Mass Customization in Mass Housing

How to design a high-rise apartment through mass customization?

Explanatory Document

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Preface

Time flies. This research project has come to an end. I am glad to have been able to develop my research question this far which I did not expect in the first place, even though I know there is much more work to do. How to design a high-rise apartment through mass customization is a meaningful question to the people who live in a metropolis, where the high price of dwellings makes living in an apartment a compromised solution.

The development of this research project did not progress evenly. For quite a long time I was wandering left and right in my research and could not find the breakthrough point. Research is painful yet gainful because when you overcome an obstacle, you overcome your disadvantage.

This research has mainly explored the first step in customizing an apartment, the space. There still left many other options which could be customized. So far, I have not seen anyone who has done work like mine, as for architecture, this (mass customization) is still a fresh topic. I hope this explanatory document will benefit other students who would follow this topic.

Through this research project, I have learned the method of how to research on a new question, and this method will significantly benefit my future career. I sincerely thank my tutor, teachers, and the architecture school of Unitec.
Abstract

Mass production is an important factor of modern industry, which provides adequate quality products, such as machinery, with affordable prices. In the 20th century, especially after World War II, modernist architects put their efforts into solving the housing shortage. Mass housing was practised and developed in many countries, using prefabricated panels and modules.

However, most of those practices proceeded in low-rise residences such as houses. As per high-rise residences, standard products still dominate the market. In the city centre where the high-rise residence is the major typology, there is a conflict between construction efficiency and personalised needs.

Mass customization (MC) aims to offer personalized products massively, without losing the efficiency of mass production. As a business paradigm, mass customization has emerged in the past two decades, but, for the housing industry, it is still a new field. Some research has been done by scholars and architects, such as the book *Mass Customisation and Personalisation in Architecture and Construction*, but the research field has progressed slowly. There have been many precedents about the customization of houses since the 1920s, such as Baukasten, and Copper houses by Gropius. And, there were a few high-rise residences related to my research such as the “capsule tower” by Kurokawa. However, these precedents either have too few variations for users or did not involve users in the design process; in other words, the dwellings were not customized by users.

Through a case study of online customized consumer products such as BMW cars, and a literature review of the principles of modularized
products, this research has explored the possible ways of mass customization in high-rise apartments, and has developed some concepts such as MC Boundary and Free Space to support the final design project.

At the same time, this research has explored solutions to technical problems caused by mass customization and finally placed the experimental building on a real site in the city centre to examine whether it could comply with urban planning regulations.

With respect to limitations, this research does not contribute to the adaptability of the dwellings during their whole life span. Because replacing or rearranging parts of a dwelling is unaffordable for most individuals, so it would be much more possible and efficient to customize a dwelling before construction. Moreover, it does not include how to manufacture or deliver the modules and elements of MC housing.
CONTENT

PART ONE (Research) ........................................... 8
  1. Introduction .................................................. 9
  1.1 The Contradiction .......................................... 9
  1.2 Background .................................................. 10
  1.3 Research Question ........................................ 15
  1.4 Project Outline .............................................. 15
  2. Scope and Limitations ....................................... 16
  3. State of Knowledge .......................................... 18
  3.1 Mass Customization ........................................ 18
  3.2 Precedents .................................................... 19
  3.3 Sphere of Control .......................................... 24
  3.4 Modularized Product ....................................... 25
  3.5 Container Building ........................................ 28
  3.6 Considerations .............................................. 30
  4. Research Methods ........................................... 30
  5. Results of the Research ...................................... 34

PART TWO (Design) ............................................. 36
  6. Research Process ............................................. 37
  6.1 Pre-design Study ............................................ 37
    6.1.1 The test site and existing building ............ 37
    6.1.2 High-rise apartments in Auckland ............ 41
    6.1.3 Building regulations ............................... 44
  6.2 A Failure Example .......................................... 52
  6.3 Principles of MC Design ................................... 54
    6.3.1 Learning from urban planning ............... 54
    6.3.2 The grid system of modules .................... 61
6.3.3 Product Family ........................................ 63
6.3.4 MC Units (Template and Module) ... 66
6.3.5 Combinations ........................................ 71
6.4 Experiment and Test ................................... 73
   6.4.1 Product Family test ............................... 73
   6.4.2 Floor plan design ................................. 75
   6.4.3 Engineering challenges ......................... 78
   6.4.4 Façade design experiment ...................... 83

PART THREE (Result) ........................................... 91

7. Design Outcomes and Evaluation ........................... 92
8. Conclusion and Perspective ................................ 109
9. Bibliography .................................................. 111
10. Illustrations .................................................... 115
11. Appendix ....................................................... 120
   11.1 Case study of apartments in Auckland ...... 120
PART ONE (Research)
1. Introduction

1.1 The Contradiction

Through human history, in any era, the dwelling is the most expensive personal property, and it is immovable, long-running and complex. For many people, a dwelling is not just a product or a living machine, it is also a dream, a sanctuary of beloved and a symbol of success.

High-rise apartments were born for mass housing with the development of the typical floor plan. The repeatable floor plan contributes to industrial construction, which indeed accelerates urbanization. A typical plan has an obvious disadvantage because it limits the variations of layout and façade design. The customer may compromise this within a period of house shortage, but in a saturated market, “as the market became more saturated the demand for differentiation increased”. Unfortunately, personalization decreases the efficiency of mass production and consequently increases the dwelling price.

So, here comes the contradiction: on one hand, we need mass production to reduce the cost of dwellings, but, on the other hand, people prefer their homes to be more personalized.

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Given those facts, mass customization might be a workable solution for this contradiction, especially under the fast development of information technology and prefabrication.

1.2 Background

After two industrial revolutions, mass production has hugely increased productivity in the world. Through making standard products with machines, this is the first time in human history that people can produce more than they need.

Mass production was applied in the housing industry as well but ended differently. In the twentieth century, modern mass housing is a world-famous scheme. Part of the reason was the huge demand for dwellings after the war. In about 1950, William and Alfred Levitt were running a successful business of mass-producing houses by assembly-line in a factory. The Levitts divided the process of construction into 26 steps, which finally produced a house every 15 minutes. Later on, in many countries like East Germany, the United States, and China, modernist architects developed their own ways of the mass housing to solve the urgent house demand.

Corbusier states that “a house is a machine for living in”. To massively produce these “machines”, traditional construction methods and architectural design are no longer suitable. Modernist architects then developed their own language, like “form follows function” and “less is

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more”. Mass housing became global and new modern buildings were erected everywhere with industrialised façades.

The post-modernist architects were against the extreme simplicity of international style which was the dominant style for mass housing. However, many people prefer an image of a beautiful city: “compact block perimeter buildings with no more than five stories and facades that reflected pre-modernist European design and local traditions”,⁴ which describe the real needs of personality.

Although mass housing has developed for decades, customization is not always an option for customers. For products like cars or clothes, manufacturers could massively produce them in different colours and sizes to suit people’s personal preferences, so people are actually choosing what they want instead of being offered the products made to their individual requirements. This principle works well in the industries of cars, electronics and clothes in modern society, but it progresses very slowly in housing production. The reason may due to the characteristics of housing.

Firstly, a house is huge compared with most products, which means producing a house in the factory and transporting it to the site is not an easy job.

Secondly, a house is so expensive that many working-class people may afford one or two houses at most in their whole lives, so it is

impossible to have many alternatives for house owners.

Nonetheless, factory-made single houses have been widely accepted, and the industry developed well through the assembly-line approach (Figure 1). There are already many companies contributing factory-made houses, such as the Toyota Housing Corporation (Figure 2) which have commercialized factory-made houses since 2004. However, there is no high-rise apartment produced in a factory.
Thirdly, even though a house has a simpler structure than a car, the site on which to place a house is much more complex than the road on which to run a car (Figure 4). For example, in different countries and different zones, there are diverse regulations and limitations for a house, such as height control, sunlight control, FAR (Floor Area Ratio) requirement, outdoor living space need, outlook space requirement, circulation and exit requirement, etc.

As a matter of fact, you can hardly create a one-fits-all solution for the housing industry. Fortunately, through online interactive design (Figure 3), designers can communicate with many users simultaneously now. So, it becomes possible to collect hundreds of users' personal demands in a short time.
Figure 4  Differences between the building industry and the motor industries (Source: Thillart and Merkelbach, Payman, Customised Industrialisation in the Residential Sector, 14.)
1.3 Research Question

Since my research project is about customization in mass housing, and there already are predecessors who are doing mass production and customization of single houses, why not try to research customization in a high-rise residence which is a born massive habitat.

My research question is how to design a high-rise apartment through mass customization?

1.4 Project Outline

This project is going to be a high-rise apartment building located in Auckland Central, which will provide users with the possibilities of customizing their new home in terms of size and layout from the design stage.
2. **Scope and Limitations**

Around the world, the housing situation varies between different countries significantly. In New Zealand and Australia, the dominant housing is detached dwellings. In European cities, most people live in terraced houses, while in Asian cities such as China, Singapore, and Korea, the mainstream of housing is the high-rise apartment.

In terms of customization of the apartment, there are many aspects to customize such as according to climate, cultural values, demographics of the residents, and commercial activity. However, this project has not contributed to those aspects. **Instead, it has explored the method of customizing the size of spaces, and how to assemble those spaces in various ways (layout),** because space is essential to architecture, if the sizes of spaces cannot be customized, then the variations will be very limited.

There has been lots of research and development of houses in the fields of mass customization, prefabrication and assemblies, and modularized panel systems. **However, they rarely studied the field of high-rise residence solutions and how to customize the size and layout of spaces.** For the buyers, choosing the right size and special layout is the first step when they are planning to purchase an apartment. Much

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personal information could be reckoned by the sizes they choose, such as family members and their financial situation.

This research project aims to reveal the method of customizing high-rise apartment units, in order to solve the first step of mass customization. This project has developed a sample product family and applied it to the site. Nonetheless, it also explored possibilities of façade design.

In terms of limitations, due to the fact that real estate development is a cooperative work by investors, contractors, architects, engineers, marketing agents, and customers, it is impossible to provide a one-fits-all solution. So, the final result of the mass customized apartment will vary from case to case.

Even though this study has addressed some concepts like Free Space, MC Boundary (Figure 49) and External Shaft (Figure 75) which are essential key points that can be applied in any project, this research is mainly addressing the question of customizing dwellings before they are built, so it does not contribute to the adaptability of the dwellings over their life span. Moreover, this research does not include how to manufacture or deliver the modules of MC housing.
3. State of Knowledge

3.1 Mass Customization

“The goal of mass customization is to provide customers with what they want without losing the efficiency of mass production. However, to apply this apparently simple statement in practice is quite complex”

Mass customization (MC) is a business paradigm announced originally by Davis and Pine in the 1990s. It is the middle stage between mass production and individual customization according to the long-tail concept (Figure 5).

In the mass production stage when Corbusier stated that a house is a machine for living in, standard products (typical plan) were provided to most customers. However, households have never stopped personalizing their homes, and even in a rented house, people plan to make their own mark.

Frank Gehry’s practice reveals a new era of personalization. The upgrading for customization in the residential industry is on the way.

In the modern competition, “particularly in global competition, the customer has numerous alternatives to choose from. There is great

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6 Poorang A.E and T. Piller, Mass Customisation, 17.
7 Kaj A. Joergensen et al., "Customization Issues: A Four-Level Customization Model," Lecture Notes in Production Engineering Proceedings of the 7th World Conference on

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pressure on companies to offer tailored applications at the same price as standard products". Sales pressure will push the manufacturers to provide customized products for their customers.

3.2 Precedents

The adaptable house is a long-standing topic of architectural design, and it was practiced in many ways either by forms or by techniques. Avi Friedman gives adaptability a definition: “providing occupants with forms and means that facilitate a fit between their space needs and the constraints of their homes either before or after occupancy”.  

Adaptable housing has a similar goal with mass customization, they both manage to provide personalized dwellings to satisfy people’s needs. But, mass customization is about how to realize this goal before construction; on the

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9 Friedman, The adaptable house, 1.

Successful from the Average? (Turku, Finland: Benchmarking, 2013), 7.
contrary, adaptable housing is about what variations the users will have after construction.

There are many precedents of adaptable housing. One type is trying to create multi-functions or changeable spaces through moving walls or fit-out.

In 1924, Gerrit Rietveld applied a mountable and movable interior panel wall system in the Schröder House, which defines the space as a living room at the daytime then as sleeping spaces at night (Figure 6). However, regularly moving these panels troubles the occupiers, and a movable wall panel usually has poor acoustic insulation due to the tiny gaps between components.

Some predecessors tried to provide tremendous variations to users in one building to fulfill their personalized needs.

In the 1940s, Le Corbusier provided more than three hundred apartment units with dozens of layouts in Unité d'habitation (Figure 7). Then in 1967, Safdie materialized his idea of the modularized habitat by Habitat '67 which transferred 365 modules into a high-rise apartment comprised of 158 units (Figure 8).
Figure 6 Floorplans of Schröder House

Figure 7 Unit floorplan of Unité d'habitation
These two precedents both adopted a simple rectangle as the basic shape of the unit, and they provided many variations. However, neither of them had occupants involved in the unit design initially, so these variations were actually assumed by architects themselves and other consultants.

The last precedent that I want to introduce is the capsule tower in Japan (Figure 9), designed by Kisho Kurokawa in 1972. As a representative of the Metabolism movement, this project did not function well and was once faced with demolition. This project is actually a very good model for mass customization, because it adopted replaceable modularized units which have the potential to be customized according to the user’s personal preference.

Unfortunately, this project only had standard units with limited variations, and those units could not make combinations with each other to accommodate a large household. No wonder this building had only 20 fulltime occupiers, and it is
considered as a temporary accommodation by people.\textsuperscript{10}

The units of the capsule tower were designed to be able to be replaced every 25 years, which would have kept the apartments well maintained and upgraded along time, and this concept is essential to the Metabolism movement. However, 45 years have passed, and none of the units has been replaced due to the high cost. So, this unique precedent suggests to us that in a high-rise apartment building, supposing that property owners would replace their units is unrealistic due to the unaffordable cost unless there are efficient and economic methods adopted.

\textsuperscript{10} “Nakagin: 140 plug n’ play capsules float in metabolist tower”, You Tube video, posted by Kirsten Dirksen on August 9, 2015, https://www.youtube.com/watch?v=sXRJE2caPNY.
3.3 Sphere of Control

“Customers’ latent wishes and dreams can be expressed in house building in three main areas: the exterior shape of the dwelling, its layout and the level of services it contains”.

For high-rise apartments, individuals cannot decide the shape, because the appearance of the buildings are under assessment of the government in order to maintain a harmonious urban view.

To customize collective housing, first, we need to identify the zone of customization; in other words, we need to distinguish between the common and individual spheres of control. The interior layout apparently belongs to the individual sphere, and this is the field where customization occurs. The common stairway and structure belong to the common sphere, but the façade will be affected by both individuals and the public, so I add a hybrid sphere to categorize façade (Figure 10).


3.4 Modularized Product

Manufacturers have realized that the way of achieving mass customization is to modularize the product, then the customers could choose variations to satisfy their needs.

“The goals of modularizing products are to achieve the following: A wide range of products with the smallest possible number of modules. The ability to meet customer requirements quickly and cost-effectively”.

Other industries have taken the lead, such as BMW, TOYOTA, Nike, and even Domino’s Pizza.

These mass consumer products have implemented the online customization system.

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Customers just need to visit the website and follow the instructions, then the customization will be done.

Taking BMW and TOYOTA cars as examples, first, customers will choose which series they would like. Then they will determine secondary options, and next, they will be provided with various templates which could customize tires, navigation systems, heated seats, moonroof and LED light etc. Finally, they can choose elements such as exterior color, tow bar, or weather shields etc.

Nike has a similar process of customization. Firstly, the buyers will choose the series in terms of running shoe, basketball shoe or football shoe etc. Then, they need to make a further decision about which style they prefer. And finally, they could customize the exterior color, the personal word-logo, the lace style, and other elements of shoes.

Generally, they obey the following five steps:

1) **Series**: the significantly distinctive products.
2) **Styles**: the major distinguishing types of a particular series.
3) **Templates**: the recommended structures of organizing modules.
4) **Modules**: the basic functional units.
5) **Elements**: the parts of the modules.

In this project, steps 1 and 2 are combined.
Figure 11 MC of BMW car (www.bmwusa.com)

Figure 12 MC of TOYOTA car (www.toyota.co.nz)

Figure 13 MC of Nike shoe (www.nike.com)
3.5 Container Building

This skyscraper is a competition winning proposal, which is a 100 metres high-rise. Every eight stories, there is a platform on which self-supported containers are placed.

Actually, I found this typology after having had the scheme for my project. Nonetheless, this case’s floor plan (Figure 15) is indeed a valuable reference which accords with my proposal (Figure 70) in several aspects.

First, this project is a high-rise residence which adopts a linear structure to organise the household units as well.

Second, each household comprises three units which are also rectangular in shape and linked with each other by only one pathway (the red dash). This is what I claim to be necessary: having the very least joins (Figure 69) to connect
each module, so as to provide more flexibility to customization.

Third, each household (called Templates in my research) is separated by a void space which provides more possibility of ventilation and daylight.

Fourth, kitchens and toilets are located adjacent to vertical ducts which provide exhaust, drainage, water supply, and electricity. And, the ducts are out of the plan of the units, which prevents the ducts from interrupting interior space.

This project has successfully demonstrated a workable solution for organising rectangular units in a high-rise residential building. However, this skyscraper proposal does not explore the possibility of mass customization. The units which have mostly standard layout are still designed without interactions from the future users.
The practice of high-rise residential buildings has obtained the abilities to implement mass customization, and the examples from other industries have shown practical directions and processes to realize mass customization. Given that, designing a high-rise apartment through mass customization is doable.

However, a car or a pair of shoes just serve a single customer, but an apartment building serves a group of customers so that we cannot simply copy from other industries without considering the unique characteristics of apartment buildings.

4. Research Methods
Mass customization is a paradigm which emerged two decades ago in the industrial market. So, this is a cross-disciplinary study. Actually, I met with a dilemma at the beginning due to numerous information and professional terms.

I started to research by studying adaptable housing which is more tangible, but it contributed little to my research because mass customization is still quite new for architects, so the previous study had not much reference. The breakthrough took place when I studied the cases of online ordering of BMW cars and other brands. **So, one research method is the case study of mass customized consumer products.**

To study these cases, I played the role of a customer to operate these online customization systems, and download images from the websites. Then I summarised the common points of those examples and compared their features to summarise a systematic process.

**The second research method is a case study of high-rise apartment products in Auckland.**

Because this research project aims to improve the efficiency of apartment design without losing the quality of the current design, an adequate understanding of the existing apartment buildings in Auckland is essential. This case study will summarise the key types of the household, the basic structures of various units, and the ways of how to deal with the conflicts between the built environment and buildings.

To approach this goal, the first step is to set up a database of cases. This study will collect around 40 cases (Figure 27) of household units through real estate websites and the Unitary Plan to
obtain a general idea about the current situation of the apartment market in Auckland.

The total collection contains around 15 one-bedroom units and studio units, 20 two-bedroom units and 5 three-bedroom units.

Each sample has one or two pages of information (Figure 17) which include address, unit floor plan, area, building façade, interior views, and building size.

Collecting and studying of these cases, it will enable the design of practical units plans which would eventually become the standard templates of mass customization.

The third method is the literature study. The most directly related book I found is *Mass Customisation and Personalisation in Architecture and Construction*. There are not many publications about MC in architecture, just as the author said that “there has been no dedicated publication focusing on the topic of mass customization in the built environment. Our
book is a first start to provide a platform for a more focused discussion of its kind”.

Other related literature includes adaptable houses, prefabricated dwellings, mass customization, building codes, and high-rise apartment design. This literature gave me the clues for addressing my research question.

The fourth research method is experimental design. Due to the fact that my research question is about residence and customization, it is very important to develop adequate samples of apartments to visualize thinking and test new ideas.

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5. Results of the Research

For a buyer to customize an apartment, the first thing is to determine the size of the dwelling because usually, the buyers have not many ideas about what kind of dwelling they actually want until they see the plans. But, there is one thing they already know, that is the size. And most of the time, the size will determine the total price of a property. So, the first step of customization is to let buyers choose the size of their home (similar of what they do when they are buying a car).

For architects, size means the amount of space. So, it is essential to provide buyers the possibilities of changing spaces of the apartment.

The previous design methods, such as adaptable housing, provided plenty of variations such as an adaptable layout, selectable façade, and changeable fit-out. However, they did not jump out of the circle that all these variations have to be within the boundary of the building’s external walls. If you do not change the external boundary, you cannot provide many variations of spaces, the total variations will be too few to be called mass customization. No wonder those predecessors ended up either just adopting modularized elements such as wall panels or kitchen cabinets etc., or just providing couples of whole house options to customers.

With respect to customizing spaces of an apartment, this research has realized the research question within the scope and limitation of the research project. It has successfully developed concepts such as MC Boundary and Free Space, and principles of planning the MC Units. So, the final design
provides a workable typology solution for mass customization in a high-rise apartment.
PART TWO (Design)
6. Research Process

6.1 Pre-design Study

6.1.1 The test site and existing building

I started from exploring the city in which there are high-rise apartments, and I found several candidates (Figure 20 to Figure 23) which follow the criterion that the site needs to be reasonably small because my project is a typology study of a single building.

These candidates are located in different contexts, some are very close to adjacent buildings, some have no neighbouring buildings around. Finally, I chose 23 Anzac Avenue as my test site due to its suitable size, its level difference, and irregular shape, which give more complexity.

Figure 20 82 Wakefield Street, Auckland Central
Figure 21 34 Kingston Street Auckland Central.

Figure 22 18 Gore Street Auckland Central.
This site is located in the central Auckland zone, and close to the harbour. According to the Auckland Unitary Plan, this site belongs to the City Centre Zone in which the maximum height of buildings will be less than 50m.
Here, the existing building was finished last year. It comprises two towers connected by several sky bridges every four or five floors. Each of the towers is located on different levels (about 10 metres different). One of the towers faces to the west, the other faces to the east, but there is a dark and narrow channel between the two towers, and this channel is the main orientation of less than half of the total rooms (Figure 26). Each tower comprises of three (left tower) or five (right tower) units which are mostly two-bedroom households.

I was thinking about the plan, and I asked myself why did not the architect orientate the habitable spaces to the north which has the most access to sunlight. If you look at the elevations of the building carefully, you will find that there is no window on the northern side external wall.

Figure 25 The section of towers
6.1.2 High-rise apartments in Auckland

I have collected more than 40 cases of high-rise apartments (Figure 27) in Auckland central, which give me a database. Categorizing these cases, I found the majority of apartment units are one-bedroom units and two-bedroom units. Three-bedroom is rare but will appear in high-end projects.

Figure 26 9-16 floor plan of 23 Anzac Ave (source: Auckland Council)

Figure 27 Apartment case study of Auckland central (source: www.realestate.co.nz)
In many cases (one-bedroom), it is common for a bedroom to get ventilation and daylight from windows or doors opened to the living room (Figure 28).

For a two-bedroom unit, in many cases, architects open a high window on the external wall which is adjacent to the corridor (Figure 29). So that the second sleeping space could get ventilation from the open corridor, and the whole unit can achieve cross ventilation as well.

The project that failed to obtain an open corridor usually will end up with a “study” room instead of a bedroom (Figure 30). This “study” room has no window for natural ventilation and daylight. In the city centre where the rent price is super high, it is hard to say that these uninhabitable spaces will not be used for habitation. It is also our
architects’ social responsibility to prevent this “misuse”.

Then, I collected interior pictures of the existing building on 23 Anzac Avenue (Figure 31), which show an interesting point where the architect extends part of the floor slab to create a high and narrow window for a living room instead of a wide window facing north.

![Figure 30 70-74 Anzac Avenue, Auckland Central](image)

![Figure 31 The case on 23 Anzac Avenue, Auckland central.](image)
6.1.3 Building regulations

After checking out the existing building, two questions come to my mind: Why was the current building designed like this? Why are the two towers connected by sky bridges? Then I started to study the building regulations of the Auckland centre.

- Safe path

As Auckland building codes and standards require that “every occupied space in a building shall be served by two or more escape routes”, each high-rise apartment in Auckland needs at least two safe paths (exit) on each floor for protection from fire. In terms of safe path, an external escape route such as an open balcony or open stairway could be considered as a safe path. Providing some conditions, people could escape through the adjoining building, which means two buildings could actually share two safe paths. This is the reason why the two towers are connected with each other by bridges (shared safe path).

- Travel distance

Travel distance is “the length of the escape route as a whole or the individual lengths of its parts”. This travel distance should not

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17 New Zealand, The Ministry of Business, Innovation and Employment, C/AS2, Acceptable Solution for Buildings with Sleeping (non institutional) (Risk Group SM) For New Zealand Building Code Clauses C1-C6 Protection from Fire,

18 Ibid, 39.

19 New Zealand, C/AS2, 18.
exceed the number of the table below (Figure 32). This requirement aims to avoid the occupants from traveling too far from their home to the safe path (stairway) once there is a fire. For a high-rise apartment which is higher than 25 metres, a type 7 fire system will be required, then the max travel distance will be 40 meters for the dead-end open path and 100 metres for the total open path.

![Table 3.2 Travel distances on escape routes for risk group SM](image)

<table>
<thead>
<tr>
<th></th>
<th>No system and Type 2 system</th>
<th>Type 4 and Type 5 system</th>
<th>Type 6 system</th>
<th>Type 7 system</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dead end open path</td>
<td>20 m</td>
<td>30 m</td>
<td>30 m</td>
<td>40 m</td>
</tr>
<tr>
<td>Total open path</td>
<td>50 m</td>
<td>75 m</td>
<td>75 m</td>
<td>100 m</td>
</tr>
</tbody>
</table>

If open path length increases for smoke detectors are being applied, where Acceptable Solution FJ/A51 allows heat detectors to be substituted for smoke detectors, not less than 70% of the fire cell shall be protected with smoke detectors. Heat detectors cannot be substituted for smoke detectors in exitways.

If smoke and heat detection systems are installed in order to extend permissible travel distance in accordance with this table and are not a requirement of Paragraph 2.2.1 then Fire Service connection is not required.

**Figure 32 Travel distance**

- **Outlook space**

  Outlook space is the space in front of the habitable space. Keeping a reasonable outlook space could assure a decent feeling for the inhabitant by a reasonable standard of visual and acoustic privacy.

  In the Auckland city centre zone, it will not be permitted to face the living room of your apartment to the neighbouring site unless you have a written approval from the owner of your neighbouring site. Otherwise, you need to keep your external wall 20 metres away from your neighbour’s building, which is usually only available for a large site.

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However, the outlook space of a bedroom is merely six meters, which often suits a studio typology.

- **Minimum dwelling size**

  At least $35m^2$ for studio dwellings including the balcony of depth no less than 1.2m.

  At least $50m^2$ for one, or more bedroom dwellings including the balcony of a depth no less than 1.8m.

- **Ventilation**

  The ventilation is very complex and highly depends on your ventilation systems such as whether it is natural ventilation, mechanical ventilation, or a combination ventilation system.

*Figure 33 Outlook space requirement (source: Auckland Unitary Plan)*
Generally, the common method would adopt natural ventilation for habitable space, but mechanical ventilation for bathroom or kitchen. However, unless you adopt a continuous mechanical extract, then the maximum depth of the household unit could reach 10 metres\(^\text{21}\), otherwise, it will be only 6 meters which is not an economic depth.

Height, depth and width of units

Since we are going to design a few typical units for mass production, we need to identify the appropriate height and width.

In terms of height, usually, it will require a minimum of 2.4m net height for interior space, plus the space occupied by the structure, the minimum total floor to floor height would be 2.7m for residence. To improve the ventilation of indoor space, most of the time people would prefer higher space with a floor to floor height of 3m. However, 3m is generally an edge for resident space, just as Wang Shu said, “the space below 3 metres is for people, but that above 3 metres is for gods”.22

Another factor influencing height is the depth of the unit. According to rules of thumb, some specialists considered that: “(a) the maximum room depth is four to five times the height of the window, (b) window area is approximately one-tenth of the square of the room depth”.23 Given the fact that most of the apartment floor height is 2.9 or 3.0 metres, assuming that the height of windows head is 2.4m, the reasonable room depth of units would be no more than 2.4x4=9.6m. And for

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units having two aspects for daylight, it would be no more than 9.6x2=19.2m.

By considering ventilation, Auckland Design Manual gives a suggested depth of 8m for single-aspect (Figure 35) units and of 14m (exclude balcony) for a double-aspect apartment (Figure 36).

![Figure 35](http://www.aucklanddesignmanual.co.nz)

**Figure 35 Natural ventilation from a single aspect (windows on one side) (Source: http://www.aucklanddesignmanual.co.nz).**

**Figure 36 Double-aspect apartments. (Source: http://www.aucklanddesignmanual.co.nz)**

- **Room size**

  **Living room.**

  As we know, a very important activity of the living room is watching TV. “The Guidelines from the Society of Motion Picture & Television Engineers recommends sitting at a distance where the screen fills up about
30° of your field of vision as a minimum for a good experience” (Figure 37). Plus the thickness of walls and people, so that we could reckon that the minimum width of a reasonable living room is 3 metres (10 feet).

Figure 37 Proper distance for watching screens (source: https://www.rtings.com/tv/reviews/by-size/size-to-distance-relationship).

Bedroom.

The main function of the bedroom is sleeping, so that the minimum size of a bedroom relies on the size of a bed, for example, whether the bed is a king size or single size. For king size bed, the minimum bedroom needs 3.3m deep by 3.0m wide, and for single size bed, it will be 2.7m by 3.0m (Figure 38).

**Bathroom and kitchen.**

Generally, if the fixtures of a bathroom or a kitchen are arranged linearly, the minimum width of the room will be 1.8m which could contain a fixture and a pathway, and the length needs to be 2.7m which can accommodate three fixtures (Figure 39).
6.2 A Failure Example

After the pre-study, I developed a scheme. It solves most of the technical issues but without many variations.

In this proposal, the customization is achieved by various combinations of different single units (Figure 40, Figure 41), and options of interior layout.

At this stage, even though I have already developed the module system (Figure 42), this system did not boost my research much, because the boundary of the unit is still fixed, so the number of variations is very limited if we could only change the inner layout.
Nevertheless, this proposal has established some basis of the final design such as the structure of the whole floor plan, and the void space between two units.

Figure 41 The floor plan of combined single units

Figure 42 The module system idea
6.3 Principles of MC Design

6.3.1 Learning from urban planning

An independent house is usually considered as a personalized dwelling which is designed according to the preferences of the house owner.

People are happy to obtain their own customized house. So, how do the urban planners plan a huge city in a short time without losing the possibility for people to get their customized houses?

If you look at the plan of a residential zone in Auckland (Figure 43), you will notice that the planners actually divide the land into numerous small lots, each of which has an appropriate size, neither too big nor too small for a normal family. All of these lots which mostly have rectangular shapes are arranged one next to the other. The circulation system, road and street, connects with every unit to finally form the whole residential urban fabric.

Figure 43 Ponsonby, Auckland Council GeoMaps

Each lot has a boundary, height control, and other rules, which prevent adjacent houses from negatively affecting each other, such as blocking...
the sunshine or opening a window against the neighbour inappropriately that it disturbs people’s privacy. Other than that, house owners would have full freedom to create their dream homes, their customized dwellings.

If we zoom in to see the figure-ground relationship of a residential block, we would notice that, first, each house has a different shape and size. Second, the land lot is not fully occupied by the house. Third, the widths of the gaps between houses are various but almost even.

After observing, you will find that each house has a different width and length, concave and convex, which reflects the needs of different users.

Comparing houses by width and length, we can find that there is more difference of length than
that of width (Figure 45). So, we can conclude that the direction of length has more possibility for customization.

So, I suggest principles of mass customization that:

(1) Divide the whole space into units which have standard or similar sizes, and the shapes of the units are easy for organizing.

(2) To customize a unit, there must be free-space between the body(building) and the boundary. The more Free Space there is, the more variations could be provided (Figure 46).

(3) When customizing a unit, all variations have to be within the boundary, and will not affect adjacent units.

Then, how can we apply these principles to a high-rise apartment?

Figure 45 Comparing the sizes of houses.

Figure 46 Free-space for customization.
If we assume the street as the corridor and lots as the units of apartments, we will see the similarities and differences between residential planning and apartment design (Figure 47):

(1) They both adopt rectangular as the shape of units, which is ideal to organise a group of units. And, they both have a linear circulation which connects all the units.

(2) A house does not fully occupy the lot, there is plenty of free space left for expansion. So, it is possible for an independent house to be customized. On the opposite, an apartment unit has none of the free space within its boundary (the walls), which means it cannot change its shape and size. In other words, it cannot be customized to expand but only change the inner layout.

Figure 47 Comparison between urban planning and apartment floor plan.
So, if we could provide the apartment units with the conditions that an independent house has then we could have personalized apartment units, the sky house (Figure 48). In the sky house, the boundary will no longer be the party wall and external wall but the fence of your sky lots.

![Image of the sky house](image)

*Figure 48 Assumption of sky houses*

Generally, this will not happen due to several reasons:

1. The channels between units have poor access to daylight and nearly no sunlight. This situation is not the same as an independent house.
2. Each unit needs to build its own external wall, which causes tremendous waste compared to a party wall. The apartment is a type of residence that values efficiency and integrity, to which the sky house does not correspond.
3. Totally personalised houses could not be serviced with a drainage system efficiently because of too many positions of bathrooms and kitchens. Normally, the drainage pipes will go straight without too many turns.
4. The most apartments space is tight, so that the empty space of the sky house is not economic.

However, we can still provide free space on the front and back sides of the units, which will not affect adjacent units called MC Mid Units (Figure 49). And for the MC End Unit, there is extra free space on the side for customization. Nonetheless,
it is decided by the designers how much free-space there will be.

So, we can develop three strategies for arranging a group of MC units (Figure 50). The type (A) represents that the corridor will keep straight, (B) shows that the edge of the balconies will stay in the same line, (C) demonstrates that the front external walls of units will align with each other.

Figure 49 MC Unit typology.
These three types could be applied in different ways according to the situation of context. For example (Figure 51), when the building faces to main streets, to obtain a tidy appearance, we could place the rear of type (A) and the front of type (B) to the street side.

Another method for floor plan design is to arrange templates instead of modules (Figure 52). In other words, we consider each template as a household, and give up the flexibility of combinations of adjacent modules. This method will provide more
convenience for planning because of the reduction of variations. Nevertheless, each template still has dozens of options, but the ratios of the templates are fixed in advance.

In the residential design (Figure 53), 300mm could be applied to create many useful dimensions, such as 600mm which will be suitable for the width of most desks, cabinets and wardrobes, 900mm which will be acceptable for the width of a passage or a door, 1200mm which is enough for a person to squat in front of a cabinet with its door open, and 1500mm which could contain a study desk with a computer chair.

**Figure 52 Example floor plan organized by templates**

6.3.2 **The grid system of modules**

To establish a series of products, we need a general measurement system. In the building industry of China, there are several dimensional modular systems, and 300mm is one of them which is suitable for residence design. And interestingly, 300mm is almost equal to 1 foot (304.8mm). So, we adopt 1 foot as our grid system.
I designed a group of rooms (Figure 54) with various functions and layouts to study the minimum dimensions needed by each function, and to test whether this one-foot grid system is flexible.

For example, for a bathroom, 2700mm long and 1800mm wide (grids align with the centre of walls) is suitable for fitting in three sanitary appliances. The minimum size of a double bedroom would be 3300mm by 3000mm, which could contain a double bed and a wardrobe without losing maneuverability.
Additionally, adopting a constant grid system will provide much possibility and flexibility for assembling various functional spaces (Figure 55).

Through this practice, we could conclude that a 300mm (1 foot) grid is suitable for application in mass customization of apartments.

![Figure 55 The flexible variations of adopting 300mm grid system.](image)

6.3.3 **Product Family**

Product Family Architecture (PFA)\(^{25}\) is an important concept in mass customization. PFA provides the possibility that certain modules could be shared between different templates so that the manufacturers could make a high number of variations with a limited number of modules.

In this research, PFA is identified by the width of the units. Because the units will only change their length longitudinally, so the widths of a group of units could be a constant which will be the feature of a product family.

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Figure 56 Product Family Architecture (PFA)\textsuperscript{26}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{pfa_diagram}
\caption{Product Family Architecture (PFA)\textsuperscript{26}}
\end{figure}

Figure 57 Product Family identified by the width of units.

In a real project, it is possible that several product families will be adopted in the same floor plan to make the most of the land.

The principles of selecting a product family are:

1) Collecting data and suggestions from market research, which will suggest a suitable size that your potential home buyers would purchase.

2) If possible, try to adopt as few types as you can because “while mass customization provided high variety for consumers to choose, such high variety also introduced manufacturing complexity in the assembly system”\(^{27}\), which eventually increases the cost of products.

\(^{27}\) Ibid.
6.3.4 MC Units (Template and Module)

- **Templates**

Modularized products are considered as a solution for mass customization, which aims to provide “a wide range of products with the smallest possible number of modules”.\(^{28}\)

According to the analysis in the paragraph 3.4, we already know that the first phase of MC is choosing templates which comprise several modules. Learning from the typologies study in the apartment market in Auckland, I have summarised five one-room-templates (including studio), two two-room-templates, and one duplex-template (Figure 59).

The modules in those templates are designed based on the principle (shown in Figure 49) that each of the modules could expand in two directions: front and back, except when it is an end unit. So the expansions will not affect adjacent units.

In a MC apartment, the template is a type of structure which demonstrates the relationship (layout) between modules and indicates the positions (doors and path) for connecting them.

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Table 1 Abbreviation of rooms

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Room Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>BA</td>
<td>Bathroom</td>
</tr>
<tr>
<td>BR</td>
<td>Bedroom</td>
</tr>
<tr>
<td>R</td>
<td>Dining Room</td>
</tr>
<tr>
<td>BAL</td>
<td>Balcony</td>
</tr>
<tr>
<td>EN</td>
<td>Entry</td>
</tr>
<tr>
<td>LR</td>
<td>Living Room</td>
</tr>
<tr>
<td>KIT</td>
<td>Kitchen</td>
</tr>
<tr>
<td>ST</td>
<td>Storage</td>
</tr>
<tr>
<td>STU</td>
<td>Study</td>
</tr>
<tr>
<td>TOI</td>
<td>Toilet</td>
</tr>
<tr>
<td>W/D</td>
<td>Washer/Dryer</td>
</tr>
<tr>
<td>MBR</td>
<td>Master Bedroom</td>
</tr>
</tbody>
</table>

Figure 59 Templates of 3600 Product Family (see Table 1 Abbreviation of rooms)
So, let us take one of the templates and see how it will work.

In this case (Figure 60), there are three typical combinations, the small, the medium and the large, which represent the combinations of the different sizes of modules. The maximum length difference is 2.4m due to the accumulated length differences between modules. Of course, these modules could combine with each other in various ways, which will result in the lengths varying from 9.9m to 12.3m.

Figure 60 Length difference of various combinations
**Modules**

The second phase of MC is choosing modules.

**In a MC apartment, the module is a basic space segment which contains one or more functions (e.g. bathroom, living room).**

So, I designed three options for most of the modules (Figure 29). Each option is 300mm longer than the last one, so the difference of the total length of the templates will not exceed 2400mm, which would not cause significant problems to design.

As we know, architecture is an art of space. So, providing different sizes as options to space is essential for customization.

However, we had better not provide too many options for each module because this will not help the users to make decisions, in fact, “too many options can actually reduce customer value instead of increasing it”.

In each module (Figure 61), there are several solid triangles which indicate the connecting point to other modules. In this way, there are rules to ensure that modules will follow the reasonable structure.

Some modules, for instance, the BA (bathroom), actually have two types which will be suitable for different templates (one-bedroom-template and two-bedroom-template). Notice that the BA STR type is for duplex typology.

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Figure 61 Single Module

Figure 62 Collocation between modules and templates

Figure 63 Options for each module.
The modules may be applied in different templates as long as they accord with the attributes. The modules hence will be in a limited number, which maintains the efficiency of mass production. So, through various combinations of modules, architects provide mass customization.

6.3.5 **Combinations**

To find out how many combinations could be created by the modules, I start with a simple example which comprises three modules (no balcony). Then, I assemble them by all of the possibilities, and finally I get $3 \times 3 \times 3 = 27$ combinations. Next, I draw dimensions for each combination and find out that I have a group of numbers which range from the minimum length of 8700mm to the maximum length of

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30 Kaj A. Jørgensen, "Product Configuration and Product Family Modelling", accessed September 14, 2018,

10500mm with an interval of 300mm.

So, for the 3600 Product Family with eight templates, if every template comprises four modules on average and each module has three options then the total number of combinations would reach:

\[ 3^4 \times 8 = 81 \times 8 = 648 \]

So, we could create 648 various combinations through around 42 different modules. Notice that it depends on how you design the templates and modules to keep the most flexibility where different templates could share the same modules.

We could create combinations with floor areas ranging from 34sqm to 44sqm, and 68sqm to 88sqm with an interval of 1.08sqm (3.6m×0.3m=1.08sqm). So, the total number of variations by area is around 30.

And we could create combinations with length differences ranging from 9.9m to 12.3m with an interval of 0.3m. So, the total number of variations by length is 9.

The conclusion is, even though just providing three options to each module, the total number of combinations could reach a high level which covers a wide range in terms of size and area.
6.4 Experiment and Test
6.4.1 Product Family test

I made all the modules into blocks with magnetic cardboard, so that I could simulate the process of customization. And this also demonstrates the main process of online customization.

Through moving, replacing and comparing, I tested the modularized apartment units (Figure 67).

For a single unit, it is comparatively simple because of the linear structure of the template.

For a two-bedroom unit and duplex unit, I found an important point for designing: the join. As shown in Figure 69, if two or more single MC units are composed together, providing only one join, or as few as possible, would increase the flexibility.

The reason for this is obvious: since the combinations of modules vary, the more joins (restrictions) there are, the flexibility will be less.
Figure 67 Four steps to customize a unit.

Figure 68 Practice of combinations of the duplex unit (left) and two-bedroom unit (right).
Through the study of site, regulations, and context, we already know that the main living space needs to face the frontages of the site. And if windows of the external wall are opened toward the adjoining site, there must be a distance between the external wall and the site boundary. This distance for the living room is 20m, and for the bedroom is 6m. So, apparently that we would place two groups of MC units to the sides where the building faces the street (Figure 70, part A, C), then place MC studio units (part B) in the centre of the site and orientate them to the north which provides inhabitants with adequate sunlight. Meanwhile, because these studio units only have bedrooms, they correspond to the distance required by planning regulations.

Another point we need to pay attention to is the MC Boundary of the units. Before managing your floor plans, you need to know the size of MC Boundary of the product families which you will adopt. These MC Boundaries represent the maximum potential size of the units which should not exceed the site boundary or cause other breaches to regulations.

In the floor plan, part A adopts one-bedroom units without a void. Part B contains studio units with the external wall staying on the same line. Part C

Figure 69 The join of two units.

6.4.2 Floor plan design

Through the study of site, regulations, and context, we already know that the main living space needs to face the frontages of the site. And if windows of the external wall are opened toward the adjoining site, there must be a distance between the external wall and the site boundary. This distance for the living room is 20m, and for the bedroom is 6m. So, apparently that we would place two groups of MC units to the sides where the building faces the street (Figure 70, part A, C), then place MC studio units (part B) in the centre of the site and orientate them to the north which provides inhabitants with adequate sunlight. Meanwhile, because these studio units only have bedrooms, they correspond to the distance required by planning regulations.

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In the floor plan, part A adopts one-bedroom units without a void. Part B contains studio units with the external wall staying on the same line. Part C
which has a void in the centre to provide extra
daylight and ventilation comprises two 1Bedroom
units and a 2Bedroom unit.

All of the three parts adopt the 3600 Product
Family which has high adaptability for the scale of
residential spaces.

These three parts demonstrate the different
strategies of arranging MC units to adapt to
various contexts.

Never the less, it is important to make use of the
irregular shape of the floor area by placing
staircases or elevators. Furthermore, in some
cases, architects could provide specific templates
and modules for utilizing the irregular floor area.
Figure 70 A floor plan of the proposed apartment.
6.4.3 Engineering challenges

- Service system

In a high-rise apartment, the drainage system is designed as in Figure 71. The main feature is that each sanitary fixture connects to vertical common pipes horizontally, and each exhaust duct connects to the vertical common stack within each floor.

![Figure 71 Drainage system](source: www.pipelt.com)

So, for MC units which have no fixed positions for bathrooms and kitchens, we may meet with two problems:

1) The vertical shaft (the red colour in Figure 72, Figure 73) may interrupt the arrangement of furniture in rooms, because in some cases the shaft may be just in the middle of a room instead of in the corner.

2) Given the fact that the drainage pipes are placed under the floor slab, the horizontal parts of the pipes (purple and blue colour) may cause visual discomfort for the inhabitant downstairs (Figure 73, 1).
For solving these two problems there are two aspects:

1) We could sacrifice some variations to fix the bathroom within a particular area, which will
not let pipes and ducts pass through other rooms vertically. In other words, we fix the positions of bathroom modules in every unit, just as we do in an apartment with a typical floor plan. However, this will reduce the flexibility of MC, so we may consider using interior design to minimise the effect (Figure 74).

2) Another method is that we open a void space every two units, which provides air and daylight to the central corridor and the habitable space located deeply. Furthermore, the vertical shaft which I call the “external shaft” (Figure 75), could be placed in this void freely without interrupting internal space.

Figure 74 The influence of vertical shafts.

Figure 75 External shaft perspective.
3) The third method is adopting a same-floor drainage system which would partially lower the slab to keep pipes being laid within the same floor so that there is no interruption to downstairs. However, this method will to some extent reduce the net height of interior space.

- Structural challenge

The structure system (Figure 77) would choose the shear wall system. Shear walls will be placed every two units with a reasonable interval of around 8m which is a suitable span for beams. The variations of MC units will be realized by the cantilever, and the span of these cantilevers will not exceed 3m due to the maximum length difference shown in Figure 60.

*Figure 76 Same-floor drainage system (source: www.concerto.com.my/)*
Figure 77 Structural solution

Figure 78 Structural plan
6.4.4 Façade design experiment

For years, architects and planners have designed residential districts. To avoid monotony, architects keep trying to imitate the natural atmosphere of mature residential villages. However, it is still easy to identify a new town which does not have rich memories.

The Pritzker Prize winner Wang Shu talked about his idea of his design of the New Academy of Art in Hangzhou that he aimed to let “people not know if this is a new or an old building when they enter it”, and let people feel like it has been completed by a group of architects.\(^\text{31}\)

In MC, we do not bring in a group of architects; instead, we bring in a group of users to get them involved in the design. Through MC, users could determine the layout of their units and consequently define the look of their apartments together.

However, because the façade belongs to the hybrid sphere of a building, it also has to be in accord with the public requirement. So, architects may need to balance these factors to create a widely acceptable solution.

To build a test model, I set a group of units with various shapes of balconies but still harmonious, then I assemble them together randomly to simulate that they are selected by different users.

- Triangular balcony

\(^{31}\) Louisiana Channel, The Chinese architect Wang Shu’s buildings, https://www.youtube.com/watch?v=n7S3rZ01X1U
There could be many types of triangle, but too many types will destroy the harmony of the facades. Some types of triangles obtain the sense of orientation, which will be suitable for the site where there is a valuable view from a particular direction. Another example is the balcony with colorful sun-breakers to prevent glaring.
Figure 79 The colors of the balcony, United Habitation.
• Rectangular balcony

This method can be applied to other shapes such as the rectangular balcony. In this example, variations are limited to keep the façade changing under a small range.

• Inner balcony

The inner balcony typology has better privacy for the household, it also has a clearer sense of boundary, which helps to identify the individual.

For the outer balcony, in some cases, the upper unit is shorter than the lower unit, which causes part of the balcony of the lower unit to have no canopy. For the inner balcony, there will be no such problem.
Furthermore, we could try integrated typologies to provide more options, such as colours, styles, and different materials to the users.

- Façade test gallery

By providing various options to the element of the balcony, we could increase the variations of façade and vice versa. Even though users get involved in the decision of the façade, architects could still control the direction and extent.

To create a rich façade, architects do not need many variants, the following images show some possibilities of modularized façades. The lengths of the balconies are 1.2m, 1.5m, and 1.8m (Figure 80). Each unit module is progressively 0.3m longer than the former. I just made 21 types and randomly assembled them to create facades.
By changing the element and style of the balcony, architects could enrich the façade design. In this process, customers will play a role in locating different units provided by architects to the places they want, so that will finally create the design together with designers.
PART THREE (Result)
7. Design Outcomes and Evaluation

The final design has been practised in three situations (Figure 84).

Part A is a regular part which adopts one-bedroom and two-bedroom units. The corridor is in the fixed position on every floor.

Part B comprises only studio units because of the planning regulation which requires that only bedrooms can face the adjacent site with a distance of 6m. To make full use of northern sunshine, I set the front side of the MC boundary fixed in a line, then let free of the back side, so the profiles of corridors are different on every floor.

Part C contains one or two-bedroom units, but it introduces a void to provide the extra ventilation and daylight. This void space also accommodates vertical external shafts, so it enables the arrangement of connections freely.

The irregular spaces like the triangle shaped space in the centre have been used for staircases or service rooms. The corridors are located at the southern part of the building, which occupies no precious northern side.

Each unit is customized by the user through the selection system which I have demonstrated. The final design adopts only one product family, the 3600 product family, to simplify the design. Just through one product family, the project contains 8 templates which comprise more than 600 different combinations. This wide range of options will enable people to find exactly what they need.
**Compared with the existing building:**

1) The total floor area on each floor of the new proposal is around 610 sqm which is almost the same as that (625 sqm) of the existing building.

2) Most of the units in the new proposal have achieved natural cross ventilation, and the units in the centre have perfect access to northern sunshine. In this part, it performs better than the existing building.

3) Users could decide whether they will have a bigger bathroom or smaller balcony through the MC system which could provide hundreds of combinations. However, the existing building only has no more than 10 variations.

4) The existing building adopts a typical floor plan, so it could achieve the most construction efficiency. The new proposal has a regular structural system basically, but the frequent cantilevers may increase the cost.

5) The new proposal does not have a fixed ratio of different households, so it can adapt dynamically to the ratios of different customers. So, MC could boost the speed of selling.

Because we cannot wait till the last unit is sold when we start the construction, when an MC apartment starts construction, there will be part of the units (maybe 30%) are not customized by users, instead, these units will be made from existing market data and customer’s preferences.
Figure 82 The context model (1)

Figure 83 The context model (2)
Figure 84 Representative floor plan (1)
Figure 85 Representative floor plan (2)
Learning from urban planning:
Planners use linear structure and rectangular shape to organize lots.
A house does not fully occupy the lot, there is plenty of free space left for expansion. So, it is possible for an independent house to be customized.
To establish a series of products, we need a general measurement system. In the building industry of China, there are several dimensional modular systems, and 300mm is one of them which is suitable for residence design. And interestingly, 300mm is almost equal to 1 foot (304.8mm). So, we adopt 1 foot as our grid system.

Product Family Architecture (PFA) is an important concept in mass customization. PFA provides the possibility that certain modules could be shared between different templates so that the manufacturers could make a high number of variations with a limited number of modules. In this research, PFA is identified by the width of the units. Because the units will only change their length longitudinally, so the widths of a group of units could be a constant which will be the feature of a product family.
In an MC apartment, the module is a basic space segment which contains one or more functions (e.g., bathroom, living room).

The template is a type of structure which demonstrates the relationship (layout) between modules and indicates the positions (doors and path) for connecting them.
The structure system would choose the shear wall system. Shear walls will be placed every two units with a reasonable interval of around 8m which is a suitable span for beams. The variations of MC units will be realized by the cantilever, and the span of these cantilevers will not exceed 3m due to the maximum length difference. The shear walls and the giant cross-bracing can resist lateral forces from both sides.
Roof Garden
8. **Conclusion and Perspective**

From the views of users, what do they want to customize when they need a new apartment? A dwelling is not complex with respect to function. Just like a customized jacket from a tailor, it always contains collar, sleeves, and lining. What the users need is just a little more fit to their body because this jacket (dwelling) is so expensive that they can only afford one or two.

A dwelling is so expensive even nowadays that every user expects their home to be a long-lasting product with the least maintaining possible. So, I consider it is not necessary to enable the whole apartment unit being able to be replaced due to the complexity of construction. And I also do not consider it as a workable solution to let users themselves change the layout such as moving some panel walls, because it is time-consuming and will not provide enough variations. Moreover, mountable wall panels usually mean insufficient acoustic insulation. On the contrary, we would better satisfy users’ personal needs from the beginning, the design stage of a building.

Some may argue that MC does not provide a solution to adaptability through the whole life of a dwelling. No, it does not, but just like in the second-hand housing market, buyers would not expect much customization when they decide to buy a used product which was customized for others. And we do not need to expect every dwelling in the housing market to be able to be customized. Because customized dwellings are just part of the market the same as standard dwellings.

**In conclusion**, the most important points found in this research are the MC Boundary, and
modularized templates. The MC Boundary could be understood as a dynamic boundary as well. Many people may think that the module of a dwelling should be a room, but the definition of a module in MC is different from that. The MC module is defined by space size and the connecting point (circulation) instead of function.

Through the concepts of MC Boundary and modularized template, this project has developed a workable strategy to provide customization from the design stage of a high-rise apartment. This project mainly contributes to the customization of spaces. It did not work on element customization such as kitchen fit-out, sanitary fixtures, or flooring. And, this project has not studied the influences on apartments from users’ different backgrounds in terms of income or personality.

**With respect to perspective**, it would be a workable direction to apply MC principles to container buildings or vice versa, because there already exist many useful practices of pre-manufactured container buildings, and container buildings adopt very similar rectangular units and linear structures of floor plans as well. Another possible direction is applying MC principles in other typologies of dwellings such as multiple-storey dwellings or houses as well.

The principles developed in this research project could be considered as an architectural tool of mass customization. But, the MC design tool is not an automatic design robot which will replace architects. It just partly shares the right of designing with users. Architects could focus on designing the common sphere (see paragraph 3.3), and develop numerous innovative templates and modules.
As per how to use this tool, this project has just given one simple example, and there are far more possibilities waiting for architects to research and practise in various residential buildings.

9. Bibliography


10. Illustrations

Figure 1 Greg Tilley’s Modular Homes factory in Bossier City.......................................................... 12
Figure 2 Toyota Housing Corporation ..................... 12
Figure 3 Online home design
   (https://home.by.me/en/) ........................................ 13
Figure 4 Differences between the building industry and the motor industries (Source: Thillart and Merkelbach, Payman, Customised Industrialisation in the Residential Sector, 14.)............................................. 14
Figure 5 The long tail of the building industry
   (Source: Poorang A.E and T. Piller, Mass Customisation, 211.)...................................................... 19
Figure 6 Floorplans of Schröder House............... 21
Figure 7 Unit floorplan of Unité d’habitation..... 21
Figure 8 Habitat ’67 under construction
   (source:........................................................................ 22
Figure 9 The capsule tower in Japan............... 24
Figure 10 Spheres of control.............................. 25
Figure 11 MC of BMW car (www.bmwusa.com)...... 27
Figure 12 MC of TOYOTA car (www.toyota.co.nz) .......................................................... 27
Figure 13 MC of Nike shoe (www.nike.com)........ 27
Figure 14 Container Skyscraper for Mumbai Slum
   (Source: Ganti & Associates Inc.)....................... 28
Figure 15 Container Skyscraper (Source: Ganti & Associates Inc.)................................. 29
Figure 16 Another example of the container housing................................................................. 30
Figure 36 Double-aspect apartments. (Source: http://www.aucklanddesignmanual.co.nz) ................................................................. 49

Figure 37 Proper distance for watching screens (source: https://www.rtings.com/tv/reviews/size-to-distance-relationship)........... 50

Figure 38 Minimum size of a bedroom.................. 51

Figure 39 The minimum size of a bathroom or a kitchen.................................................................................. 51

Figure 40 The floor plan of single units............... 52

Figure 41 The floor plan of combined single units ............................................................................................................. 53

Figure 42 The module system idea ....................... 53

Figure 43 Ponsonby, Auckland Council Geo Maps ............................................................................................................ 54

Figure 44 Figure-ground relationship of a residential block................................................................. 55

Figure 45 Comparing the sizes of houses........... 56

Figure 46 Free-space for customization............... 56

Figure 47 Comparison between urban planning and apartment floor plan..................................................... 57

Figure 48 Assumption of sky houses .................. 58

Figure 49 MC Unit typology.................................. 59

Figure 50 Arrangement of MC units.................... 60

Figure 51 Example master plan of MC units........... 60

Figure 52 Example floor plan organized by templates ........................................................................................................ 61

Figure 53 Residence design (Source: China architecture design handbooks(中国建筑设计资料集))................................................... 62
Figure 54 Grid system for apartment................. 62
Figure 55 The flexible variations of adopting
300mm grid system........................................ 63
Figure 56 Product Family Architecture (PFA)... 64
Figure 57 Product Family identified by the width
of units............................................................. 64
Figure 58 Modules for 3600 Product Family (48
items).................................................................. 65
Figure 59 Templates of 3600 Product Family (see
Table 1 Abbreviation of rooms) ....................... 67
Figure 60 Length difference of various
combinations ....................................................... 68
Figure 61 Single Module ........................................ 70
Figure 62 Collocation between modules and
templates.......................................................... 70
Figure 63 Options for each module.................... 70
Figure 64 Range of length ..................................... 71
Figure 65 Model of the structure with the three
levels..................................................................... 71
Figure 66 Magnetic physical module blocks....... 73
Figure 67 Four steps to customize a unit............ 74
Figure 68 Practice of combinations of the duplex
unit (left) and two-bedroom unit (right)........... 74
Figure 69 The join of two units............................. 75
Figure 70 A floor plan of the proposed
apartment.......................................................... 77
Figure 71 Drainage system (source:
www.pipelt.com).................................................. 78
Figure 72 MC units drainage system (1)............ 79
Figure 73 MC units drainage system (2)............ 79
Figure 74 The influence of vertical shafts. .......... 80
Figure 75 External shaft perspective.............. 80
Figure 76 Same-floor drainage system (source: www.concerto.com.my/)............................. 81
Figure 77 Structural solution................................ 82
Figure 78 Structural plan................................... 82
Figure 79 The colors of the balcony, United Habitation....................................................... 85
Figure 80 Facade design experiment modules.. 87
Figure 81 Minor adjustment on the balcony..... 90
Figure 82 The context model (1)....................... 94
Figure 83 The context model (2)....................... 94
Figure 84 Representative floor plan (1).......... 95
Figure 85 Representative floor plan (2)........... 96
Table 1 Abbreviation of rooms...................... 67
11. Appendix

11.1 Case study of apartments in Auckland

- 82 Wakefield Street, Auckland Central, 26sqm+4sqm balcony

- 14G/57-59 Wakefield Street, City Centre, 30sqm+5 bal

- 820/10 Waterloo Quadrant, Auckland Central
- 70-74 Anzac Avenue, Auckland Central
- 4B/26 Poynton Terrace, Auckland Central 53sqm+bai 17
- 6 Victoria Street East, Auckland Central, 57sqm, 1999
- 4C/11 Nicholas Street, 49 sqm
• 10 Waterloo Quadrant, Auckland Central, 32sqm

• 2408/1 Courthouse Lane, Auckland Central, 63sqm

• 14F/8 Bankside Street, Auckland Central

• 9L/156 Vincent Street, Auckland Central Completed 2009, 62sqm
• 1F/147 Hobson Street, Auckland Central

• 23 Anzac Avenue, Auckland Central, 65sqm

• 23 Anzac Avenue, Auckland Central

• 23 Anzac Avenue, Auckland Central F9-F15
- 610/85 Beach Road, Auckland Central

- 1802/26 Albert Street, Auckland Central, 115sqm

- 709/37 Symonds Street, Auckland Central

- 808/207 Federal Street, Auckland Central, 61sqm
• 6H/22-28 Beresford Square, Auckland Central, 110sqm

• 901/157 Hobson Street, Auckland Central

• L8US/15 Union Street, Auckland Central, 56sqm include bal

• 1 Greys Ave, Auckland, 1010
Declaration

Name of candidate: ................................. Chenghao Wang ........................................

This Thesis/Dissertation/Research Project entitled: Mass Customization in Mass Housing: How to design a high-rise apartment through mass customization? is submitted in partial fulfilment for the requirements for the Unitec degree of Master of Architecture (Professional).

Principal Supervisor: ............................. Cesar Wagner ........................................

Associate Supervisor/s: ......................... Daniel Irving ........................................

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Student number: ................................. 1477044 ........................................
Full name of author: Chenghao Wang

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