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[Design and Implementation of a 3d-Printed Village for Refugees in Taiwan: A Solution For Protection In The Event Of An Attack From China]

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Abstract

This master's thesis delves into the promising potential of additive manufacturing (AM) using bamboo, a traditional and sustainable material for building construction in Taiwan. The primary objective is to explore the application of 3D printing technology in the context of constructing refugee camps, with a specific emphasis on providing secure and safe living conditions for displaced individuals, particularly in light of potential threats posed by malevolent countries.

The design process draws inspiration from the rich heritage of traditional Japanese architectural elements and incorporates the architectural fusion style of Minyang in Taiwan. The aim is to develop efficient and resilient structures that meet the evolving needs of the refugee camps. Recognising the advantages offered by 3D printing technology (3DP), this study highlights the compatibility between the innovative COBOD BOD2 on-site printer and the sustainable construction approach pursued in the research.

By harnessing the capabilities of 3D printing technology and utilising bamboo-based materials, this thesis seeks to optimise space utilisation and minimise construction waste in the construction of refugee camps. The research encompasses various facets of the 3D printing workflow, encompassing algorithm design using Grasshopper 3D definitions (GHD), housing unit design, and printing strategies tailored to the specific context of the camp.

Keywords

Computational Design; Digital Fabrication; Large-Scale Additive Manufacturing; Design for Manufacture and Assembly; Sustainable construction; Refugee camp; 3D printing technology; Efficient space utilisation; Cultural fusion, Taiwan.

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2 Introduction

This chapter provides a comprehensive introduction to the core topics that form the foundation of this project. It begins by exploring the historical timeline of Taiwan under various ruling entities, delving into the initial conflicts between Taiwan and China. Furthermore, it examines the existing infrastructure in Taiwan and highlights the advantages of additive manufacturing within this context. Lastly, a detailed overview of the project site, Hualien City, Taiwan, is presented, providing essential background information for the subsequent analysis and implementation of the study.

2.1 History and the Following Conflicts Between Taiwan and China

After 1949, the Chinese Civil War ended with the Communist Party of China (CPC) victorious and the Nationalist Party (Kuomintang or KMT) fleeing to Taiwan. The CPC established the People's Republic of China (PRC) on the mainland, and the KMT established the Republic of China (ROC) in Taiwan (see Figure 1). The PRC claimed Taiwan as part of its territory and sought to reunify Taiwan with the mainland through diplomatic and military means. However, the ROC government and the majority of the population in Taiwan did not recognise the PRC's claim to Taiwan and sought to maintain their independent government [1]. This political and territorial dispute has continued to the present day, with Taiwan maintaining de facto independence but not being recognised as a sovereign state by many countries which officially recognise the PRC as the legitimate government of China.

Figure 1: History timeline of Taiwan under periods ruled by different countries.

In recent years, tensions between Taiwan and China have been increasing as the Chinese government has become more assertive in its efforts to assert its sovereignty over Taiwan. The Chinese Government has been pressuring international companies and organisations to list Taiwan as part of China on their websites and materials, which the Taiwanese Government and the people of Taiwan see as a violation of their sovereignty [2].

Additionally, the COVID-19 pandemic has created tension between Taiwan and China, as Taiwan has been excluded from World Health Organization (WHO) meetings and other international events, despite having a relatively successful response to the outbreak. The constant unpleasant behaviours from China have led to accusations that the Chinese Government is using the pandemic to isolate Taiwan further internationally.

The recent events have created an agitated and uncertain situation between Taiwan and China, with the potential for further escalation and conflict. Moreover, the ADIZ [1] and territorial water [2] between the three

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[1] ADIZ stands for Air Defense Identification Zone. It presents airspace over land or water in control of all aircraft (excluding Department of Defense and law enforcement aircraft).

[2] Territorial water/border information was released by the official government departments of each country.

countries have also been problematic issues. The ADIZ was created by the countries that claimed the territories (see Figure 2). However, the tension has risen in recent years, followed by the rising tension between China and Taiwan, the overlapping ADIZ, water territories, and the persistent entry of Taiwan's ADIZ with Chinese fighter jets.

Figure 2: ADIZ and territorial water between China, Japan, and Taiwan.

Figure 3 (left side) depicts the square areas that overlap with Taiwan's water territory, which were declared by the Chinese Government on August 7th, 2022 [3] [3]. This declaration coincided with the planned visit of United States congresswoman Mrs Nancy Pelosi to Taiwan and her scheduled meeting with President Tsai Ing-wen. The Chinese Government justified these military exercises as preparation for a potential invasion of Taiwan. The maroon areas on the Taiwan map highlight the cities that could be targeted in a land invasion by the People's Republic of China (PRC). On the right side of the figure, we observe 14 areas and cities that are vulnerable to being the first targets due to their easily accessible beach zones [4]. Notably, the East Coast is excluded from this list due to the topography of mid-Taiwan, which serves as a natural defence. Consequently, cities like Hualien and Taitung have gained strategic importance for Taiwan, requiring enhanced protection, security, and potential evacuation plans. The encroachment of Chinese military forces into these cities and water territories has prompted the United States and Taiwanese militaries to collaborate and devise contingency plans for escape and transportation routes with diverse purposes in mind [5].

2.2 The Crucial Infrastructures and Planning on the East Coast

Regarding the threats from China, it is highly plausible that if the hypothesis war has happened, Japanese territories would be the first choice for Taiwanese refugees to flee due to the intimate relationship and cultural connection between the two countries. Considering the unofficial diplomatic relationship, the closest cities between Taiwan and Japan, Hualien City (Taiwan) and Yonaguni (Japan), have yet to offer a direct connection, creating a new emergency route for Taiwanese when in needed. However, the route is only for emergency use in this scenario.

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[3] Military exercise areas declared by China on 4th to 7th August 2022, source released by Chinese media reports, Marine Regions.

[4] China would first invade the 14 locations in Taiwan, source from the present researcher Ian Easton from the Project 2049 Institute. [4]

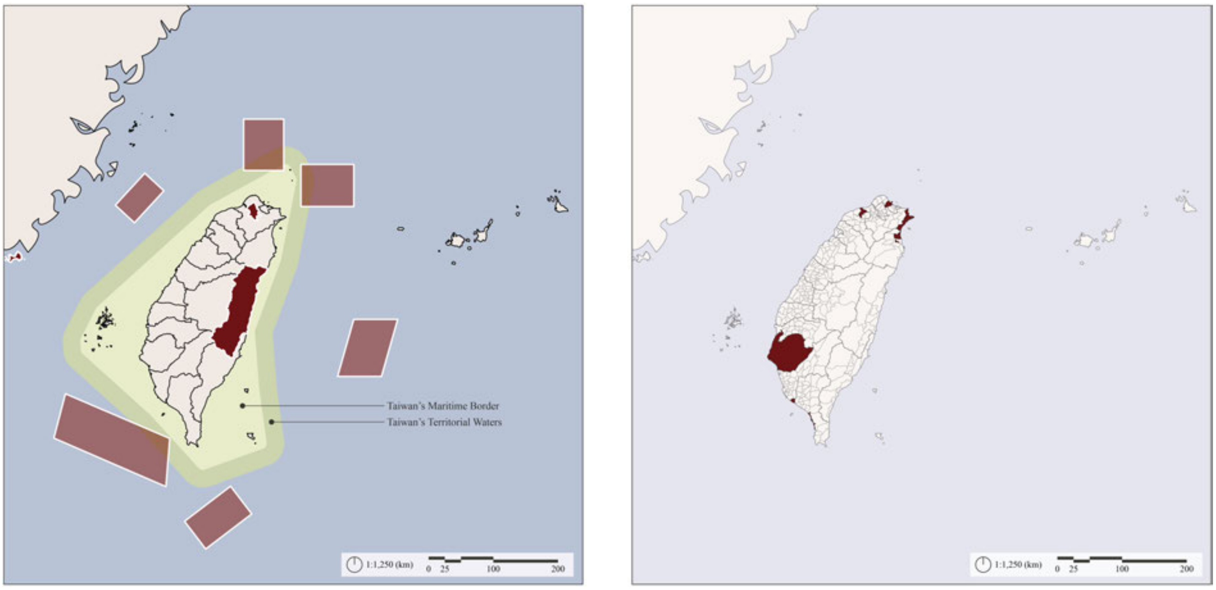


Figure 3: The possible attack areas and danger zones declared by the Chinese Government (left), possible be attacked cities analyzed by the Senior Director Ian Easton from the Project 2049 Institute.

Hualien City, Taiwan is a unique location that offers a variety of benefits due to its proximity to key infrastructure and natural features. One of the major benefits of Hualien City is its proximity to schools. The city is home to a number of universities and colleges, which can provide educational opportunities for both local residents and those who choose to relocate to the area (see Figure 4). This can be especially beneficial for families with children, as the presence of schools can provide access to quality education and can help to create a sense of community among families.

Another benefit of Hualien City is its proximity to hospitals. The city is home to several major medical facilities that can provide medical care for various conditions. This can be especially beneficial for older residents and those with chronic health conditions, as it can provide easy access to medical care without the need to travel long distances. Hualien City also offers benefits due to its proximity to airports and harbours. The city's airport is well-connected to other parts of Taiwan and the region, which can make it easy for residents to travel to other cities or countries for work or leisure. The harbour located in the city also allows for easy access to shipping, which can benefit businesses and residents who rely on shipping for their livelihoods (see Figure 5). Additionally, the topography of the mountains near Hualien City creates a natural self-defence zone (see Figure 6). The city is surrounded by mountains which provide a natural barrier, making it a relatively safe place to live. This can be especially beneficial for those concerned about security who want to live in a relatively protected place from external threats.

Overall, Hualien City offers a number of benefits due to its proximity to critical infrastructure and natural features. In Contrast, the topography of the mountains can provide a natural barrier to security. The primary focus of this thesis project is the site selection of Zouchang Park, which offers a spacious and expansive landscape and proximity to nearby shelters and hospitality facilities (see Figure 7). With its location within the education area, the park offers convenient access to underground shelters and bunkers, benefiting from the proximity to several surrounding schools.

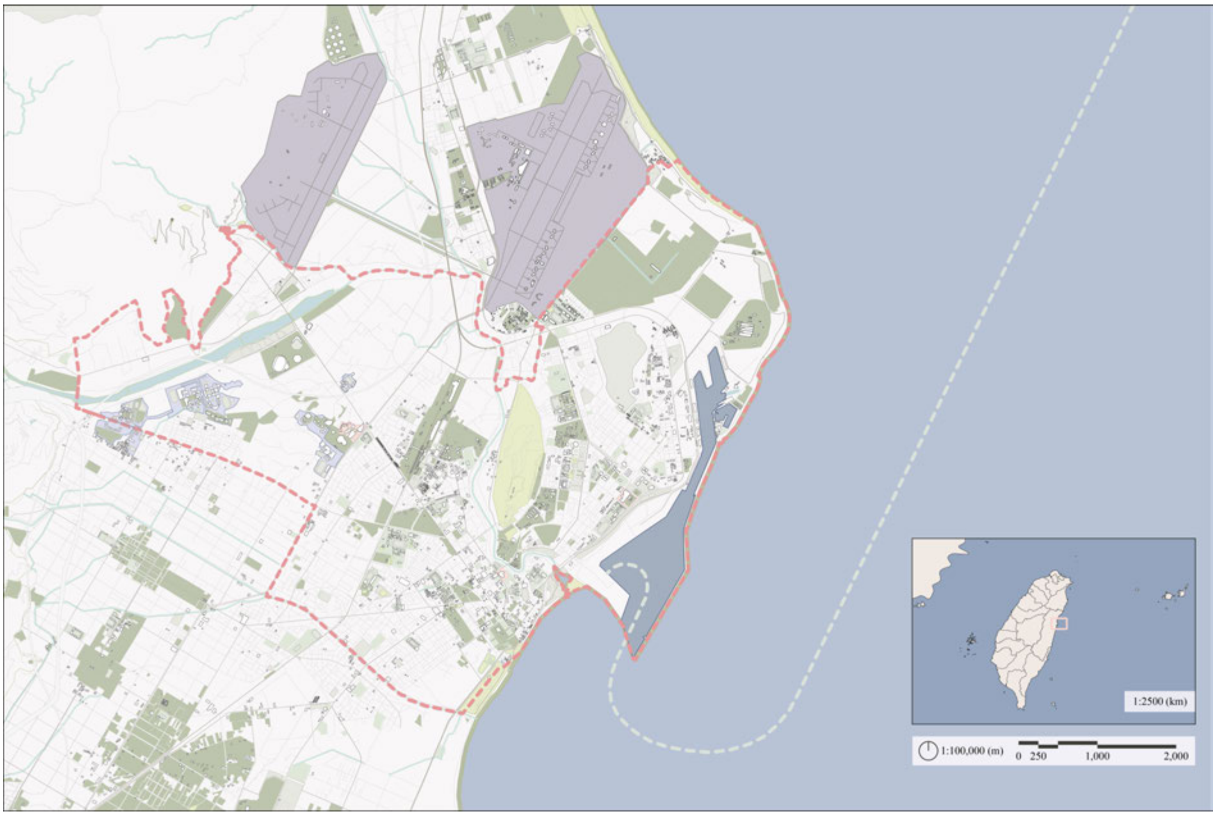


Figure 4: Hualien City master plan.

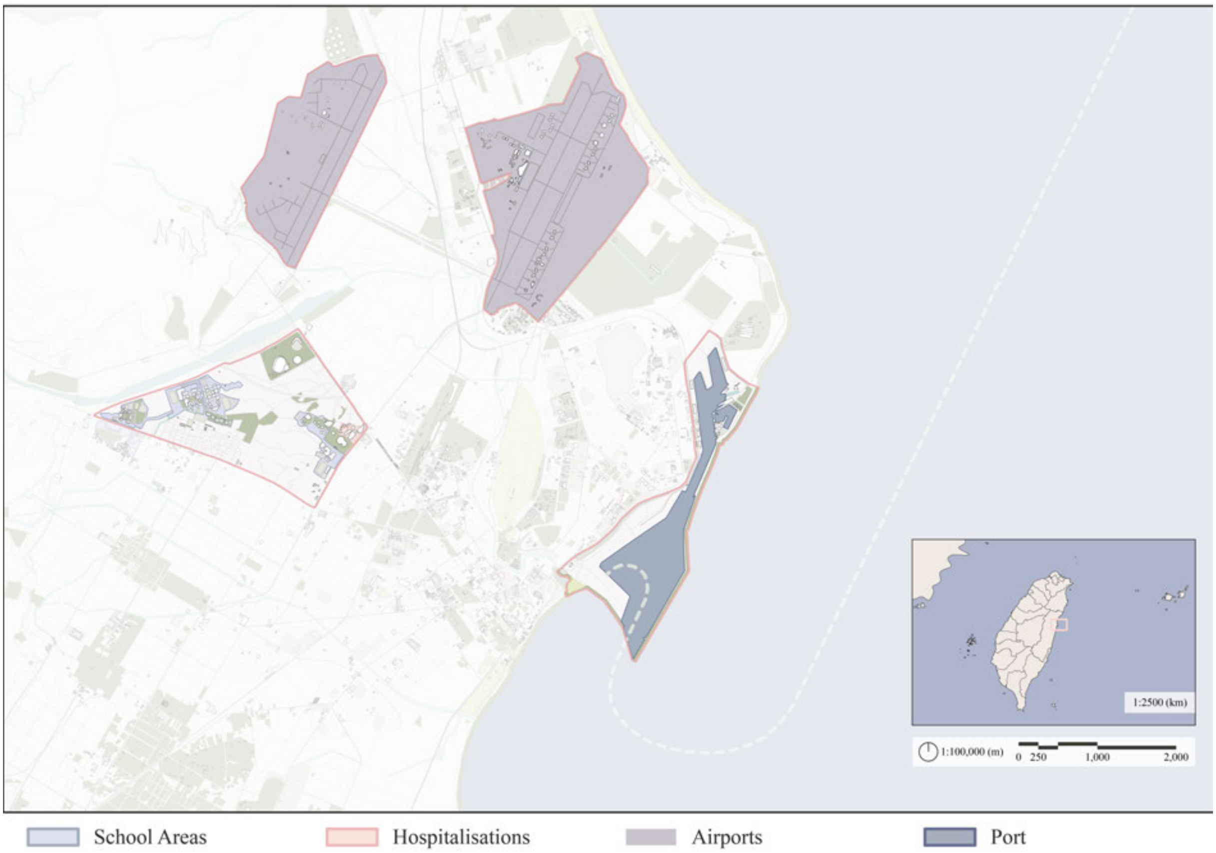


Figure 5: Hualien City contains multiple essential infrastructures, including education areas, hospitalisation, a harbour, an airport, and two military airports.

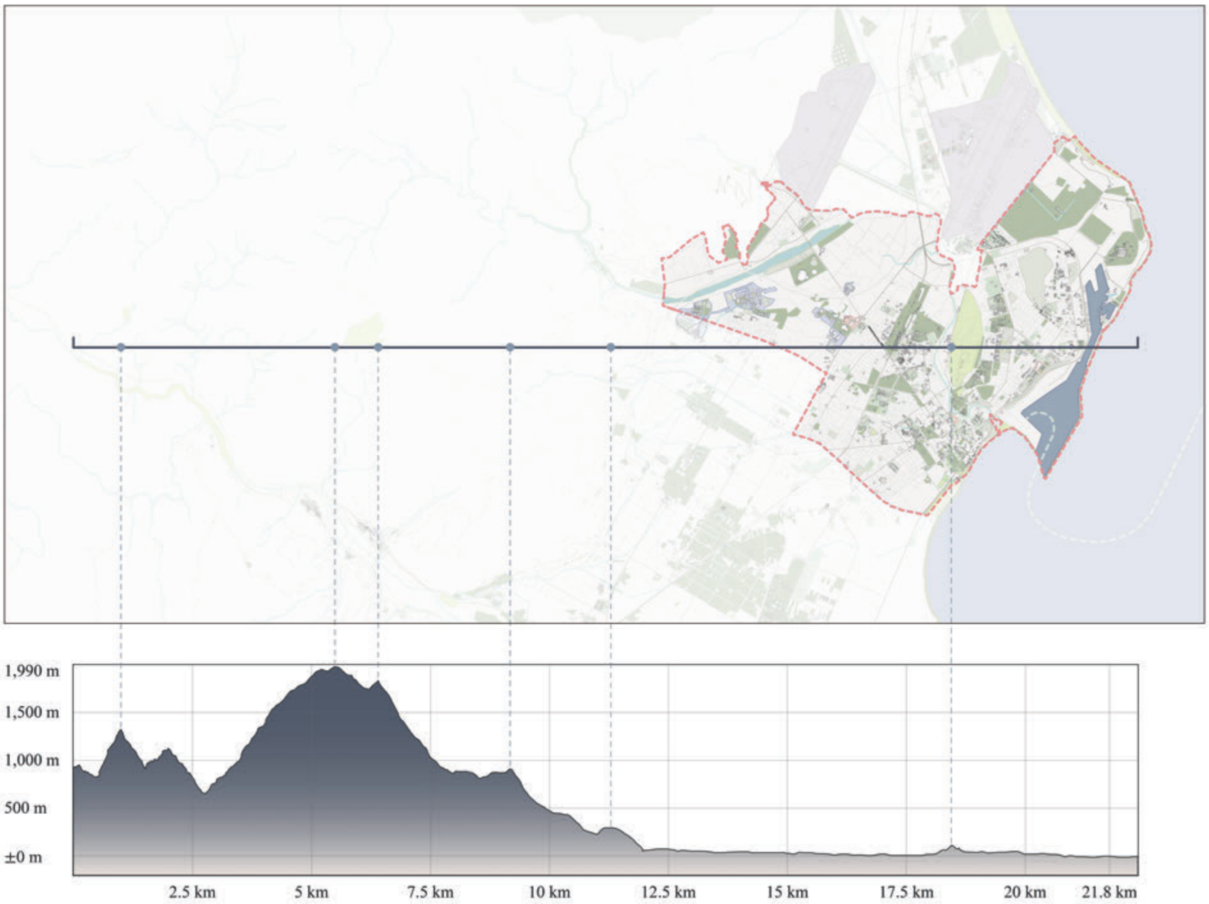


Figure 6: Topography elevation shows the natural defense for the city.

Figure 7: The main focus of this thesis is the park area in Hualien City: Zuochang Park.

2.3 Innovative Housing Solutions in Hualien City

Hualien City, Taiwan, boasts numerous advantages due to its strategic location and infrastructure. Notably, it is a pioneering hub for 3D concrete printing, a technology enabling immediate shelter and building construction. This innovation is precious for addressing disaster-prone housing needs and assisting distressed communities. With its proximity to universities and research institutions, Hualien City serves as a centre for research and development in this field, fostering advancements in efficient and cost-effective construction methods.

The benefits of 3D concrete printing are speed, affordability, and adaptability. This technology allows for the quick creation of complex structures, significantly reducing construction time compared to traditional methods. Moreover, it offers cost-effective solutions by optimising material usage and minimising labour costs. Consequently, Hualien City can efficiently provide durable shelters for individuals in urgent need of housing, such as those affected by natural disasters or experiencing economic hardships.

By embracing 3D concrete printing, Hualien City demonstrates its commitment to innovative approaches to address societal challenges. The city can swiftly construct shelters and homes, providing essential support to vulnerable populations. This convergence of critical infrastructure and advanced construction techniques positions Hualien City as a model for sustainable and resilient urban development, reinforcing its reputation as a forward-thinking and socially responsible city.

2.4 Advantages of Additive Manufacturing: Time Efficiency and Material Recyclability

AM is a rapidly evolving and innovative manufacturing method that has a wide range of benefits. One of the critical advantages of this technic is its time efficiency. Traditional manufacturing methods often require complex tooling and lengthy production cycles. Still, with 3DP, intricate shapes and structures can be created in hours and at a lower cost. This speed and flexibility can significantly reduce the time for new products and enable faster product iterations [6]. Another benefit of 3DP is its material recyclability. Traditional manufacturing methods often generate significant waste, but 3DP uses recyclable materials, such as biodegradable plastics, to reduce environmental impact.

Furthermore, 3DP can promote more sustainable production by allowing for the creation of products on demand, reducing the need for mass production and storage [7]. Overall, 3DP technology has the capacity to transform the manufacturing industry through the implementation of efficient and sustainable production methods. With advantages such as time efficiency and material recyclability, it presents an appealing choice for companies seeking to enhance their manufacturing processes and minimise their ecological footprint.

2.5 Comprehensive On-Site Information Planning

This section offers a comprehensive examination of essential emergency preparedness and infrastructure elements. It encompasses the analysis of emergency escape routes leading to nearby shelters, considering their maximum capacity. Furthermore, it explores the duration required for travel by foot or scooter, considering the proximity to vital transport stations. Additionally, it investigates the availability and accessibility of nearby sanitary stations, ensuring the provision of necessary facilities for public health and hygiene.

2.5.1 Emergency Escape Routes

Figure 8 provides a visual representation of the underground shelters situated within close proximity to the education and hospitalisation site. As per the information obtained from the Civil Defense Office in Taiwan, these shelters collectively have a maximum capacity of approximately 39,114 individuals [8]. The nearest shelter to Zuochang Park is located at a distance of approximately 472.58 meters, capable of accommodating approximately 2,000 people.

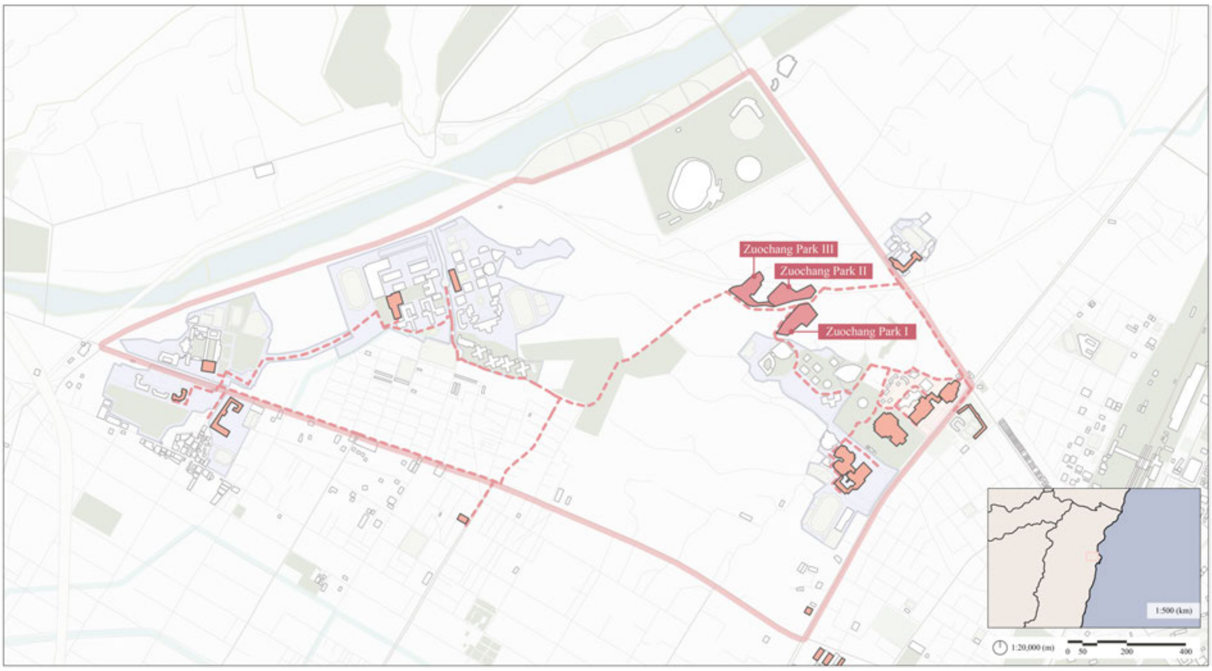


Figure 8: Proximity-based emergency shelter mapping shows each distance from the project location to the nearby shelters.

Based on the hypothesis presented in equations at section 5.3, it is assumed that Zuochang Park I can accommodate approximately 224 people. Considering that the park can accommodate a total of 672 people (224 x 3), in the event of an evacuation, the closest shelter would be the primary choice for on-site users (see section 5.4 for the accurate maximum number of individuals).

2.5.2 Strategic Transport Routes

Figure 9 delineates the pivotal transport stations in Hualien City, prominently featuring the international container terminal situated at the port. This port assumes heightened significance, particularly in times of war, as it serves as the conduit for direct maritime access to foreign territories, facilitating international protection for individuals seeking refuge. Complementing this strategic hub are an airport, a nearby military airport, and four major train stations strategically positioned throughout the city. Notwithstanding the prevalence of scooters as the primary mode of transportation for Taiwanese residents, their efficacy and safety during periods of conflict or emergencies may be compromised. Therefore, it becomes paramount to establish and maintain robust contingency plans and alternative travel arrangements to ensure seamless mobility and connectivity.

2.5.3 Sanitary Stations

Figure 10 provides an overview of the principal sanitary stations in Hualien City, highlighting their pivotal role in providing a fundamental resource for human survival: water. The Taiwan Water Corporation assumes a critical

Figure 9: The essential transport hubs in Hualien City.

responsibility in effectively managing and regulating the water supply, underscoring its utmost importance. The sanitary station at far West on the map, nestled within the mountainous terrain, is of particular significance, serving as a vital water source for Hualien City. Recognising the essential nature of water, especially during periods of war, it becomes imperative to prioritise the preservation and safeguarding of this station. This entails a steadfast commitment to ensuring its uninterrupted operation and resilience in the face of emergencies, thereby safeguarding the essential water supply for the well-being of the city's residents.

Figure 10

3 Methodology

This chapter introduces the research objectives and outlines the research model employed in this thesis, along with a diagrammatic representation illustrating the project's timeline and process. It provides a clear framework for understanding the goals and methodology of the study, facilitating the comprehension of the subsequent chapters and the overall structure of the thesis.

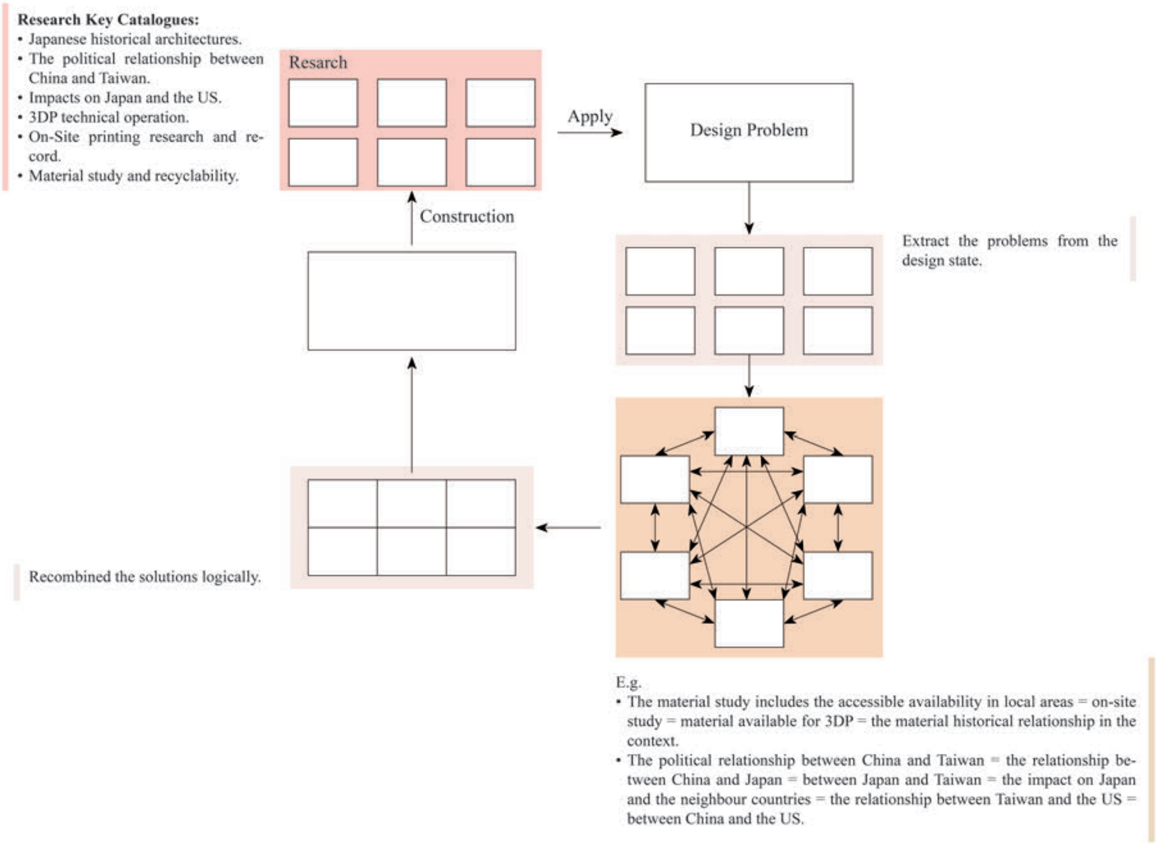
3.1 Research Aims

The purpose of this project is to develop defence and protection strategies for Taiwan, in anticipation of potential military attacks from neighbouring countries. To achieve this, the project will focus on several key aspects, including the political relationships between China, Japan, Taiwan, and the United States, as well as the impact of Japanese architecture on Taiwan. Additionally, the project will explore the feasibility of rapidly constructing housing units using additive manufacturing technology within a tight timeframe while considering the accessibility and recyclability of the 3D printing materials. The project will require ongoing evaluation and revision to ensure its overall coherence and effectiveness.

3.2 Research Framework

This paper primarily focuses on the research stage of a Master's thesis, utilising the complex intellectual activity model proposed by Milburn (2003) [9] as the research method. The method structure involves a series of steps, namely Research, Design, Application, Synthesis, Construction, and Evaluation, which are repeated in a loop to achieve an optimal design strategy (see Figure 11. Throughout the research stage of this thesis, it is crucial to ensure that the methodology is based on accurate information and is in line with other pertinent aspects of the topic, which necessitates rigorous fact-checking and evaluation.

In addition to the research method, the next step involves applying the results obtained from the research stage to develop architectural designs. Specifically, the 3D models resulting from the research process are translated into a format compatible with 3D printers. By utilising the information and insights gained through the research method, the resulting 3D models and 3D printed designs have the potential to improve the overall design strategy and enhance the quality of the final product. This demonstrates the significance of an effective and thorough research methodology in the field of architecture.



Research Key Catalogues:

- Japanese historical architectures.
- The political relationship between China and Taiwan.
- Impacts on Japan and the US.
- 3DP technical operation.
- On-Site printing research and record.
- Material study and recyclability.

Extract the problems from the design state.

Recombined the solutions logically.

E.g.

- The material study includes the accessible availability in local areas = on-site study = material available for 3DP = the material historical relationship in the context.
- The political relationship between China and Taiwan = the relationship between China and Japan = between Japan and Taiwan = the impact on Japan and the neighbour countries = the relationship between Taiwan and the US = between China and the US.

Figure 11: The research method study model: complex intellectual activity model loops to evaluate the methodology statement and design proposal. Figure reference: Milburn, L. A. S. (2003)

4 Research Method

This chapter builds upon the foundation established in Chapter 2 and explores several key topics relevant to the architectural landscape in Taiwan. The research methodology emphasises examining various architectural elements that have evolved over the past decades and their impact on the field. Additionally, this chapter introduces bamboo as a locally sourced and sustainable material that can enhance the structural properties of concrete for 3DP. Furthermore, it delves into the preparation process and highlights the advantages of implementing 3DP techniques directly on-site.

4.1 Japan-Taiwan Partnership: Strengthening Defense Against Potential Threats from China

Historically, Taiwan was under Japanese rule from 1895 to 1945(see Figure 12), when it underwent significant modernisation and development. However, Taiwan was ceded to Chinese control after World War II due to the Japanese surrender of the war.

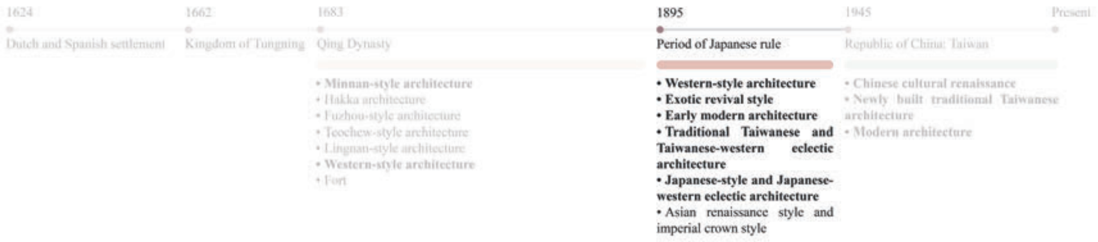


Figure 12: History timeline: Taiwan as a dependency of Japan developed architectural elements.

In recent years, the relationship between Taiwan and Japan has been cordial but not officially diplomatic [10]. Both Taiwan and Japan have close economic ties, and Japan is one of Taiwan's major trading partners; Taiwan and Japan also have cultural exchanges. However, the relationship is complicated by China's claims to Taiwan as a part of its territory and the PRC's pressure on other countries not to recognise Taiwan officially.

The relationship between Japan and Taiwan can help strengthen Taiwan's defence against potential threats from China by fostering strategic partnerships in intelligence sharing, military training, and technology transfers [11][12]. Japan's advanced military capabilities and shared geopolitical concerns with Taiwan can provide a valuable source of support in any military conflict. Cooperation between Japan and Taiwan can bolster the international community's support for Taiwan's security and sovereignty.

4.2 Architectural Elements Study and Extract

When designing housing units that incorporate traditional Japanese and Taiwanese Minyang fusion architecture, it is essential to consider each style's specific elements and design principles in order to extract and adapt to the project.

While developing in Taiwan, features such as shophouses, verandas, L-shaped windows, elevated floors, and wood truss structures are essential for traditional Japanese architecture (see Figure 13) were also well developed in Taiwan in the early 20th century. Additionally, traditional Japanese homes often have a sense of hierarchy, with specific areas designated for different activities such as sleeping, eating, and entertaining. Minyang architecture, as a mixed culture from European Baroque, South-East Asian, and traditional Chinese features, is known for its vibrant colours and intricate patterns[13] [14]. Traditional Japanese architecture can incorporate in-depth details through decorative elements such as tile work or conventional textile patterns [15].

It is essential to consider the function and practicality of the housing units when incorporating these architectural styles. It is necessary to ensure that the design is suitable for emergency living, with proper insulation, ventilation and lighting, and accessibility for people with disabilities.

Overall, the design strategy for extracting traditional Japanese architecture and Taiwanese Minyang fusion architecture and creating housing units involves a balance of incorporating specific elements and design principles regarding living comfort and practicality while ensuring that the final design is cohesive, functional and practical.

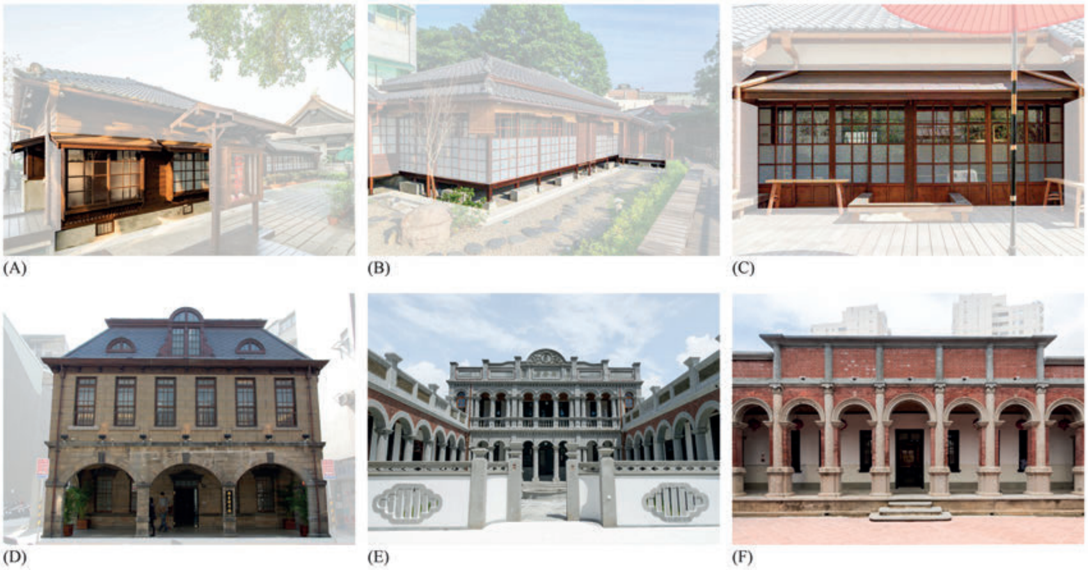


Figure 13: The case studies primarily focus on traditional Japanese and Minyang fusion in Taiwan, built in the Japanese rule period. (A) Bushido Hall, Daxi Wood Art Ecomuseum, Taoyuan, Taiwan. (B)(C) Craftsman Story House, Daxi Wood Art Ecomuseum, Taoyuan, Taiwan. (D) The Taipei Futai Street Mansion/ Yamato-chō Mansion, Taipei, Taiwan. (E) Jukuiju Mansion, Taichung, Taiwan. (F) Yide Mansion, Taichung, Taiwan.

4.3 Extracted Architectural Elements Impact

The architectural elements incorporated in the housing unit design for Hualien City are carefully selected based on previous case studies. The main focus is on improving ventilation and creating an effective rainproof system suitable for Taiwan's scorching, humid weather. Additionally, considerations are given to the region's vulnerability to typhoons and earthquakes, informing the choice of construction materials and structures that can withstand potential destruction. Verandas are integrated into the design to provide both rain protection and additional resilience against Taiwan's frequent rainfall.

The development of a new camp unit design in Hualien City aims to meet the specific needs of its users while accounting for the local climate. By combining traditional architectural studies with innovative approaches, the design seeks to strike a balance between adapting to Taiwan's weather conditions and optimising comfort and functionality. These architectural elements not only address the challenges posed by the climate but also create a harmonious living environment for residents.

4.4 Material Accessibility And Recyclability From Local Resource

This section aims to analyse suitable composite materials for 3DP, with a specific focus on bamboo. Bamboo is highly regarded in the Taiwanese material scratch industry and is considered a sought-after material. Nantou City, located near Hualien City, serves as the largest exporter of bamboo products in Taiwan, providing easy accessibility and cost-effective resources for the region (see Figure 14). The abundant availability of bamboo resources near Hualien City reduces material transportation costs, making the incorporation of bamboo into the 3DP process more feasible [16].

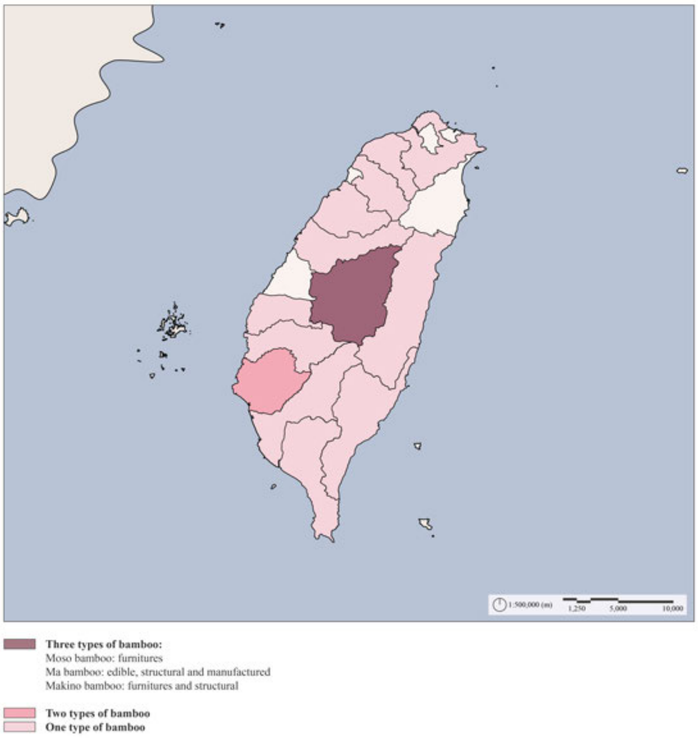


Figure 14: Three shades of pink on the map show Taiwan's most significant production of the bamboo industry (dark maroon with three types of bamboo in Nantou County).

The inspiration for utilising a bamboo-cement composite as the printing material stems from traditional construction techniques developed in Taiwan for centuries. One such technique is the 'Bamboo-mud wall' or Taiwanese wattle and daub, which gained popularity during the early 20th century under Japanese rule [17]. This construction method involves creating a structural frame using bamboo strips of varying thicknesses and applying a mud mixture of clay and chaff as daubing. The wall is then covered with hemp plaster for the final layer [18][19]. The project uses a composite bamboo-cement material as the primary printing material for on-site 3DP, drawing inspiration from this method.

The composite material suitable for on-site 3D printing is created by grinding bamboo into a powder and combining it with cement. Leveraging the mature construction techniques developed in Taiwan for large-scale structures and architecture using bamboo [20], the project benefits from the speed and efficiency enabled by working with lightweight bamboo materials.

The utilisation of bamboo in the project yields multiple benefits. Firstly, the use of locally sourced bamboo supports the local economy and reduces reliance on imported materials. Secondly, bamboo aligns with sustainable practices, contributing to the project's environmental goals. Additionally, incorporating bamboo allows for applying familiar construction techniques, ensuring compatibility and feasibility. Lastly, bamboo's lightweight properties facilitate faster construction processes and easier handling during 3DP operations.

4.5 Material Composite In Additive Manufacturing

Several factors come into play when evaluating material composites for 3DP, including stability, accessibility, compatibility with 3DP technology, and environmental sustainability. In pursuit of sustainable construction practices, the utilisation of bamboo-based bio-material composites has gained significant attention. Bamboo represents a green alternative to conventional materials like concrete and steel, particularly in modern architectural designs [21].

Bamboo's selection as a primary material for 3DP is driven by its sustainability attributes. Being a fast-growing renewable resource, bamboo exhibits excellent potential for environmental friendliness and resource efficiency. Its rapid growth rate and high carbon sequestration capacity make it an appealing choice for reducing carbon footprints associated with construction activities. Additionally, bamboo possesses remarkable strength and flexibility, making it suitable for reinforcement purposes in concrete composites.

In particular, bamboo reinforced concrete holds promise for low-cost and low-rise building designs [22]. Using bamboo as a reinforcing material offers advantages such as enhanced tensile strength, improved ductility, and increased resistance to cracking. These properties contribute to the structural integrity and longevity of the constructed elements. Moreover, bamboo's low embodied energy and minimal processing requirements make it a favourable option for sustainable construction practices.

Furthermore, bamboo's utilisation in construction has a minimal impact on climate change and global warming. As a renewable resource, bamboo cultivation helps in carbon dioxide absorption, thus mitigating greenhouse gas emissions. By incorporating bamboo-based bio-material composites in 3DP, the construction industry can contribute to reducing carbon emissions and fostering more sustainable building practices.

In summary, the incorporation of bamboo-based bio-material composites in 3D printing aligns with the goal of sustainable construction. Bamboo offers numerous advantages, such as sustainability, strength, flexibility, and low environmental impact [23]. As a green alternative to traditional materials, bamboo reinforced concrete presents an attractive option for low-cost and low-rise building designs. Embracing bamboo-based materials in 3DP can support environmentally conscious architecture while addressing the challenges of climate change and global warming [24].

4.6 3D Concrete Printing On-Site

During the research phase, the BOD2 3D Construction Printer, developed by COBOD INTERNATIONAL, emerged as the preferred choice among competitors offering gantry systems for on-site printing construction. Compared to other printers, such as *P1 from BetAbram*, *Vulcan II from ICON*, and *ARCS from SQ4D*, BOD2 boasts a larger printing area. It offers a more comprehensive plan for assembly and printing methods. Unlike its counterparts, BOD2 does not necessitate a completely flat concrete base, making it adaptable to even ground surfaces without prominent visual disturbances. Additionally, BOD2's practical experience in printing tiny houses positions COBOD as a trusted source for small unit printing methods, aligning well with the requirements of this project. With notable advantages, including high printing speed and a versatile printing area, the BOD2 printer stood out as an optimal choice. Detailed specifications of the BOD2 printer can be found on the official website of COBOD INTERNATIONAL, serving as a valuable open-source reference for this project [25][26].

The printer's dimensions for this project are (W)14.6 m x (L) 34.3 m x (H)8.5 m. It is worth noting that the printer's length is not limited, as additional gantry systems can be incorporated as required by the designers (specifications see Table 1). This unlimited-length capability provides a significant advantage and helps optimize space utilization by eliminating any unnecessary gaps between the gantry systems and construction sites.

Maximum Printing Length:	Unlimited
Maximum Printing Width:	14.6 m
Maximum Printing Height:	8.1 m
Maximum Printing Speed:	Up to 1000 mm/s (1 meter/s)
Layer Height:	5 - 30 mm
Layer Width:	30 - 100 mm
Movement system:	Servo
Material Flow:	< 3,6 m^3/hour
Maximum Aggregate Size:	< 10 mm
Printer Setup Time:	8 Hours
Printer Takedown Time:	4 Hours
Manning:	2 Operators
Connection:	Wifi or LAN
Interface:	Web Client
Slicer Software:	COBOD Slice (Windows, MacOS), Third party slicers
Power Supply:	32 A, 400 V, 3 Phase

Table 1: The table shows several advantages of working with BOD2, such as its printing speed and unlimited length. Data retrieved from COBOD INTERNATIONAL.

Another advantage of the BOD2 printer is its easily adaptable and interchangeable nozzles, which offer a range of options in terms of layer widths and heights. This feature enables precise control over the printing process, creating intricate and complex structures with desired levels of detail and accuracy.

Furthermore, the BOD2 printer incorporates flaps that facilitate the smoothening of walls during the printing process. This feature helps enhance the overall finish and appearance of the printed structures, contributing to their aesthetic appeal and structural integrity. Combined, these advantages make the BOD2 printer a reliable and efficient choice for the project, ensuring the successful implementation of 3D construction printing with optimal material compatibility, customizable layering options, and improved surface quality.

By implementing robust reinforcement strategies and incorporating earthquake-resistant design principles, such as using reinforced concrete and strategically placing load-bearing elements, the printed houses can withstand seismic forces and minimize the potential for structural damage during earthquakes. This ensures the residents' safety and well-being and contributes to the long-term durability and sustainability of the constructed buildings.

5 Design Proposal

This chapter provides a comprehensive overview of the project design development process, encompassing the evolution of architectural elements, their on-site impact, and their benefits to users. Additionally, it explores the implementation of Grasshopper (GHD) for improved adaptability, incorporating computational and realistic preparations for on-site 3DP housing units. By examining these essential aspects, the chapter offers valuable insights into the holistic approach to optimising the project design and enhancing its practicality and functionality.

5.1 Architectural Elements from Case Studies

The housing unit design in Hualien City draws from previous case studies to enhance ventilation and establish an efficient rainproof system. It considers the region's susceptibility to typhoons and earthquakes by selecting materials and structures with enhanced durability. The inclusion of verandas provides additional rain protection. By incorporating traditional architectural principles and innovative solutions, the design achieves a harmonious balance between adapting to the climate and meeting the needs of residents, ensuring a comfortable and resilient living environment [27] (see Figure 15).

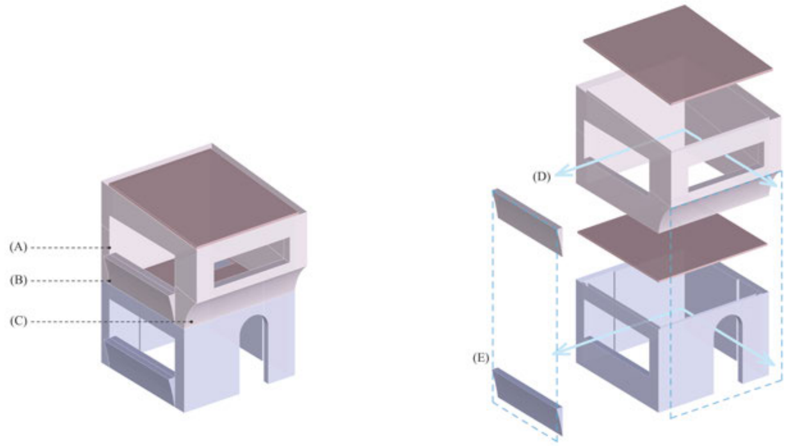


Figure 15: The combined architectural elements extracted from several traditional housing genres improved the ventilation and rainproof system, offering practical strategies on-site. (A)L-Shaped Window, Opened Windows (adaptable) (B)Veranda (C)Shophouse, Veranda (D)Wide opened windows prevent heat gathering and improve the ventilation situation (E) Veranda design offers rainproof space for users on-site.

The selection of materials and structures for housing units prioritises durability while including verandas enhances rain protection. By integrating traditional architectural principles and innovative solutions, the design balances climate adaptation and residents' needs, creating a comfortable and resilient living environment.

5.2 Leveraging Grasshopper 3D Plugin for Environmental Analysis

The project utilises simulation tools such as Grasshopper 3D with the Ladybug plugin[5] to optimise the living conditions further. The simulation focuses on total sunlight hours and humidity levels, taking into account the scorching and humid weather prevalent in Taiwan, particularly during the period from 01.05 (1th of May) to 01.10 (1th of October) when temperatures are highest, as mentioned in section 4.3. The extracted architectural elements aim to improve ventilation design and manage sunlight direction. The simulation results indicate

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[5] Grasshopper 3D plug-in Ladybug. Url:`https://www.ladybug.tools`

that Units (d)(c)(f), which face direct sunlight and receive approximately 107 to 123 direct sunlight hours within the five months (direction: NE), benefit from higher roof structures that allow for ventilation windows beside the roofs. On the other hand, Units (a)(b)(e), as shown in Figure 16 from a Southern perspective, receive only approximately 15 to 30 hours of direct sunlight within the same period. The analysis presents a significant advantage for residents of these units, as direct sunlight in Taiwan is strong and can create an uncomfortable indoor living environment.

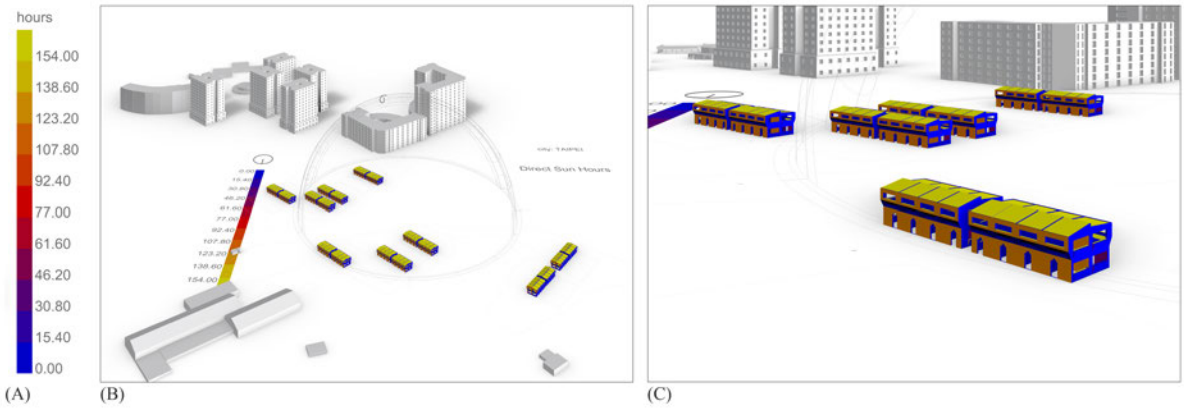


Figure 16: The Grasshopper plug-in Ladybug analysed the impact of direct sunlight hours on-site to the project. (A)The hours' bar shows shades of colours from blue to red to yellow, presenting the least to the most direct sunlight hours it recorded. (B)The North perspective shows that the most sunlight is on roofs (approximately 154 hours). (C)A closer perspective shows that the North-East elevation receives approximately 107 to 123 direct sunlight hours.

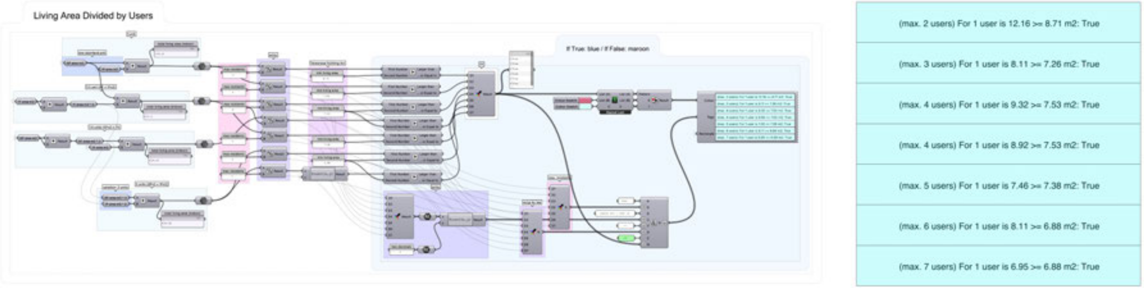
By integrating the insights from simulation analysis, the housing unit design in Hualien City is optimised to provide adequate ventilation, manage sunlight exposure, and create comfortable living spaces that mitigate the challenges posed by the region's climate.

5.3 Automatic Determination of Measures from Specification

This section is dedicated to creating indoor living areas in compliance with building regulations, ensuring a minimum level of comfort for unit users [28]. The living area is determined based on the Taiwanese Building Act, and the following paragraph provides the living area range divided by the minimum and maximum number of users.

1 user = 13.07 m^2
2 users = 8.71 m^2/ per user
3 users = 7.26 m^2/ per user
4 users = 7.53 m^2/ per user
5 users = 7.38 m^2/ per user
6 users ≥ 6.88 m^2/ per user

To assess compliance with regulations, the GHD calculates (see Figure 17) by dividing the unit's living area by the number of users, utilising a boolean toggle to indicate if the results meet or exceed the regulation. For example, the ground floor area of 11.36 m^2 combined with the first-floor area of 12.97 m^2 totals 24.33 m^2. Dividing this by three users yields 8.11 m^2, which is greater than the minimum requirement of 7.26 m^2 for a shared flat with three users.



```
(max. 2 users) For 1 user is 12.16 >= 8.71 m2: True
(max. 3 users) For 1 user is 8.11 >= 7.26 m2: True
(max. 4 users) For 1 user is 9.32 >= 7.53 m2: True
(max. 4 users) For 1 user is 8.92 >= 7.53 m2: True
(max. 5 users) For 1 user is 7.46 >= 7.38 m2: True
(max. 6 users) For 1 user is 8.11 >= 6.88 m2: True
(max. 7 users) For 1 user is 6.95 >= 6.88 m2: True
```

Figure 17: Automatic Measurement in GHD calculates the minimum area for accommodation.

The chart on the right side of Figure 17 visualises the results in blue when they are equal to or exceed the regulation, signifying a True boolean value.

5.4 Units Combine Variations

The project is primarily focused on Zuochang Park, as highlighted in Figure 7. While printing the maximum capacity of accommodation blocks on-site is technically feasible, it may not provide optimal comfort. Therefore, the project adopts a phased approach, initially printing 30% of the accommodation blocks. For instance, in Zuochang Park I, eight blocks will comprise 64 units. Referring to the calculated results in section 5.3 and considering the user capacity mentioned in the preceding paragraph, Zuochang Park I can accommodate a maximum of 192 people.

Figure 18 illustrates the master plan for constructing 30% of the accommodation blocks across each site. This arrangement aligns with the GHD calculation, which resulted in a 70% reduction in the number of blocks. The light pink blocks represent the designated positions for accommodation within the three parks. As a result, a total of 18 blocks are available for housing units. Combining the capacity of these blocks, Zuochang Park I, II, and III can accommodate a maximum of 432 individuals.

Figure 19 provides a visual representation of the partial definition in Grasshopper, showcasing the intricate calculations employed to determine the optimal arrangement of printed blocks on the master plan (see Figure 19a). Based on GHD, these calculations consider the maximum capacity of the site and highlight the specific dark blue blocks that meet the necessary criteria for on-site printing using BOD2 technology (see Figure 19b). The figures offer valuable insights into the complex process and decision-making in placing printed blocks within the project.

The master plan provides a comprehensive depiction of the accommodation blocks, along with the accompanying shared kitchens and sanitary facilities. The allocation of toilets and showers adheres to the Laws and Regulations of the Taiwanese Government on dormitory planning. Detailed drawings of the four-block and two-block kitchen plans, as well as the shared sanitary facilities plans for both four-block and two-block configurations, are presented in Figures 20 and 21.

These detailed drawings offer a visual representation of the layout and design of the shared spaces within the accommodation blocks. The inclusion of shared kitchens and sanitary facilities is essential for fostering a sense of community and convenience among the residents. By adhering to the regulations set forth by the

Taiwanese Government, the project ensures compliance with established standards and guidelines for dormitory planning [29]. The precise depiction of these facilities in the master plan allows for effective implementation and construction, promoting comfortable and functional living spaces for the intended occupants.

The ground floor plan (see Figure 22a) illustrates various configurations of user living arrangements, featuring foldable beds and distinct layouts in the living room area. In situations where needed, the ground floor offers the possibility of combining two units into a single unit specifically designed for wheelchair users. While technically, the GHD calculation allows for multiple wheelchair users to share a wheelchair-accessible ground floor living flat, it is advisable to accommodate only one wheelchair user along with their accompanying family member or caregiver. This recommendation ensures that the wheelchair has sufficient space for a 1.5-meter turning circle.

The incorporation of different user living arrangements, including foldable beds, within the ground floor plan caters to the diverse needs of residents. This versatility provides the flexibility to adapt living spaces to suit individual preferences or changing circumstances. Additionally, including wheelchair-accessible units demonstrates a commitment to promoting inclusivity and accessibility in the housing design. This approach prioritises the safety and convenience of wheelchair users, enabling them to navigate the living space comfortably.

The first floor serves as an accommodation area for multiple users. The left side of the first-floor plan (see Figure 22b) illustrates the merged area of these units, allowing for shared flats with 1.5 units created by combining the ground floor unit for wheelchair users. According to the GHD calculation in Figure 17, $Ground - Floor + (First - Floor x2) = 37.3\ \mathrm{m}^2$, accommodating a maximum of four users. Additionally, the first-floor plan demonstrates the possibility of one user living alone in a single unit. Consequently, a single unit has the capacity to accommodate up to three users, as illustrated by Units (a) to (f). By merging units with neighbouring ones and combining the ground and first floors, two units can accommodate a total of seven users, as determined by the GHD calculation (refer to Figure 17). Consequently, when eight single units are combined into one block, a maximum of 24 users can be accommodated (3 users x 8 single units) = 24 users).

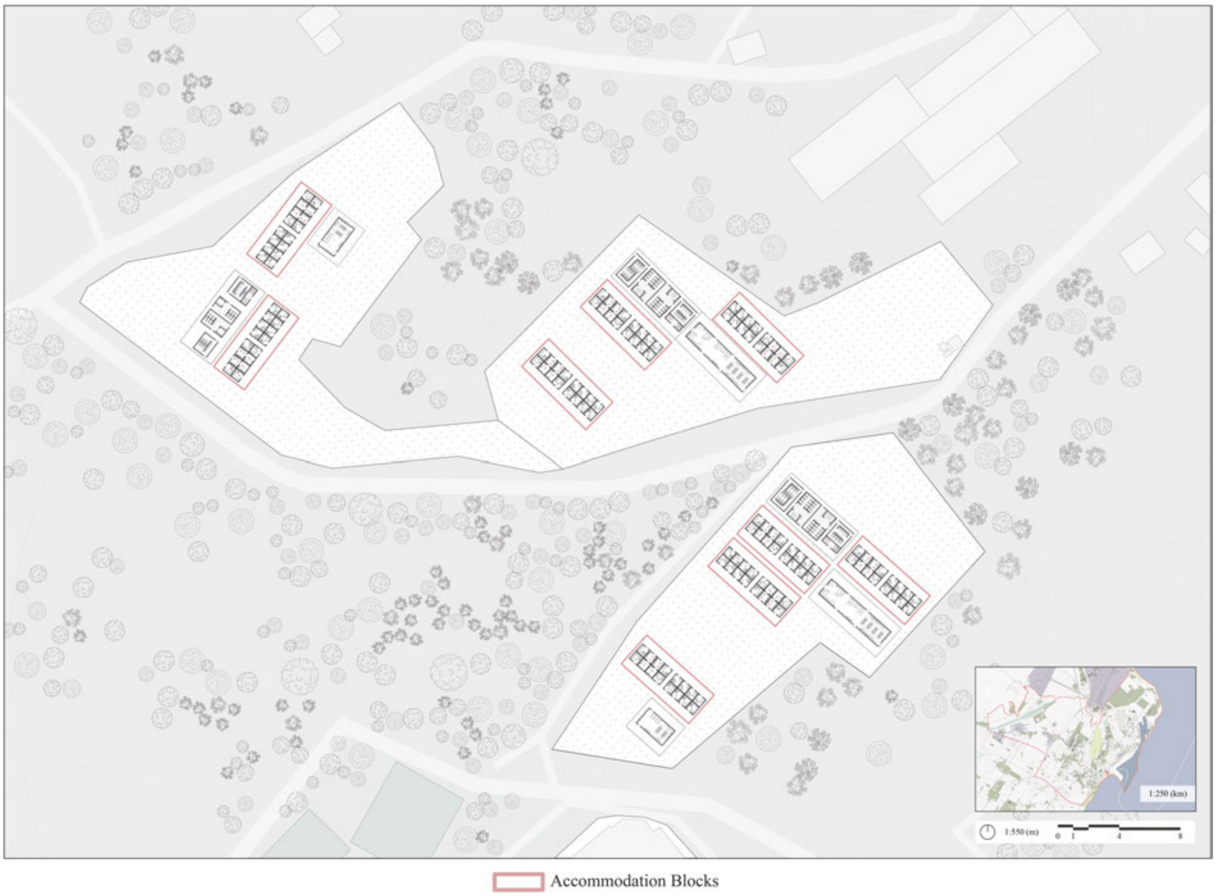
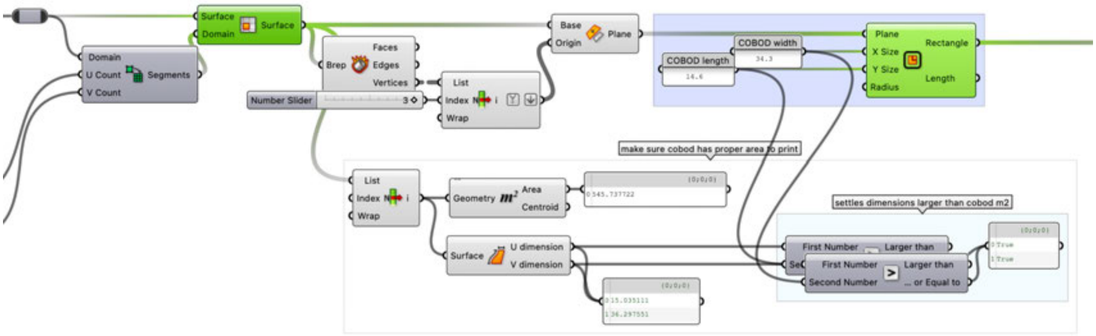


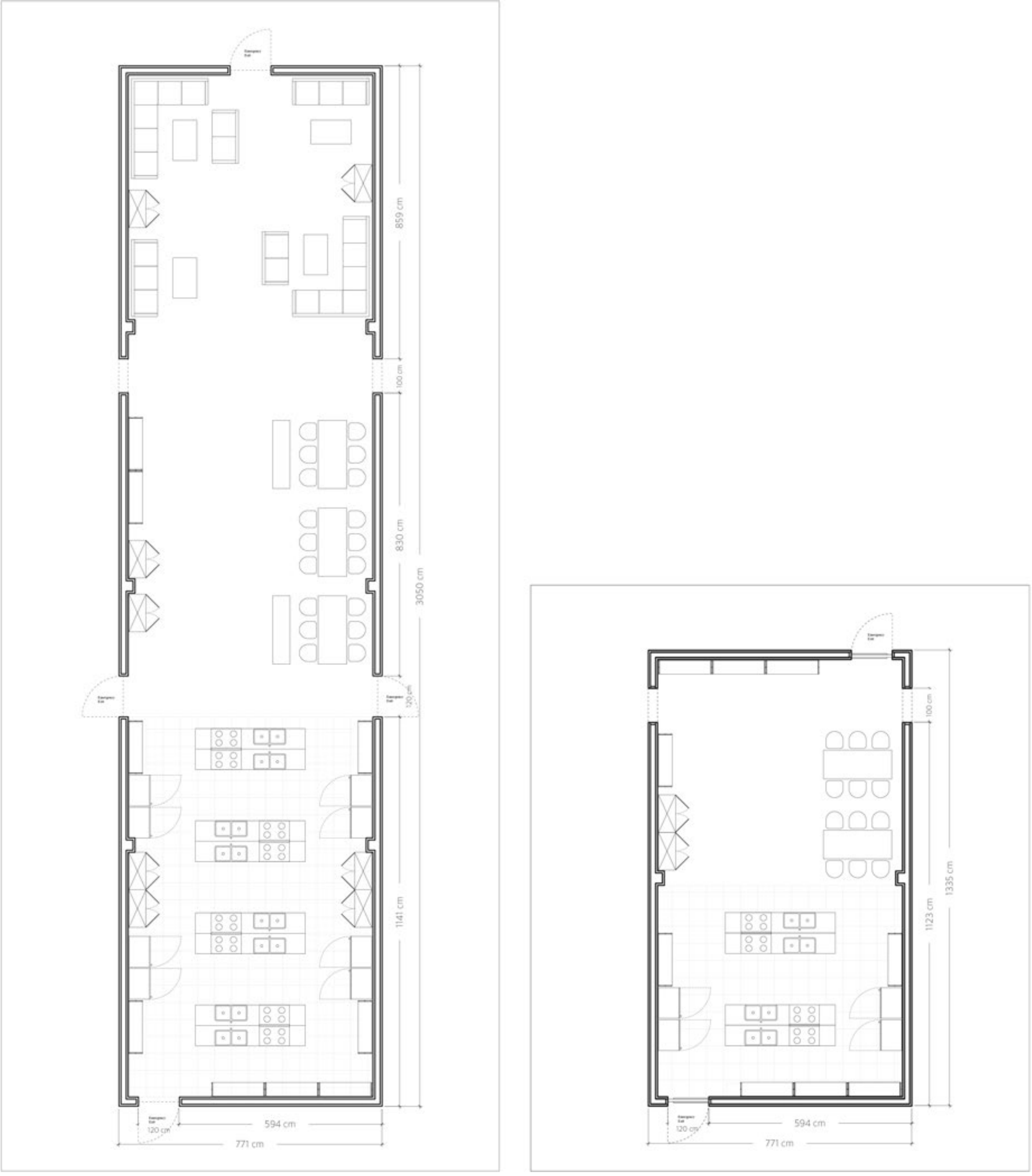
Figure 18: The master plan showcases the implementation of 30% of constructed units within park areas, complemented by additional blocks designated as shared sanitary facilities and kitchens.



(a) The figure shows the partial definition from Grasshopper about how the calculations were operated.

(b) The arrangement of printed blocks on the master plan is based on GHD calculations for maximum site capacity, with only the dark blue blocks deemed suitable and compliant for on-site printing using BOD2.

Figure 19: The figures show the partial definition in Grasshopper (19a), illustrating the calculations used to determine the arrangement of printed blocks on the master plan (19b).



(a) Four blocks shared kitchen Scale: 1/200 (m).

(b) Two blocks shared kitchen Scale: 1/200 (m).

Figure 20: Two distinct kitchen plans are featured in the master plan. Plan entails a kitchen facility shared among four blocks, accommodating a total of 96 individuals (20a). On the other hand, plan 20-b comprises a kitchen shared by two blocks, accommodating 48 individuals (20b).

(a) Four blocks shared sanitary facilities Scale: 1/200 (m).

(b) Two blocks shared sanitary facilities Scale: 1/200 (m).

Figure 21: Two distinct lavatory plans are featured in the master plan. Plan 20-a entails a sanitary facility shared among four blocks, accommodating a total of 96 individuals (21a). On the other hand, plan 20-b comprises a lavatory shared by two blocks, accommodating 48 individuals (21b).

(a) Ground Floor Plan Scale: 1/200 (m).

(b) First Floor Plan Scale: 1/200 (m).

Figure 22: Accommodation ground floor (22a) and first floor (22b) plans with two printed blocks (in the maximum BOD2 printing area without extended cranes.)

5.5 Preparation and Adjustment for 3D Printers

The term "overhang" refers to a specific aspect of the printing process where a portion of a printed object extends horizontally or at an angle without underlying support structures. Overhangs present a challenge in 3DP, resulting in poor surface quality, drooping, or sagging if not adequately addressed. Limiting the overhang angle to around 35 degrees is generally recommended to maintain high printing quality. However, this value may vary depending on factors such as the printer's capabilities, filament material, and the complexity of the printed model (the material property is included in section 4.5). Several considerations should be considered when working with on-site 3D printers for printing houses. Firstly, the design of the house should be optimised to minimise the presence of large and unsupported overhangs, as these can compromise the structural integrity of the printed components. It is essential to carefully analyse the architectural design to ensure proper support and minimise the need for extensive support structures during printing.

Moreover, it is essential to conduct thorough testing and validation of the 3D printing system and process before embarking on large-scale house construction. This includes evaluating the printer's capabilities, optimising printing parameters, and assessing the overall quality and reliability of the printed components. Regular maintenance and calibration of the printer are also necessary to ensure consistent performance and accurate reproduction of the intended designs.

In Figure 23, the GHD incorporated algorithms and mathematical calculations to determine the maximum angle reached by the overhangs. By evaluating the angles at different points along the mesh surface, the GHD generated data that quantifies the extent of the overhang. The data is visualised within the Rhinoceros 3D environment, using shades of green on the mesh and a chart to represent the varying degrees of overhang (see Figure 24).

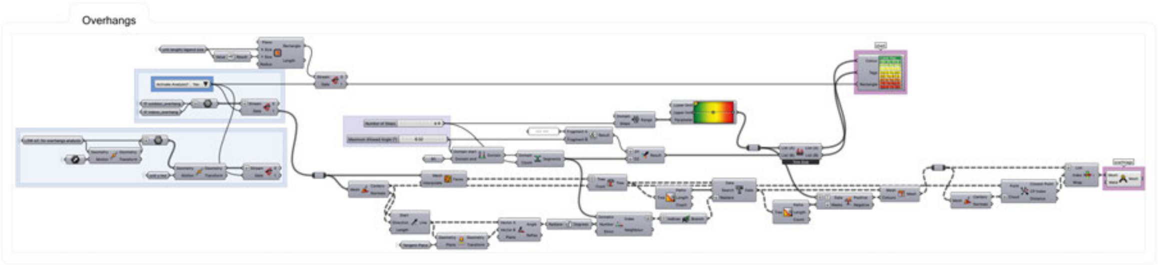


Figure 23: In this GHD, the unit balcony and veranda were transformed as mesh and shown in shades of green to red to present the angles of unsupported structures.

Concisely, integrating Grasshopper offers a powerful solution for calculating and analysing overhangs for on-site printing projects. Using Grasshopper definitions, unsupported structures such as balconies and verandas can be transformed into meshes and assessed for maximum angles. This analysis provides valuable insights into the feasibility and quality of the overhangs, allowing designers to optimise their designs and make informed decisions regarding the need for support structures or design modifications [30][31].

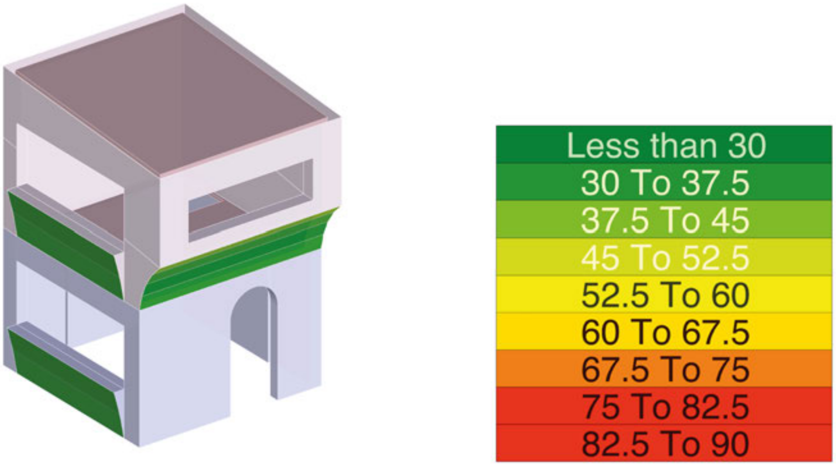


Figure 24: Overhang mesh in colour shades shows angles in the chart.

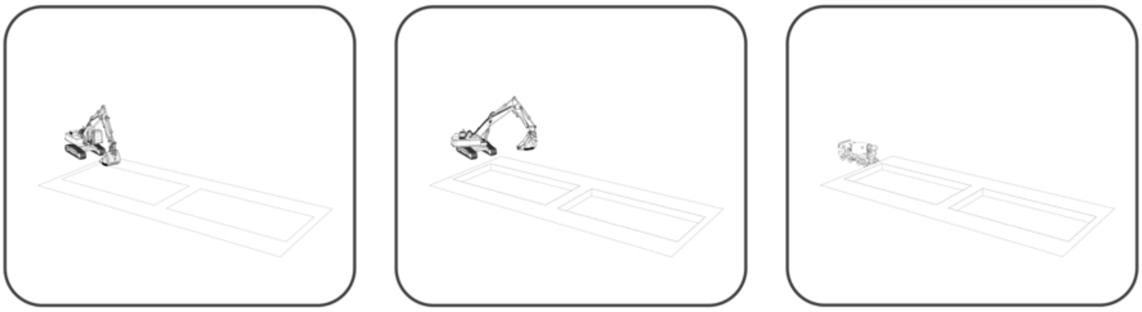
6 On-Site Construction

This chapter presents a detailed and comprehensive construction plan utilising the BOD2 3D construction printer developed by COBOD INTERNATIONAL. Through a series of diagrams and illustrations, the chapter provides a step-by-step explanation of the construction method, highlighting the intricacies of the manual construction process. Additionally, the chapter concludes with a comprehensive calculation of the total construction duration. By delving into the specifics of the construction process, this chapter offers a realistic and practical framework for implementing the BOD2 technology in construction projects.

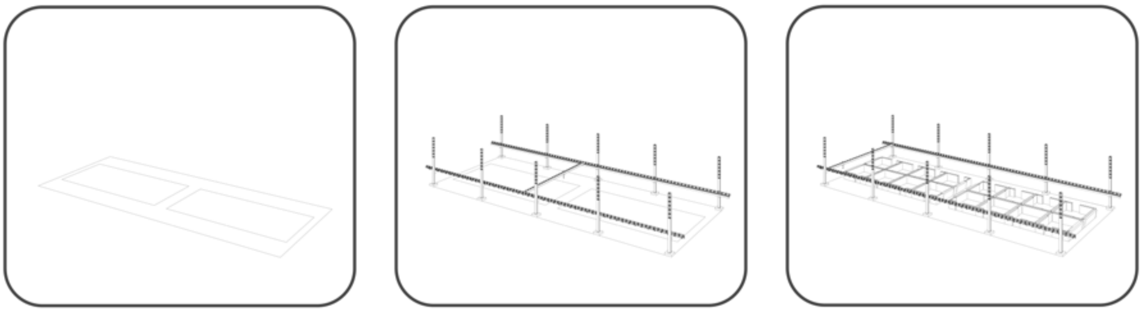
6.1 Steps of the On-Site Construction Method

The construction process begins with terrain preparation, involving the removal of earth to create a flat base for the project (see Figure 25a25b). Concrete bases are then created using concrete mixer trucks to ensure indoor living comfort (see Figure 25c25d). Once the bases are dry, the on-site assembly of the COBOD BOD2 printer can commence. The dimensions of the printer for this project are (W)14.6 m x (L) 34.3 m x (H)8.5 m, with a floor area of 501 m^2 [25]. The printing area's length can be extended as needed by incorporating additional cranes, allowing for flexibility [32].

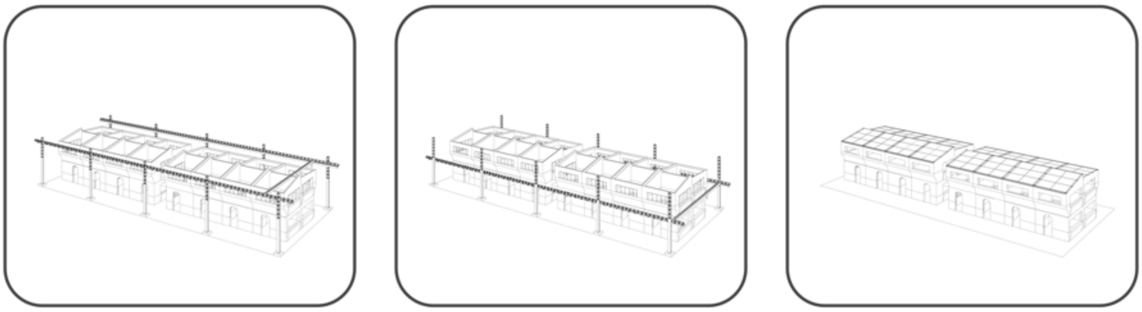
In this project, two blocks with an approximate area of 234.7 m^2 can be printed simultaneously within the maximum printing area. During the ground-floor printing process, the printer pauses to adapt windows and doors with support systems for the top layers (details see Figure 26b26c). Once the ground-floor printing is complete, the printers pause again to construct the ground-floor ceiling and the first-floor slab manually (see Figure 26e). The construction order for the first floor follows the same structure as the ground floor. After the printing process is finished, the printers are removed, and the ceilings and roofs are constructed manually (see Figure 25i26i). Figure 26 presents a comprehensive diagrams depiction of the construction method in steps, offering detailed information on each layer, including the support for windows and doors and the adaptation process for ceilings and roofs.



(a) Remove earth. **(b)** Finished removing. **(c)** Pour in concrete bases.

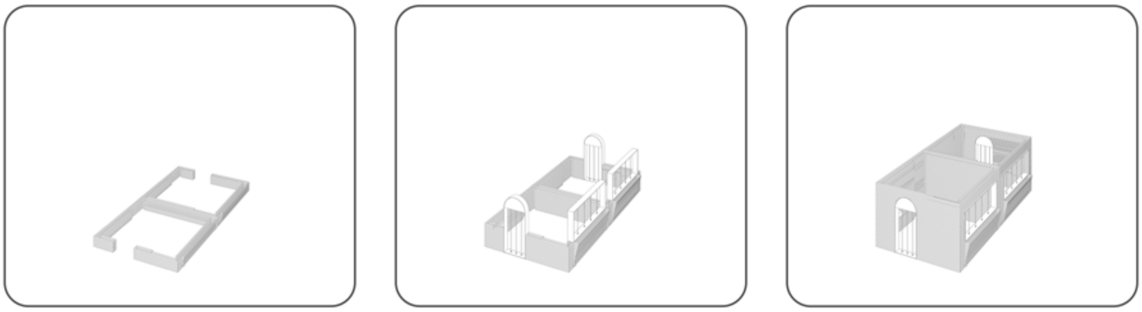


(d) Dried concrete bases. **(e)** Start to assemble BOD2. **(f)** Start to print the ground floor.

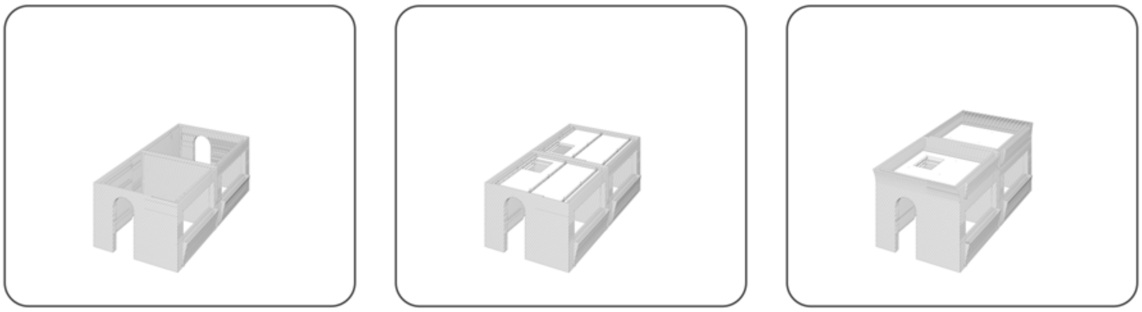


(g) Adapted the first floor slabs. **(h)** Finished the printing process. **(i)** Adapted the roofs.

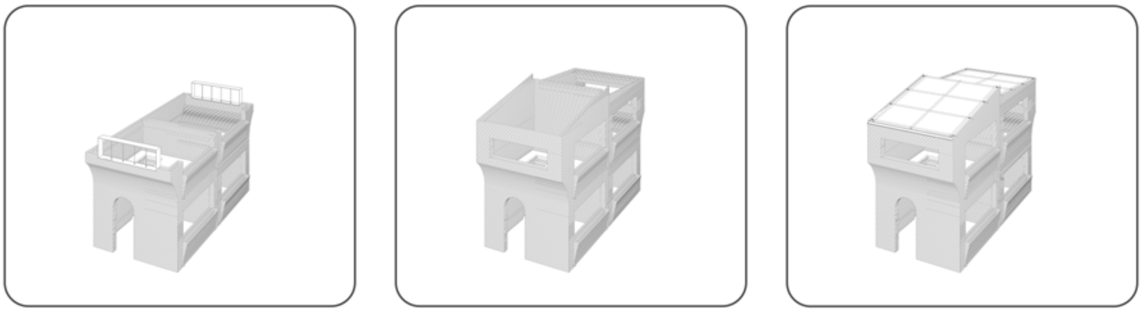
Figure 25: The construction process for the two-blocks involves utilising the COBOD BOD2 from the initial stage of terrain preparation, followed by on-site assembly of the BOD2 system and subsequent manual adjustments for ceilings and roofs.



(a) Ground floor printing. **(b)** Pause BOD2 to adapt supports. **(c)** Finished the ground floor printing.



(d) Remove the supports. **(e)** Adapt the ceilings and slabs manually. **(f)** First floor printing.



(g) Pause BOD2 to adapt supports. **(h)** Finished the first floor printing. **(i)** Adapt the ceilings and roofs manually.

Figure 26: The algorithm outlines the sequential construction order, using Units (a) and (d) as representative examples.

6.2 Construction Details

Regarding the ceilings and roofs adaptation manually, this section thoroughly explains the structural details. Figure 27 shows the ceiling details in an explosion drawing with joints and supports. A more detailed drawing is shown in Figure 28 as sections. The ceilings are supported by three layers of bamboo beams (Fig.28-F) attached with M20 threaded rods (Fig.28-G) and M12 threaded rods (Fig.28-H) as connected joints to the printed walls, with wood wool cement boards (WWCB)(Fig.28-D) as the indoor ceiling of the last visible indoor layer on top, designed as exposed ceilings, creating an aesthetic atmosphere for indoor areas. Above WWCB, M20 threaded rods are vertically attached to C-profile and L-profile steels (Fig.28-C) to support the first-floor slab - bamboo wool wood board (BWWB)(Fig.28-B), and at last, connected the steels are to BWWB with threaded rods with Q11 ST hex screws (Fig.28-A).

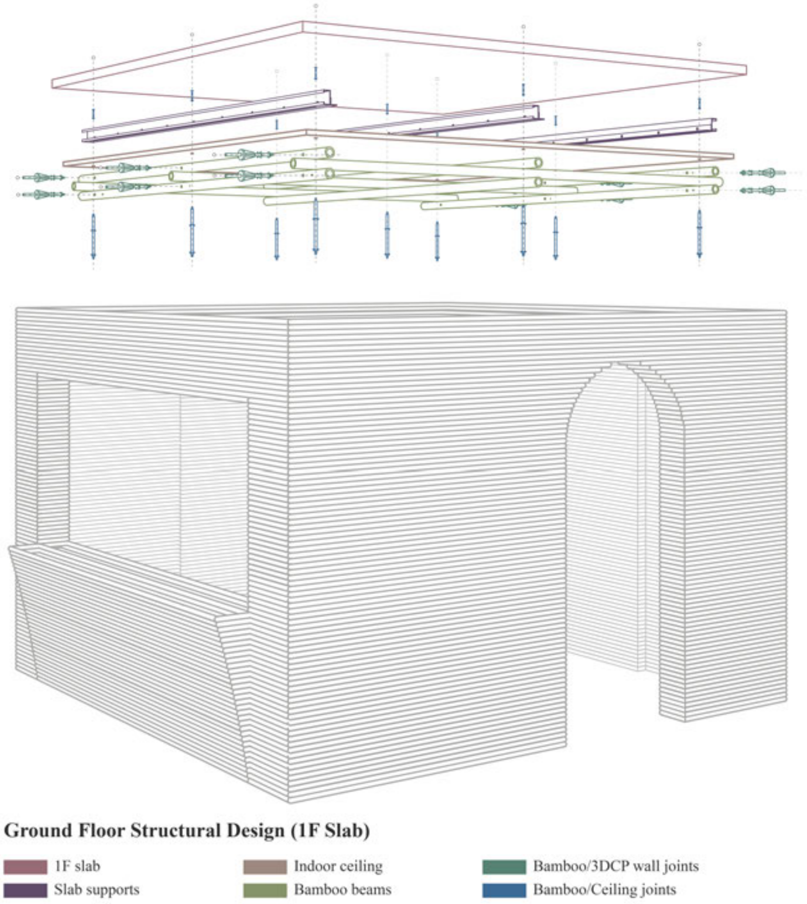


Figure 27: Ground-floor ceiling structural details in explosion drawing.

WWCB is chosen as the indoor ceilings for this project have not only created an aesthetic environment with the bamboo beams. WWCB is well-known for its porous structure on the wood wire cement board's surface, making it perform well in heat insulation, sound absorption and moisture regulation[33][34].

This section provides a comprehensive explanation of the manual adaptation process for ceilings and roofs. Figure 27 depicts the ceiling details through an explosion drawing, while Figure 28[6] offers more specific sections. The ceilings are supported by three layers of bamboo beams (Fig.28-F) connected to the printed walls using M20

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[6] Dimension unit in millimetre.

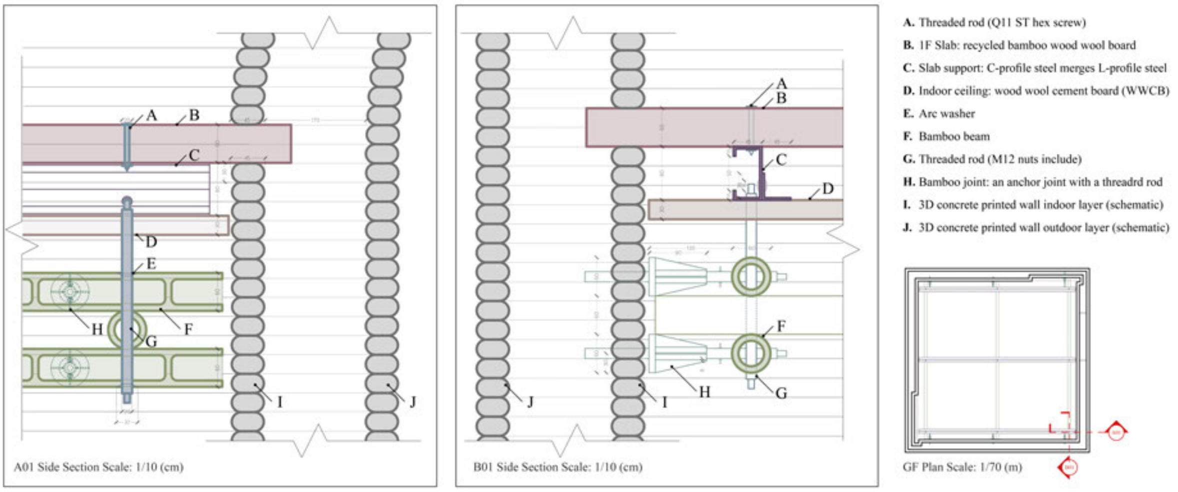

Figure 28: Ceiling Structural Details: A01 and B02

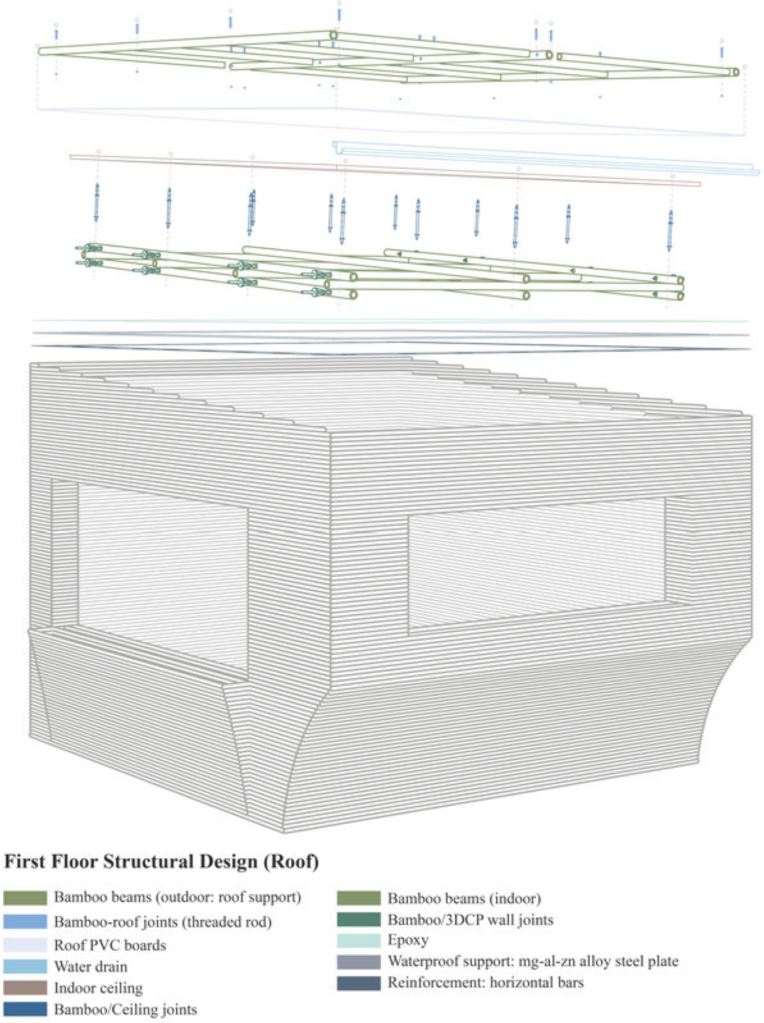

Figure 29: First-floor roof structural details in explosion drawing.

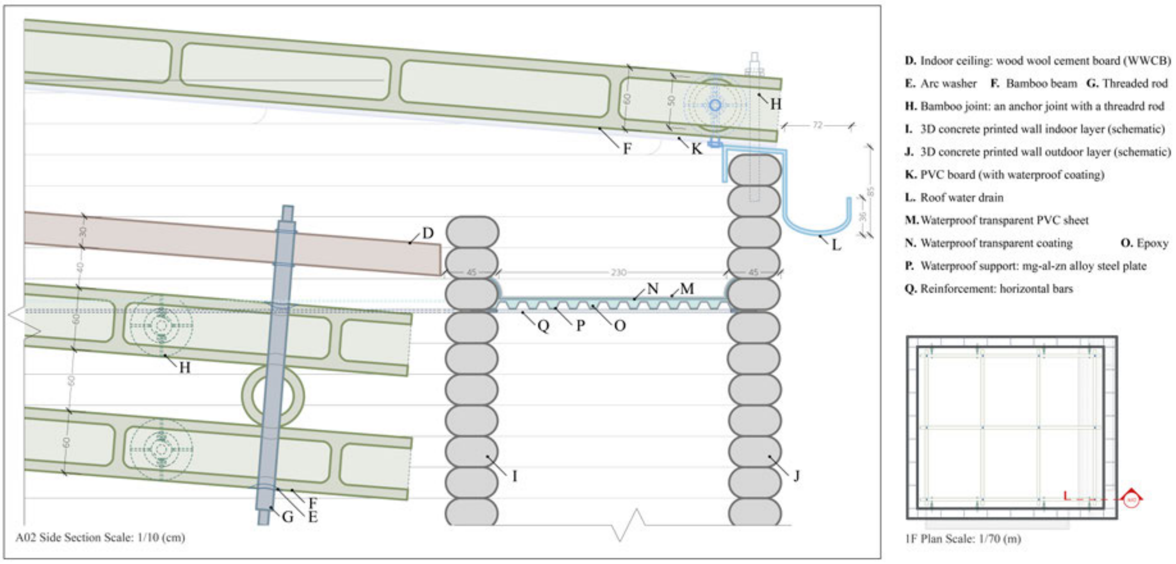

Figure 30: Roof Structural Details: A02

threaded rods (Fig.28-G) and M12 threaded rods (Fig.28-H). Wood wool cement boards (WWCB)(Fig.28-D) serve as the indoor ceiling, creating an exposed and aesthetically pleasing atmosphere.

The choice of WWCB for indoor ceilings contributes to the visual appeal and offers excellent heat insulation, sound absorption, and moisture regulation due to its porous structure. Figures 29 and 30[7] further illustrate the construction details for the first-floor ceiling and roof. The construction method remains consistent with Figures 27 and 28. However, additional waterproofing measures are applied above the WWCB since it serves as the outdoor roof layer.

Within the printer wall, a reinforced air chamber is formed layer by layer using horizontal bars, followed by the application of waterproofing materials. The layers include a layer of Magnesium Aluminum Zinc Alloy steel (Mg-al-zn alloy steel)(Fig.30-P), epoxy (Fig.30-O), a transparent coating (Fig.30-N), and PVC sheets (Fig.30-M). The PVC boards (Fig.30-K) with waterproof coating are then attached to the bamboo beams and the top layer of printed walls. To ensure proper drainage, a water drain (Fig.30-L) is incorporated between the top layer and bamboo beams at the roof's edge to channel rainwater effectively.

6.3 Total Duration of the Block Construction

The duration of printing for each unit is determined using GHD calculations, which involves slicing the unit into joined breps with a sliced height of 30 mm, corresponding to the maximum printing height of BOD2. The resulting sliced curves represent the path followed by BOD2 during the printing process. To calculate the total printing duration, the total length of the printing paths is divided by the printing speed of BOD2, which can reach a maximum of 1000 mm/s (1 meter/s) (see Table 1) [32]. The calculation of the printing duration can be expressed using the formula provided below (see Equation (1)).

$$\frac{5113.91\text{m}}{1\text{m/s}} \times \frac{1\text{h}}{3600\text{s}} = 1.42\text{h} \tag{1}$$

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[7] Dimension unit in millimetre.

The printing duration for a single unit amounts to around one and a half hours. However, it is essential to consider that the construction process involves intermittent pauses for the installation of window and door support, as well as the adaptation of ceilings and roofs. These pauses are necessary to ensure the integration and structural integrity of the printed units. Moreover, the manual construction of certain elements, specifically ceilings and roofs, contributes to the overall construction time.

The estimated total duration for the construction of eight units, forming a single block, is approximately 18.52 hours for the printing process alone, as calculated using the GHD procedure outlined in Equation (2). This estimation is based on slicing the block with *Contours*, summing up the total lengths, and deriving a result of 66,701.02 meters. The total printing hours are calculated based on this summed-up length. However, it is important to note that the manual construction time for elements such as ceilings and roofs should be considered separately, as it may add additional time to the overall construction process.

$$\frac{66701.02\text{m}}{1\text{m/s}} \times \frac{1\text{h}}{3600\text{s}} = 18.53\text{h} \tag{2}$$

When utilising a BOD2 printer with dimensions (W)14.6 m x (L) 34.3 m x (H)8.5 m and a floor area of 501 m^2, the printing capacity allows for the simultaneous printing of two blocks. This doubles the printing time required for the 3DP process. Based on this configuration, the estimated total printing time for two blocks is approximately 37.05 hours. It is important to note that this calculation solely considers the 3DP process and does not account for any additional time required for manual construction tasks or other factors.

In conclusion, based on the data presented in Table 1, the BOD2 printer requires 8 hours for setup and 4 hours for takedown, resulting in a total assembly time of 12 hours for one BOD2 printer on-site. In accordance with the hypothesis, the adaptation of one unit's ceilings and roof would take approximately 4 to 6 hours. Therefore, the manual adaptation of two blocks would require a maximum of 96 hours. Taking into account the printing time of 37 hours, the total construction duration for two blocks of units can be estimated as approximately 145 hours, equivalent to approximately six days or a week (see Equation 3).

$$12\text{h} + (6\text{h} \times 16) + 37\text{h} = 145\text{h} = 6\text{days} \approx 1\text{week} \tag{3}$$

7 Project Timeline

In this final chapter, the hypothesis of three distinct eras in the future is expounded upon, informing the construction plan that aligns with the specific requirements of each period. The chapter outlines not only the envisioned block building plans for these different eras but also explores alternative approaches and potential programs that should be considered as the on-site construction progresses from 30% to 50% and ultimately reaches 90% completion. By presenting a comprehensive description of each stage of construction, this chapter offers valuable insights into the adaptable and progressive nature of the project, ensuring its alignment with the evolving needs and objectives of each era.

7.1 From Turmoil to Triumph: Unveiling the Chronology

This project is predicated on the hypothesis of a potential hostile incursion from a neighbouring country. The primary objective of this refugee village extends beyond merely creating a temporary settlement for those in need but also takes into account a broader perspective encompassing various stages in the chronology. The people of Taiwan have endured a long-standing threat and prevailing tension, which has instilled the realisation that seeking refuge or relying solely on declarations of peace will eventually prove insufficient. It is imperative to contemplate the subsequent measures pertaining to self-protection and self-defence. Therefore, this project transcends the scope of a conventional refugee camp, incorporating a comprehensive plan that encompasses the pre-war, wartime, and post-war periods. It serves as a practical endeavour for Taiwanese society to be fully prepared for the potential conflict that lies ahead.

This chapter focuses on the sequential progression of the three distinct eras. The construction plan for the refugee village has been divided into three stages. Only 30% of the accommodation blocks will be built during the initial stage. When confronted with the first attack or at the onset of war, the construction plan will advance to encompass 50% of the accommodation area. Subsequently, the printing process will continue until reaching 70% to 90% of the total accommodation capacity. However, reaching 90% will only be pursued in response to significant demand. It is crucial to consider the subsequent phases of this project thoughtfully. Printing a large number of units may pose environmental concerns, as they may not align seamlessly with the overall plan. Thus, the subsequent sections will expound upon the three eras in order to comprehensively illustrate the proper implementation of this project.

7.1.1 Pre-War

The focus of this section is to address the hypothetical scenario in which Taiwan is in the pre-war period and preparing for an impending conflict. In this context, the project takes on a crucial role as the construction process commences, starting with a 30% allocation of construction on-site. The timeline presented in this thesis is based on this hypothetical scenario, considering the upper limit of users, the number of individuals in the nearby escape routes, the capacity of air-raid shelters, and the specific structures to be printed, all under the assumption that only 30% of the construction is completed (see Figure 18).

During this preparatory era, the constructed blocks can serve various functions, such as cultural and creative marketplaces, farmer's markets, and accommodations for locals and students. Additionally, they can potentially function as local emergency centres or shelters, aligning with the need for readiness in the face of possible wartime conditions. This multifunctional approach demonstrates the project's adaptability and preparedness for different scenarios, contributing to the overall resilience and security of the community.

7.1.2 Wartime

Upon reaching the midway point of the construction planning, approximately 720 individuals can be accommodated across the expansive 29094.8 m^2 park sites with 50% of printed blocks (see Figure 31). The primary focus at this stage is to provide a safe haven for individuals seeking protection, awaiting transit, or in need of evacuation. Notably, reputable organisations such as UNHCR report that in many instances, Taiwanese individuals opt to remain on the island rather than pursue evacuation, with evacuation being considered a measure of last resort[35].

During this construction phase, special consideration is given to the safety and well-being of vulnerable populations, particularly children. In times of conflict, children often face displacement due to repeated evacuations or the loss of their families [36]. Disturbingly, UNICEF highlights that since the onset of the war in Ukraine in March 2022, more than 4.3 million children have experienced displacement, surpassing the country's child population of 7.5 million [37]. Given these circumstances, prioritising children's protection and care becomes paramount, underscoring the need to create safe havens within the constructed facilities.

The design and utilisation of printed units are specifically tailored to provide a nurturing and child-friendly environment, promoting a sense of safety and normalcy amidst challenging circumstances. These units incorporate programs that address the psychological and emotional needs of children, facilitating their ability to process traumatic experiences, develop effective coping mechanisms, and rebuild a sense of stability and resilience. By integrating child-focused programs within the printed units, the project aims to adopt a holistic approach to meeting children's physical and mental health needs during times of conflict and displacement. The ultimate goal is to create an environment where children can thrive, grow, and regain a sense of normalcy, even in the face of adversity.

7.1.3 Post-War

In the aftermath of the war, a significant number of printed units may become abandoned and unused. As highlighted in sections 4.4 and 4.5, the recyclable materials derived from local resources can undergo various processing methods to be reused. The bamboo-based cement composite, for instance, can be reprinted or used in conjunction with traditional construction techniques to construct future buildings, ensuring sustainable material utilisation.

During this period, it was hypothesised that 90% of the blocks would be printed to accommodate the high demand before and during the war (see Figure 32). This would result in approximately 500 units of housing (without lavatories and kitchens) and around 1500 individuals in the park sites depicted in Figure 18. Although such a densely populated arrangement may be overcrowded for the limited space available, it is conceivable for future occupants to continue living in these units. Nevertheless, to enhance living comfort and adhere to Building Act regulations [29][28], the project may adopt new programs and prioritise material reuse to promote environmentally friendly practices.

Furthermore, the project is envisioned to have a second life beyond wartime. As previously mentioned, the units may not provide the same level of comfort as regular dormitories, given their emergency-oriented design. However, it is feasible to implement adaptations such as installing new doors, establishing interconnections between units, and creating larger indoor spaces to accommodate single or double occupants. These adjustments would serve to improve the functionality and livability of the units, facilitating their repurposing for a diverse range of future uses.

In the aftermath of the war, numerous printed units within the project may become abandoned and no longer in use. This scenario parallels the situation faced by military dependents' villages in Taiwan during the 1950s [38]. These villages were constructed by the KMT in response to the Chinese Civil War and the subsequent invasion of Taiwan, primarily between the years 1945 and 1949. However, these villages fell out of favour over time due to their inexpensive construction methods and temporary design styles[8]. An example of the preservation and repurposing of such villages is the Shi-Shi South Village, which was recognised as a historical heritage site in 2001[39]. Currently, four buildings from the original village have been preserved and incorporated into

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[8] The construction of military dependents' villages in Taiwan during the 1950s reflects the ambitious aspirations of the KMT to stage a comeback following their defeat in the Chinese Civil War. Consequently, these villages were built with cost-efficient and temporary designs. However, the envisioned fairy tale ending, where the KMT would successfully reclaim power, never materialised. Ironically, in the present day, the KMT has developed a more cordial relationship with the CCP, marking a significant shift from the revolutionary fervour and determination espoused by Sun Yat-sen and the aftermath of the Chinese Civil War several decades ago.

the Cultural and Educational Zones. The open spaces within the village often serve as venues for events and performances. Situated at the heart of Taipei City, across from the renowned Taipei 101 skyscraper, the village's low-rise structures, with their retro design, have attracted numerous tourists and locals.

Drawing inspiration from such examples, the thesis project in Hualien City holds the potential to forge a similar future akin to the transformation of the Shi-Shi South Village. While emphasising the importance of material recyclability, the preserved units can be further developed to encompass entertainment-oriented functions. By repurposing the spaces to offer engaging and culturally significant experiences, the project can enhance its appeal and contribute to the local community's cultural and tourism landscape. This approach aligns with the broader goal of preserving historical heritage while simultaneously revitalising abandoned structures for contemporary and future purposes.

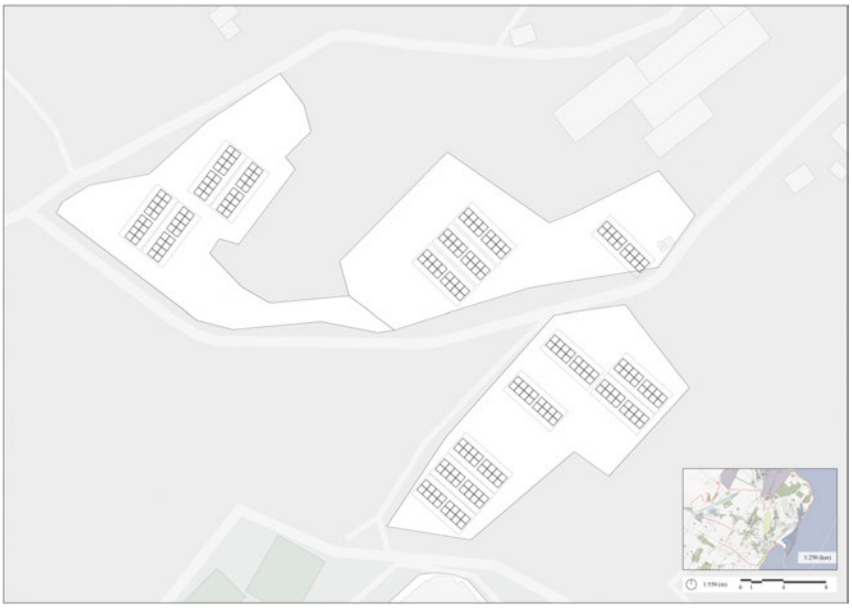

Figure 31: The plan showcases the implementation of 50% of constructed units on site.

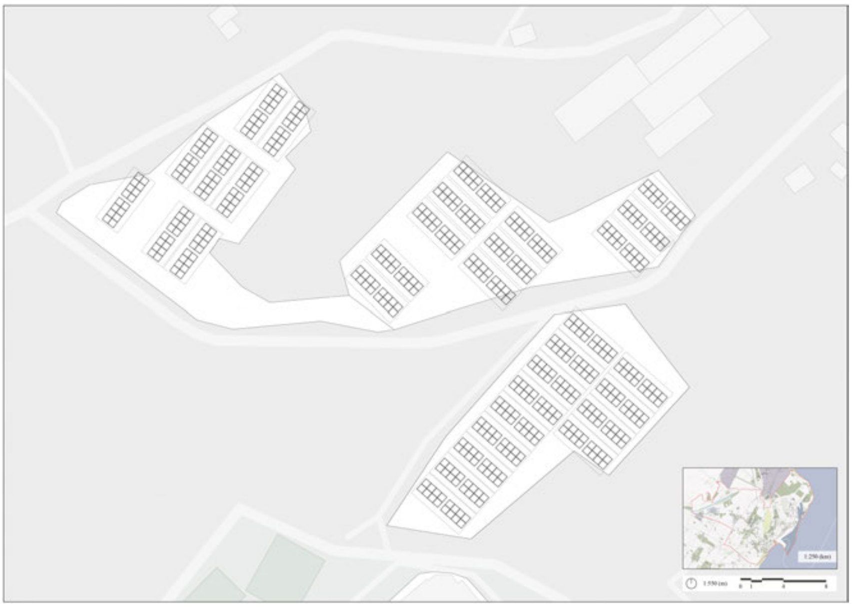

Figure 32: The plan showcases the implementation of 90% of constructed units on site.

7.2 Concluding Remarks

In conclusion, the modular design and adaptable nature of the minimum comfort units make them suitable for various programs, particularly in both pre-war and post-war contexts. The future development of these units will depend on the prevailing circumstances faced by the Taiwanese population, which directly impacts the required quantity of printed units. The Shi-Shi South Village represents just one example among the 879 military dependents' villages in Taiwan. This case study highlights the limited functionality of its temporary structure, rendering it primarily of historical significance. Unlike the Shi-Shi South Village, the refugee villages in this project offer more significant potential for reusability in different scenarios. These villages can serve as valuable assets, capable of addressing diverse needs and providing practical solutions during periods of instability and displacement.

In Section 7.1.2, it is crucial to recognize that millions of children have endured displacement during times of war. Innocent individuals often bear the brunt of the consequences resulting from political decisions. The plight of refugees who have lost their homes due to the chaos of war has served as the driving force behind the initial concept of rapid on-site construction in this project.

The design of these villages takes a pluralistic approach, aiming to fulfil basic physiological needs such as lavatories, canteens, and bedrooms. However, as discussed in the previous paragraphs and sections of 7.1, the programs within these villages have the potential to expand and diversify in response to changing eras. This adaptability opens doors to future programs that specifically focus on supporting and assisting vulnerable groups, particularly children and women who have experienced displacement and hardships caused by conflicts. These programs can provide essential services such as educational support, healthcare facilities, and counselling centres to uplift and empower those affected by war.

Furthermore, as these units continue to evolve and serve the needs of the community, they can also play a significant role in preserving the spirit of Taiwan's independence and honouring those who support this idea. With careful consideration and planning, these future units can be repurposed and retained as memorials and historical sites, symbolizing the resilience and determination of the Taiwanese people in the face of adversity. This dual functionality, both as practical spaces for community support and as a testament to Taiwan's struggle for independence, adds depth and meaning to the ongoing development of these villages, ensuring their lasting impact and legacy.

Conclusion

In conclusion, this study underscores the urgent need for the Taiwanese population to proactively prepare for plans and programs similar to the project discussed herein, demonstrating caution and readiness for potential conflicts. The existing built blocks serve as practical examples of rapid on-site construction, providing valuable insights into the challenges that may arise and the duration of manual construction. Considering the potential constraints in terms of time and resources, it is imperative to initiate construction preparations and secure necessary materials as early as possible, with immediate action being even more advantageous.

In addition to the 3D printing techniques examined in this thesis, alternative construction methods, such as using pure bamboo or traditional concrete, are viable options for this project. However, it is crucial to carefully consider the drawbacks associated with traditional concrete, including the generation of unsustainable and non-recyclable waste due to the need for moulds. Moreover, without the utilisation of 3D printers, the construction process would rely heavily on manual labour, which is not ideal when working within narrow timeframes.

The research phase of this study placed significant emphasis on the selection and implementation of the BOD2 3D Construction Printer developed by COBOD INTERNATIONAL. The versatility of this technology demonstrated its effectiveness and efficiency for the housing project, including its ability to print different types of mortar, adapt to various nozzle configurations, and incorporate smoothening features. The modular design and adaptability of the minimum comfort units proved to be suitable for a wide range of programs, enabling the accommodation of different scenarios and addressing the evolving needs of the Taiwanese population. By combining earthquake-resistant design principles with 3D construction printing, a viable solution was developed to tackle the seismic challenges prevalent in Hualien City, ensuring the safety and long-term durability of the constructed buildings.

Furthermore, it is essential to highlight the critical importance of preparedness for possible future wars and the significance of safeguarding the spirit of Taiwan's independence and those who support this ideal. While the existing built blocks offer practical experience in rapid on-site construction, it is crucial to acknowledge that manual construction may take longer than initially anticipated. Therefore, in light of potential constraints related to wartime fabrication under limited time and resource availability, commencing construction preparations and material sourcing as early as possible becomes even more critical and advantageous.

This thesis has explored the potential of 3D construction printing, focusing on its application in this project context in Hualien City, Taiwan. The findings underscore the significance of preparing for future scenarios, embracing innovative construction methods, and preserving the historical and cultural heritage of the region. Sustainable and efficient housing solutions can be achieved by considering 3D printing techniques with large-scale on-site printers. This interdisciplinary research opens up opportunities for further advancements in technology, materials, and design strategies. Architects, engineers, and policymakers can leverage these findings to inform future housing development projects, particularly in areas prone to seismic activity and those grappling with post-war challenges.

In conclusion, this thesis urges the Taiwanese population to embrace the transformative potential of 3D construction printing and take proactive measures to address societal challenges. By integrating principles of resilience, sustainability, and inclusivity, this approach can shape a more sustainable and adaptable built environment, supporting the well-being and aspirations of the community at large.

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