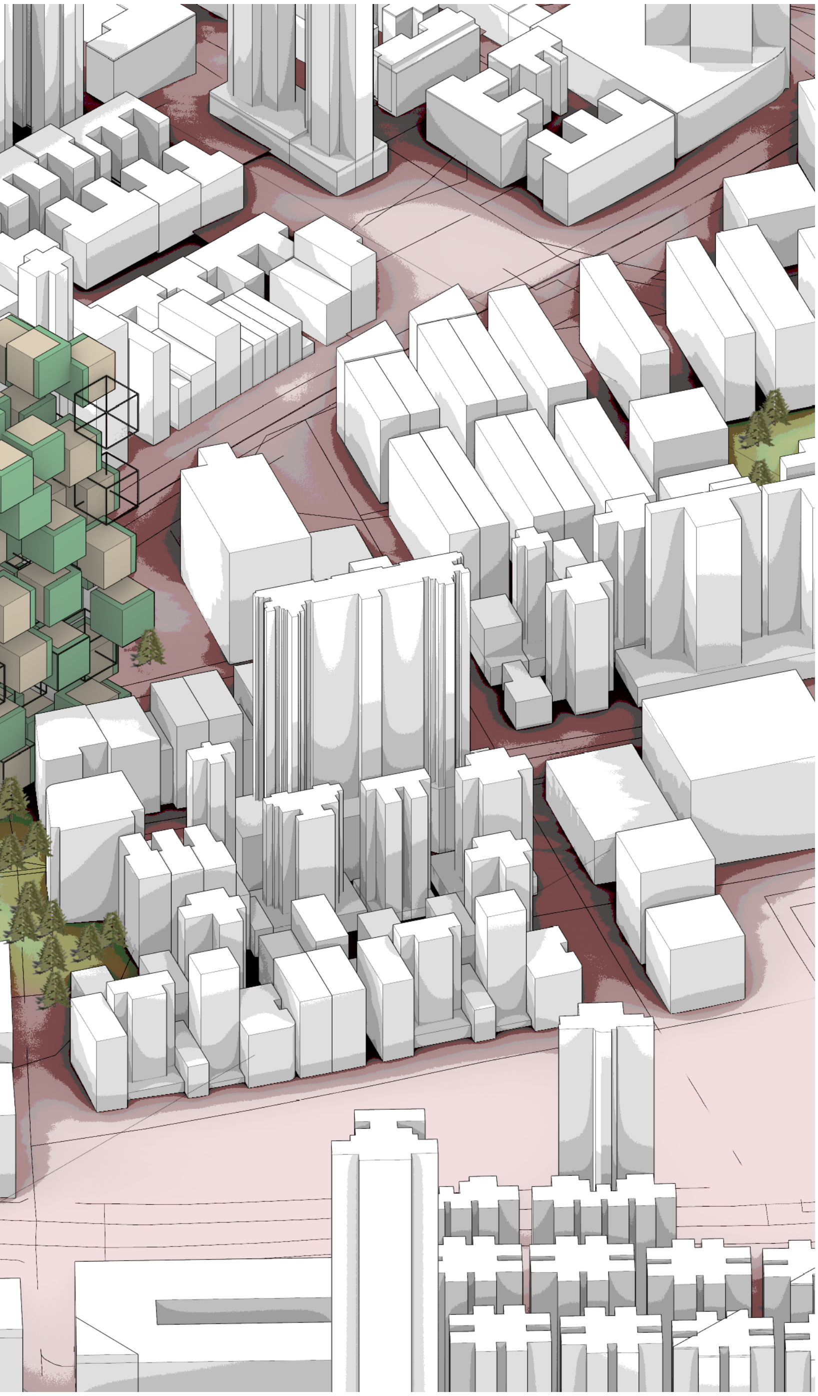


Figure 18. Schematic plan for integrating shelters into the Ma Tau Wai Road area. *Source: Author.*



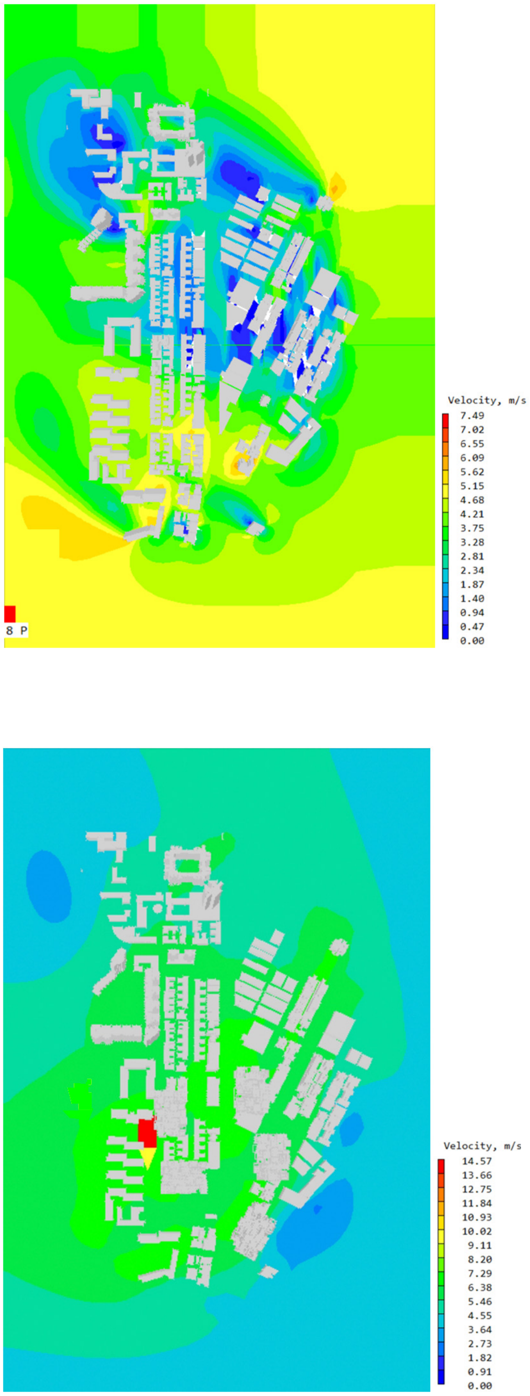
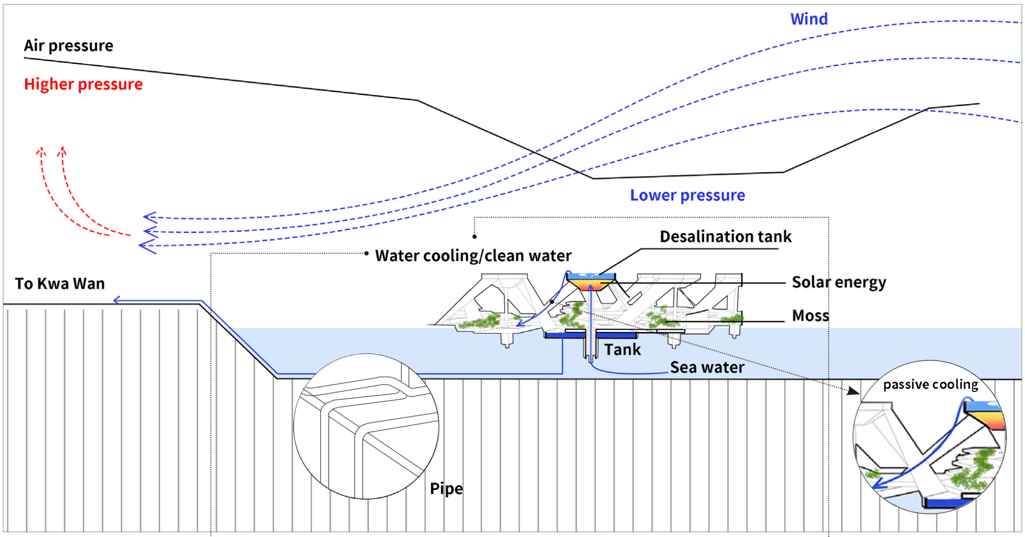


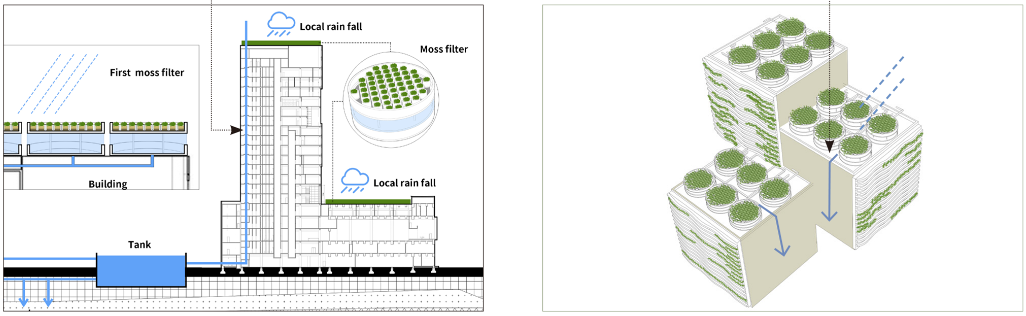
Figure 19. Wind simulation using Phoenics shows that the centre wind speed before the design (top panel) is lower than after the design (bottom panel). *Source: Author.*



City floating island seawater desalination system

Case study - The water cooling system from foraminiferal structures

Apply passive cooling through aqueducts in foraminiferal structures to existing building structures in To Kwa Wan to reduce the heat island effect and water consumption.



Seawater/Rainwater transportation cooling system for To Kwa Wan buildings

Figure 20. Putting an available seawater desalination system into To Kwa Wan. *Source: Author.*

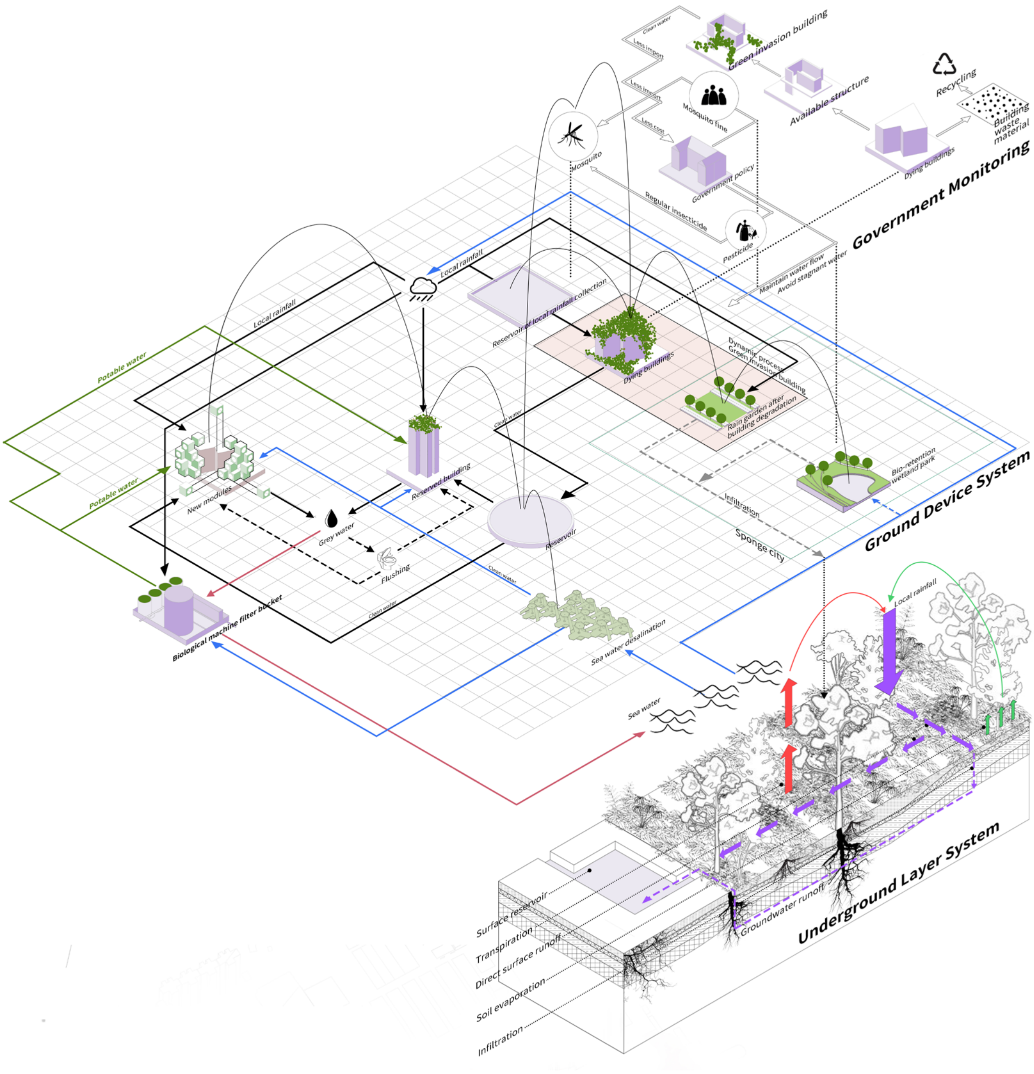


Figure 21. Macro system – Water circularity in multiple layers: How to influence each other with different elements. *Source: Author.*

Figure 22. Four design stages for To Kwa Wan. *Source: Author.*

Figure 23. Design vision of To Kwa Wan. *Source: Author.*

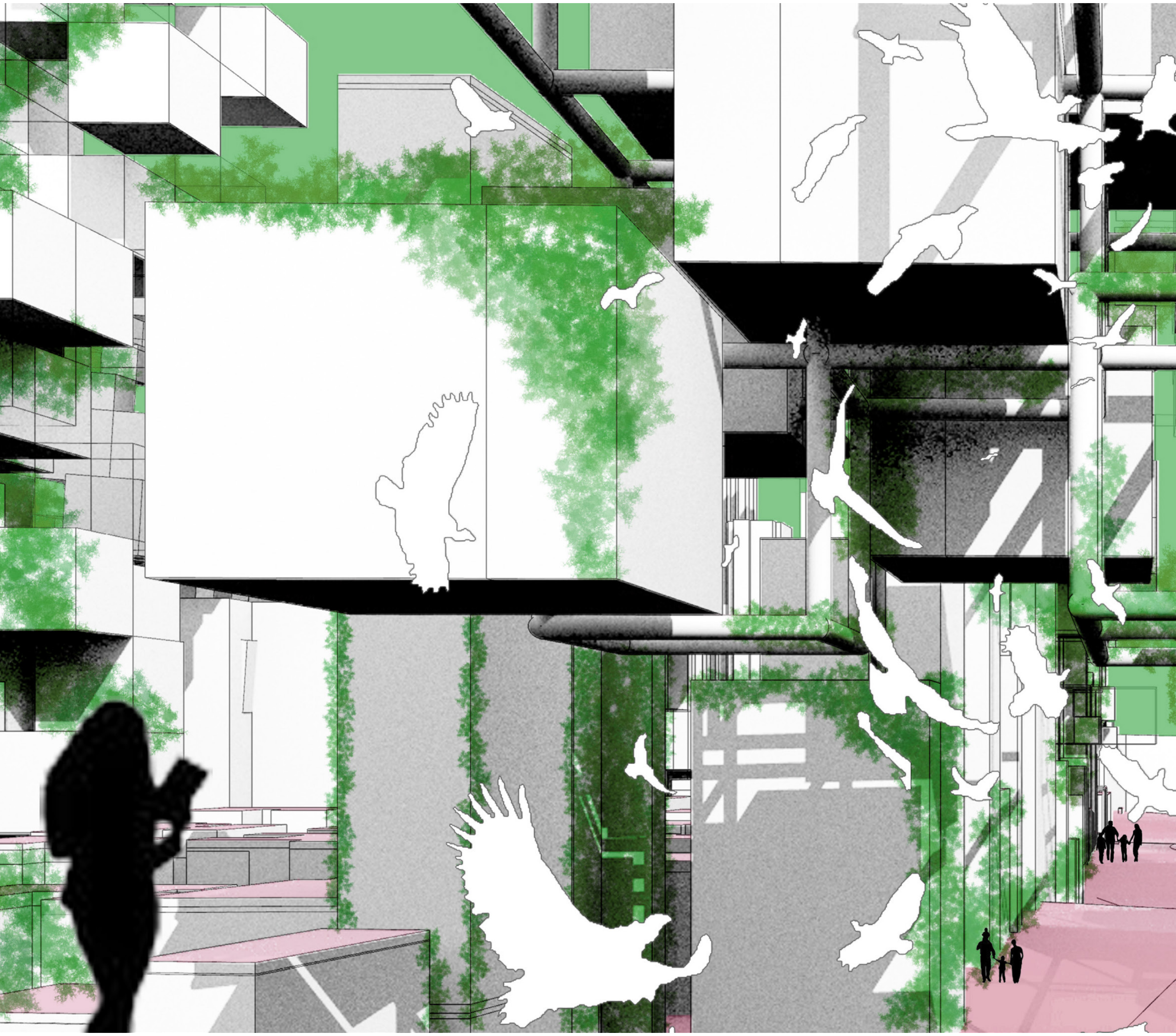
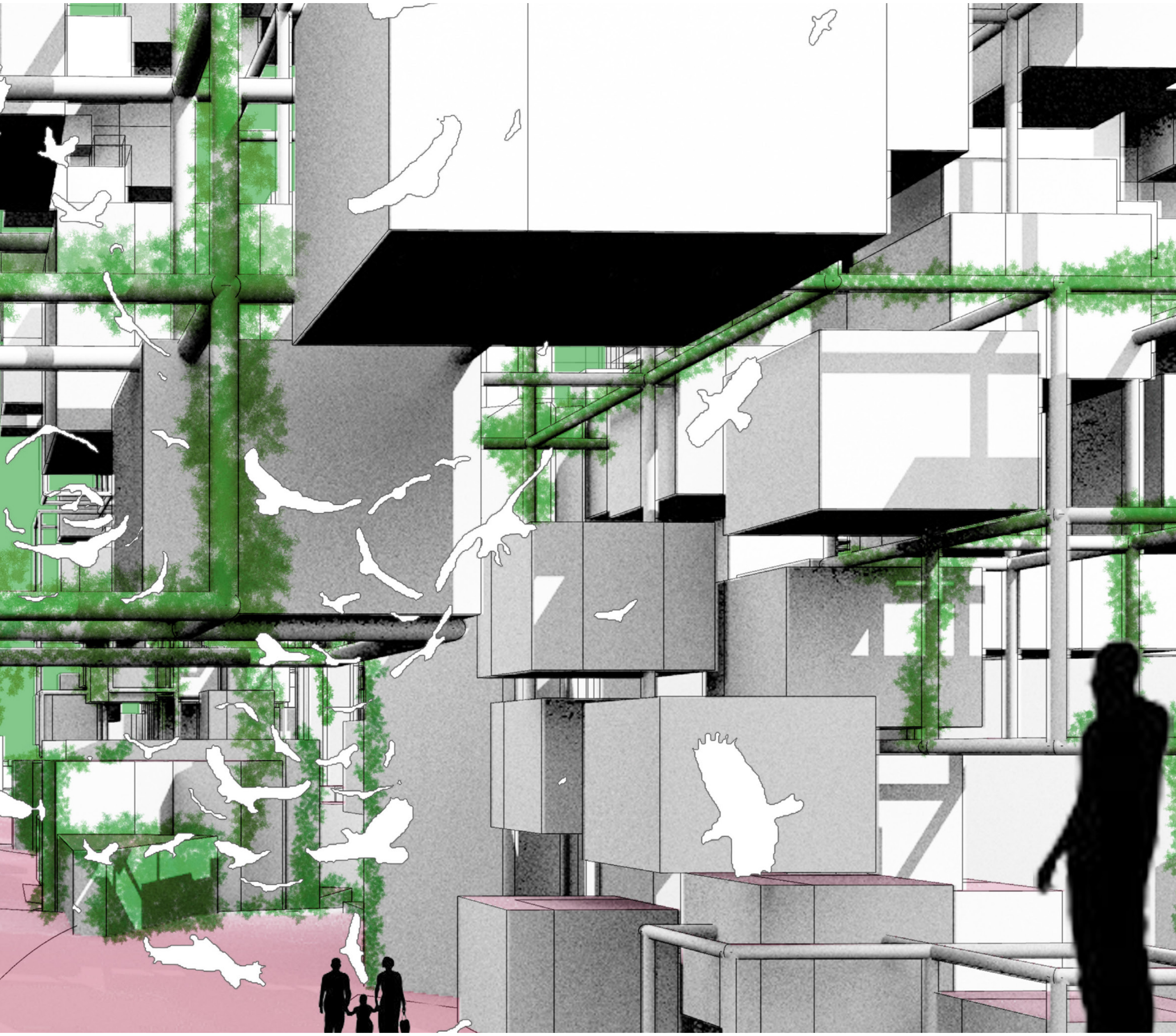


Figure 24. Regenerative Biosphere - Future freshwater shelter.

Source: Author.



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Bio

Chen Xi is currently a research assistant at the School of Design at Hong Kong Polytechnic University. Holding a Bachelor’s degree in Architecture and a Master’s degree in Transitional Environments Design, she was previously a teacher of media, space and landscape design at Tianjin College of Media and Arts. Her research focuses on the design of regenerative urban environments, architectural conservation design and computational design strategies based on sustainable urban research.

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