Medium Density - Adaptable Amenity:

A flexible housing system to facilitate change and maximise production efficiencies.

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ABSTRACT

Medium-density Group Housing (“MDH”) has been defined as “a number of horizontally attached (or directly related) dwellings which are normally of one or two stories and rarely exceed three stories above the ground” (Judd 8).

In the context of the New Zealand built environment, this housing typology is widely perceived as being a ‘cheaper’ form of construction, providing a lower standard housing environment. This perception has arisen for a number of reasons. Specifically, *MDH* is often regarded as lacking appropriate ‘fit’ with the existing urban character and is seen as giving rise to a number of problems associated with close visual and acoustic living proximities, inadequate privacy and daylight, insufficient outdoor private and public spaces and lack of design flexibility. These issues have resulted in *MDH* being viewed as an urban housing typology that, while accepted as being necessary to meet space and budget constraints, is very much ‘second best’, problematic and not as being particularly desirable.

With shortages of suitable land and existing housing, intensification is a growing issue for policy planners and developers, and a growing focus of residential development.

This research investigation looks at how design and construction of *MDH* could be enhanced through use of prefabrication in order to provide an inspirational and affordable housing alternative that promotes efficient land use, positive health outcomes and social wellbeing and which can generally enhance the lifestyles of occupants. In this context *MDH* may offer a possible part solution to what is viewed by many as a current crisis in New Zealand housing.

Modular and panelised technologies offer possible solutions to the challenge of providing housing that is efficiently produced, provides flexibility and adaptability in terms of spatial configurations and functionality, offering high levels of customisation and personalisation.

These solutions are explored in this thesis through research of theory, literature and precedent studies which inform a *design framework*. This *framework* is developed under the following subject areas, namely;

- *density and amenity;*
- *environmental fit;*
- *flexibility and adaptability* and
- *production efficiencies*

and are used as a basis for design and project evaluation.

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PROJECT INTRODUCTION

PROJECT BACKGROUND/GROUNDING

It is the New Zealand ethos that everyone has the right to a roof over their head. In the 1950's we were the quarter acre pavlova paradise (Carroll, Witten and Kearns 354). However, providing this traditional suburban lifestyle has become increasingly problematic, particularly over the last five years or so, given both the cost of, and demand for land in close proximity to city centres and ever increasing construction costs.

Urban intensification, and more specifically *MDH*, is a common response to these land and housing deficits. "To ensure the sustainability of Auckland in terms of infrastructure and transport and contain urban sprawl, there has been a focus on developing medium and high density multi-unit housing..." (356).

This intensification is predominantly driven by private enterprise, with a tendency for repetitive, cost-effective typologies that have proven themselves financially reliable and compliant with basic standard and code requirements. In addition to cheaper constructions, issues with privacy, appropriate 'fit', closer visual and acoustic living proximities, inadequate privacy and daylight, insufficient outdoor private and public spaces and lack of design flexibility have resulted in poor social environments and increasing health issues, resulting in a negative public perception of intensification. In order to offset this resistance, rigorous steps and assessment criteria (in the form of a *design framework*) must be used to "enhance the quality of life for residents, increase public acceptability of more intensive housing, and contribute to the building of more sustainable communities" (Turner, Hewitt and Wagner 4).

RESEARCH QUESTION

How can the design and construction of *medium-density* housing be improved through use of prefabrication technologies so as to provide greater flexibility to meet changing demands of residents for both indoor and outdoor space?

PROBLEM STATEMENT/RESEARCH RATIONALE

Specifically, issues with *MDH* which are addressed in this thesis stem from;

- limited indoor and outdoor space;
- lack of flexibility;
- perceived cost and production inefficiencies and
- lack of privacy.

“As city centres intensify, more families are moving into inner-city apartments” (Carroll, Witten and Kearns 353) for work, cultural and transport benefits. There are however clear consequences for these families and children. The study conducted by Carroll et al. identifies that while families find inner city Auckland living affordable and convenient, there are major disadvantages with “insufficient indoor and outdoor play spaces... [with] poor design and construction quality as well as concerns about safety...” and privacy (356). This has led to families moving back into family orientated suburban communities, with safer, larger open spaces for children and family living, but further from work and central city attractions.

In addition, there is a need for new housing to accommodate shifting requirements and to adapt with changing demographics and social environments. Schneider and Till’s article *Flexible Housing: Opportunities and Limits* (the first of two journal articles) identify a general and global tendency for both developers and occupants to view housing “as a disposable commodity with the implicit suggestion that people just move on to the next property when their personal circumstances change” (163).

New Zealand housing is often designed to fixed parameters, it is inflexible, static and unable to easily adapt as occupants needs and demands change. There is a global “tendency to design buildings that only correspond to a specific type of household at a specific point in time reflecting a way of thinking that is predicated on short term economics” (157). New Zealand housing follows similar pattern with developers seeking to maximise profits with little consideration of future uses. Buildings are too often constructed using inflexible methods with poor placement of load-bearing walls, fixed roof trusses and (hard to access) services which prohibit future adaptations. While economic motivations result in sites being developed to their maximum ‘fixed’ potential, there is no planning for future flexibility or the effects a changing environment has on privacy, daylight and outdoor space.

The thesis explores the architectural tectonics and construction possibilities of the prefabricated industry (specifically, modular and panelised technologies) with the view of identifying whether an innovative, flexible, production and cost effective system can improve the issues of 'character fit', daylighting, outdoor space and privacy which taints opinion on intensification.

The modular construction system that is developed is tested on a Mt Cook (Wellington) site so as to assess the practicality and flexibility in a real-world context.

The project seeks to;

- develop a construction system that can accommodate a growing families requirements for expansion and additional space. It develops a dwelling typology that is "designed for [future] choice at the design stage, both in terms of social use and construction, and designed for change[s] over its lifetime" (Schneider and Till, Flexible Housing: Opportunities and Limits 157);
- provide a flexible system that suits a multitude of sites and a variety of forms and scales with a strong focus on amenity and urban environmental fit. Unsurprisingly, as densities increase, limited outdoor spaces diminish further and thus the "quality of landscape design becomes more important" (Judd 27);
- respond to this growing lack of habitable outdoor space by allowing 'outdoor' modules which stack and extend from various floor and roof spaces; and
- provide efficient, affordable, family orientated safe development that improves social opportunities for all residents.

CHAPTER TWO

METHODOLOGY AND THESIS OVERVIEW

The thesis scopes a range of *macro* and *micro* design scales, from complex urban analysis and site planning through to the technical detailing which addresses the constructability of the system.

Having introduced the project in *Chapter One*, this chapter establishes methodologies for *design-led research*.

DESIGN-LED RESEARCH

Design-led Research is defined as a “systematic inquiry directed towards the creation of knowledge” (Snyder). Undertaking a technically grounded *design-led research* project requires pragmatic, sequential research and design techniques. Necessarily, this requires “a conscious demarcation of how particular information is culled from the rest of our experience, how it is categorised, analysed, and presented” (Wang and Groat 8).

This inquiry/thesis is based on *design-led research* and relies on two stages of examination, namely;

- (i) ‘*research-for-design*’ (Downton 17) and
- (ii) ‘*research-through-design*’.

The two stages complement each other, allowing an evolving refinement of design outcomes and, through rigorous assessment, expansion of our knowledge base (Wang and Groat 8). The two stages can be summarised as follows.

RESEARCH-FOR-DESIGN

This is the first stage for *design-led research* and sets the foundation for the design enquiry which then follows. *Research-for-design* is broken into stages and dealt with in the following chapters;

Chapter Three: Investigates theory and literature in the *framework* areas of *density and amenity, flexibility and prefabrication and standardisation vs customisation and production efficiencies*. This research critically evaluates key theorists and challenges traditional understandings, informs new perspectives and helps establish the parameters (scale and scope) of the project.

Chapter Four: Case study research is the “empirical inquiry that investigates a [design] phenomenon or setting” (Wang and Groat 418) relating to the *framework* areas in *Chapter Three*. Precedent analysis demonstrates how the researched theories and principles work in real-life contexts.

Chapter Six: Quantitative site analysis critically investigates movement patterns and zoning and building footprints which along with quantitative research techniques (privacy studies, analysis of the surrounding urban grain and fabric) inform site massing and planning strategies.

RESEARCH-THROUGH-DESIGN

The second step to *design-led research* involves research through design. This stage is dealt with in *Chapters Five* through to *Nine* as follows;

Chapter Five: Begins the design phase through the prototype construction of the modular and panelised system. This 'prototyping' is both;

(i) quantitative (geometric studies, spatial measurements and proportions); and

(ii) qualitative (exploratory research based on the observations of the outputs produced which can further enhance design).

The chapter concludes by testing the construction system in several design simulations. This experimental research (through digital and physical modelling and computer rendering) is a key production and development technique. These simulative research methods calculate future realities, indicating how the designs will operate.

Chapter Seven: Further expansion of *research-through-design* is then set out in *Chapter Seven* which involves the application of the construction system in a specific *MDH* project. This step explores several *Design Generations* which further develop the modular system and communal spaces through rigorous experimentation, testing and evaluation.

Testing the system outcomes in a realistic project ensures universal compatibility and flexibility. A number of simulations ensure the modular dwellings can ably accommodate expanding families (from 2 to 4 and 6 members respectively).

Chapter Eight: Refines the treatment of site corners and the construction system.

Chapter Nine: Deals with the technical detailing/constructability of the system.

Chapter Ten: Reflection and concluding statements. Throughout the project there is continual evaluation of design outcomes against project and *framework* objectives. This identifies strengths and unforeseen weaknesses, re-informing design and ultimately leading to new, developed outcomes.

“Masters degrees involve a demonstration of mastery or considerable competence in an existing field and perhaps via this competence the demonstration of new relationships within the field” (Downton 6).

CHAPTER THREE

LITERATURE AND THEORY REVIEW

This thesis examines how flexible housing systems, with emphasis on *medium-density* and adaptable amenities, can facilitate change and maximise production efficiencies through use of hybrid prefabricated construction technologies.

It is helpful to break the theoretical component into three *framework* categories, namely;

- i. *Density and Amenity;*
- ii. *Flexibility and Prefabrication; and*
- iii. *Standardisation vs. Customisation and Production Efficiencies*

and to comment on these individually.

DENSITY AND AMENITY

MEDIUM-DENSITY

There are many texts exploring the relationship between private amenity and housing density and, in particular, the negative correlation that exists between increasing density and reduced private amenity.

Density is a measurement of the number of people or dwellings *per area* of land. In New Zealand it is usually stated as the number of *dwellings per hectare* (“DPH”). Judd identifies that in Australia these figures range from detached and sparsely populated suburban housing typologies (with a low end figure of 2 DPH) which tend to sprawl outwards from city centres, to highly compact high-rise apartments (>85 DPH); an epitome of central city dwelling (9). These measurements are equally applicable to the New Zealand context.

In the context of New Zealand, *medium-density* housing (MDH) measures between 30-66 DPH (Turner, Hewitt and Wagner 22). However, given this figure can be achieved through many forms and scales of building, it is necessary to set qualitative parameters concerning the physical characteristic of housing in order to classify buildings of *medium-density* typology. Equally applicable to the New Zealand housing environment is Bruce Judd’s Australian definition which limits the parameters of MDH to “a number of horizontally attached (or directly related) dwellings which are normally of one or two stories and rarely exceed three stories above the ground” (8). The term ‘horizontally attached or related’ refers to semi-detached, duplexes, and attached row/terrace housing typologies.

Fig 3. 01. Right. Densities between 30-66 DPH showing the wide range that constitutes housing of medium-density classification. Note: diagram based loosely on Judd’s ‘Typical Net Densities for Common Housing Types’ table (9).

RESIDENTIAL OPPOSITION

Perceptions of density are culturally based and acceptance is often dependent upon local norms, which varies significantly between countries. Despite (or perhaps because) our housing density is low in comparison with many other countries, there is resistance to intensification in New Zealand. This resistance links to long-standing, traditional desires for the quarter-acre section and the amenity value associated with this iconic, lifestyle. This is reflected in the “*nimby*” (not in my back yard) resistance frequently seen in the context of Auckland’s housing problems.

MDH however provides the necessary intermediate step between the quarter-acre suburbia and higher density apartment living. Judd notes that with “leisure and cultural pursuits, the demand for housing closer to opportunities in the CBD will occur” (5). In order to successfully increase housing density, notions of this housing typology lacking residential amenity and environmental fit must be resolved through consistently better design qualities.

RESIDENTIAL AMENITY and ENVIRONMENTAL FIT

Central to successfully increased density is '*environmental fit*'. Also described as 'visual appropriateness' by Bentley et al. this is the study of surrounding design features ranging from larger scale features (vertical and horizontal rhythms and skyline patterns) through to small scale features (windows, doors and ground level details) (80). This concept addresses how the physical character of a new density development fits within an existing urban context.

Often intensification developments in New Zealand are planned in areas that have already "developed a distinctive and unified character which is highly valued by their residents and, in some cases, is of heritage significance" (Judd 26). It is important for designers to consider the appropriate extent to which the physical fabric of new development (construction aesthetics, forms, scales, site plan and coverage) fits with existing grain. Too little continuity within an urban setting leads to a lack of identity and character in an overall area. Too much continuity leads to repetitive designs which lack individuality within an 'identified' setting.

Flexible modular construction systems can allow this delicate balance to be met, contributing new and diverse construction aesthetics, continued variation in housing form and a level of personalisation while still allowing enough flexibility in form, scale, materiality and colour etc. for appropriate 'fit'.

Another issue with increasing density is a reduction of residential amenity levels. This addresses facilities, standards and living quality provided in the urban environment at both private and public levels, which affect the well-being of individuals, families and communities. In the private context, a study conducted by Carroll et al. found that the biggest domestic amenity driven issues

for Auckland families and children in medium and higher density developments were security/safety, solar access/natural daylighting, privacy and a lack of private, outdoor, storage, kitchen and play space (361). At a public scale, issues affecting the health and well-being of residents also arise from a lack of quality open public space, pedestrian accessibility/wayfinding, traffic and safety, vehicular access, street parking, noise and communal privacy.

Effective urban intensification requires careful consideration for the provision of amenities, especially in a flexible MDH development where the relationship between buildings and outdoor space is subject to continual change. Judd identifies that where the quantities of amenity (public and private) cannot be retained, then the quality of the designed environment must be improved.

"As density increases the proportion of landscaped to built area decreases and dwellings become more closely related, horizontally and vertically attached and eventually vertically stacked... However, as the quantity of landscaped area decreases, quality of landscaped design becomes more important and strategic in relation to issues such as building scale, solar access, safety, security and privacy and requires closer integration with the design of building form" (Judd 27).

Accordingly, with modular construction strategies it is important to assess the future feasibility of expansion, and to give effect to planning guidelines and rules which dictate how and where indoor and outdoor private space may interchange; with consideration of the amenity issues outlined earlier.

PRIVACY AND AMENITY

One very important amenity consideration is the relationship and transition between private and public outdoor living space.

Privacy is measured by the 'permeability' of the designed environment; which itself is determined by the visibility and physical accessibility between spaces (Bentley, Alcock and Murrain 12). Public space is both visually and physically permeable, and private space necessarily limits physical accessibility and visibility. This relationship is depicted in the graphic below.

Fig 3. 02. *The author's privacy gradient above depicts the hypothetical relationships between visual and physical permeability and the effect these determinants have on privacy levels between public and private space.*

Adequate private and public outdoor space is necessary for the welfare and happiness of occupants, especially for families. However these spaces are often insufficient due to the financial interests of developers who seek to maximise site coverage at the expense of open space.

According to Marcus and Sarkissian however, this "space for children's play [however,] depends less on its size than on its intimacy and security, its location close to the kitchen, and its ease of access to main pedestrian routes" (96). The value and effectiveness of private open space in higher densities is determined by its connection and integration with adjacent public or communal spaces, the level of activation along the boundary, and the accommodation these spaces have for varying recreational needs.

FLEXIBILITY

Currently in New Zealand “the standard house is built as a highly static and immovable object, but the people who occupy them are not. Families grow, shrink and change and so do the occupants and their needs” (Hartany and Le 1). This statement highlights the difficulty for housing to evolve with occupants needs. “Radical social changes in family structure, such as nuclear families versus extended families, single parent family units, childless couples, ageing populations...” (Judd 5) are not reflected in New Zealand housing typologies. In addition to family growth, as children ‘leave the nest’, downsizing the physical structure is impractical and remaining occupants either rattle around a dwelling that is no longer ideally suited to their requirements or they move, either willingly or, as they age.

DWELLING MIX

One approach that accommodates changing needs in residential amenity is the concept of ‘*dwelling mix*’ proposed by Marcus and Sarkissian. The concept proposes fixed dwellings of varying amenity, but allows “households to move within the same neighbourhood or development as their space needs change” (21). Whilst this strategy allows occupants to retain social connections, there are complications finding suitable, available houses to exchange between.

A modular construction typology can enable the forms and amenity of a building to change over time, without need for relocation; providing not just “a shelter but a place which can evolve with its people’s needs and individual changes: a home” (Saifi, Yuceer and Bilge 1869). It provides a place which is never complete and is continually reflective of the contemporary needs, social use and lifestyles of residents.

Schneider and Till view the ability of dwellings to accommodate changing requirements as being determined by two factors. “First the in-built opportunity for adaptability, defined as ‘capable of different social uses’, and second the opportunity for flexibility, defined as ‘capable of different physical arrangements’ (Schneider and Till, Flexible Housing: Opportunities and Limits 157).

These concepts of adaptability and flexibility with prefabricated construction are regulated by both construction and planning limitations.

These may be considered in two steps, as follows;

- i) Firstly, it is necessary to understand the makeup of different prefab technologies and the flexibility presented by each; and
- ii) Secondly, it is necessary to identify the relevant strategies recognised by Till and Schneider’s varied texts that can be adapted to the construction and planning of flexible modular-panelised housing.

PREFABRICATION

Prefabrication is the off-site construction of building elements, ranging from framing timber and trusses through to larger segmented buildings which are then assembled on-site.

In traditional building manufacture construction is undertaken in-situ (on-site), with quality, time and cost being three interdependent ‘constraints’. With factory manufacture these constraints share a counter-intuitive relationship, with cheaper, consistent products delivering projects “30–50% faster than traditional building methods” (Eglinton, Modular Building - A Model Method 71).

Prefab typologies offer the building industry some of the best strategies for achieving flexibility and production efficiency in design. Advantages include bulk purchase and minimum wastage of materials (resource efficiency), mass production, factory precision and high quality assurance, labour and time efficiencies; with time spent on the construction phases halved as compared to tradition on-site builds (Elliott 31). Site preparation and factory construction can also begin independently and simultaneously and “the average cost of a manufactured home per square foot is one-half of what a site-built home is” (Elliott 31).

Fig 3. 03. Below. The prefabrication cycle

In the New Zealand housing context, prefabrication takes a variety of forms and can be categorised into four main typologies of increasing complexity and scale, namely; components, panelised, modular and complete manufactured homes (Page and Norman 3).

Fig 3. 04. Illustrated in the graph is a hypothetical depiction of how typologies within the prefab industry differ in relation to scale, flexibility and opportunities for mass-production, standardisation and ultimately mass customisation.

CONSTRUCTING FOR FLEXIBILITY

A major limitation on flexibility is the construction techniques used. For example roof trusses prohibit vertical alteration, inflexible load bearing partition walls and inaccessible service strategies prohibit maintenance and plan adaptation.

LAYERS AND ELEMENT BREAKDOWN:

A response to the lack of flexibility in traditional and prefabricated building systems, due to the adjoining of construction layers (from timber framing to prefab SIP's panels), is found in Stewart Brand's concept of 'Layers' (right), which appear in various texts; from Schneider and Till's book *Flexible Housing* to Ryan Smith's book *Prefab Architecture: A Guide to Modular Design and Construction*.

Schneider and Till's second journal article *Flexible Housing: The Means to the End* recognises the need for a "clear identification of layers of construction from structure, skin, services, internal partitions to finishes. This allows increasing control (and so flexibility) as one goes through the layers" (288). The issue with many prefab typologies is when it comes to joining separate units, "it is difficult to break through the module walls except at the pre-formed openings, this dimension fixes the layout of the housing to the limits of the modular width" (Schneider and Till, *Flexible Housing* 176).

A hybrid prefab building typology allows separation between modular structure and infill, removing the load bearing capacity from the panelised infill's. These infill's can be added or removed independently, exposing the underlying structural system and allowing it to be adjoined with new structure.

Fig 3. 05.

Below. The authors graphic depicting Stewart Brand's concept of 'Layers'.

SUPPORTS AND INFILL

John Habraken's book *Supports: An Alternative to Mass Housing* identifies the principle of 'supports', (which also depicts Stewart Brands concepts of 'Layers'), with large spanning structure permitting non-load-bearing infill wall partitions. This approach allows "the provision of dwellings which can be built, altered and taken down, independently of the others" (Habraken 13).

Fig 3. 06. *Right. The concept can operate at several scales. Firstly, a larger scale where a structural system is infilled with components (i.e. panels or whole modules), and secondly, a small modular scale where the structure is infilled with panelised components. This reinforces reasoning for a 'hybrid' prefab system which separates structure from infill.*

Habraken believes housing should follow this model of supports and infill's. "The supports provide the basic infrastructure and are designed as a long-life permanent base. The infill's [(whether panels or complete modules)] are shorter life, user determined and adaptable. The support and infill approach also implies different levels of involvement on the parts of the user and professional, with professionals assuming more control over the support, users over the infill" (Schneider and Till, *Flexible Housing* 168).

The concept of 'permanent structure' in a flexible housing system is challenging. Fixed structures restrict where future infill development can occur, therefore in addition to flexible infill, supporting structure should also offer a high degree of modular flexibility.

Another challenge is the relationship of control between the user and the professional. 'Supports' and infill control should be shared between the professional and the occupant, both taking control at the design stage. The professional will give forethought and set guidelines as to how and where the structure and infill arrangements can expand, with the occupant determining these changes post-occupation.

SERVICE FLEXIBILITY

Services which need to be maintained and modified are often buried in inflexible walls and floors, presenting another challenge for modular flexible housing. Services must be made accessible without needing specialist access. Service areas (bathrooms, kitchen) should be zoned around vertical distribution risers. For horizontal distribution; raised floors, lowered ceiling and wall voids allow any number of horizontal service configurations.

The second major limitation for flexible housing is restrictive planning. Poor design and lack of forward thinking often results in prefabricated building systems that lack future flexibility. “The bespoke nature of some prefabricated construction... in which the endless choice provided at design stage means that very particular spatial and aesthetic arrangements are locked in place from the start” prohibiting future flexibility (Schneider and Till, *Flexible Housing* 176). To avoid this trap designers must predict future situations through hypothetical scenarios, testing requirements for additional space, structural capacities (especially with vertical expansion), natural daylighting, servicing and accessibility/circulation options and program arrangements of future plans.

The following strategies recognised in Till and Schneider’s three texts can be adopted to the construction and planning of flexible modular-panelised housing.

FUNCTIONALLY NEUTRAL MODULES

Modules are not ‘labelled’ as bathrooms, kitchens, and bedrooms and can be appropriated with different programs. “A unit that consists of a number of rooms of equal size [(in this case modules)] invites different social interpretations that are open to diverse cultural scenarios” (Schneider and Till, *Flexible Housing* 186).

ADDING ON

When considering strategies for planning the addition of horizontal and vertical adjoining structures it is useful to consider different types of spaces and different types of internal areas in context of the uses they may be put to.

RAW SPACE

Space left unfinished where the basic provisions of structure are provided, and suggestive where future infill can occur at the occupant's discretion i.e. the open-plan office.

SLACK SPACE

The concept of 'slack space' is internal and external space in which a program occurs (i.e. courtyard, stairwell, flat roof) but anticipates different potential occupation to be appropriated in the future by building into, onto and/or enclosing the space.

STANDARDISATION VS. CUSTOMISATION AND PRODUCTION EFFICIENCIES

MASS-PRODUCTION IN GENERAL:

Given the time and cost constraints that impact mass housing production, developers have turned to a variety of efficient production techniques which require a degree of standardised production. The search for efficiencies in standardised housing typologies have resulted in the repetitive use of proven and reliable building components and materials, plan configurations and construction technology. This, along with a “lack of any real physical constraints” (Judd 5), has contributed to the monotonous housing sprawl expanding outwards from city centres. This drive for production efficiencies has resulted in tensions between private developers (seeking to standardise and maximise housing production) and the urban planners, architects, and the public who seek variety in housing aesthetic, higher levels of personalisation, customisation and quality. The problem is in part driven by buyers who aren’t prepared or able to pay for the additional costs associated with aesthetically pleasing designs and layout. Furthermore, buyers often value the square metres their dollar will buy, rather than ‘character’.

The question can be asked as to whether anything less than variety in housing aesthetic, personalisation, customisation and quality should be viewed as acceptable? This is where modular design innovation opens possibilities for developers to veer away from standard practices, taking on greater responsibility to provide efficiency, quality, flexibility and customisation with no additional cost to themselves or their customers.

EFFICIENCY:

The building industry has for many years seen prefabrication as a way of gaining building efficiencies. It is based on the concept first implemented on a major scale by Henry Ford’s *Model T Assembly Line* which revolutionised production efficiency techniques in the 20th century onwards. Prefabrication (in general) is synonymous with ideas of ‘mass production’ and ‘standardisation’, streamlining the production efficiency of buildings through factory manufacturing processes. Monica Elliot observes that “it turns out that putting cars together on an assembly line is not unlike putting houses together on an assembly line” (29). Prefabrication is intended to allow maximisation of output and quality, lessening input times and output costs. It ordinarily relies on standardisation, which “is the repeated production of standard sizes and/or layouts of components or complete structures” (Page and Norman 1), maximising production efficiency. It is applicable to all scales and typologies within the prefabrication industry.

CUSTOMISATION:

The traditional model for prefabrication views standardisation and customisation as mutually exclusive alternatives and, by definition, independent of one another. Generally, prefabricated outputs are either mass-produced in standardized form or they are one-off unique products.

Fig 3. 07. *The authors model for standardisation and customisation.*

This customised factory production often operates at minimum efficiency, and while there are some time and quality benefits as compared to in-situ construction, the cost paybacks are negligible for both buyer and seller. Generally customised house construction results in builders being on-site for longer periods and even factory produced installations for such houses, such as kitchens, are built on a one-off production basis.

Standardised factory production is planned to operate at maximum efficiency, with little or no ability to vary products. This is a calculated trade-off. Ryan Smith states “...limitations in the variety of product produced so that machines may be able to output set lengths, widths, and assemblies. This removes the waste associated with variability options and the margin of error in end products...” (11). In this definition of standardisation the word ‘limitation’ denotes the key disadvantage of standardised production of restricted options.

The restricted range of products produced in standardised production contributes to utilitarian structures that lack design flair, however this is not a reflection of prefabrication per se, but rather its application. In architecture there is an opportunity in the way you assemble these outputs which determines the uniqueness, and in this way ‘customisation’.

Fig 3. 08. *The authors model for mass-customisation.*

This is where concepts of 'interchangeability' fit with ideas of 'standardisation' and 'mass-production', producing the model of mass-customisation above. Interchangeability involves a standard output (i.e components, panels, and modules) having enough flexibility to be applicable to a number of end products. This can be likened to the concept of *LEGO* which operates with modular, three dimensional form. These standardised, mass-produced plastic components of limited form and scale act as building blocks which can be interchanged to infinitely variable custom forms and scales.

Fig 3. 09. Above. Eight LEGO modules sized to a graduated series of $\frac{1}{8}$ proportions which assemble unlimited form arrangements.

A CASE FOR A 'HYBRID' APPROACH:

In the context of the individual *LEGO* block, each block is modular. In the context of panelised construction the ability to alter the block (module) itself by breaking the structure down further to separate structure and panelised infill, would offer much wider possibilities for flexibility, optimisation (through mass-production and standardisation) and customisation.

This reflects Tatjana Schneider and Jeremy Till's understanding that "the most productive approach to prefabrication for flexible [efficient] housing is probably not one that invents new systems from scratch, but one that assembles existing prefabricated elements" (Schneider and Till, Flexible Housing 177).

Fig 3. 10. Above. Eight modules sized to graduated $\frac{1}{8}$ proportions allow assembly of unlimited form arrangements.

Combining panelised and modular construction techniques allows development of a 'hybrid' system which allows efficiencies with production, flexibility and the ability to personalise individual constructions.

Eglinton states that the "...move towards hybrid prefab systems is a logical progression for the local [New Zealand] construction industry. However, more research and prototyping is needed if this system is to meet current and future housing demand" (Eglinton, Hybrid best of Both Worlds 90).

This thesis builds upon Eglinton's observation above. It explores the potential of a flexible housing solution which adapts to meet continually changing housing demand through design prototypes. It identifies a gap which allows the provision of a modular structural system (maximising flexible configurations) which works in conjunction with flexible panelised infill components.

Fig 3. 11.

Left. Forty-six different massing arrangements using two standard module sizes. Adding additional module sizes into the mix results in infinite form possibilities.

Fig 3. 12.

Right. A design framework for the upcoming design chapters based on density and amenity, flexibility and adaptability and production efficiencies. The graphic establishes a set of design criteria at architectural and urban scales.

CASE STUDIES

The following case studies (Resolution: 4 Architecture, Dom-ino, Quinta Monro, Mountain Retreat and Heller Street Park and Residences) relate to the *framework* areas of *production efficiently, flexibility and adaptability* and *density and amenity*, demonstrating how these theories and principles work in real-life contexts.

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RESOLUTION: 4 ARCHITECTURE

A key text (and inspiration for undertaking this area of research study) is Joseph Tanney and Robert Luntz's book *Modern Modular: The Prefab Houses of RESOLUTION: 4 ARCHITECTURE*. The authors have "developed a series of typologies of unitized housing evaluating the possibility of variability within a standardised system" (Smith 258). In essence, they have "developed mass customized architecture" (258) based on a series of standard modules which demonstrate that it is possible for mass-produced architecture to be adaptable to site, functional and programmatic requirements and that cutting edge and unique architecture can be mass-produced in factory environments.

Their "Modern modular [technique] is a design and execution methodology" (Tanney and Luntz 17) and a system for unlimited design production. They have a number of predesigned '*modules of use*' which are essentially building blocks (kitchens, bedrooms, stairs, and living areas etc.) which can be programmatically and spatially arranged with ordering principles. When combined these building blocks produce the maximum number of adaptable and unique spatial configurations. RES4's '*modules of use*' are arranged in a 'typology matrix' which is "analogous to Le Corbusier's Panel Exercise based on The Modulor and the golden section. This volumetric exercise is also limitless in combinations" (Tanney and Luntz 16) and a key technique for producing affordable, mass-customised design.

Fig 4. 01. *Left. A physical model showing RES4's Artist's Retreat.*

Fig 4. 02. *Right. Communal, private and accessory 'modules of use' which can be programmatically ordered in various configurations.*

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Fig 4. 03. Right. RES4's Mountain Retreat.

*Fig 4. 04. Left. RES4's Typology Matrix which allow a limitless
combination of form.*

FIXED SUPPORTS AND INFILL CONCEPT:

DOM-INO:

Dom-ino, designed by Le Corbusier in 1915 is a 'fixed' structural system that is reflected in John Habraken's later concept of 'supports' - discussed in earlier chapters. The design establishes the 'bones'; large spanning structure permitting non-load-bearing infill wall partitions. This approach uses a standardised framework (simple and incomplete) and sets clear parameters within which infill can be constructed (also known as the concept of *raw space*). The model allows "the provision of dwellings which can be built, altered and taken down, independently of the others" (Habraken 13) and provides a base for mass house production.

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Fig 4. 05. Above. Dom-ino, designed by Le Corbusier depicts Habraken's concept of 'supports'.

One criticism of this system is the permanency of the structure in a housing system that otherwise improves flexibility. Fixed structures establish parameters which restrict where future infill development can occur.

QUINTA MONRO:

One of the most minimalistic, efficiently produced examples of flexible and adaptable architecture is Alejandro Aravena's social housing project Quinta Monro in Chile. The design, which uses fixed construction principles, anticipates and controls where extension can occur, but allows the occupant to determine these expansions post-occupation as their space requirements change. Aravena's firm Elemental applies what is called 'half of a good house' concept whereby occupant's infill the remaining frame and appropriate the space in ways personalised to their individual needs.

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Fig 4. 06. Above. Alejandro Aravena's social housing project Quinta Monro. Pre-occupation (left) and post-occupation (right).

While this precedent is a good example of flexible planning strategies (*functionally neutral space, adding on, raw space and slack space*), as depicted in the earlier theory chapters, the parameters established by the fixed construction methods and framing do restrict where future infill development can occur. The flexibility of the construction techniques should be enhanced.

MOUNTAIN RETREAT:

Mountain Retreat, designed in Kerhonkson, New York by RES4 Architecture, is a prefabricated project which incorporates concepts of mass-production and production efficiency using modular and panelised construction. While ordering principles (interior layout) within each ‘modules of use’ (essentially building blocks) provide the needed freedom in plan configuration at the design phase, there is less functional ability to accommodate future modular extensions (without original planning).

The issue is identified in Schneider and Till’s text *Flexible Housing*, in which it is stated that many prefab typologies are restrictive when it comes to joining separate units as “it is difficult to break through the module walls except at the pre-formed openings (Schneider and Till, *Flexible Housing* 176). Mountain Retreat, along with many other RES4 buildings, is reflective of this. The buildings aren’t designed to expand or contract easily post-construction as the modules are ‘permanently’ secured together and the mechanical systems and services are fixed in the concrete foundation. There needs to be a distinctive separation of structure, services and infill.

Fig 4. 07. Above. Mountain Retreat’s large central module being lowered into the pre-placed pile components.

Fig 4. 08. Above. An exploded axonometric of components, panels and modules which constitute Mountain Retreat.

DENSITY AND AMENITY

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HELLER STREET PARK AND RESIDENCES:

An example of *medium-density* development that epitomises careful, considerate and environmentally sustainable intensification with thorough provision for resident's amenity is the Heller Street Park and Residences project in Brunswick, Melbourne. The project, undertaken by Six Degrees Architects in 2011, uses a contaminated former clay-pit site which has been re-developed into ten adjoining terrace housing units. "The true success of this project is the provision of public green space in a dense urban environment. The development promotes the use of communal gardens as opposed to private backyard space" (Zulaikha).

The project is one-third private development (ten-units) and a generous two-thirds communal-public outdoor space opening directly onto the public realm. Ordinarily developer-driven projects would see full coverage of the site, contributing to monotonous housing sprawls as seen elsewhere in Melbourne. However, due to Council ownership of the land it was strictly specified that the larger portion remain publicly landscaped. Safe, family-orientated development is a key driver of this space. "The three-storey townhouses are tailored for young families — each house has four bedrooms — so the park is full of kids" (Horrocks). The landscaped communal space is undulating, circular in shape, raised at its edges with a depression in the centre. "Because this communal space is located on the street, not between houses, it is serving a wider community than do other 'commons'" (Horrocks).

Fig 4. 09. *An interior view of a unit at Heller Street Park and Residences.*

Fig 4. 10. Above. Site plan showing the large portion of landscaped park amenity compared with built form.

The development depicts a project that successfully mitigates residential concerns and enhances the community in which it was developed. Initially the development sparked concern and questioning by locals as a result of misinformation about the fencing and levels of contextual fit that such construction would impose. (Horrocks). Notwithstanding this, the project has had no such fencing and has rather been nominated several national awards for its unique, sustainable, architecturally and amenity rich design attributes.

The development forms an interesting relationship between private and public space. “Some of the key public/private mediation elements are made from plants” (Horrocks), rather than fences. Trees create a physical boundary allowing visual permeability and natural daylighting. The communal space with its raised edge forms a privacy barrier, restricting visibility into the space but does little in the way of restricting physical movement. In addition, “the circular depression creates privacy from the road, but also has the effect of further divorcing the public park from its suburban neighbours. The passive surveillance is coming from one side only — the new development” (Horrocks). This is great for a family orientated development as it separates units from the public realm (privacy gradient) and allows parents to directly survey their children’s activities; providing a high degree of safety, security and communal privacy.

Fig 4. 11. Above. The landscaped circular depression in the foreground with the MDH units in the background.

'HYBRID SYSTEM' DESIGN TESTING

FIXED SUPPORTS AND MODULAR INFILL CONCEPT

This concept is based on the 'supports and infill approach', denoting the key principles of *raw space*. It contemplates large span structural elements which permit modular infill (cores/pods) to be added, altered and removed independently of the structural and other infill components.

The significant drawback with this concept is the permanency of the structure, which restricts where future infill development can occur, thus limiting a housing system that should optimise flexibility.

Fig 5. 01.

Below. The large structural system infilled with non-load-bearing modules and panelised components aligns with John Habraken's flexible 'supports' and infill concept.

MODULAR SUPPORTS AND PANELISED INFILL CONCEPT

Fig 5. 02.

Below. The separation of panelised infill, modular structure and services in the 'hybrid' design system featured right is similar to Stewart Brand's concept of 'Layers', as shown below.

This concept of 'modular supports and panelised infill' builds on the previous fixed supports approach, but recognises that in addition to flexible infill, the supporting structure must also offer a higher degree of flexibility. This can be seen in the images featured right.

Panelised Infill

Modular Structure

Raised Floors

Fig 5. 03. *Modular structure which vertically 'slots' into adjoining structure.*

Fig 5. 04. *Panelised infill which 'pops' into the steel module frames.*

Module sizes are regulated by two main factors;

- First is the sizing required for compliant transportation around New Zealand roadways. “The maximum height for travelling on the Wellington motorway is 4.8 metres, and the maximum width is 3.7 metres” (NZ Transport Agency 4).
- Second is the need to accommodate larger domestic programs (i.e Master bedroom, living room).

Fig 5. 05. *Left. Maximum transportation dimensions for a flat-bed truck on the Wellington motorway.*

REGULATED SIZES:

In order to maximise the production efficiencies and construction viability (in terms of stacking and adding modules) it is desirable that modules follow a graduated series of sizes working from $\frac{3}{4}$, $\frac{1}{2}$, $\frac{3}{8}$, $\frac{1}{4}$ and $\frac{1}{8}$ multiples of the largest module size. This concept can be likened to *LEGO*.

The system adopts a module width of 3.6m (an even multiple of 600mm for space planning purposes) and a length of 7.2m (exactly double the width). Adopting the largest transportable ‘base’ module size of 3.6 x 7.2m (which accommodate $\frac{3}{4}$, $\frac{1}{2}$, $\frac{3}{8}$, $\frac{1}{4}$ and $\frac{1}{8}$ multiples) allows compliance with transportation requirements and accommodation for the largest program functions. Even the smallest $\frac{1}{8}$ proportioned module of 1.8 x 1.8m can ably accommodate storage or WC requirements.

Fig 5. 06. *Left. A variety of module sizes working to $\frac{1}{8}$ proportions, working with 500mm, 600mm and 750mm sq. planning grids.*

Fig 5. 07.

Right. Planning of different residential programs using a 600mm sq. spatial grid.

Fig 5. 08.

Seven 'functionally neutral' modules portioned to $\frac{1}{8}$ multiples of the largest (3.6 x 7.2m) module size, accommodating various social programs. Note: Modules evenly accommodate 600mm sq. planning grid.

Bentley, et al. believe housing variety is limited by developers and planners who (for reasons of economic performance and general management) necessarily restrict and monotonise design outcomes (27). The combination of modular structure (above) and panelised infill (right) allows developers to break away from these norms, with a construction system that promotes form and aesthetic variation.

Panelised façade material studies

Panelised façade arrangements

Fig 5. 09.

Unlimited façade variations from solid wall and garage door infill's to full glazing units. The timber-framed panel system also offers a diverse range of lightweight cladding options from timber, weatherboard, fibre cement to metal-clad systems.

Flat roof options

Pitched roof options

CONSTRUCTION PRINCIPLES

Fig 5. 11.

Below. Depicts the crude concept for timber framed 'panelised infill' which pops into the steel module frames.

Fig 5. 12.

Rough design simulations testing the system's ability to assemble a variety of forms, integrate outdoor space (green modules) at various levels and allow for modular extensions and adaptations.

The following *design simulations* test the system's ability to configure flexible houses, accommodate various residential programs, achieve an unlimited variety of forms, expand and (if necessary) contract and provide modularised outdoor space.

Units are designed to 9m widths (wider than that desirable for MDH development) and are unrestricted by material choice. They serve only as a basis for technical critique of the initial system before testing its potential application in a higher density context (upcoming design chapters).

SYSTEM DESIGN - TEST ONE

SYSTEM DESIGN - TEST TWO

+

SYSTEM DESIGN - TEST THREE

CRITICAL REFLECTION:

The three previous design simulations are 'rendered' white, and do not overlay any material possibilities onto the geometric forms. The exercise simply tests the modularity and three-dimensional outcomes that the system is capable of achieving. The results are diverse. Both pitched and flat roof typologies have been tested. The outcomes indicate that such construction (when planned correctly) is capable of accommodating expansion and contraction, and that units can adequately provide flexible modular outdoor amenity extending off various floor levels.

While the size and layout of the units are desirable in detached, sparsely populated suburban housing environments, they are far too physically wide to conform with *medium-density* scenarios. In addition to this, it is important to consider the effects small extensions and overhangs would have in higher density context. Due to the closer proximities of units, these extensions and overhangs would have negative potential to create awkward, dim spaces.

The appearance of garages at ground level (prime location for living activities and direct access to outdoor amenity) have been heavily criticised in project presentations. Should society move away from current reliance on vehicles, or should a suitable storage alternative be provided, it would be interesting to experiment with space that is presently dedicated to garaging to see how it could be used to provide living and/or social programs. Putting aside the complications that would arise regarding motor vehicle storage, if garaging was removed, the units would need additional space for the provision of general storage. This is something that would need more consideration, especially regarding the flat roof typologies which lack attic space.

SITE INVESTIGATIONS

Given the projects holistic nature and its real-world context, it is desirable to deliver a highly resolved site proposal. This requires the project parameters to extend beyond modular construction to include housing and public infrastructure (i.e roads, swales, and pedestrian foot pathing etc.), communal amenity (parks and landscaping) and resolved issues relating to the sites physical layout.

ANALYSIS

Fig 6. 01. Site maps showing the scale and location of development in the context of Mt Cook, Wellington Central.

Fig 6. 02. Above. Site perspective showing what WCC consider to be a Secondary Street frontage along the Rugby Street perimeter. City planners are particularly interested in the treatment of this site boundary (Wellington City Council).

Fig 6. 03. Left. Site mapping showing zoning, building footprints and movement volumes surrounding the 8842m² site.

THE SITE :

In order to test the design outcome in a real-world environment the modular construction system has been applied to a real-world site.

The site chosen, is an inner-city Wellington location situated on the corner of Tasman and Rugby Street. It is a large vacant lot in close proximity with Adelaide road and is centred along the core network corridor linking the CBD with Wellington's southern suburbs. Due to the site's proximity with Wellington's CBD, Massey University, Basin Reserve and Adelaide Road (Newtown's arterial route) it is perfectly situated for MDH development in this hypothetical project. It also offers a complex setting from which to test the system's ability to fit with an established urban character.

Despite being larger than one hectare, only the front 8842m² of the site is utilised for this project.

ENVIRONMENTAL FIT :

Mt Cook epitomises Judd's description of a development area that has "distinctive and unified character which is highly valued by their residents and, in some cases, is of heritage significance" (26). Newspaper reports record that "the Chinese Government is understood to have bought the site, which is just over one hectare, for \$16 million from Foodstuffs in 2014" (Nicoll). It is recognised by its Chinese owners as being in one of Wellington's older suburbs and that treatment of the site (especially in the context of issues associated with appropriate 'fit' - construction aesthetics, forms, scales, site plan and coverage) is a primary concern of planners, residents and the Resident's Association, *Mt Cook Mobilised*. Just as the development contemplated by this thesis is sensitive to the site, the current owners have indicated that development will be sympathetic with the existing urban context, rich fabric and surrounding heritage condition. Plans are currently underway for an embassy development that is a "mini village, rather than a monolithic building – two or three storeys tall in parts, and in keeping with the style of surrounding Mt Cook suburbia" (Nicoll).

Fig 6. 04. Typical three-story townhouses surrounding the Mt Cook site.

PRIVACY GRADIENT AND SITE MASSING STUDIES

PERIMETER BLOCK LAYOUT :

“A prevalent idea [in successful urban planning] has been that clear boundaries to neighbourhood (i.e. a distinct territory) will enhance functional and social interaction, sense-of-community and identity within those boundaries” (Carmona, Tiesdell and Heath 145). The most appropriate approach for providing safe, family-orientated community development is one which encloses communal space within a perimeter-block layout, which provides this boundary. Dwellings front the public street with rear yards leading to semi-enclosed communal space. While this communal space may be adequately connected within and beyond the site, because it is surrounded by houses there is limited direct visual and physical permeability with the outside public realm. This generates semi-public space, with use largely restricted to direct residents, retaining a high degree of communal privacy, accessibility and security and enhanced social opportunities.

Directly opposing dwellings (below-right) result in a high degree of visual contact between residences and lack general privacy. Diagonally adjacent spaces however (left) reduce visual contact and overlook between dwellings.

Fig 6. 05. Above and below. Site massing strategies which both promote (left images) and restrict (right images) privacy between adjacent dwellings.

Level changes in vertically terraced houses with stepped frontages are a privacy and daylighting strategy that extends units above and beyond the line-of-sight from neighbouring dwellings, while enhancing their lighting and outlook amenity.

Fig 6. 06.

Left. Four perimeter-block site planning options which dictate levels of privacy and publicness, and achieve varying levels of accessibility, security and family orientated private-communal space. Note: diagram colourings corresponds to the privacy gradient diagram below. This gradient diagram is based on literature studies from Bentley et al. and depicts the close relationship between visual and physical permeability and the effects these determinants have on public, private and communal space.

In relation to privacy between dwellings, the diagonal layouts in *Options 1* and *3* (left) offer the least visual contact amongst adjacent residence.

However, the diagonal axis cut in *Option 3* (aligning with external pedestrian movement along Tasman Street) does promote undesirable thoroughfare through the site due to its higher level of physical and visual permeability.

With consideration for public, private and communal space requirements, good accessibility for residents, security, unobstructed solar access and rich design opportunities, *Option 1* offers the most attractive layout.

Fig 6. 07. *Right. A North orientated site layout optimises the East-West sun path all year around.*

Fig 6. 08. *Right. Opportunities for mixed-use residential-commercial development to occur along the Rugby Street frontage.*

MIXED-USE DEVELOPMENT:

WCC is primarily concerned with the treatment of the Rugby Street elevation, which it deems to be a secondary street frontage running off Adelaide Road (primary street frontage). This means there is a good opportunity for commercial enterprise to extend beyond the Adelaide Road corridor to the North-eastern corner (Rugby Street) of the site, offering opportunities for a mixed-use residential and commercial development.

VARIETY

'Variety' in the built environment "implies places with varied forms, uses and meanings" (Bentley, Alcock and Murrain 27). At the scale of the individual house this 'hybrid' construction system allows variety in the forms and aesthetics between units.

The high level of activity surrounding the site necessitates greater diversity in the uses, activities and functions of buildings to extend beyond residential use. This diversity in building type is what "attracts varied people, at varied times, for varied reasons" (27) adding another level of complexity and richness to the site.

Designing "for appropriate, efficient, conveniently located and aesthetically pleasing car access and storage with high levels of safety and security is one of the greatest challenges facing the designer of *medium-density housing*" (Judd 28). A key criticism of the 'System Design Tests' referred to in *Chapter Five* is the dominant appearance of garages and the requirement for street level motor vehicle storage, which compromise the quality and amenity value of ground planes in MDH developments. Providing a parking facility for vehicle storage elsewhere on-site reduces street parking clutter and improves the amenity value of development, with ground living extending directly onto adjacent private and communal space.

The development of the residential-commercial building featured left is beyond the scope of this thesis. However, it provides a model for 'mixed-use' development which, without time constraints, would be pursued further. The concept proposes a large commercial complex at ground level, a site parking facility in the underground basement (that accommodates safe automobile storage for the entire site with provision for visitors) and several levels of residential development on the upper floors.

Fig 6. 10.

Right. The North-eastern corner of the site offers a prime location for commercial enterprise to open directly onto Rugby Street and the SH1 'ring road' around the Basin Reserve.

Fig 6. 09.

Right. The concept depicts the potential application of a 'fixed supports and modular infill' approach that (due to the scope of this thesis) is not perused further. Please note the underground garage facility featured on the right of the building.

DESIGN TESTING

Following the site-massing and layout concept set out in *Chapter Six, Chapter Seven* methodically develops aspects of the site through five '*Design Generations*'.

These five graduated developments show progressive improvement at a range of scales; from strengthening the modular construction system itself to the planning of units and their layout on-site.

This process allows exploration of the capabilities and limitations of the system in the context of flexibility and adaptability. It tests the ability to adapt to different site typographies and opportunities for expansion, variation (different roofing typologies, unit sizes, orientations, and design aesthetics) and customisation. These *Design Generations* are as follows:

- i) *Design Generation One* develops the Rugby Street frontage;
- ii) *Design Generation Two* develops the Tasman Street frontage;
- iii) *Design Generation Three* develops the Tasman Laneway axis; and
- iv) *Design Generation Four* develops the enclosed communal space.

There is a final exercise which applies the preferred earlier design outcomes to the whole site. This has been titled '*Overall Site Development*'. Together these design exercises depict a cohesive process and a progressive delineation of outcomes.

DESIGN GENERATION ONE

RUGBY STREET FRONTAGE

The North facing frontage onto Rugby Street is orientated for all-day sun and is practical for private-communal and family social spaces. The flow of indoor living space directly onto adjacent outdoor private and communal space at ground level has value as an amenity advantage (especially for families) that outweighs the value of built in garages. Removing garages at ground level increases the habitable floor

space of units (without needing to building higher) and allows greater densities to be achieved with narrower units (whilst still achieving desirable GFAs). This allows units along Rugby Street to be reduced from 9m widths (as seen in the 'System Design Tests' in *Chapter Five*) to a 7.2m widths (dimensions of the largest module size) - more suitable for *medium-density* development.

Units open north-to-east at the street frontage, with the vertically terraced and stepped frontages allowing units to open over and in front of their Eastern neighbours (maximising solar access and views). Extended outdoor living spaces (roof balconies with wooden screening slats) limit visual contact into the unit's private spaces from the road, with the overhanging roof-balcony and eaves providing summer solar shading.

Fig 7. 01.

Below. A section through the Rugby Street elevation depicts visual privacy characteristics and the transitions from public, private and communal spaces at ground level in a perimeter-block layout that is absent of garages. It provides a good amenity model from which future 'Design Generations' can be based.

FLEXIBILITY AND ADAPTABILITY:

This design has limited customisation opportunities, lacking variation and flexibility for lifecycle stages. Whilst units allow flexibility with the panelised cladding, this is not shown and, due to the modular planning arrangements, they have limited opportunity for form adaptation/extensions. The standard two-storey units only accommodate a third-story extension with the addition of three modules following the pre-determined planning scheme (identical between all units). While aesthetically proportioned, the resulting street frontage appears somewhat monotonous.

In addition, it would be beneficial to provide a double bedroom at the ground floor level. This would make the ground level 'self-sufficient', with all the necessary domestic programs for a single-storey studio living space.

EXTENDED UNIT

Fig 7. 02. Floor plans of the Rugby Street units.

5m

AMENITY AND SPACE PLANNING MOTIVATIONS:

A key driving motivation for this concept is the consideration for amenity. Sections are sized to 150m² and achieve 34m² and 44m² outdoor ground level space at the front and back of each dwelling. In addition, there are several large modular balcony spaces extending off the first and second stories. Unit ground levels comprise of 65m² open plan living, dining, kitchen spaces, and laundry and bathroom spaces. This allows living and dining areas to open directly onto fronting public and rear communal outdoor spaces in order to achieve desirable privacy transitions. This is depicted in the section cut (fig. 7.01) featured on the previous page spread.

The permeability of the open plan arrangement is ideal for indoor-outdoor flow, direct daylighting, outlook and a sense of connection with ones surroundings. In summary - despite being fully enclosed on two sides, the occupant doesn't feel boxed-in.

The disadvantage in this design is the awkward step-in along the side of the units (at ground level) which permits access to the rear yard. This is labelled as a '(1)' on the ground floor plan featured left (fig. 7.02). While planning of this type may be desirable in detached, sparsely populated, open urban housing environments (for sunny patio or cloths drying spaces), it is cramped between two units in this typology with a second storey overhang preventing natural daylighting. This creates a negative, dim space and makes poor use of 16m² that could otherwise be infilled to create higher quality, habitable indoor space. This would allow units to be shorter in length, with the (originally stepped in) infill space being an addition to the rear yard.

Second Floor

First Floor

REAR YARD

Ground Floor

5m

Second Floor

First Floor

Ground Floor

Fig 7. 03.

Shows an exploded graphic of the modules and panels which constitute the construction of the three-storey 'extended' unit.

ENVIRONMENTAL FIT:

While a common feature of the surrounding townhouses, separation of units and the appearance of awkward gaps is questionable in a housing system that otherwise maximises space efficiency. Units lose about 7m² (23m² counting the awkward step-in previously discussed) down their sides due to their awkward separation with neighbouring dwellings. The justification for this separation is the resulting

vertical limitations of the modular construction system. When level, modules can easily connect in both the X, Y and Z directions (*Diagram One*). However, due to the sloping site topography neighbouring units are vertically offset and, due to the steel framing and panelised infill system, unable to connect (*Diagram Two*). This separation does however allow easier waterproofing, acoustic control, maintenance works and flexibility (removal or replacement of panels).

Diagram One

Diagram Two

Diagram Three

RUGBY STREET PERSPECTIVE:

While bringing a diverse new construction aesthetic to the area, the three-storey, separated units are proportionately in keeping with the surrounding Mt Cook context. Ongoing experimentation offers an opportunity to explore pitched roof typologies which further relate to the adjacent neighbourhood.

DESIGN GENERATION TWO

TASMAN STREET FRONTAGE

ENVIRONMENTAL FIT:

These units front westwards and, like *Design Generation One* development, are vertically terraced in elevation. Again they bring a diverse new construction aesthetic however with a modernistic stance (larger glazing units, joined units, built-in balconies and green roofs) to the traditional Mt Cook townhouse style. They reference the three-storey, 7.2m wide, pitched roof typology associated with the surrounding character which means that, with the exception of some material choices, these units sit better with the surrounding horizontal, vertical and skyline patterns.

DENSITY AND AMENITY:

The separation of units and resulting gaps has been addressed in this design phase through use of a non-structural partition wall, which allows higher densities to be achieved. Rather than a structural wall that supports modular attachments, the modules themselves offer structural stability, sandwiching the partition which replaces the panelised infill's and offering higher levels of acoustic and fire insulation.

Aesthetically, a critique of the previous and current design generation identifies a lack of design flair along the rear façades (backing the communal space) due to design attention being primarily along the street frontage. The solar and visual attributes of the Eastern boundary warrant more consideration and variation in design form with units opening both at their front and back.

FLEXIBILITY AND ADAPTABILITY:

The unit plans are identical to that of the Rugby Street generation and utilise the same number and type of modules (with exception for the pitched roof). This illustrates the system's capacity to allow infinite variability in the aesthetic outcomes through interchanging claddings.

The street frontage (right) also depicts some variety with some modules extending off third-storey units. There still is however a general lack of form flexibility and a greater need to depict a mix of material options and different lifecycle stages.

TASMAN STREET PERSPECTIVE:

DESIGN GENERATION THREE

REFINED DESIGN

TASMAN LANEWAY AXIS

Fig 7. 04. A solar plan of Tasman Laneway running North-west to South-east.

DENSITY AND AMENITY:

Judd's identification of the need for increasing densities to integrate outdoor space, "solar access, safety, security and privacy" (27) within the buildings form is reflected in this design. Access to outdoor amenity is highly emphasised and valued in this development with the seven units opening to both the East (Tasman Laneway frontage) and West (communal space). Units are subject to all day solar exposure. Numerous outdoor living spaces extend from various floor areas at both the front and rear facades.

Fig 7. 05. The 'standard' unit with ground and first floor planning.

Scale 5m

Fig 7. 06.

The 'expanded' unit with
first floor adaptations and
second floor additions.

SECOND LEVEL

Scale 5m

FIRST LEVEL

AMENITY AND SPACE PLANNING MOTIVATIONS:

Key to this concept is the ability to adapt from a single-storey studio unit (ideal for a couple) to a two-three storey, five-bedroom house that accommodates larger families. Regardless of the life-cycle stage, units are designed for flexible amenity. As units expand into two-three storey typologies, modular outdoor space becomes integrated through built-in and roof-top balconies.

As depicted in fig. 7.04 and mentioned in the corresponding text (on page 92), the units front South-west onto Tasman Laneway and have enhanced delivery strategies for flexible outdoor amenity. The fronting face has provision for a 32.4m² outdoor living space which is formed out of several adjoined modules. The space runs directly off the open-plan indoor living space, and is adequate for compact outdoor dining and other social activities. The structural frames of the modules provide the necessary vertical elements to support future overhead housing expansion. It also provides the necessary framing to allow raised decks to be placed over 'subfloor' framing with privacy screens, slatting and raised gardens running between the frames. Greenery can also be grown over the frames to enhance the privacy break and provide a well-formed 'interface' between the public street and neighbouring units.

The ground level comprises of a bedroom, living space (open plan kitchen, dining, and living/lounge) and a bathroom facility, with laundry space directly accessing onto a 26m² rear yard space. This yard runs directly onto the enclosed communal space and provides a perfect space for child play, clothes drying, patio area and other outdoor living functions.

Fig 7. 07.

Different lifecycle stages and flexibility options that accommodate changing spatial requirements. Note: The standard unit can when required contract into a smaller single storey 'studio' option. These above simulations ensure dwellings can ably accommodate expanding families between 2, 4 and 6 members respectively. The design of units heavily incorporate principles of 'slack space' and 'adding on'.

PERSONALISATION AND CUSTOMISATION – FORM FLEXIBILITY:

Judd recognises that ‘place identity’ is either determined by the designer (providing a variety of dwellings) or by the user having the ability to personalise developments (29). “Supporting personalisation includes making it physically easy. This means that the technology of the design should be well-matched to the expertise of the likely users” (Bentley, Alcock and Murrain 100). The systems simple technology allows the user to control their environment, and “encourages people to put their own mark on the places where they live...” (11). This means individual dwellings have a sense of ‘place identity’ that is easily distinguishable and recognised as ‘home’.

Fig 7. 08. A section render showing the interior fit-out, materiality and construction aesthetic of the interior ground floor living space.

Fig 7. 09. A section render showing the interior fit-out, materiality and construction aesthetic of the stair case and first floor.

Fig 7. 10. *Different flexibility scenarios (using 'adding on' and 'slack space' concepts) that are designer-anticipated but user determined along the Tasman Laneway frontage.*

The modular supports and panelised infill approach forms an interesting relationship when it comes to levels of control between the professional (designer) and the occupant. Much like Alejandro Aravena's social housing project *Quinta Monro* in Chile, this design has guidelines and anticipates where extension can occur, but allows the occupant to determine these expansions post-occupation as their space requirements change. This balance of control allows the "designer to create a varied but unified design within the parameters of market acceptance [and a cohesive street frontage], yet gives residents opportunities for personal expression within this framework" (Judd 29).

Fig 7. 11. Flexibility options of the Tasman Laneway units as seen from the Eastern communal space.

PERSONALISATION AND CUSTOMISATION – MATERIAL FLEXIBILITY:

Panelised infill's permit a high level of variety and allow designers and occupants to regulate any cladding aesthetics and control levels of personalisation and customisation. Both graphics depict the same design with different infill's demonstrating the high level of variety generated by simple material changes.

VARIETY OF FORM, MATERIAL AND LIFECYCLE STAGES:

The resulting combination of flexible form, diverse cladding infill's and different lifecycle stages give the opportunity for a high level of housing variety. Despite these levels of customisation there is still a cohesive street frontage and clear design language. This is for the following reasons;

- i) Building parameters are established and controlled by the designer at the design stage with desirable extensions anticipated and allowed for in unit planning. This early control lessens chances of occupant developments ruining the public street frontage.

- ii) Seven proportionate module sizes require the frontages to be vertically and horizontally ordered. Unit widths are limited to 7.2m which requires multiples of 1.8m for even infill. Unit frontages are proportionately halved using two 3.6m module widths allowing high levels of flexibility and accommodate all residential programs without structural penetration.

The orientation and planning of units means that extensions have minimal interference on neighbouring views, daylight and privacy.

Fig 7. 12. *Left. Shows a variety of unit forms at different lifecycle stages.*

Fig 7. 13. *Below. Shows a variety of material and form aesthetics resulting in a high level of variety, customisation and personalisation amongst units.*

DESIGN GENERATION FOUR

COMMUNAL SPACE DEVELOPMENT:

Fig 7. 14.

The relationship between private and communal space at the 'interface' (formed as a terraced perimeter wall).

ENHANCING THE AMENITY VALUE OF DEVELOPMENT:

This generation focuses on the *communal space* enclosed by the perimeter-block layout previously explored in the design generations.

The space is large, approximately 885m², and could (by definition of *MDH* ranging between 30-66 *DPH*) account for an additional 3-6 units. Such construction does not happen often due to the driving financial motivations of such projects. It is appreciated profit-orientated developers would be unlikely to commit to such landscaping due to the financial cost incurred unless incentivised by interested parties such as local government.

However, it was an early design decision to keep the space open. This is because the amenity value, improved communal interactions, social opportunities and safety and security advantages outweigh the revenue generated from additional cramming. The space is attractive for all stages of a family's life cycle, and brings similar advantages to the extra space and amenity as seen with detached housing forms.

When comparing the outdoor facility to design qualities established by Carmona et al. the space offers protection (from vehicles, crime, and weather), comfort (opportunities for walking and seating) and positive sensory experiences (solar access - sun/shade, warmth/cool, ventilation and visual outlook - planting and trees) (209). The space forms a 'weak sense-of-enclosure' because of the large width to height ratios between the outdoor space and perimeter buildings respectively (Carmona, Tiesdell and Heath 183). Its openness would enhance the quality of life for residents, particularly those with families and is a primary rational for undertaking this thesis.

PUBLIC TO PRIVATE:

Public and private "spaces cannot work independently. They are complementary, and people need access across the interface between them... Indeed, this interplay between public and private gives people another major source of richness and choice" (Bentley, Alcock and Murrain 12). Notwithstanding this, clear distinctions at the 'interface' must be provided for seclusion and security reasons while still allowing physical (and possibly visual) connection.

The distinction between private and public space is apparent in the concepts featured left. The perimeter walls act as a physical 'interface' limiting visual and physical permeability, allows physical movement around the communal space boundary and provide levels of security and seclusion for residents. Note: openings allow access to and from residences for those permitted to cross.

Fig 7. 15. *Left. Several design studies within the perimeter-block boundary.*

FLEXIBILITY AND ADAPTABILITY:

In many ways the fixed spatial arrangements and high level of design refinement limits opportunities for user-interpretation. The advantage of large open spaces lies in the flexibility and variety of options in recreational use. The level of design refinement as seen in both diagrams left, shows a design that, while nicely landscaped and visually attractive, closes opportunities for uses other than those controlled by the fixed layout of paths, walls and pergolas (i.e. limits activities such as sports, communal gardening etc.). It must be noted that if the level of landscape development is taken further, the level of refinement would need to be re-considered. An equally attractive option that enhances flexibility could be adopted.

DESIGN GENERATION TWO

DESIGN GENERATION THREE

DESIGN GENERATION ONE

DESIGN GENERATION FOUR

Fig 7. 16.

Design Generations One, Two, Three and Four as seen from an elevated perspective. Note: the physical 'interface' limits visual and physical permeability but allows physical movement around the private-communal boundary.

TASMAN STREET

RUGBY STREET

PHASE TWO

PHASE ONE

PHASE THREE

The design outcomes developed to this point conform to the *design guidelines* in respect of the *framework* established earlier in the thesis (page 28). Note: the *framework* is featured left.

The following observations are made:

- The hybrid system minimises site assembly and maximises production efficiency, standardisation, and flexibility. It also allows opportunities for mass-customisation;
- In the context of *density and amenity*, the horizontally attached, two-three story, 'front-to-back' perimeter housing enable development of appropriate scale, coverage and planning which fits with existing grain and allows opportunities for enhanced residential amenity.
- The site massing and limited visual and physical accessibility limit vehicular and pedestrian accessibility, retaining a high degree of communal privacy, safety and security for all residents.
- Wayfinding is clear for those pedestrians and vehicles that do use the space and provision of separate parking facilities for motor-vehicle storage opens up ground levels and street planes. There is also a clear privacy gradient from public street frontages to private dwellings, private yard and rear communal spaces. This connection with the rear communal spaces directly improves family amenity and allows free-flow child play and improved supervision over youths.
- In terms of the perceived lack of design flexibility in New Zealand housing: initial development of the system saw the delivery of construction system that was versatile in site and programmatic requirements. *Design Generations 1, 2 and 3* then gradually refined a building typology that enhanced options for unit extensions/adaptations, and through controlled planning, mitigated issues of daylighting, solar access, visual outlook, amenity and privacy (that arose due to the dynamic built form). This leads to a development that contributes diverse new construction aesthetics but is planned in overall form, scale, materiality and colour etc. for unified character and appropriate 'environmental fit'.
- Balanced levels of control between the architect, owners and other stakeholders allow dwellings to expand within strict parameters which are anticipated, but user determined.

The result is a building development of variety – varying lifecycle stages, customised forms and materials and personalised touches.

SITE DEVELOPMENT

Design Generation Five address the overall development of the site. It takes the highly resolved design outcomes from *Design Generations Three* and *Four* and applies them to the still undeveloped areas of the site. This gives an accurate indication of the densities that could be achieved should this project be taken further and also provides reassurance that the treatment of the individual road frontages combine to provide a cohesive overall development.

Fig 7. 17. *An elevated perspective of the site showing the unresolved corner junctions*

Total Area: 7378m²

Total Area: 1464m²

1 Hectare = 10,000m²
MDH = 30 - 66 units per 10,000m²

Area developed for MDH: 7378m²
Min no. of units: 22
Max no. of units: 48

Despite the high-level of outdoor amenity and open space, the total achieved units in the developed 7378m² is 32. This equals 43 DPH (mid-range MDH).

Review of the overall site planning reveals two further matters for consideration. One is the treatment of the corner junction of Tasman Street and Tasman Laneway (fig. 7.17) which is addressed in *Chapter Eight*, and the other is the separation of units along Rugby Street. With time, resolution of these issues would permit densities >46 DPH to be achieved (simply by fully developing the perimeter-block footprint more efficiently) without encroaching on the communal or other amenity rich outdoor spaces.

Fig 7. 18. Left. Communal space perspective one.

Fig 7. 19. Next page spread. Communal space perspective two.

SYSTEM DEVELOPMENT AND CORNER REFINEMENT

Evaluation of site layout in the previous chapter identified awkward angles and gaps occurring at the junctions/corners of separate *Design Generations* - particular the Tasman Street – Tasman Laneway junction (featured below). This is less an inherent limitation of the modular system, but rather a weakness in site-layout and urban planning. Use of the perimeter-block layout and angled axis cut has, on balance, found favour and therefore this corner junction is unavoidable.

There are two possible ways to address this issue, namely;

- i) Leave the space as open communal space. This presents several issues. Firstly, it's an unpleasant space wedged between two retaining walls. Secondly, moving the Tasman Laneway development South-east connects the corner space to the internal commune, allowing visual and physical permeability (a reason why site massing *Option 2* was avoided). This ruins any justification for a perimeter-block massing that otherwise limits thoroughfare, enhances security and privacy.

- ii) Celebrate the current corner and refine the modular system to accommodate angular irregularities.

On balance, option (ii) is favoured and possible solutions are explored and set out in the following.

SYSTEMS ANGULAR DEVELOPMENT

FIRST APPROACH

Fig 8. 01. *The first approach uses a hinge-like system that allows modules to pivot at their ends and accommodate varying angles (1). The problem remains when infilling this space which cannot be done evenly with regular modules (2, 3, and 4).*

2

4

SECOND APPROACH

Produce specific-angled modules or design the structural frames to be malleable with any requirements. This is very expensive, difficult to weathertight, causes irregular and awkward structural penetrations through living spaces and numerous other issues. Where vertical elements can more easily pivot, horizontal elements (floors, floor structure, ceilings) cannot be angularly flexible.

THIRD APPROACH

Fig 8. 02.

Below. Disassemble modules into their pre-assembled components which differ little to regular SHS. This offers little advantage over regular in-situ construction which uses easier, cheaper building materials such as timber framing.

Despite much consideration, no successful system could be identified for angular infill. This leaves two options. Either plan the site regularly and avoid angles altogether or celebrate the corners inherent opportunity for a fixed, mixed-use, iconic infill that stands out against its modular neighbours.

Zoning Plan

Movement Volumes

FIXED CORNER INFILL:

While not directly related to the modular aspect of this thesis, addressing the corner is an important consideration for the wider design issues (medium-density, amenity, context, variety, mixed-use development, urban planning) covered by this thesis, and necessary for resolving the site. This holistic approach was outlined in *Chapter Six – Site Investigation* (page 64) where it was identified that a complete and whole site proposal was necessary.

Due to the corners prominent location along Tasman Street and the high level of surrounding activity (Massey University, pedestrian and vehicular traffic and the *CBD*) it's logical to bring public functions into the building. The design makes a strong statement on the corner, standing out against the modular dwellings it's wedged between but retaining their vertical and horizontal proportions.

The design contemplates flexible internal space, accommodating various mixed-use commercial/public and residential/private functions. Its development raises the total site density to almost 45 *DPH*. The space is targeted for a work-from-home occupant (i.e. architect, artist) with the ground level acting as the businesses public front (i.e. exhibition space, office, gallery etc.) The upper two levels of the building focus on the residential requirements of 'dwelling' with living, bathroom, bedroom and kitchen facilities.

Fig 8. 03.

Right. Sections A and B illustrate the interior fit-out of the building. Note: the practicality of a light-well and vertical circulation at the buildings rear which is otherwise too angled for other program functions.

Fig 8. 04. *With the frontage facing west, the building captures afternoon and evening sun making it perfectly suited for social and living space functions. The ground level comprises a large, open flexible space that can accommodate various private-public functions - from a small architectural office to a coffee shop and artist's gallery. Note: Please refer to the previous spread to view the section cuts.*

Fig 8. 05.

Left. The first floor accounts for various communal and social-living functions (kitchen, dining, lounge, studio/office space etc.). The large void in the studio/office space has direct connection with the private residential foyer space.

Fig 8. 06.

Right. The second floor accommodating private living functions (bedroom and bathrooms).

Fig 8. 07. *External perspectives showing the corner development in the context of Tasman Street (below) and Tasman Laneway (right).*

Fig 8. 08. *External night perspective.*

Fig 8. 09. Bedroom two perspective.

Fig 8. 10. *Bedroom one perspective.*

Fig 8. 11. *Living space void perspective.*

Fig 8. 12. *Living space perspective.*

Fig 8. 13. Ground level public space seen used as a coffee shop/gallery space.

TECHNICAL RESOLUTION

OVERVIEW:

The previous chapters demonstrate the aesthetic possibilities of modular prefabricated construction. This chapter looks at the technical development of the system at a conceptual, but highly resolved level. Upon professional review, detailing would be subject to changes. It takes three simple modules (two 3.6 x 7.2m modules and one 1.8 x 5.4m module) and arranges them to achieve the maximum number of varied, complex corner, roof and foundation junctions that would typically arise in residential construction. The following technical drawings demonstrate the designs viability with focus on waterproofing and structures.

Specifications are compliant with New Zealand building codes in so far as practically possible, given the broad scope and new construction technology explored. This ensures building components achieve a minimum 50 year durability performance. Primary compliance is with NZBC E2/AS1 External Moisture, B1 Structure, B2 Durability, and Standards New Zealand: NZS 3604 – Timber-framed Buildings and NZS 3602 – Timber and Wood-based Products for Use in Building.

Fig 9. 01. *Right. The basic configuration of three modules achieving complex corner, roof and foundation junctions which are used to test and exhibit the functioning of the system.*

Because modules are planned to a 600mm grid, it allows floor and wall panel products (usually 1200mm in width) to be evenly placed. The plan above shows the layout of the steel sub-floor framing which is spaced to a 600mm interval. This allows 19mm x 1200x2400mm plywood sheets for 2kPa floor loading to be evenly laid, maximising production efficiency and minimising wastage.

Subfloor Plan
Sheet Number:
Scale:

A100
1 : 50

Ground Floor Plan

Sheet Number:

A101

Scale:

1 : 50

While the range of lightweight claddings are broad, the following details depict panelised infill using vertical shiplap weatherboard cladding over a 30mm cavity system.

These details illustrate the panelised systems ability to connect at an internal and external corner and flat wall junction. The timber framed panels (initially unlined) pop into the steel module frame (along with the correct flashing profile) where they are bolted in place (with varying expanding Hollo bolts) and internally lined.

GIB 10mm x 1200x2400mm Standard Plasterboard and GIB 10mm x 1200x2400mm Fyreline

2500 x 90x45mm framing timber studs for non-loadbearing wall panels. Spacing 300-400mm for very high wind zone

Expansion Hollo bolt (sizing TBC) for connection between panel infill and the SHS module frame

5 x 40x40mm SHS sub-floor truss for raised 2kPa structural floor - 600mm spacing

1 Panel Junction
1 : 5

Plan Details
Sheet Number: A103
Scale: 1 : 5

3 Internal Corner Junction
1 : 5

2 External Corner Junction
1 : 5

First Floor Plan
Sheet Number:
Scale:

A104
1 : 50

1 Section One
1 : 50

Sections One and Two
Sheet Number: A105
Scale: 1 : 50

2 Section Two
1 : 50

Section Three
Sheet Number:
Scale:

A106
1 : 50

Section Details

Sheet Number:

A107

Scale:

1 : 5

Section Details

Sheet Number:

Scale:

A108

1 : 5

Section Details

Sheet Number:

A110

Scale:

1 : 5

Section Details

Sheet Number:

Scale:

A112

1 : 5

Section Details

Sheet Number:

Scale:

A114

1 : 5

Section Details
 Sheet Number:
 Scale:

A117
 1 : 5

20mm vertical shiplap
 Cedar weatherboard

2500 x 90x45mm framing
 timber studs for non-
 loadbearing wall panels.
 Spacing 300-400mm for
 very high wind zone

H3.2 horizontal Radiata
 pine batten for 30mm
 cavity. 30 degree tapered
 top with a 7mm rebate for
 drainage. 400mm centres

3600
 First Floor

90x45mm H3.1 framing
 bottom plate

Modular bottom-framing
 structure (hot rolled 9 x
 100x100mm SHS)

Cavity flashing

3300
 Sub-Floor Two

Perimeter flashing

90x45mm H3.1 framing top
 plate

GIB 10mm x
 1200x2400mm Standard
 Plasterboard and GIB
 10mm x 1200x2400mm
 Fyreline

Unspecified floor finish

19mm x 1200x2400mm
 structural Ecoply flooring
 sheets for 2kPa loading.
 Tongue and groove edge
 profile. H3.2 CCA
 treatment for ground level
 modules in close contact
 with ground atmosphere

5 x 40x40mm SHS sub-floor
 truss for raised 2kPa
 structural floor - 600mm
 spacing

150mm PIR insulation board
 panels

Modular top-framing
 structure (hot rolled 9 x
 100x100mm SHS)

5 x 40x40mm SHS sub-
 floor blocking frame

1
 A105

Section Four
Sheet Number: A118
Scale: 1 : 50

Option A - Rock site

Several areas of concern were raised when speaking to construction and structural specialists.

- i) First is the layout of foundation piles and the exact tolerances required for the modules to vertically slot in place. A foundation template is proposed to set out and align the piles (above).
- ii) Second is the size and type of foundation piles for different soil conditions. The distinction between the two types (A and B) can be seen in the surrounding graphics with the table below (derived from soil classifications in NZS 3604) identifying the different soil conditions that these options need to be applied to.

Foundation Type				
Soil Classification				
Strong rock	Rock	Shallow soil	Deep or soft soil	Very soft soil
Option A		Option B		

Option B - Deep/soft soil

Hot Rolled SHS Moment Frame Structure

Seismic Zone (determined by NZS 3604)

1	2	3	4
---	---	---	---

Wind Zone (determined by NZS 3604)

L	M	H	VH	EH	SED (NA)
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100x100 x 9 SHS

125x125 x 9 SHS

Fig 9. 02. Above. Seismic and wind zones (derived from classifications in NZS 3604) corresponding to different structural member sizes.

Fig 9. 03. Left. Steel moment frame structure resisting lateral (wind and seismic) and gravitational loads. The addition of panelised infill gives the frame a huge amount of additional lateral resistance (the infill components act in the same manner as shear/rigid sheet bracing).

Another issue that was raised is the sizing of the structural members that make-up the module frames. Due to the sites very high seismic and wind zoning (Wellington), the design requires 9 x 125x125 SHS members. Despite this structure having an additional 25mm of steel compared to the 9 x 100x100mm frame (suitable for Auckland etc.) the design still works with the same construction principles depicted earlier.

1

2

3

Concern for the roof overhang was also raised in the previous construction details. These showed the overhangs as boxed out and framed-up using timber construction. This fixed construction however is not flexible and deficient in structure. In addition, when adjoining

separate modules this overhang presents a major problem, and must be physically cut away. It is proposed that the roof overhang be configured using 5 x 40x40mm framing as seen in *diagram 1* above, which can be easily unbolted from the main structure (*diagram 2*), allowing a flush finish between the two modules (*diagram 3*). The roof joint can then be sealed using the fiberglass (GRP) roofing finish.

CONCLUDING STATEMENTS

WHERE TO NOW?

Given the inevitable restrictions to the scope of this research thesis there has been limited focus on environmental sustainability, cost analysis and affordability of the proposed construction system. Given time, each of these matters could be fully researched. Initial research has identified the production attributes of prefabrication technologies (mass-production and standardisation) and its feasibility as an affordable construction technique. If the project was expanded beyond the original scope, provision of realistic cost calculations, cost-breakdowns and profit expectations would significantly advance analysis of the project's economic feasibility.

The 'modular supports and panelised infill approach' was selected early in the project in preference to the 'fixed supports and modular infill' approach (pages 41-42). This was due to what was considered to be its greater potential as a flexible housing system. It would be interesting to further test the 'fixed supports and modular infill' approach by developing the mixed-use parking, commercial and residential complex discussed in *Chapter Six*.

Other aspects that require further refinement are the untreated corner junctions, the separation of units in early design stages (*Design Generation One*), the angular flexibility of the system (*Chapter Eight*) and the overly-refined communal space that consequentially restricts flexibility (*Design Generation Four*).

CONCLUSION

This thesis has addressed the question: "how can the design and construction of *medium-density* housing be improved through use of prefabrication technologies so as to provide greater flexibility to meet changing demands of residents for both indoor and outdoor space?"

This resulting investigation has explored how use of prefabrication technologies could improve design and construction of *MDH* and provide inspirational and affordable housing alternatives. The result is a housing model which has potential

to offset the resistance and adverse public perceptions commonly associated with intensification by addressing the negative implications.

It postulates that intensification, when carried out carefully in a considered way can promote efficient land use, positive health outcomes and social wellbeing and generally enhance the lifestyles of residents and their communities.

A variety of solutions have been explored, from use of modular technologies through to enhanced site planning. Outcomes are assessed against current intensive housing issues; *'density and amenity'*, *'environmental fit'*, *'flexibility and adaptability'* and *'production efficiencies'*. These *framework* areas provided a strong basis for design and project evaluation, and form a foundation from which future design projects can be modelled.

Production efficiencies

The thesis demonstrates that prefabricated technologies offer a solution to the challenge of providing housing that is more efficiently produced and flexible. While the efficiency of this system centres on standardisation and mass-production, the possibilities arising from providing an inspirational, mass-customised housing alternative are unlimited. It is hoped this system could come to be recognised as providing an affordable alternative to the fixed, timber-framed, repetitive typologies that have proven themselves financially reliable and compliant with basic standard and code requirements. While such housing has long been the dominant form of housing construction in New Zealand, private enterprise must be cognisant of the superior attributes of modular technology, and its potential as the new model of residential construction.

Environmental Fit

Mt Cook site was chosen as a test site in part for its central location, distinctive character and strong heritage but also because it provides a challenging site in which to appropriately fit a new housing aesthetic and intensified development. Research of the area identified narrow, two-three storey, pitched roof town house typologies. Consideration was given to the extent new-density development could fit with and work into this existing context.

One aspect that has not been adequately addressed is the exploration of a housing typology that fully reflects the surrounding character. Whilst the studies so far have convinced me that it is feasible, it hasn't been demonstrated. The project could be advanced further by extending and testing the design outcomes into a number of diverse sites. Ideally these would include a site with a steeper topography (to test the construction limitations of the system) and secondly a small scale infill site to test the system 'fit' within an existing, intimate setting.

Despite these limits, the thesis concludes that flexible modular technologies and intensified development would allow a high level of 'environmental fit' with existing urban character and, with a considered approach, should be able to limit the concerns and opposition displayed by unhappy residents.

While future projects may possibly have stronger reference with the surrounding character (materiality, window patterns, doors, intricate façade detailing etc.) the development explored adequately reflects the desired level of 'place identity'. To clarify this, the intensified coverage and construction technology bring a distinctive new aesthetic to the test site, while the vertical and horizontal proportioning of units, scales, forms, skyline patterns, materials, continued variation and personalisation all reference the established character and provide a suitable balance of 'new' from 'old' - an appropriate level of contextual fit.

Flexibility, density and amenity

With adequate planning, intensification can promote both an efficient use of land (allowing developers and planners to achieve desirable densities for profit margins and urban planning purposes) while still providing high-quality, safe urban lifestyles for individuals, families and communities.

Integration of amenity is considered in several scales.

Firstly, at the modular scale, the thesis has assessed the need for New Zealand housing to accommodate shifting requirements and to adapt with changing demographics and social environments. It identifies that housing is too often designed using fixed, inflexible parameters and that modular and panelised technologies offer a solution to the challenges of providing housing that is flexible and adaptable in spatial configurations and functionality, and offers high levels of customisation and personalisation.

The system isolates load-bearing elements to the structural module frames allowing panelised infill's to be easily removed. Roof trusses come in the form of separate modules and services run through raised floors. This technology, combined with adequate planning, has resulted in the flexible housing model that can be regarded by developers and occupants as a re-usable commodity, continually subject to change.

The proposed system allows modules to stack and extend from various floor and roof spaces, with consideration for solar access/natural daylighting and privacy. As densities increase during the lifecycle of a development, limited outdoor spaces diminish further. Therefore the ability for outdoor amenity to physically adapt with a dynamic built-form is crucial. It would be interesting to test the limitations of the system in terms of the scales such a housing system could achieve.

A design weakness with the thesis is the regularity of module forms, which limit design outcomes to 'blocky' masses: expandable in only two orthogonal directions (aside from vertically). Apart from the fixed-construction corner junction, there

are no interesting angles in the modular forms because the system simply does not allow for this. This is something that could be extended in the future, as it would enhance the limited variety and uniformity of the design outcomes.

Secondly, at site scale, there is a strong focus on private and communal outdoor living space. While the perimeter of the site is developed to its maximum covered potential, there is planning for vertical expansion and for high levels of personalisation, customisation and variation. Consideration is given to the effects such changes will have on privacy, daylight and outdoor space.

The thesis outcome identifies that despite closer living conditions and a density of 45 *DPH*, (this could be even higher with resolution of the separated Rugby Street units and corner junctions) sufficient outdoor private and public spaces, generous unit sizes, adequate visual and acoustic privacy, daylight, play spaces, security and safety, pedestrian accessibility and wayfinding, traffic management and off-street separate parking can be achieved.

SUMMARY STATEMENT:

This thesis presents the case that considered use of prefabrication technologies can help revolutionise *medium-density* housing and illustrates that it need not automatically be viewed as a cheap form of mass housing construction. It seeks to demonstrate that prefabrication has the potential to help solve the significant housing issues that we face given demand for housing outstripping supply and well located land being a finite and sought after resource. Hopefully it may help spark new enthusiasm for the topics of flexibility and intensification because together these concepts have potential to “enhance the quality of life for residents, increase public acceptability of more intensive housing, and contribute to the building of more sustainable communities” (Turner, Hewitt and Wagner 4).

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