A new building typology for the changing society.

The usage of modular architecture and mixed buildings to aid the Dutch housing shortage

Master Thesis

By Anwar Lemnawar
4727576
AR3AD100
Advanced Housing Design, Ecologies of inclusion MSc 3

Mentors:
Anne Kocklekorn
Olv Klijn
Ruurd Kuijlenburg

Content

Introduction

In the past few years, the housing crisis has become an increasing problem globally. This issue is not as simple as it seems and is a problem that consists of political, economic and physical factors.(Lengkeek & Kuenzli, 2022)

Affordability has become a topic which is the focal point in the Dutch discussion about the housing crisis. Most students and starters cannot find a place to live. If these target groups want social housing they end up on waiting lists where they have to wait for multiple years. Buying is out of the question unless you have 2 high earners and private rent has become too expensive and scarce. There is too much demand and too little supply (in desired areas). On top of that material prices are rising incredibly fast due to supply chain shortages which were amplified by the COVID pandemic.

The target group that is being hit the hardest during this housing crisis are starters and single-person households.(Van der Heijden and Boelhouwer, 2018) These groups which overlap, are in dire need of affordable and qualitative living spaces but due to financial constraints(high land price, high entry barriers), they are unable to find good homes that fit their living need. According to Hoppesteyn (2012) the elderly, a group of people with the age of 65+, will increase by 30% from 2012 until 2035. This means the increase in elder homes and 1 person-household dwelling are important to facilitate.

On top of this trend, there is also the fact that land is finite which means that there is a need to use land as efficiently as possible if we want to keep living on this planet. Production is being pushed out of the city and this means that we need land for living and land for production. If we as designers can find an efficient way to mix the usage of land for production and living we can house more functions without the misuse of land which can also help in affordability.

In this graduation studio we are desiging a mix used building in the Keiler Harbour in Rotterdam. The Keiler Harbour is a harbour in Rotterdam that was mainly used for industrial purposes, throughout the years the usage of that harbour area has changed. The harbour is now largely used for creative production and production that is normally not desired in the city and mostly pushed

outwards (i.e. waste management). The municipality and urban planners see the possibility of the area being used for housing and production with their urban plan called M4H. They have the ambition to house new ways of manufacturing and mix this with dwelling but if a closer look is taken at the plan of M4H there are no ambitions to create affordable housing. But the redevelopment of the Keiler Harbour is an opportunity to research the possibilities to create affordable housing and production spaces using a modular architecture.

1.1 Problem statement

The housing market in the Netherlands, which is heavily influenced by governmental policies, is under pressure as it has become unable for the majority of starters and single-person households to acquire a home. There is a housing demand that can't be met, resulting in the Dutch housing shortage. This paper researched the long-term and short-term solutions to this problem but also with a design aspect.

Almost every industry has had automation become a part of its supply chain, automotive and electronic industries produce their products in a automated factory (Luther, 2009). Architecture/housing has lacked this innovation of automation on a large scale. Prefabrication is mainly used for small parts of a building and not the complete building. Although it was seen as one of the ways to solve the growing need for housing by many 20th century architects like Le Corbusier, Moshe Safdie and Kisho Kurokawa.

An architecture that can incorporate this automization is called modular architecture,this is a kind of architecture that utilizes modules which are built off-site and put together on-site to speed up the building process like in Habitat 67. Although this kind of building process is being used on smaller scales it could be a possible way to impact how fast we can build and help reduce the short-term housing shortage.

So with this paper, we research how modular homes can be used as a way to make affordable housing that is sustainable not only for environmental standards but also for an ageing society. Modularity brings more advantages besides building faster or cheaper it also makes the building process more efficient as there is 60% less construction waste (Jaillon et al, 2009)

Secondly a mix-use typology that facilitates living and new ways of manufacturing is a needed typology for the future and is something this research and design answers.

The main research question that emerges from the problem statement and the relevance is:

How can the mix of modular homes and new ways of production help in solving the housing crisis in the Netherlands in terms of affordability, scalability, and sustainability?

1.2 Methodology

To answer this question a literature review will be conducted to find the answers to a set of research questions. These questions are described at the end of this chapter.

Chapter 2 begins with the definition of the housing crisis that the Netherlands is facing at the moment. Furthermore the chapter wil explain how this housing crisis can occur and which factors play a role. These are explained by literature review which gives an overview of the main problem and what the reasons are for this problem. From this chapter we learn what is needed to better help the housing crisis the Netherlands is facing.

Chapter 3 explains the need for a mixed building typology their benefits and their challenges. This is done by analyzing literature reviews and the usage of new manufacturing typologies. Furthermore the term hybrid factory will be explained and an approach to designing these spaces for future sustainability.

Chapter 4 focusses on modular architecture. This research w explores how modular architecture can help in reducing the housing shortage. This means it is important to know the definition of modular architecture. The chapter contains a brief historical analysis about modular architecture. Afterwards it will give an insight in what different types of modular architecture there is and what the positive/negative outcome is for using this type of architecture. The questions that are answered in this chapter are: What is modular architecture?

What are the benefits of modular architecture? How can modular homes fulfil living demands for starters, the elderly, and makers for the present and the future? This is done by literature review and case studies.

Chapter 5 is about the contemporary living needs as it is important to know what current living needs are and the changes that are happening in our society. These needs and future needs are analyzed by using literature reviews and using case studies.The main question that this chapter answers is How can modular homes be used to fulfil living demands for starters,students, the elderly, and makers?

The case studies that will be studied are:
Bremer Punkt, Nakagin Capsule Towers, Habitat 67.

This theoretical framework provides a better understanding of the housing crisis, modular architecture and how to create qualitative dwelling for the proposed target group. This output will be implemented in the design of the graduation studio.

Research questions:

- What are the factors that play a role in the Dutch housing crisis? Political? Financial? Physical?

- What are the benefits of mixing production and dwelling and how can a designer facilitate this mix?

- How can we mix production and dwelling?

- What is modular architecture?

- What are the benefits of modular architecture?

- How can the design of a mix use unit contribute to affordability in M4H.

- What are the living needs for elderly,starters and students.

- How can modular homes fulfil living demands for starters, the elderly, and makers for the present and the future?

1.3 Relevance

Altough there are papers on the subject of modularity and creating housing quickly by using this typology, these researches tend to focus more on the technical aspects than the societal or political aspects. The housing crisis as been proven to be a problem which has factors on multiple levels. Due to this being a multiple faceted problem it is important to have research that covers modularity on all these different fronts.

It becomes clear after this research, that modular architecture can have economical benefit/value if used correctly and on a larger scale it can have an environmental value as well as using modularity reduces waste and creates a certain circularity in the building process.

This research also focusses on how a designer can think about creating spaces where students, elderly, starters and makers can work/live together. This research can have a societal impact or contribution.

Raworth (2018) brings an important point forward as she states that for a large period in time industry is focused on generative design. This means resources from earth are used to produce something and at the end we throw it away. But this system has a negative effect on the earth as it is finite. There needs to be a change in our industrial system to a regenerative design. This means you have a system that is circular where once waste is the others resource.

Thirdly our society is changing continiously, and our current housing stock is struggling to facilitate this change twards single person households. It is important for the built environment and society that we better understand how to design buildings that are flexible, affordable and mix-used.

This topic and research can contribute to this point, as there are modular ways of building that enforce this regenerative design but also from a programmatic

standpoint where production and living can be programmed in a way that it is functioning as a circulative economy.

1.4 Theoretical framework

1.4.1 Affordable Housing and the housing market

Van der Heijden and Boelhouwer (2018) are leading experts on the housing-market in the Netherlands. Their research and analysis of the housing market will be defining for our understanding of the housing crisis. Lengkeek and Kuezli have analyzed the housing shortage from a different angle namely from the angle of a shared economy. They make an argument for cooperative housing ,a new form of financing housing, and their financial but also architectural benefits. They explain what is necessary to make cooperative housing work in the Netherlands. The Urban Land Institute a global non-profit research and education organization did research for intermediate housing and what bariers exist to increase housing supply and providing more intermediate argue that modular construction can help provide intermediate housing.

1.4.2 A mixed used building

The need to use land more efficiently has become important since the housing crisis. Urban planners are more aware that land is finite and that there is a benefit in finding ways to incorporate manufacturing into the urban fabric. The work of Nina Rappaport "The need for a hybrid factory" speaks about the need to incorporate manufacturing into the urban fabric and its benefits to the city,workers and citizens. To understand how we can design these types of buildings "A New Model of Hybrid Building as a Catalyst for the Redevelopment of Urban Industrial Districts" by Timothy Love (2017) is used to see what challenges, mixing these functions can bring and how to mitigate those challenges as designers.

New manufacturing methods are important in the mixing of manufacturing with other functions as they have better aligning needs than traditional manufacturing. For this analysis "The rise of 3-D printing: The advantages of additive manufacturing over traditional manufacturing" by Mohsen Attaran (2017) is used to understand what the benefits of new production methods like 3D printing bring and their impact on the city and its citizens.

1.4.3 Modularity

In this research we find out how modularity can help in the current housing crisis but also its impact on sustainable building design for the future. The history of modularity is important to understand what challenges modularity has faced and is facing at the moment. Marquit (2013) has done a thorough analysis of this history and is used to better understand this history. Luther (2009) is used to understand what modularity is and what its benefits are to the building process but also to the future of housing production. Bremer Punkt designed by LIN Architects is one of the case studies we analyze to see how modularity can be implemented whilst providing quality to the city, neighbourhood and its residents.

1.4.4 Contemporary living needs

As one of the problems are that living needs are changing in our society (source) and our housing market is inflexible in facilitating this change(further explained in chapter 2 and 4) it is important to understand what the current living needs are of this society and what trends are seen in this change. When we as designers better understand this type of living we can facilitate flexible housing that can house different housing needs for now and the future. BPD(2015) a housing organization in the Netherlands has done extensive research in housing needs in the Netherlands and the type of living environment our target groups want to live in.

Chapter 2: The Dutch housing shortage

As stated earlier the costs of housing have gone up significantly and it has become incredibly hard for single-person households and starters to buy or even rent. Waiting lists that last for years are common now and it has become a large crisis that the Dutch government has appointed a minister of housing which was disbanded from 2010 until 2022. Therefore it is important to look at the history of the housing market to understand what this crisis is and how these problems occurred.

2.1 The Financial crisis in 2008

In 2008 the whole world was hit by a financial crisis which occurred because banks and other financial institutions where giving a large amount of mortgages to people who could not afford them. They took too much risk in these mortgages. When the housing prices started to decrease and a lot of people could not pay their mortgage these "safe" investments started to fail. This hit the economy hard as a large sum of money disappeared in a short period.

According to Van der Heijden and Boelhouwer (2018) the Dutch housing market reacted immediately to the financial crisis of 2008. Trust in financial institutions and the economy was lost and the housing market entered a slumber. The number of transactions on the housing market declined from 202.000 in 2007 to 110.000 in 2014. The amount of houses that were being sold was 25 times higher than the houses that were bought and the value of these houses decreased by approximately 20%.(Van der Heijden and Boelhouwer, 2018)

A large amount of the houses had a lower value than their mortgage and because of this debt most people could not afford to move. The demand for rental housing rose because the flow between rental and owned housing was too low. During this the production of new housing decreased from 80.000 in 2017 to 45.000 in 2014. This decrease was only in owned housing until at least 2012. This meant that the flow between rental and owned housing was even lower and this increased the demand for rental housing.

This reduction in housing production also resulted in problems for municipali-

ties and companies in the building sector, as most of their income comes from land sales and building. During the crisis land was not bought as frequently which meant that most land was a cost sink for municipalities and developers. This meant that municipalities and companies had to sell their land for extremely cheap prices which resulted in a loss of billions (Van der Heijden and Boelhouwer, 2018). The building production was reduced by 75% compared with the building production in 2007 and the employment opportunities shrunk by 70.000 working years. (EIB, 2014)

2.2 Policy during the crisis

During the crisis, some major policy changes were introduced. The government started subsidies and law changes in 2010 to finance and build, building projects more quickly. There were no concrete agreements formulated for the municipalities as they were in charge of housing. In 2011, financial institutions and policy changes made it more difficult to get mortgages. Financial institutions had high demands and not everyone could get a mortgage, also the rents were raised to a point where it was not interesting to get a mortgage for people. This then impacted the owned housing sector as there were not enough buyers to meet the demand, which in turn impacted the rental housing sector.

In 2013 the housing crisis reached a peak as political parties made the 'Woonakkoord' which introduced a 1.7 billion euros imposition on regulated rental housing (which was mostly social housing) and an income-dependant landlord levy. This made it near impossible for housing corporations to invest and lead to the further reduction of housing production. The housing production of corporations shrunk from 10.000 in 2010-2012 to 5500 in 2013-2016.

The government and financial institutions took a pro-cyclical approach which means they invest when the economy is in a good state but thrift when the economy is in a bad state.

2.3 The aftermath of the crisis

During this crisis one factor that kept growing was the population, working immigrants made the population grow faster than was expected because of its unpredictability. The prognosis was originally 20k per year but it was larger as it was between 40k and 80k. (Van der Heijden and Boelhouwer, 2018). Although the growing population was not the only problem as the number of households grew which also meant that housing demands grew. Households grew as the average age was growing and people live independently for a longer time.

At the moment the average usage of m2 per person in different households is skewed. As you can see in the diagram below the average m2 per person in a single-person household was 70m2 (CBS,2018). In 2021 the CBS has updated this figure and it has risen to 88 m2 for a single person household. The average for a two-person(couples) household is around 64 m2 which is 27% less than one person households. If we compare this with three-person(couples with kid) household the average goes down to 34m2. The reason one person households usage of m2 are higher than the other household types is not mentioned by the CBS but the restricted flow between housing for mainly elderly can play a role in this number being high. As they are not motivated to move to a smaller dwelling because there are no viable options for them. According to CBS (2021), single-person households will grow by approximately 800.000 by 2050. The large amount of square meters that are used for 1 personal household shows that this has a role in the housing shortage as people live on too many square meters than necessary.

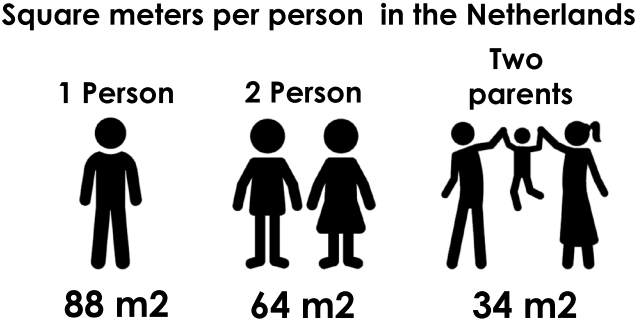


Figure 1: All the average square meter usages for the 3 different types of households. This shows the large difference between 1 person and multiperson households. (CBS, 2021) Drawing by Author.

Due to the reduction in housing production and the increase in households, the housing shortage is up to 200.000 according to Van der Heijden and Boelhouwer (2018). To solve this a yearly housing production of 75.000 to 80.000 are needed during the time of their research. That number has grown over the years as the shortage has increased each year. If we look at housing production, in 2015 the amount of housing that were built was 50.000, in 2017 63.000 and in 2021 79.000 as can be seen the growth in housing production is relatively slow.(Van der Heijden and Boelhouwer, 2018)

Now housing prices have recovered and have grown significantly but there is still a housing shortage. Due to the fact that during the economic crisis and the reduction in employment opportunities in the built environment, a large amount of building companies and employees had to look for ways to earn a living as housing was not viable anymore. This meant that there was and untill this day still is a shortage of manpower, knowledge and in turn materials. During the economic crisis, most of the plans for development were scrapped and abandoned. Scaling the housing production has been an issue because the few companies that exist cant scale easily as they are dependent on manpower, development plans and knowledge. Apart from the manpower and material availability the average time it takes to build in the Netherlands is around 5 to 10 years, this is also due to the bureaucratic processes that are needed for development.(Van der Heijden and Boelhouwer, 2018)

More homes are needed to properly house the Dutch population, and also to facilitate the growth of this population. For the long term, it is important to also look at the availability of building plots. Research from the ABF (2018) shows that there is enough building capacity until 2025. The current policy is to build mainly in urban areas and optimize the possibility to build homes in the city. But most building plots are located in the provinces Noord-Holland, Utrecht and Noord-Brabant but these locations are also places where the need for living is not as high as in the popular locations in the Netherlands according to Van der Heijden and Boelhouwer.

2.4 The housing corporation and middle segment

Aside from the issues surrounding the start of building projects, there is a second problem in the current market. The Netherlands has a flow market which means that households fulfil their changing living needs with the action of moving to another house. To make this flow model work it is important to have a wide variety of not only housing typologies but also ownership typologies. This is also necessary to facilitate the changes over time in demand for rented or owned housing.

The current market in the Netherlands has a hard border between different segments which makes it hard for people to make the next step. Housing corporations are mainly responsible for building affordable housing for lower-income households. This responsibility is for existing housing in their portfolio but also for newly built housing. The segment of mid-range housing and expensive housing is fulfilled by private developers. If the history of housing corporations in the Netherlands is researched it becomes clear why their main focus is/was on low-income housing.

In the early 19th century industrialization in the Netherlands created a high demand for labourers in the city. Many workers came to the city which created a high demand for housing. This led to one of the first housing crises in the Netherlands. The rent for housing was extremely high compared to the salaries workers was paid and the living conditions were unhealthy. This forced the government to take action and introduce the Woningwet in 1901. This law was meant to ensure that housing was being built to be affordable and qualitative. This law also introduced housing corporations that would get support through subsidies, guarantees and loans from the government. To create these housing corporations the one condition was that they were not disrupting the market. In the later years, the main criticism of housing corporations was the fact that they were given benefits which other investors/developers in the private sector don't have. They had lower rents on loans, they had support from a central fund for public housing and they had lower prices for land. (Kuenzli and Lengkeek, 2022)

In 2015 a new Woningwet was introduced that regulated housing corporations more to address the concerns mentioned earlier. The most important rules that have an impact on the housing market are the following.

- Create affordable housing

The most important task for housing corporations is creating affordable housing for low-income households.

- Assign housing accordingly

Housing corporations have to assign 85% of their housing to households who earn less than 42.000 . The other 15 % is for households who earn more than that amount.

- Division in social and economic ventures.

Housing corporations need to separate social and economic ventures so the taxpayers won't pay for investments that don't work out.

Because of these restrictions a lot of housing projects from housing corporations were sold to private investors and the housing corporations are limited in providing housing for mid-range and high-range households. (Kuenzli and Lengkeek, 2022)

This fact makes it harder for housing corporations to fulfil the living needs of mid-range households (between €35k and €50k income) and the private developers don't develop enough housing in this segment as they are mostly focused on maximizing profits which in turn means they mainly develop for the high-range households. Van der Heijden and Boelhouwer (2018) mention that the supply for rent between €750-€1000 is extremely limited. It is important to understand that this report about the housing shortage in the Netherlands is done in 2018. This means that now 5 years later, the rent for mid and high range housing has increased. This means the flow in the housing market has become even more constricted which in turn again has an increasing effect on housing costs. On top of that mortgages became difficult to get as the requirements became stricter, which made it harder for starters to own a house.

Access for mid-range households (which also means starters) is mainly the crux of this problem. There is no affordable housing in the rental sector for mid-

range households which makes it impossible for them to rent. On the other side they don't earn enough for an owned house as the requirements of mortgage loans have become stricter. Mid-range households that live in social housing won't leave because the next step is unaffordable for them. This makes the waiting list for social housing longer and longer. Because of these facts, the flow in the Dutch housing market is becoming constricted. This hits especially starters and mid-range households which in turn hits every other household that participates in the housing market.

Now we have a better understanding of the problems that resulted in the current housing crisis, this can help us as architects and developers to help solve this problem, but there is one big factor which is the housing market itself. The notion of commodifying housing is one of the reasons we are experiencing housing crises in general. The capitalistic system is based on demand and supply, land is limited which means that in time the land will always grow in value as our population grows. So we need a solution for the long term to keep houses affordable, although the housing corporations have the sole purpose of creating affordable housing they are still functioning within the logic of the market and are still profit-oriented, but Kuezli and Lengkeek (2022) argue for new types of ownership they say to create a sustainable system for housing. The cooperative model is a model where people together finance housing and live in it. This model has been particularly successful in Zurich in creating affordable and high-quality housing.

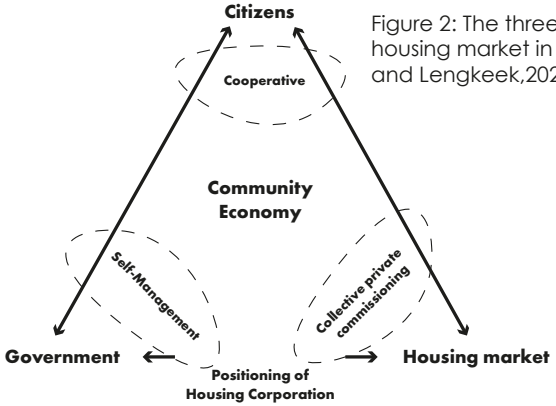


Figure 2: The three forces that move the housing market in the Netherlands. (Kuezli and Lengkeek,2022) Drawing by author

In the diagram, we can see the three forces that are part of the housing system. At the moment the government and the market are seen as the main

forces that need to solve the housing issue. But the force of citizens and the benefits they can bring is often ignored. If we lean towards citizens in this housing system we get the term housing cooperative. A housing cooperative is what Kuezli and Lengkeek call a community economy. This means the economy of this housing cooperative is focussed on the community, their shared goods and their own system of rules and transactions that are sustainable. A housing cooperative starts with the initiative from citizens that unite and start an institution that has the sole goal of creating affordable, qualitative and good housing. The tenants band their capital and are co-owners of the cooperative. The tenants can use their dwelling and shared services at a price of cost-rent. Cost rent is rent that is calculated on the cost of maintenance and providing the dwelling without profits. So in essence a housing cooperative doesn't focus on profits like the other housing forms do but on the usage/ need.

Housing is not a commodity in a housing cooperative but a necessity or a right without the logic of the commercial market. The tenants decide together in this cooperative on every aspect. (Kuezli and Lengkeek, 2022)

2.5 The core of the current Dutch housing crisis

From the analysis of the Dutch housing crisis by Van der Heijden and Boelhouwer (2018) and the research by Kuezli and Lengkeek (2022), it becomes clear the Dutch housing crisis is a multi-faceted problem that needs solutions for the long term and the short term. The following problems are the reason we are in the current housing crisis:

The financial crisis in 2008 started a domino effect on the housing market due to the acyclic approach to the housingmarket from financial institutions and the government. Because of the lack of jobs building companies pivotted or dissapeared. On top of that households increased more than expected.

After the housing market recovered and there was a need in housing again the following issues started to form the Dutch housing crisis.There was a restricted flow in the housing market due to the middle segment staying in their low-income housing which restrict the lower segment. When the housing market started to rise again there started to be a shortage in material, manpower

and knowledge. The housing market is not flexible enough to facilitate the change in households and the flexibility in ownership. Due to the existing shortage our building speed is not fast enough to stop it from snowballing. Housing corporations are limited in their capabilities while they are part of a possible solution to the housing crisis. There is no proper policy in the Netherlands to facilitate new forms of financing housing like the housing corporative.

To prevent future growth of the housing crisis the problems that cause the current housing crisis needs to be addressed from a political, urban and architectural standpoint.

The hardest hit target group are mid-range households who are mostly starters and elderly which obstructs the housing flow in the market. This impacts lower-income households as the mid-range households stay in lower-income housing because the next step is either to expensive or not available. So the focus in this housing crisis should be on these starters, elderly and low-income households.

There is need for quicker building processes not only physically but also in policy. Land for long-term affordable housing needs to be sold with a far lower price than market-value because this is one of the biggest factors in the rise of prices we are seeing. But also in the actual building process there is a need to work more efficiently with materials and labour time. When this can be implemented the flow of the housing market can get unclogged which stops the snowballing effect of the housing shortage,

The housing stock is not flexible which makes changes in household compositions and housing demand harder to facilitate. The future housing market in the Netherlands needs to find a way to create flexible housing stock which can be placed where its needed and removed where it is not needed anymore.

Policy changes need to be made regarding new forms of ownership. Since 1951 the main actors in the housing eco-system are the government housing associations and private investors. Citizens of the city can help in new ways of providing housing and this comes with new types of ownerships like cooperative housing.

To help solve the Dutch housing crisis the following strategies need to be implemented on the long and short term:

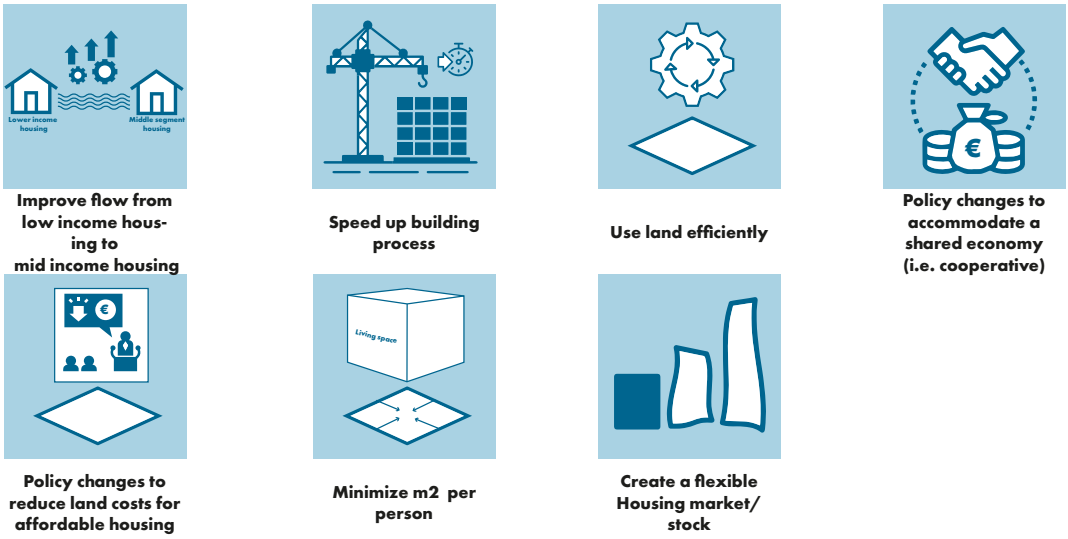


Figure 3: Strategies to tackel the housing shortage on short and long term. Drawing by author (Lemnawar, 2022)

Now that we have a better understanding of the Dutch housing crisis we have to take a deeper look into using land efficiently and using mixed building typologies to achieve this goal. Modularity will be analyzed as a possible solution for issues like speeding up the building proces and creating a flexible housing market/stock

Chapter 3: Mixing production and living, the need for a hybrid city.

As the housing shortage is discussed in this research it is important to include the role of production and manufacturing. The land is limited and the efficient usage of land is becoming more and more important. As our project is located in the Merwe haven in Rotterdam which was and still is a place where production can flourish it is important to research the possibilities of combining production with living.

3.1 The history of production and the city

Since World War 2 and after the war production was moved to the urban borders, this was mainly due to the pollution in terms of noise and sound and the impact on health. But still, there is a push out of the city attitude towards production in the Netherlands due to its challenge to mix it with living. If land use needs to be more efficient it is an important goal to research how production can be mixed with living.

Nina Rappaport an architectural critic, who is the director of the think tank Vertical Urban Factory, studies contemporary factories in terms of technology and the architectural issues that have an impact on the city and its users. In her article Hybrid Factory | Hybrid City (2017) she tries to give a historical context for the relation between production and the city and the opportunities that exist due to new manufacturing processes. The vertical urban factory began with manufacturers that built factories in the city to efficiently use workers, entrepreneurs and natural resources. With everything close together this eco-system provided not only employment but also opportunities for workers and economic gain for entrepreneurs in an integrated cycle of production and consumption

Harvey(1973) states that the relation between cities and production is defined by fertile environments where work, talent, entrepreneurial and financial skills provide a breeding ground for capitalist creativity and invention. Rappaport adds that diversity, flexibility and innovations add to the form of this relationship between production and the city. This relation becomes stronger with personal interaction instead of segregating people socially and economically

in "remote enclaves" which was the norm of this relationship in the past.

3.2 The need for Hybrid factories

As stated earlier fertile environments are needed to create a good relationship between production and the city but why is this needed? Timothy Love (2017) speaks about this topic in his paper called "A New Model of Hybrid Building as a Catalyst for the Redevelopment of Urban Industrial Districts", he states that industrial districts serve a vital function in a city by providing goods in a fast manor and services that are needed in the city. Examples are fresh foods and fabrication shops that work directly with designers on prototypes for new goods and products. On top of that industrial districts make the city a central hub for innovation and new technologies which in turn brings value to the city and its inhabitants.

Industrial districts are under pressure due to the real estate market as in most high-value cities there is more need for housing and industrial zones are seen as non-compatible with residential functions. It is vital for the survival of industrial zones in the city to move towards the concept of a hybrid factory. A hybrid factory is a mixed building that is used partially for production and the other part for other functions such as residential, cultural or multiple other functions. Rappaport states that there is a benefit to integrating production in everyday life for workers, as they become transparent for the consumers and can harness this transparency to increase working conditions and social justice. Consumers are more aware of what is happening in these factories and experience them in a different way, because they are not hidden away in hybrid factories. It brings them closer to the product, they see how it is made where it originated from and the transformation of the product while the workers are making it. A hybrid factory can also help in affordability as production can be used to partially finance the residential function that is mixed with it. This makes it also an important reason to create hybrid factories as it can help with the recent and future need for affordable housing.

Love (2017) describes a prototype and the challenges they need to overcome and this prototype tries to solve these issues. One of the issues is flexibility, this is important as the use of the production facilities changes over time. Second-

ly, the logistics are important for the prototype as it needs to be designed in a way that doesn't disturb residential functions.
He suggests a grid of 9,1 meters x 13,7 meters built with a column structure to ensure flexibility. The building will have 2 staircases on the edge to facilitate 2 streams of circulation for multiple tenants but also to fulfil safety regulations without interfering with the flexibility. These are some concepts that can be used in the design for Merwe Harbour with some slight alterations to fit the urban situation.

3.3 Hybrid factories and the city

Her idea of a hybrid factory corresponds to ideas of open cities and the way in which people mix and communicate with each other. She believes that factories can be reintegrated into cities by using new manufacturing methods and spatial organization. Production is not static and keeps changing and evolving over time in aspects like design, scale and production spaces. Production from the past is being redefined by the usage of advanced manufacturing which is cleaner, greener and most of the time smaller. This influences the potential for a factory to be located in the city. The new manufacturing methods are e.g. 3D printing CNC and CAD-CAM computers for additive manufacturing processes. Products can be made in parts which in turn minimizes the space that is needed. These 'smart' factories that can be connected remotely with modern-day technology are making it possible to create on-demand instead of a continuous production which we see normally. So these products are made in real-time and not stockpiled and waiting to be sold. This concept gives the possibility to create a prosumer instead of a consumer as someone who could choose their products for use rather than just buys what is available.
These technological changes are revolutionizing the systems and spatial organization that is needed in factories. One of these changes is the change of scale, the number of workers and the amount of physical space that is needed is smaller without losing output. Rappaport argues that one of the downsides is that there is less need for workers so it is harder for people to find jobs but this doesn't take into account that these technologies have more impact on the spatial need we have for production than the number of jobs that are available. Because if this is true it means that the demand for products would never grow and are always in equilibrium which is not the case, new innovations create new products which in turn creates new markets.

She states that there are 4 ways to integrate manufacturing in the city at the building scale:

1. Manufacturing and commercial
2. Manufacturing and cultural use
3. Manufacturing and residential users
4. Manufacturing as an integrated mixture with multiple functions

In this research, we are focusing on how we can successfully integrate manufacturing and residential users in Merwe Haven. Combining manufacturing with a residential function is challenging due to the fact that manufacturing and residential needs clash. Manufacturing needs include truck traffic, noise, smell and sound pollution. The new innovations in the manufacturing space create a viable solution to this problem with 3D printing.

3.4 3D printing

3D printing, also known as additive manufacturing, is a process of creating a physical object from a digital model by laying down successive layers of material. 3D printing can be done with a range of materials the most common ones are metal and polymer materials. Metal 3D printing is mostly used for parts in the automotive, nautical and medical industries. Polymer materials are mostly used for products that have complex geometry in the retail and apparel industries. 3D printing can even have an impact on the food industry where the materials could be liquid food ingredients, products that could be made with this technology is chocolate, candy, pasta and flat foods such as crackers and pizza. (Attaran, 2017)

According to Attaran (2017) there are many benefits to the usage of 3D printing manufacturing namely:

Quality

Due to the precision of the technology parts can be created with a higher quality. e.g. medical hips which can be produced by 3D printers can be accurately produced so it fits the patient perfectly which in turn improves the quality of care for the patient.

Speed

Due to the ease of editing a model it is quicker to use for prototyping and producing a finished product that works perfectly. Also with rapid research and innovations in the printers the speed of production will also be quicker than traditional manufacturing when the printers are improved.

Impact

The impact on a social level and on an environmental level are immense with the rise of 3D printing production. On an environmental level there is the ability to recycle and reuse materials to produce new products, as the materials are brought to a powder or rope form which can be reused. It removes the need for logistics on a large scale as the 3D file can be sent everywhere with a working internet connection and a computer. This means the products can be produced locally instead of overseas. On a social level, the impact is also about sustainability and consume culture because it becomes easier to make items on demand there is no need to pre-produce parts in high quantities which in turn changes the way people consume and the waste that is linked to that consuming.

Transformation/Innovation

3D printing will transform the manufacturing space in the future due to its characteristics and the abilities it provides. On top of that, there is innovation possible because of this technology new products which were not able to be made can be made now or in the future.

Cost

Because it is easier to edit models and there is no need to change the whole production change it is reducing the costs of custom parts. It is also cheaper to produce products on demand with 3d printing because of this. Because of increased supply chain proficiency, it is reducing the cost of logistics as well.

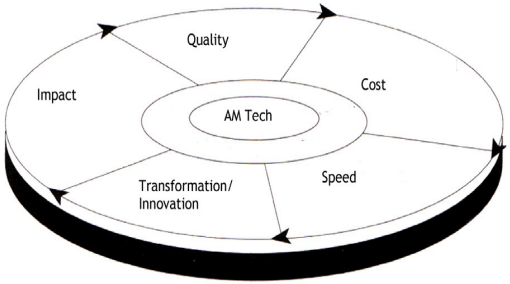


Figure 4: The 5 advantages additive manufacturing has on traditional. (Attaran, 2017)

Most equipment used for 3D printing is sound and smell cancelling as the products 3D printing produces are made in a controlled environment. These products need to be precisely made so the temperature and airflow needs to be controlled in these machines. This makes it the perfect way to mix manufacturing with residential use as their needs are more aligned than other types of manufacturing. On the topic of logistics it also has multiple benefits as 3D printing are mostly small objects or objects that can be assembled into a bigger object, this makes the logistic smaller scale than manufacturing processes that produce large objects in one go.

As it is hard for businesses to change their supply chain it is also hard to transition to 3D printing at a rapid tempo, this also has to do with the fact that it takes a lot of time to create a 3D printing facility that produces in the same rate as traditional manufacturing when transitioning. There are also some technical restrictions as ad 3D printer can't produce something that is bigger than the printer itself. To solve this problem there is a need for more research and the production of larger and quicker printers. At the moment the 3D printing sector is still not fully implemented businesses use it for a portion of their products but it is still an extra way of manufacturing the way to manufacture. According to PWC (2018), a study conducted by Strategy& (a daughter company of PWC) shows that 3D printing was responsible for 0,49 percent of the products in the aerospace and space industry in 2015, they expect this share to grow up to 5,2% in 2030. They expect that the true economic benefits of 3D printing are emerging now into finalized products instead of prototyping. This growth, as in most technology, will most likely grow exponentially as true usage of this technology is discovered.

Industry	Applications	Benefits Gained
Aerospace	Prototyping Component manufacturing Reducing aircraft weight Engine components for the Airbus Flight-certified hardware Manufacturing of satellite components	Produce very complex work pieces at low cost Allow product lifecycle leverage Objects manufactured in remote locations, as delivery of goods is no longer a restriction A reduction in lead-time would imply a reduction in inventory and a reduction in costs On-demand manufacturing for astronauts Eliminate excess parts that cause drag and add weight Improve quality
Automotive	Prototyping Component manufacturing Reducing vehicle weight Cooling system for race car	Help eliminate excess parts Speed up time to market Reduce the cost involved in product development Reduce repair costs considerably Reduce inventory Could effectively change the way cars will look and function in the future Improve quality
Machine Tool Production	Prototyping Reducing grip system weight End-of-arm for smarter packaging	Quick production of exact and customized replacement parts on site Allow for designs that are more efficient and lighter
Healthcare and Medical	Fabricating custom implants, such as hearing aids and prosthetics Manufacturing human organs Reconstructing bones, body parts Hip joints and skull implants Robotic hand	Reduced surgery time and cost Reduced the risk of post-operative complications Reduced lead-time
Dentistry and Dental Technology	Dental coping Precisely tailored teeth and dental crowns Dental and orthodontic appliances Prototyping	Great potential in the use of new materials Reduced lead-time Prosthetics could be fabricated in only a day, sometimes even in a few hours
Architectural and Construction	Generating an exact scale model of the building Printing housing components	Producing scale models up to 60% lighter Reduce lead times of production by 50–80% The ability to review a model saves valuable time and money caused by rework Reduce construction time and manpower Increase customization Reduce construction cost provide low cost housing to poverty-stricken areas
Retail/ Apparel	Shoes and clothing Fashion and consumer goods Consumer grade eyewear Titanium eyeglass frames Production of durable plastic and metal bicycle accessories	On-demand custom fit and styling Reduce supply chain costs Create and deliver products in small quantities in real time Create overall better products Products get to market quicker
Food	Chocolate and candy Flat foods such as crackers, pasta and pizza	The ability to squeeze out food, layer by layer, into 3-D objects Reduce cost Feasibility of printing food in space

Figure 5: All the different types of applications for 3D printing.(Attaran, 2017)

Now that we know the advantages of 3D printing and that it can have minimal disturbance on residential functions compared to normal production methods, we need to think about how this production-type can be incorporated into the design on a building level. It is important to understand the different types of 3D printing there are and their spatial needs. The diagram below shows the 3D printing systems that are popular and what their entry points and products are.

	FUSED DEPOSITION MODELING (FDM)	STEREOLITHOGRAPHY (SLA)	SELECTIVE LASER SINTERING (SLS)	MATERIAL JETTING	METAL 3D PRINTING (METAL FDM, DMLS, SLM)
Build volume	Up to 300 x 300 x 600 mm (desktop and benchtop 3D printers)	Up to 300 x 335 x 200 mm (desktop and benchtop 3D printers)	Up to 165 x 165 x 300 mm (benchtop industrial 3D printers)	Up to 300 x 200 x 150 mm (benchtop industrial 3D printers)	Up to 300 x 200 x 200mm (metal FDM), 400 x 400 x 400 mm (large industrial DMLS/SLM)
Price range	Starting from $2,500	Starting from $3,750	Starting from $18,500	Starting from $20,000 (multi-material starting from $100,000)	Starting from $100,000
Materials	Standard thermoplastics, such as ABS, PLA, and their various blends.	Varieties of resin (thermosetting plastics). Standard, engineering (ABS-like, PP-like, silicone-like, flexible, heat-resistant, rigid), castable, dental, and medical (biocompatible).	Engineering thermoplastics, typically nylon and its composites (nylon 12 is biocompatible + compatible with sterilization).	Varieties of resin (thermosetting plastics).	Stainless steel, tool steel, titanium, cobalt chrome, and aluminum.
Ideal applications	Basic proof-of-concept models, low-cost prototyping of simple parts.	Highly detailed prototypes requiring tight tolerances and smooth surfaces, molds, tooling, patterns, medical models, and functional parts.	Complex geometries, functional prototypes, short-run or bridge manufacturing.	Highly detailed prototypes, including multi-material and full-color realistic prototypes.	Strong, durable parts with complex geometries; ideal for aerospace, automotive, and medical applications.
Disadvantages	Lowest resolution and accuracy; not ideal for complex designs or parts with intricate features.	Some materials are sensitive to long exposure to UV light.	Slightly rough surface finish, limited material options.	Limited material options. Finished products tend to be brittle and photosensitive; less suitable for functional prototypes.	High costs and complexity, stringent facility requirements.

Figure 6: The most popular printing methods, their output and their requirements. (How Much Does a 3D Printer Cost?, n.d.)

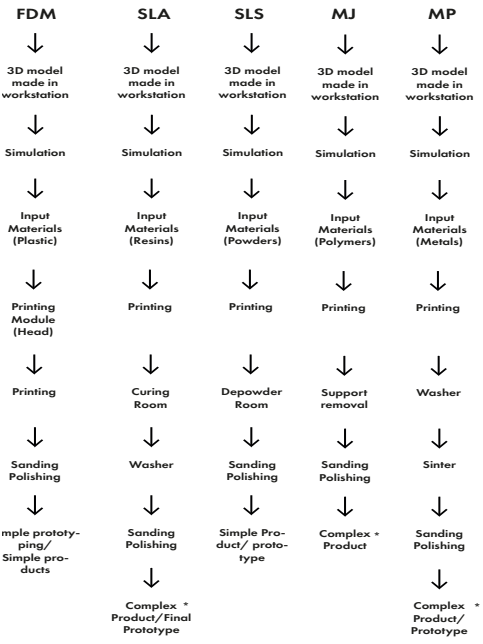


Figure 7: The eco-system of the most popular 3d printing methods. Drawing by author (Lemnawar, 2022)

The diagrams below show this ecosystem on a more abstract and understandable level. We can also see what the spatial needs for these rooms are so we as architects know where and how to place the spatial des

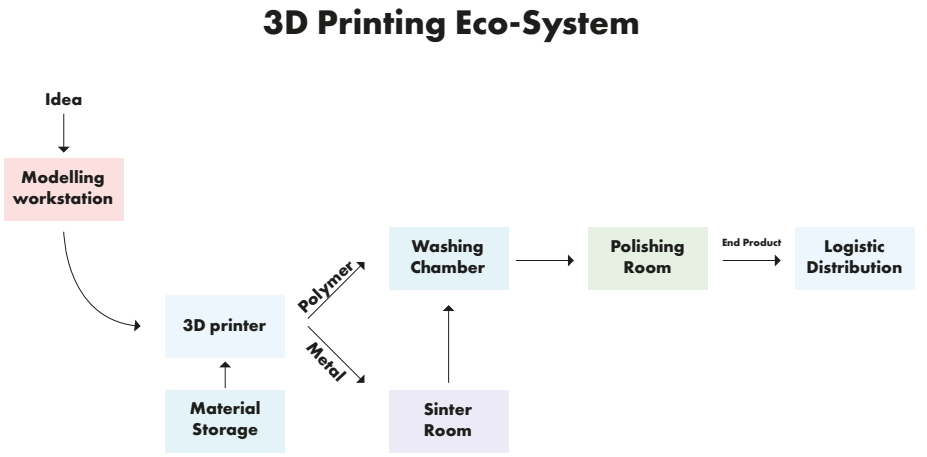


Figure 8: 3D printing Eco-system in an abstract way. Drawing by author (Lemnawar, 2022)

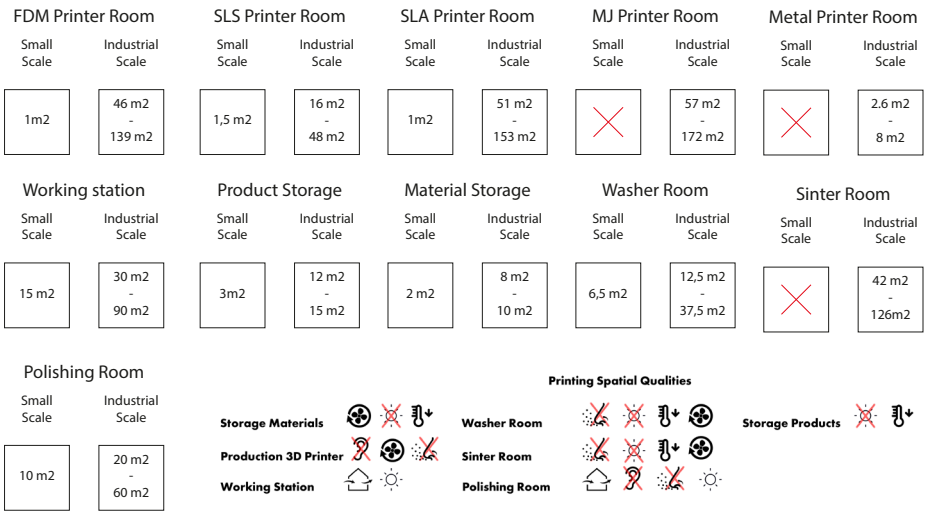


Figure 9: All roomsize requirements for the eco-system of 3D printing. Drawing by author (Lemnawar, 2022)

An architect still needs to design these spaces in a logical way as these sizes are the average but they change according to the specific machines that are used. 3D printing factories are not something architects are actively designing as it is still an early concept that is not fully adopted yet there are almost no examples or they are difficult to find. This analysis can give some guidelines so architects have a grasp of the system and also the room requirements that are needed.

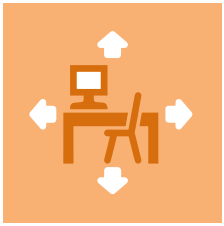
3.5 Creating Hybrid Factories

From this chapter it becomes clear there are multiple benefits and needs to mix production with different functions. For the city it enlarges the economic revenue and provides a breeding space for innovation which in turn means more investment for the city. For the workers and citizens it means they have a connection with the process of making. Which translates to better working conditions and social justice for workers, and a more conscious way of consuming for consumers.

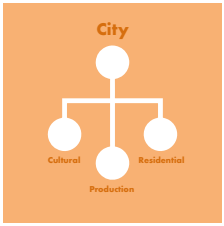
The main challenges of mixing production with different functions and especially residential functions is that the mixed functions have clashing needs. Production and its sound and smell pollution have impact on residential functions or cultural functions. With the new innovations in production it has become possible to combine these functions easier as new ways of manufacturing are more compatible with other functions.

Additive manufacturing is one of these examples that allow for a mix with residential functions. It happens in an controlled chamber which makes it have less smell and noise pollution than traditional manufacturing methods. On top of that it has multiple benefits in CO2 reduction, cost reduction and being able to combat overconsumption. It is digitally connected an can be accessed from all over the world which makes it the perfect type of manufacturing to be used in new projects that try to implement a new way of living.

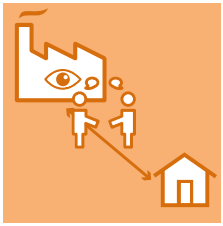
From this chapter the following strategies can be implemented to create a mixed building that has production in it:



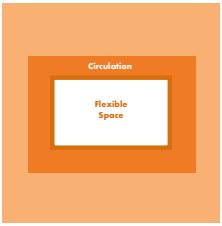
Create flexible production spaces that can fit different functions



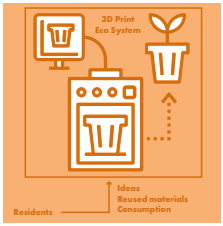
Design an infrastructure that works for all functions



Create a transparent production space and stimulate interaction



Place circulation around the flexible space to ensure its flexibility



3D printing allows for a mix with interactive benefit

Figure 10: Strategies to design a Hybrid Factory. Drawing by author. (Lemnawar, 2022)

Now that an better insight in mixing functions has been established the next step is to understand the concept of modularity and how the housing crisis can benefit from modularity.

Chapter 4 Modularity

Modular architecture is a term that is very broad and changed over the decades which is why it is important to establish what is meant by modular architecture. Modular architecture is an architecture that is built by using a modular building technique, this means that the building is composed of modules, components or elements which are built off-site.(Marquit, 2013) These modules can be identical but there can also be different types of modules which together form one building. These modules are then transported to the site and either put together on-site or if already put together placed on the foundation.

When talking about modularity there are three different modular building categories, panel systems, skeletal systems and cellular systems. In this chapter, the focus will be put on their benefits and their relation with automation. During this chapter the source of Marquit(2013) called "From Sears & Roebuck to Skyscrapers:A History of Prefabricated and Modular Housing" will be used to understand the history of modularity and its image, by Luther (2009) will be used to understand the benefits of modularity and Bremer Punkt will be analysed to see how modularity can be used in practice.

4.1 The history of modularity

According to Marquit (2013)1624 marked the start of prefabricated housing as a dissasembled house was transported from England to Massachusetts. The balloonframe construction method was created in Chicago in 1833 and soon spread across the country. It involved employing uniform wood studs fastened together with mass-produced nails. Prefabricated home kits were being transported to California by train in 1849 during the gold rush. Many contemporary technologies and advancements are related to prefabricated construction the convenience of assembling building elements off site.

The Industrial Revolution, which began in the mid-eighteenth century, started factory production and the development of prefabricated houses sold through catalogues. Aladdin Readi-Cut Houses was the first company to offer prefabricated houses in 1906, but Sears, Roebuck & Co. was the most well-known provider of mail-order houses from 1908 to 1940. Nearly 450 different types of Sears houses have been identified, and they were popular due to their lack of iconography and classic American-inspired designs.

Assembling a house from a prefabricated kit was significantly cheaper than a custom-built alternative.

In the beginning of the twentieth century, architects worldwide were struggling with the question of how to efficiently and simply house a fast-growing population. Le Corbusier proposed a simple reinforced concrete structure supported by slim beams. This was a cheap way of building and not difficult to reproduce. During the second world war sheet-metal constructions which were prefabricated were used for military barracks and mobile trailers in huge numbers. It was seen as useful especially because of the temporal character of these types of buildings they were easy to de-construct and transport. After the war the image of prefabricated housing was less attractive to the mass. But because of the post-war housing shortage, prefabricated materials were still necessary. (Marquit, 2013)

Modularity and prefabrication were not ignored entirely by everyone the suburban boom relied heavily on pre-cut, standardized housing designs and economies of scale. Especially the American suburbs are a good example of this where most were using pre-cut materials and standardized designs to create quick and effective housing. But the general consensus for modularity was that it is seen as unaesthetic and only seen as viable for one typology mostly "trailers" which were not seen as qualitative. The legislation for these types of housing was also not supportive of its development. The concept of modularity seems to be seen as inexpensive and unaesthetic. (Marquit, 2013)

By 1967, modularity was once again an interesting topic for the general discussion with the construction of Habitat '67 designed by Moshe Safdie for the Montreal World's Fair. But the idea of modularity has shifted as the design consists of a large apartment building made out of individual "modules" that complete the larger whole. The purpose of Habitat 67 was to design a building which is easy to duplicate due to the design of the modules. These modules could be assembled anywhere regardless of location. Although it was unsuccessful in that way as it was never constructed anywhere else, it was successful in creating new insight into the meaning of modularity.

Habitat 67 designed by Moshe Safdie is a building that tried to answer a va-

riety of urban and architectural questions. It tried to create a three dimensional building system which could be altered to any context and is easily manufactured on a larger scale. According to Safdie (1967), the building tries to show the architectural industry and the construction industry how a building could be developed using assembly-line production. An assembly-line is characterized by its need for repetitive elements which make up the final product. The bigger the number of elements that are repetitive results in a higher output of final products.

The concept for Habitat 67 was to create a building that acts as an eco-system that can be altered and grow over the years and act as a neighbourhood. Moshe Safdie's design was also a response on the generic brutalist Highrise that was common in North America. All these buildings were stacked on top and generic, with this design he tried to show that it is possible to create diverse dwelling types and to fulfil the need for affordable housing in a high density without losing variety. He wanted to provide open space, garden terraces and other amenities that were normally reserved for row housing typologies.

Metabolism is the name for this architectural movement and it was started by Kisho Kurokawa (designer of Nakagin Capsule Towers), Kiyonori Kikutake, Fumihiko Maki ad Noburu Kawazoe. They wanted to use architecture as a tool to accomodate a changing society. This meant they wanted to develop buildings that could grow,change and evolve with the society. In Habitat 67 it can be seen that it is dynamic and it has a lot of playfulness to it even though the material choice (concrete) is robust and massive.

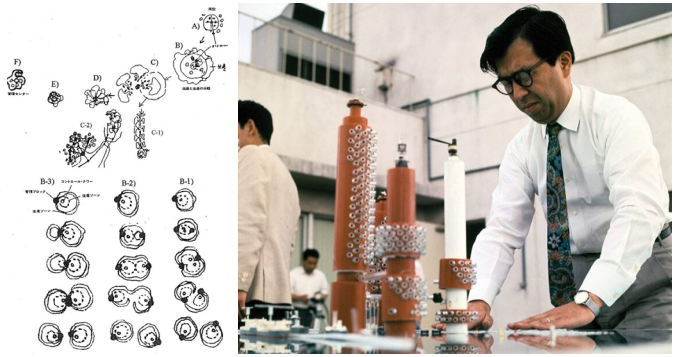


Figure 11: Metabolism as a concept. (Sabukaru.online, n.d.)

Habitat 67 shows us that we as architects can create a lot of different typologies by using the same element in different configurations. This shows us that automation can be incorporated in the building process without losing individuality. Each module measures 12 m x 5.33 m x 3 m, or 56 m2

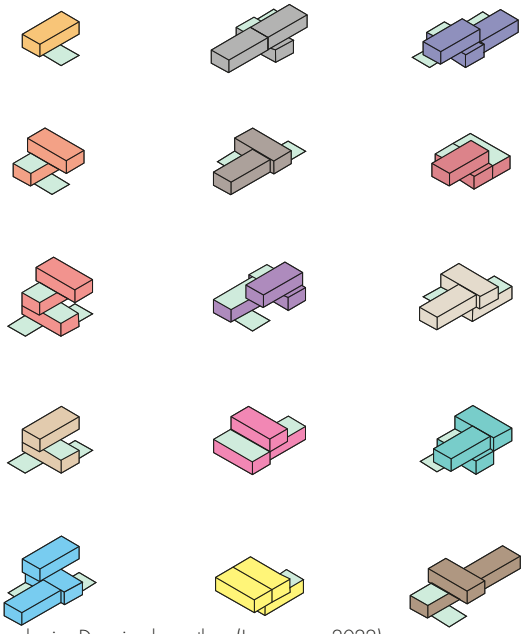


Figure 12: All the different typologies Drawing by author. (Lemnawar, 2022)

Habitat 67 can be divided into 3 sections that each function as their own little community. They have their own circulation space that creates interaction between the residents in those section.

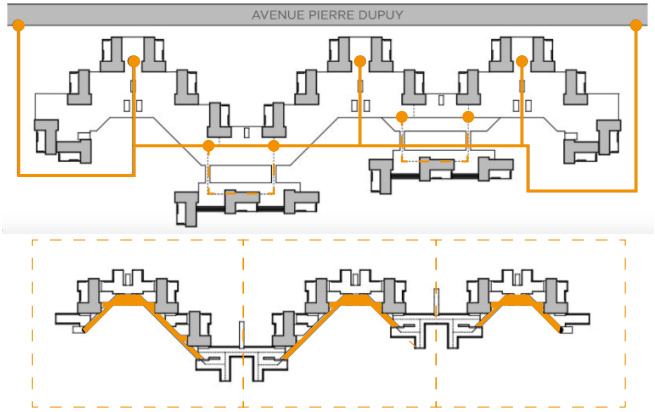


Figure 13: Circulation in Habitat 67 divided in 3 sections that act as their own community. Drawing by author (Lemnawar, 2022)

This type of modular architecture consists of units that together form one mass. Which creates this playful architectural composition.

Figure 14: Habitat 67 from outside. (Safdie Architects,n.d.)

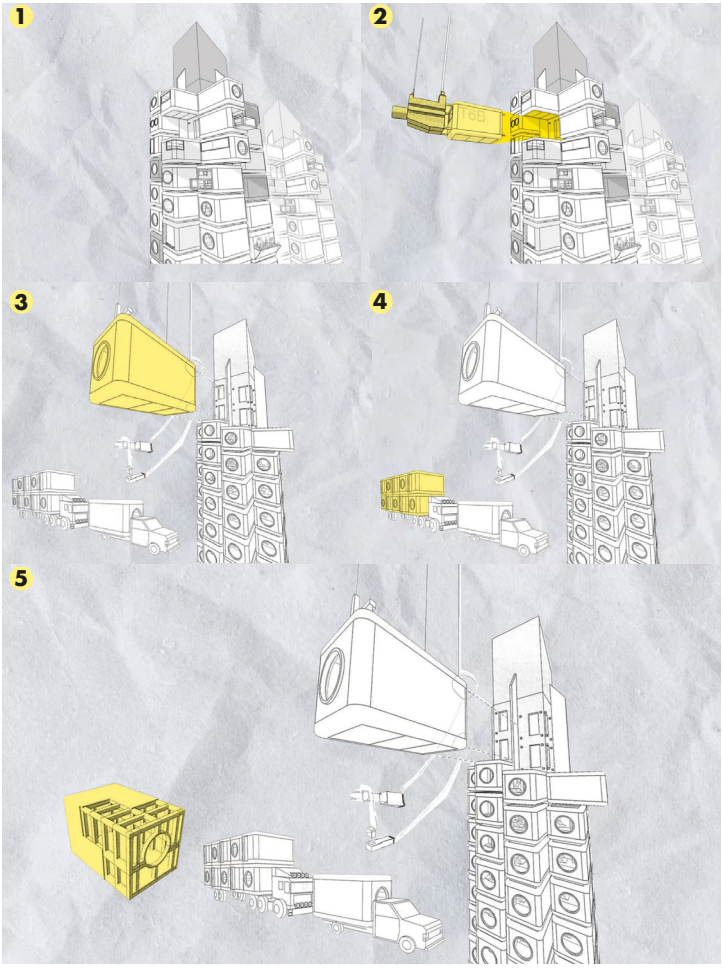
In the end Habitat 67 ended up costing more than regular construction but this was mainly due to the investment needed to create new types of building processes. Over time these processes have become more streamlined and it has become cheaper to build using these methods than it was in 1967.

The Nakagin Capsule tower which is designed by Kisho Kurokawa is a building which was using the same concept of metabolism. The building consists of two circulation cores that has capsules attached to that core. The capsules is a one room apartment that has storage and a bathroom built in it. The capsules are designed for minimal living which could be used by businessmen in Tokyo.

The capsules were meant to be replaced every 25 years where they could be detached and repaired. If there was more room needed more capsules could be added to increase the space of a dwelling. The capsules were prefabricated off-site and later installed onto the core. This prefabrication had the advantage of creating custom capsules, each capsule was designed according to the needs of the resident and each capsule was unique.

This concept would make it possible to adjust the building to the demand that is needed at the time and thus creating a building that evolves with the city. This would ensure its survival and also the ability of the building. The capsule replacement is dependent on the residents around the capsule they all have

to give permission before a capsule can get replaced. This never happened which let the building concept fail as it never got repaired. The demolition of the building has already started and unfortunately an architectural piece of history is gone and has not fulfilled its purpose.



1. Original building
2. Identify which capsule to remove
3. Remove capsule
4. Transport it to offsite factory
5. Alter/repair or recycle capsule off-site

Figure 15: Modular building concept Nakagin Capsule Towers. (Architecture with ahsley, 2022)

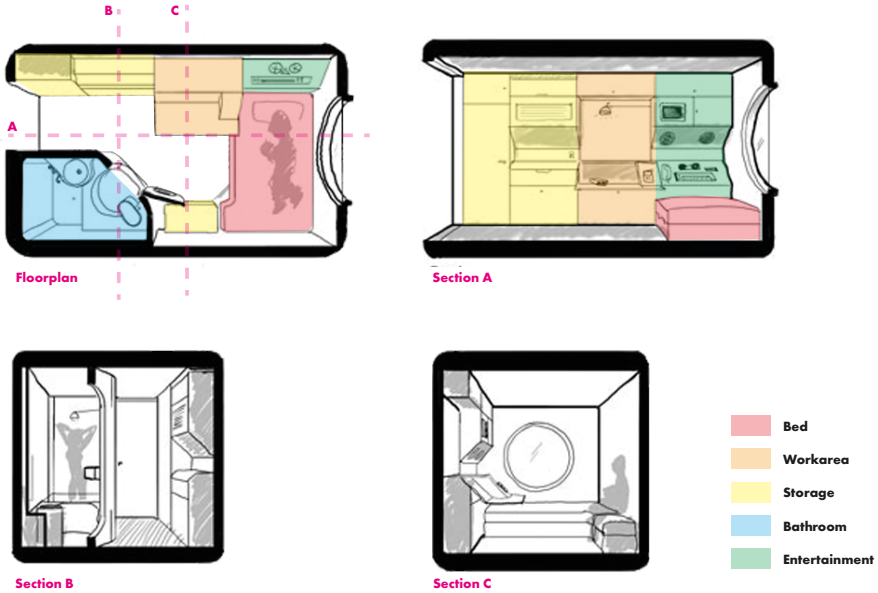


Figure 16: Nagakin Capsule (Harbison,2009) edited by author

According to Marquil(2013) from the 70's until the 80's the general per-

Figure 17: Nakagin Capsule towers before and after. (Metalocus,n.d.)

ception of modularity hasn't changed too much as it was still used for mostly temporal living accommodations and for poor families who couldn't afford regular homes. This negative connotation towards modularity by the consumer was still the biggest barrier to the growth of modular housing, even though modularity touched both ends of the housing spectrum- that of design and that of low-income necessity.

The innovation in the technological aspect of modularity was further developed during the 80's and the 90's which made it easier to create designs that are better fit for highway transport. Therefore it was easier to build buildings which put an end to the single-story structures associated with manufactured housing and opened the door for larger and multiple-story structures. In the late 90's modularity was more used and accepted by consumers and developers, this is mainly due to its convenience, low cost and efficiency. But due to the fact that modular building companies still produced trailers and mobile homes the image of modularity was still merged with this view of trailers and mobile homes.

Marquit (2013) stated in her research that in the early 2000's modular housing was still only 3% of the existing single-family homes even if it saved costs up to 15% at the time. The explanation for this is that the concept of modularity is not influenced that much by consumers but more by architects. Architects did not include modularity in their designs and relied more on traditional building techniques. As building information modelling was more integrated into the process the potential for modular elements was also increased greatly this is mostly due to the fact that the use of BIM makes complex designs easier.

In the present time, modularity has become much more adopted and more accepted but the reason for the modularity has also shifted. The environment and the impact the built environment has become more important and a topic that must be addressed. Modularity is seen by many as a solution to minimize the impact on the environment through minimizing the usage of materials and reducing the carbon emission which is produced during traditional building methods.

In the past, the main benefit that modularity brought was speeding up the

building process and the convenience of temporal building. With the introduction of BIM and sustainability, modularity brings a wide range of benefits in the building process.

4.2 Benefits of modular architecture

According to Luther (2009) typical mass housing construction can be characterized by on-site construction with the usage of traditional materials. Some prefabrication is used but mainly for roof trusses and wall framing. Construction is mostly applied on site which takes space on site and is performed by a skilled labour force such as bricklayers, carpenters and plumbers.

The main disadvantages of traditional building methods compared with modular are:

- **The costs**

50 per cent productivity or less is common to building processes and is relatively low if compared to other manufacturing industries like the car industry, where more than 90 per cent productivity exists in controlled production facilities

- **Variable quality**

The overall quality of a building can vary with traditional building processes an example of this would be thermal efficiency as it is dependent on craftsmanship and human error.

- **Time-consuming**

The amount of time it takes to build a building with conventional methods can be up to 6 times greater than modular off-site building methods.

- **Environmental impact**

Conventional building methods yield high embodied energy processes which produce a huge amount of waste and CO2 emission.

- **Flexibility**

Because modular construction is made up from different parts they are easy to assemble and disassemble. This makes it transportable and adaptable. This

makes it have an edge on traditional building methods as flexibility is something that's become extremely important in our modern society. As was stated in chapter 2 the housing market is not flexible at all and it is hard to facilitate changes in the housing needs.

Luther (2009) makes a comparison with the history of the car industry and it becomes clear that automation can play a big role in combination with modularity. In 1913 the automotive industry was revolutionized by introducing an assembly process which divided the manufacturing of a flywheel magneto into 29 steps. Each employee was told to place one part in the assembly process before moving the flywheel to the next station. This reduced the process from originally 20 minutes to 5 minutes which made it 4 times more efficient and cheaper to produce.

This ability to automatize the process of building makes it an important tool to create housing with greater speed, reducing costs and without the loss of building quality.

4.3 A modern approach of modularity

If we look at chapter 2 it becomes clear the housing market needs to become more flexible to accommodate a changing society. The previous two examples show an approach to modularity but because of the units and the impact on residents a new way of modularity has to be researched. Modular construction has the advantage of being assembled and disassembled easier than traditional construction. Instead of changing units the other approach involves creating separate elements that can be removed on the inside, one of these examples is Bremer Punkt.

4.3.1 Historical Context

In 2011 GEWOBA one of the biggest housing associations in Bremen launched a competition called Ungewonlich Wohnen. Most of their housing stock was built during the 1950s and 1960s and mostly with 3 to 4 bedrooms. Many housing cooperatives in Germany have renovated and expanded their housing as a result of increased demand for more affordable and more liveable housing. GEWOBA's housing typology was too homogeneous for an increasingly individualised society. Therefore they wanted to see what possi-

bilities there are for flexible or unconventional living in Bremen. 5 plots were chosen and 15 architects were invited to create a concept for this flexible and unconventional way of living to see how these trends can be facilitated. (GEWOBA, 2020)

Figure 18: Gartenstadt Süd in Bremen, Germany picture(LIN Architects, n.d.)

LIN Architects were one of the winners of this competition with their design called Bremer Punkt which I will analyse on multiple levels in this research. After the competition the housing association GEWOBA established 5 goals that their new housing stock needs to fulfill(GEWOBA, 2020)

- Barrier-free
- Affordable
- Adaptable
- Multifunctional
- Variable

All these 5 goals they have established with their competition are goals I like to achieve with my project. And the insights of this analysis are beneficial as they can help my project become stronger to achieve these goals.

GEWOBA's portfolio consisted of buildings which were primarily built during the 50s and 60s. These buildings were built with large public spaces which are grass fields with some trees. These buildings were built after the second world war in the rebuilding stage with the target group being the nuclear family. Most of these buildings reuse the same floor plans and design and do not take the change of family structures into account.

Bremer Punkt or the so-called "Bremer Cube" is a building concept which has a compact size of 14 meters x 14 meters and facilitates a range of different housing typologies. Their project is designed for repetition, the exploration of new ways to densify and further urban development in an environmentally friendly way.

The floor plan kit they designed for this design has twenty-two apartment typologies which can be combined in over sixty variations. These apartments vary in size from 30 m2 one-room apartments to 138 m2 six-room ap

LIN Architects believe that the existing neighbourhoods require new and future-proof residential formats which are built in a sustainable and innovative way. Bremer Punkt tries to use modular design to create a building that can change according to the following influences (LIN Architects, 2021):

- Inner-city Living
- Accessibility
- Communal living
- Inclusion
- Affordability
- Varying living formats

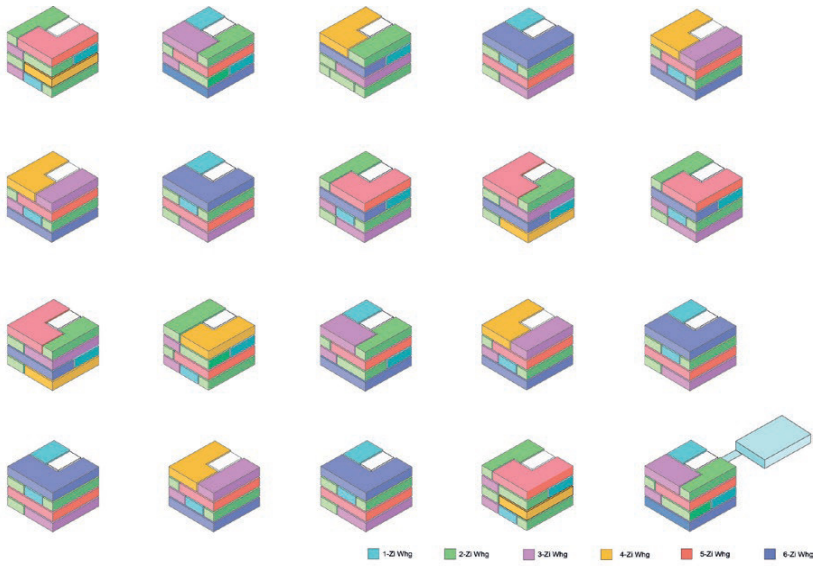


Figure 19: Different combinations possible in the Bremer Punkt drawing by LIN Architects, (LIN Architects, n.d.)

The building is built 6 times and 4 are in construction at the moment bringing the total to 10 Bremen cubes as they call them. The project is mainly meant for tenants who need accessible housing, so they can still live in a familiar neighbourhood. Furthermore, this building can also meet other living demands for other target groups due to its variability and flexibility due to the usage of modular design.

4.3.2 Urban Context

The Bremer Punkt aims to enrich the neighbourhood by creating a space which is new but can integrate with the existing context. Bremer Punkt is placed in the spaces between the 4-floor buildings. The original structures are storage spaces/garages. This in-between space is mostly green public space with some trees.

Figure 20: Urban context of Bremer Punkt, Drawing edited by author (GEWOBA, 2015)

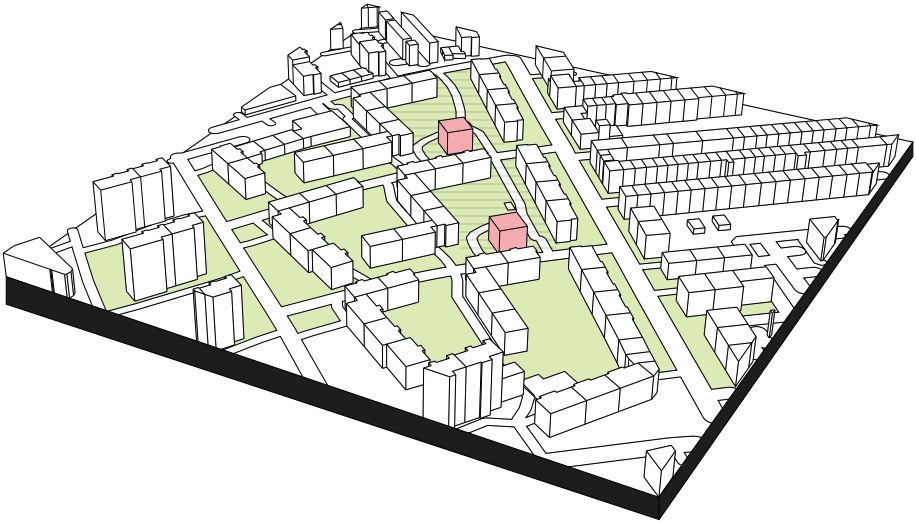


Figure 21: Urban context with the inbetween spaces highlighted. Drawing by author Drawing by author (Lemnawar, 2022)

LIN Architects believe that a transition space between these two spaces can help in creating a communal and active environment on the street level.

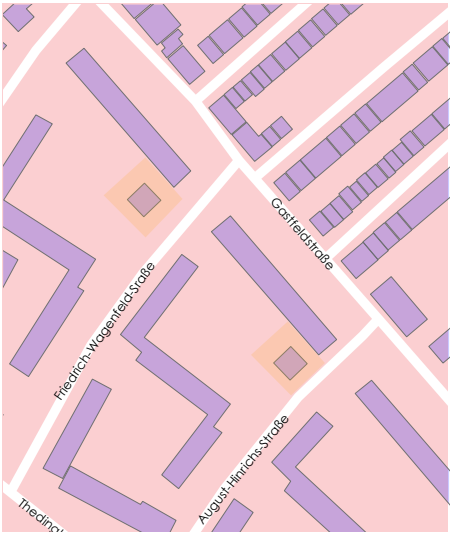


Figure 22 : Urban context and the types of spaces. Drawing by author (Iemnawar, 2022)

Figure 23: Urban context render by LIN Architects (LIN Architects, n.d.)

The apartments on the ground floor are extending towards this public space with their own garden. The architects themselves see the space around the cube as a collective area that provides space for activities, parking and greenery. So this transition space as they call it is filled with functions that the collective can benefit from.

As they want the cube to be integrable into the old dwelling that already exists they have proposed a solution where one of the old apartments gets reduced from a 3-room to a 2-room apartment to facilitate a bridge/arcade that connects the two. In the drawings below this solution is illustrated, from the documentation that is available online none of the cubes that are built now actually use this tool to connect with the existing housing but it does give some insight into the possibilities the cube has in regards to integrating with an existing structure.

Transition space/ Activities space

Dynamic bridges

Figure 24: The transition spaces as designed by LIN Architects and the dynamic bridges that connect the new building with its existing context. Drawing by Author (LIN Architects, n.d.)

The circulation in the Bremer Punkt is done by stairs and elevators as they want

the building to be barrier-free. In the next diagrams, 2 form types of this circulation can be seen in the different Bremer cubes. In the first Bremer Cube, the circulation is not optimised yet if compared with the second. This optimisation means that there is more space left for dwelling functions.

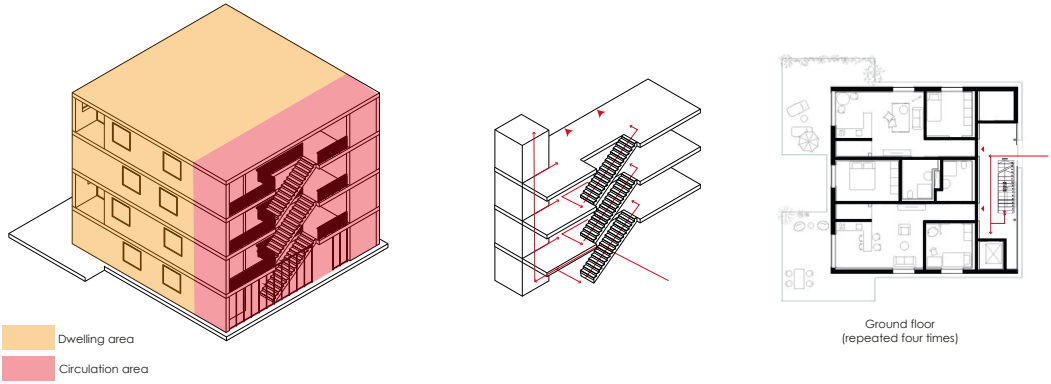


Figure 25: Circulation type 1 in Bremer Punkt 1. Drawing by Author. (Lemnawar, 2022)

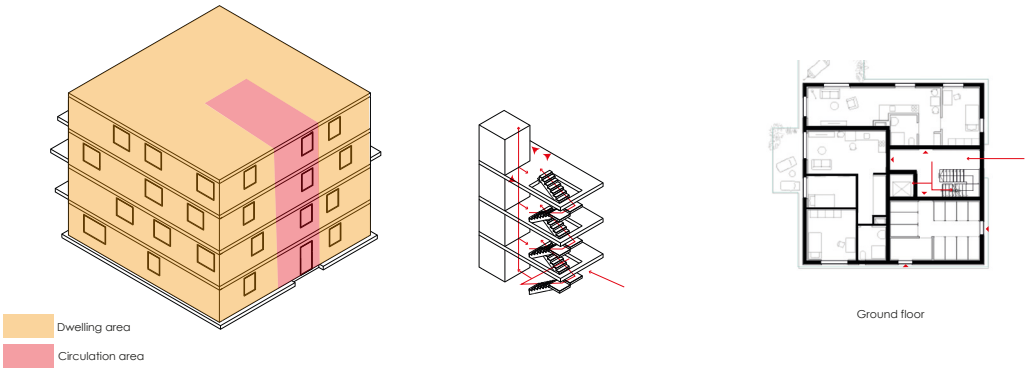


Figure 26: Circulation type 2 in Bremer Punkt 2. Drawing by Author. (Lemnawar, 2022)

4.3.3 Modularity and its role in Bremer Punkt

In the design of Bremer Punkt modularity is a keystone in the concept. There are multiple benefits from using modularity in Bremer Punkt on the following levels:

The flexibility and variation in the floor plans and façades are possible because of the modular and prefabricated construction methods which are used. In total the building houses 11 apartments that range from 1-room to 6-room typologies. In total, more than 60 variations are possible with a total of 22 different typologies. (GEWOBA, 2021)

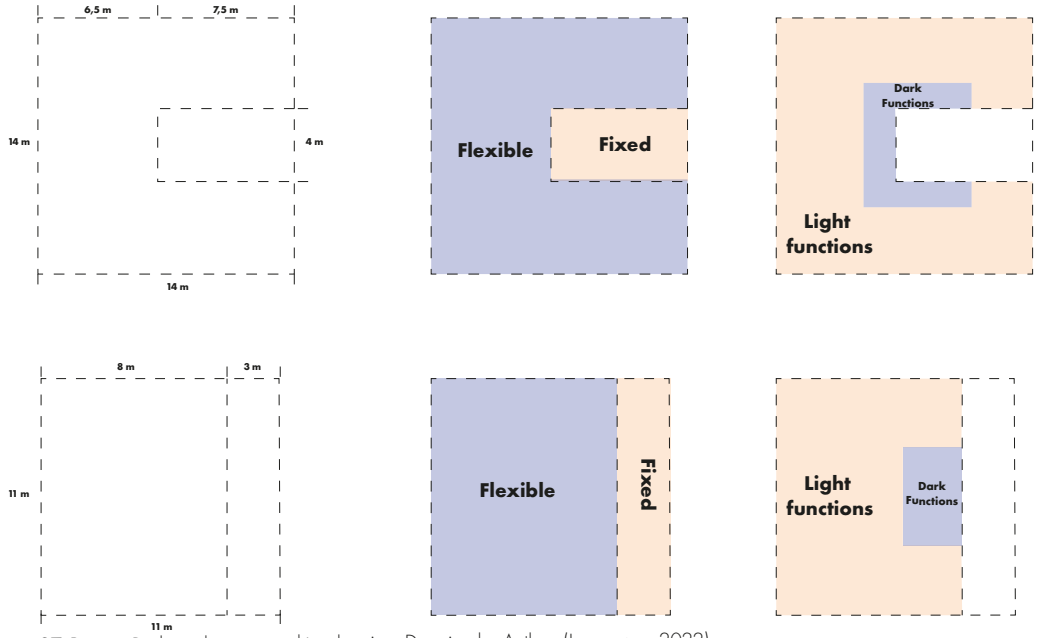


Figure 27: Bremer Punkt grid system and its planning. Drawing by Author. (Lemnawar, 2022)

Figure 28: All apartement types in Bremer Punkt's concept. Drawing by Author. (Lemnawar, 2022)

level without much effort. This is all possible due to the modular nature of the construction and design. This makes it a perfect solution to upgrade existing buildings as an extension and increases liveability.

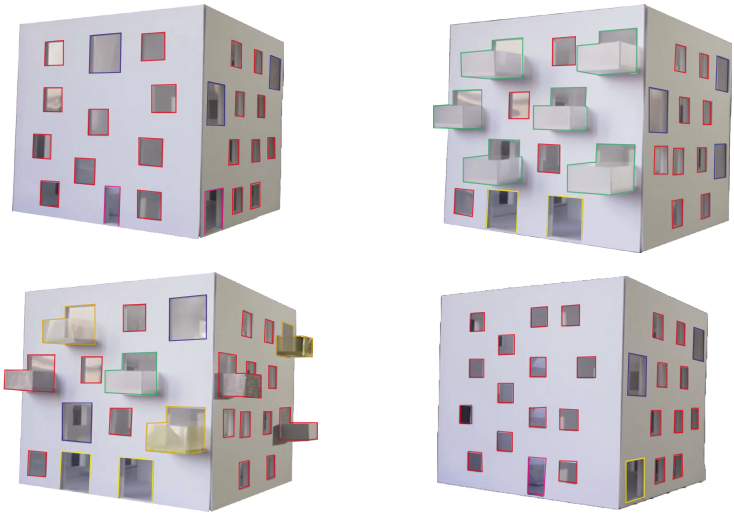
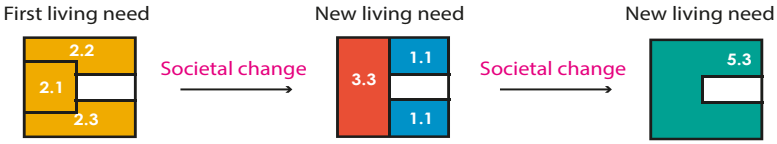


Figure 29: Variable and flexible facade which has multiple variants using different elements. Drawing by Author.

The Bremer Punkt uses a variety of facade elements to construct a playful facade. The facade openings that we can see in the built Bremer Punkt are elements from the surrounding buildings. They integrated the cube by using these elements but still kept a unique and modernistic expression by avoiding simple repetition in their facade. They also used the same materialistic expression to integrate it with the surrounding buildings. But it also is a possible solution to a changing society which has its own living or production needs. In the diagram below we can see this concept and how it could change over time. This flexibility is one of the major benefits on not only an architectural level but also on an urban level.



The way the cube is designed also makes it possible to choose the distribution

Figure 30: The possibility to change the Bremer Punkt due to the change in society. Drawing by Author. (Lemnawar, 2022)

in shared space and private space. One of the cubes that are built is built by a cooperative that uses a shared living concept which means that inhabitants share certain functions but have their own private space. The flexibility as mentioned earlier gives the opportunity to create a communal living which enriches the whole neighbourhood. One of the advantages of building in components is that there is less disturbance in the neighbourhood with the process of building a Bremer Punkt. The components can be assembled within 20 days with minimal sound pollution.

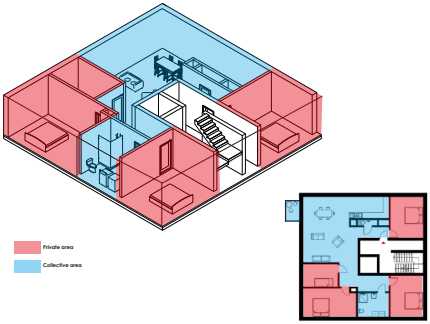


Figure 31: Collective and private space in Bremer Punkt's communal living types. Drawing by Auth or. (Lemnawar, 2022)

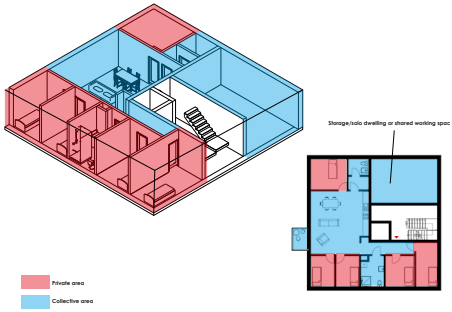


Figure 32: Collective and private space in Bremer Punkt's communal living types. Drawing by Author. (Lemnawar, 2022)

The modularity which is used in Bremer Punkt makes it possible to create affordable apartments, this is because prefabrication reduces the cost to build because materials are used more efficiently but also because it saves time due to the possibility to complete processes simultaneously.

The second economic benefit is that because the building is designed for reproduction (using modularity) municipalities and planning organizations become more familiar with the building which speeds up the process of developing a Bremer Punkt in the future. This is an important tool to facilitate faster building. (GEWOBA & LIN Architects, 2020)

Due to the usage of modularity in Bremer Punkt, the components were pre-

fabricated in a controlled environment. Therefore they were able to construct the building with a high dimension and accuracy which increases thermal efficiency and efficient usage of climate-friendly building materials. It almost achieves passive housing standards with its building envelope. (GEWOBA & LIN Architects, 2020)

So next to the architectural benefits of modularity there are more ways modularity brings value to the city and its environment.

Bremer Punkt adds value to the city by offering a barrier-free and flexible living space that is affordable for multiple groups. While still providing comfort and living quality higher then is usual for social housing.

The Bremer Punkt is financed 75% by public funds and 25% privately financed. For social housing, they achieve a € 6,50 rent per m² (GEWOBA & LIN Architects, 2020) which means the smallest apartment rent of € 195 euros and for the biggest which is a six-room apartment € 680. If we compare this with the average square meter price in Bremen and Germany which were in 2022 € 7,90/m² (Mietübersicht Bremen 2022 - Gutachterausschuss Bremen, 2022) (this takes all areas of Bremen into account) The Bremer Cube has achieved almost a 20% decrease compared to the average.

Secondly, It gives value to public space that is mostly empty and transforms these spaces into collective spaces that make the neighbourhood a more connected and resilient place.

The design concept of the Bremer Punkt is a serial housing concept that can be reused by the city multiple times due to its adaptability and flexibility. This gives value to the city because associations and municipalities can speed up the building process without compromising on dwelling quality.

Bremer Punkt reduces its CO2 footprint with the usage of a modular hybrid

construction made of wood and concrete. They have solar panels on top of the building and use floor heating in combination with a heat pump. With the efficiency achieved by constructing off-site, they have reduced CO2 footprint by 90%. Almost all the heating and Electrical needs are met by the solar panels on top of the building but they are not yet fully energy neutral. They have already reduced a large chunk of the CO2 footprint due to modular construction but they still have room to improve and to become eventually energy neutral. (GEWOBA & LIN Architects.2020)

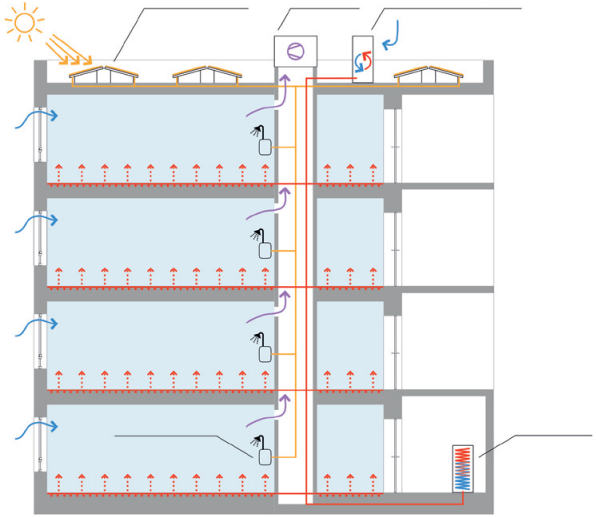


Figure 33: The energy concept in Bremer Punkt. (GEWOBA & LIN Architects. 2020)

Figure 34: Bremer Punkt 1 the first prototype. (LIN Architects, n.d.)

Figure 35: Bremer Punkt 1 circulation space at night. (GEWOBA & LIN Architects, 2020)

Figure 36: Open Kitchen plan facing open facade. (GEWOBA & LIN Architects, 2020)

Figure 37: Lodgia concept with large glass surfaces. One example of better living quality compared with regular social housing (GEWOBA & LIN Architects, 2020)

Figure 38: Optional balconies that can be attached and removed whenever the needs arises. (GEWOBA & LIN Architects, 2020)

Figure 39: Internal circulation space in the Bremer Punkt. (GEWOBA & LIN Architects, 2020)

4.4 Adaptability for the changing society

From this chapter it becomes clear that modularity has a deep history in our society but it still has a negative image to overcome. Although prefabrication is being used at the moment it still has to evolve to a point that an entire building is prefabricated. From our historical case studies Habitat 67 and Nakagin Capsule Towers it becomes clear that the historical approach to modularity was about creating units and stacking those to create a metabolical entity. Although their history has proven it is hard to facilitate due to technical constraints and issues around ownership and changing units. A more modern approach is Bremer Punkt which shows that modularity can be used to create a building shell that can be altered from the inside. Bremer Punkt provides a wide range of housing and flexibility that makes it an important case study to understand the benefits of modularity and its actual implementation.

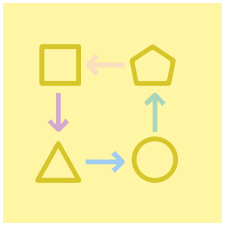
Modularity has a wide array of benefits that can help the housing shortage in general but specifically the Netherlands. In chapter 2 we concluded that the main strategies are that we need to increase building speed, create a flexible housing market and reduce costs. These are all things that modularity is able to do.

The housing industry has been lagging for a few years compared with the automotive industry. Modular architecture opens the possibility of automation and mass production for a low cost without losing individuality. As we see with technology in general it always advances almost logarithmically which means that in due time modular construction will be so advanced that the idea of a housing factory wont be that strange anymore.

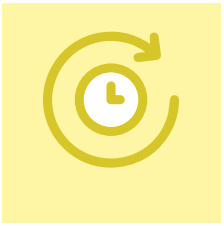
When designing for modular architecture it becomes important to design a modular grid that can house multiple function sizes when trying to create a building that evolves over time. As living needs and our society changes over time this ensures the survivability and adaptability of a building.

The following benefits and strategies are what we have learned from chapter

3:

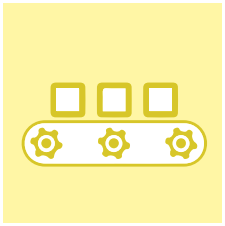


Modular architecture allows for flexibility through assembly and dissasembly(and transportation)

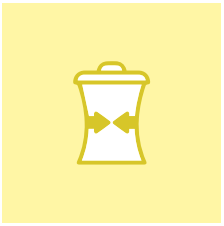


Modularity can increase building speed

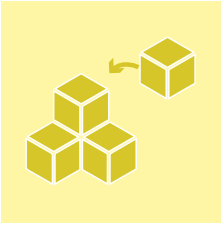
Modularity can reduce costs in the construction of buildings



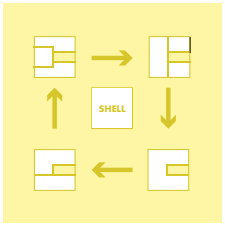
Modularity through standarization opens up the possibility to automate (Increases speed and reduces costs more)



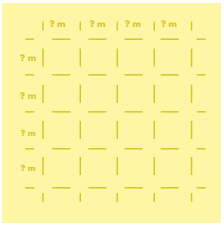
Modularity can reduce waste up to 70%



Historical approach stacking multiple units to create one entity that is dynamic (metabolism)



Modern approach of modularity: all elements are prefabricated and form a shell that is dynamic



Determine a grid where variety of function sizes can fit to ensure future flexibility

Figure 40 All benefits and strategies of modular construction. Drawing by Author, (Semester, 2022)

Now that we have a better understanding of the benefits of modularity we have to look at contemporary living to understand what designers need to take into consideration to achieve a flexible design.

Chapter 5 Contemporary Living needs

If we as designers want to use modularity to create an adapting building there is a need to understand what contemporary living needs our target groups have to ensure our flexible design can facilitate different types of living. In this chapter we are creating 3 ideal target groups to focus on in this housing crisis and for the Keiler Harbour. For this we are using BPD's (2015) research in living needs in the Netherlands. As stated in chapter 2 one of the largest target group that needs to be facilitated is 1 person households around 40% of the households in the Netherlands.

BPD (2015) has performed surveys to understand the living needs for 1 person households so we can better facilitate these new dwellings that are necessary to fix the shortage. In the diagram below we can see the results of the survey and the satisfaction of the current dwelling these 1 person households are living in. Secondly we can see what rooms they spend most of their time in and in which one they spend the least.

1 person households spent most of their time in their living room or bedrooms, these are also the rooms they are most satisfied with. They think light is important in these rooms thats why they prefer big windows in these rooms. They mostly sleep in 2 person beds even if they are living by them selfs so their bedrooms need to be big enough to fit this.

The kitchen and bathroom is were most dissatisfaction is occurring, they think they are too dark and crammed. They dont like to have washing machines or toilets in their bathroom. The kitchen needs to have a lot of storage space as 1 person households use the kitchen for 30-40 minutes a day and they want it to be clean. Now that we have a general overview of 1 person households we are creating 3 Ideal target groups and what they find important in their housing.

Figure 41: results from survey performed with solo dwellers regarding living needs. (BPD,2015)

Students

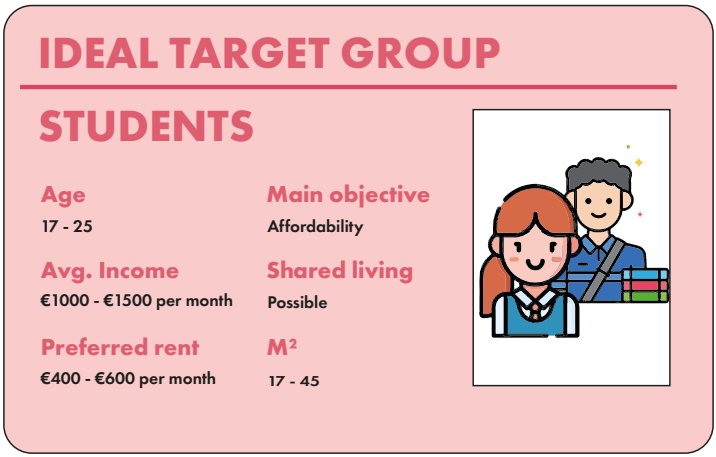


Figure 42: Ideal target group Students and their important factors. Drawing by Author. (Lemnawar, 2022)

ABF Research et al.(2020) has done quantitative research towards current living situation of starters and their preferred living situations. In the diagram below shows the situation in 2019-2020.

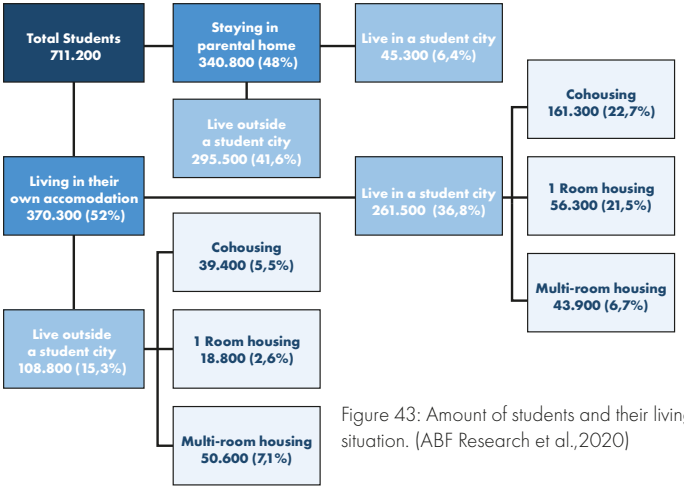


Figure 43: Amount of students and their living situation. (ABF Research et al.,2020)

Around 52% of the students live by themselves, the other half stays in their parental home.

In general they do not have a large income. For this group affordability is one

of the most deciding factor in the housing they choose. Students move to be closer to their school environment. Social interaction is extremely important for this target group as most students that live by themselves do so in a unknown city. They have to make new friends in and outside of their school environment.

This group is used to sharing as there are not a lot of affordable spaces where they do not have to share but also because their need for social interaction is bigger than other target groups.
When designing for students it is important to take their daily routine into consideration. Most students spend their time from 8 a.m. untill 6 p.m. outside of their house. In the evening they are more at home. They use their home for: sleeping, studies, cooking and personal hygiene. Most of the functions that are shared in student dwelling are kitchens, living rooms and bathrooms.

Students find green spaces important in their surroundings, places where they can meet and sit with friends or neighbours. Facilities in the direct surroundings are not that important for this group as they move a lot using public transport.

When designing for students they need the following functions:
- Mixed room that can be used for sleeping or as a living room

- Study space

- Kitchen (can be shared)

- Bathroom (can be shared)

Students don't need a lot of space as they do not stay in their home for a long time and their main focus is affordable housing. If there is a possibility to get more room it is preferred.

Starters

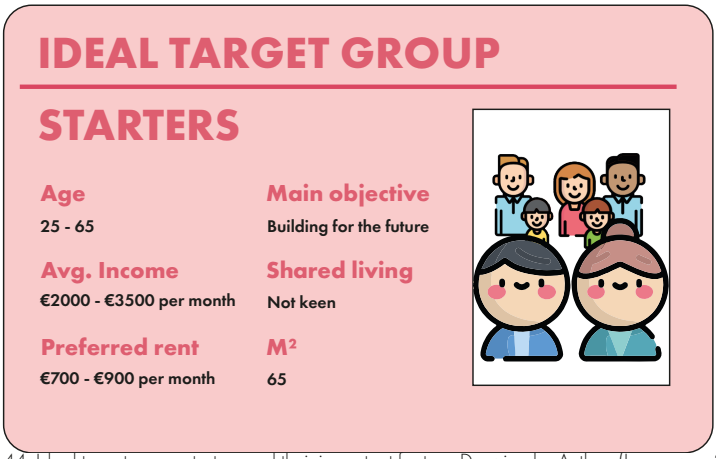


Figure 44: Ideal target group starters and their important factors. Drawing by Author. (Lemnawar, 2022)

Starters make up 60% of the housingmarket and are one of the groups that are hit hard by the housing crisis. We can split starters up in 2 groups:

Group 1:are people who are just entering the housing market for the first time.

Group 2: are people who already have housing (mostly a room or shared housing) but want to make the next step and move to own or rent their own private housing.

Group 1 starters still live with their parents or relatives. A great part of this group is students. The other part are people that have lived with their parents and just finished their studies. They are working in their first full-time job and are ready for the next step. They want to have their own space where they can build their life.

Group 2 starters are mostly living in their old student room which is shared with other people. As they are getting older and are earning more in their career they want to move to a bigger apartment or house.

These 2 groups share mostly the same ideals and like the same living environments. As they have gotten older and have their routine they are making more use of their home. These groups like to live near facilities that they can use in their neighbourhood. They mostly travel with public transport as they were

used to during the time they were students. Their motives for moving to a bigger house is because they want to prepare themselves on their future. Maybe with a partner or they want to have children. They like to live in mixed used neighbourhoods that provide a wide variety of buildings. Hybrid working has become more important for them since the pandemic as they have found that this helps them in having a healthy work-live balance.

They mostly live in apartments and don't mind if it is in a neighbourhood that still has to blossom (like Keiler Harbour). Social life is very important for this group they still meet sometimes with their friends or colleagues but also like to spend time in their home. Interaction with people in their neighbourhoods is something they find pleasant.

Sharing facilities are frowned upon by this group because they think sharing is an intrusion on their privacy. They use their dwelling to meet with friends but also to have some alone time.

When designing for starters the following aspects are important to take into consideration:

- Ensure adequate natural light mainly into the living room, kitchen and bedroom

- Kitchens need enough storage

- An extra room is necessary for work, hobbies or possible children room in the future.

- Keep washing machines and toilets out of the bathroom

- Starters don't like the idea of living small the psychological limit is 65m2

Elderly

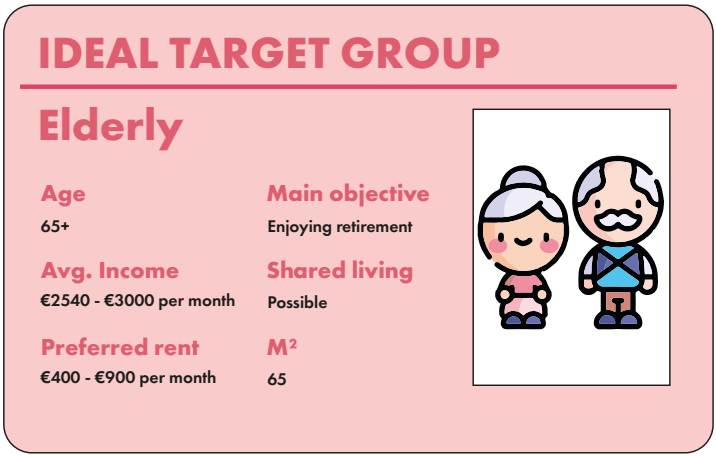


Figure 45: Ideal target group elderly and their important factors. Drawing by Author. (Lemnawar, 2022)

Elderly households make up 20% of the total households in the Netherlands. 1 person households that consist of elderly are around 10% of the households. This group has a low chance of moving, the main reason for this is that they are attached to their home. Elderly rather alter their existing home than move.

In chapter 2 it became clear that 1 person households are using on average 88m2. One of the reasons why is that elderly 1 person households live in housing that is too large for their need. If we want to help the flow on the housing market it becomes an important objective to make attractive housing for this target group.

One of the reasons they do move is loneliness. Most of the people around them either passed or moved which shrinks their social network. They spend most of their time socialising with fellow neighbours or their activities with associations that they are a part of. They value their own space where they can retreat but like shared facilities where they can connect with other people.

There are 3 groups of elderly:

1.Independent
These are elderly that can care for themselves and want to live independently. The community that is in their environment gives them value. These are facilities like a cafe, laundry facilities and medical care and support. The main

function of their living environment is to provide space that stimulates interaction with other people or residents.

2. Assisted
These are elderly that are not fully independent and need support to live comfortably. Their housing should steer to connect them to assisted nursing facilities. These groups need help in personal care which means eating, washing and dressing. Their living environment provides a communal type of living where they can get additional support if they need it. They make small trips outside of their residents with supervision.

3. 24 Hour Care
These are elderly that need care 24/7 in their day to day lives. They cant go anywhere by their own. They usually have dementia or Alzheimer and are in need of professional care. The living environment for these groups are steered to giving professional healthcare. Their environment needs enough space for workers and medical equipment. Their environment is steered towards communal living where almost all functions besides a bedroom is shared.

When designing for elderly the following aspects need to be taken into consideration:

- Create spaces for interaction

- Create space for personal retreat

- Provide adequate light in the dwelling

- Safety installations are important to prevent injuries

Conclusion

The Dutch housing shortage has three causes, The financial crisis in 2008 started a drop in housing value. This meant that building companies and workers disappeared. It was difficult for people to get housing due to the stricter rules, and households grew larger than what was predicted.

When the housing shortage started this meant that house prices and rents rose. This made the gap between social housing and mid-segment housing too big. This resulted in a blocked flow on the housing market. When demand grew there was a shortage in companies, building materials, workers and knowledge. Housing corporations were restricted in their abilities and could not provide enough for the middle segment. This snowballed to the housing crisis as we know it. On top of that the housing composition has changed a lot throughout the years and there is more need for single person housing. The housing market was inflexible in accommodating this change. The target group that is hit hardest are low income households and mid segment households as the shortage in mid-segment housing meant that low-income households have long waiting lists. It is important to have policy changes for new types of financing like cooperative housing. The building process needs to be sped up on the physical aspect but also the bureaucratic aspect. There is a need to use land efficiently and reduce the amount of m2 households use especially single person households.

There are multiple benefits in mixing production with different functions, cities benefit from economic revenue and investments into the city due to innovation. Residents and workers benefit from social justice, better working conditions and a more concious and innovative way of consuming. New production methods make it possible to mix production with residential functions with 3D printing. 3D printing has multiple benefits over traditional manufacturing that make it interesting to use in a mix used building due to a low pollution in smell and sound and the impact on CO2 reduction. To create a hybrid factory we need to design flexible production space which has circulation around it, create a transparent production space and stimulate interaction between functions. Design a infrastructure that accommodates all different functions that are in the hybrid factory.
Modularity brings multiple benefits to combat the housing shortage, it reduces the cost to build due to an increase of efficiency and being able to combine

processes at the same time. It increases the time to build which helps with the shortage. The ability to create flexible housing that can alter to the current and future demand.

There are two concepts of modularity one is the metabolism approach where the building consists of units that get changed over time and adapts to a unique composition. Examples of this are Habitat 67 and Nakagin Capsule Towers. From these buildings we learn to ensure the survival of these buildings, we as designers need to take into considerations what grid and technical construction is used for the design. These 2 factors lead to the fact that the Nakagin Capsule Towers could never fullfill its true purpose. The second concept of modularity is that each component of the building is modular. Flexibility is ensured by creating one shell building that has inner flexibility, this means that the building can be placed anywhere as it can adapt to its context and to the demand. Bremer Punkt is a successful example of a building that uses this concept and achieves its goal.

The three ideal target groups that need to be facilitated are students,elderly and starters as they make a large part of the households in the Netherlands and the housing shortage can be solved by accommodating this target group. Secondly because the trend in our society shows that 1 person households (starters and elderly) are going to grow more and more. Each target groups has their own goal which they achieve with their dwelling (besides having a place to sleep). Students use it as a place to sleep, meet their basic needs and study. Starters use it to calm themselves and to prepare themselves for the future. Elderly have a main focus on interaction and safety.

This research is done to help in the design for the Keiler Harbour as mentioned in the problem statement. The following diagram shows all conclusions from the chapters and how these strategies together can form a new building typology that can help in the Dutch housing shortage.

Short term

Improve flow from low income housing to mid income housing

Speed up building process

Minimize m2 per person

Long term

Create a flexible Housing market/ stock

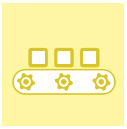
Policy changes to accommodate a shared economy (i.e. cooperative)

Policy changes to reduce land costs for affordable housing

Use land efficiently

Housing shortage

Modularity

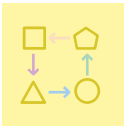


Modularity through standarization opens up the possibility to automate (Increases speed and reduces costs more)

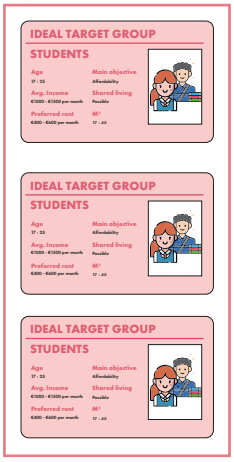
Modularity can increase building speed

Modularity can reduce costs in the construction of buildings

Modularity can reduce waste up to 70%

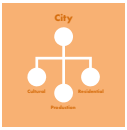


Modular architecture allows for flexibility through assembly and dissasembly(and transportation)



Mixing production and living

Create flexible production spaces that can fit different functions



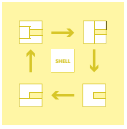
Design an infrastructure that works for all functions

Create a transparent production space and stimulate interaction

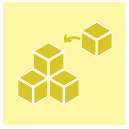
3D printing allows for a mix with interactive benefit

Place circulation around the flexible space to ensure its flexibility

Concepts of modular architecture



Modern approach of modularity: all elements are prefabricated and form a shell that is dynamic



Historical approach stacking multiple units to create one entity that is dynamic (metabolism)

Determine a grid where variety of function sizes can fit to ensure future flexibility

Contemporary Living needs

Mixed hybrid typologie that uses modularity to provide affordability, flexibility and sustainability

A new building typology for the changing society.

BIBLIOGRAPHY

Dutch housing crisis/ Housing shortage

Hoppesteyn, M. (2012, October). Bevolkingsprognose Rotterdam 2013-2030. Centrum voor Onderzoek en Statistiek (COS). Retrieved from https://onderzoek010.nl/handlers/ballroom.ashx?function=download&id=38

Vermeulen, W., & Rouwendal, J. (2007). Housing Supply and Land Use Regulation in the Netherlands. (Discussion paper TI; No. 07-058/3). Tinbergen Instituut.

van der Heijden, H., & Boelhouwer, P. (2018). Wat is er aan de hand met de woningmarkt? Vastgoedrecht (Zutphen), 2018(6), 125-131.

Rabobank, & Lennartz, C. (2018, June). De omvang en prognoses van 'het' woningtekort. https://www.retailinsiders.nl/docs/05f29555-9547-4b4e-8d92-5ec4a5d22156.pdf. Retrieved from https://www.retailinsiders.nl/docs/05f29555-9547-4b4e-8d92-5ec4a5d22156.pdf

van der Heijden, H. (2022a). De woningcrisis in Nederland vanuit een bestuurlijk perspectief: achtergronden en oplossingen. Bestuurskunde, 31(1), 19–33. https://doi.org/10.5553/bk/092733872022031001002

van der Heijden, H. (2022b). De woningcrisis in Nederland vanuit een bestuurlijk perspectief: achtergronden en oplossingen. Bestuurskunde, 31(1), 19–33. https://doi.org/10.5553/bk/092733872022031001002

Kuenzli, Peter, Arie Lengkeek. operatie wooncoöperatie. Amsterdam: trancity-*valiz, 2022.

Hoppesteyn, M. (2012, October). Bevolkingsprognose Rotterdam 2013-2030. Centrum voor Onderzoek en Statistiek (COS). Retrieved from https://onderzoek010.nl/handlers/ballroom.ashx?function=download&id=38

Modular architecture

Agha, A., Shibani, A., Hassan, D., & Zalans, B. (2021). Modular Construction in the United Kingdom Housing Sector: Barriers and Implications. Journal of Architectural Engineering Technology, 10(2).

Ferdous, W., Bai, Y., Ngo, T. D., Manalo, A., & Mendis, P. (2019). New advancements, challenges and opportunities of multi-storey modular buildings – A state-of-the-art review. Engineering Structures, 183, 883–893. https://doi.org/10.1016/j.engstruct.2019.01.061

Radwan, A. H. (2015). Containers Architecture Reusing Shipping Containers in making creative Architectural Spaces. International Journal of Scientific and Engineering Research, 6(11), 1562–1577. https://doi.org/10.14299/ijser.2015.11.012

Caldwell, C., & Hänninen, M. (n.d.). Research and Development on Shipping Container Homes Dedicated to the Finnish Market (Bachelor Thesis). Tampere University of Applied Sciences.

Luther, M. B. (2009). TOWARDS PREFABRICATED SUSTAINABLE HOUSING – AN INTRODUCTION. Environment Design Guide, 1–11. http://www.jstor.org/stable/26151879

Marquit, A. (2013, December). December 2013 From Sears & Roebuck to Skyscrapers: A History of Prefabricated and Modular Housing. NYC Buildings.

Sustainability

Jaillon, L., Poon, C.S. and Chiang, Y.H. (2009) Quantifying the Waste Reduction Potential of Using Prefabrication in Building Construction in Hong Kong, Waste Management, 29(1), 309-320.

O'Grady, T., Morrison, G. M., & Gruner, R. L. (2020). Exploring environmental benefits of reuse and recycle practices: A circular economy case study of a modular building. Resources, Conservation and Recycling, 160, 104855. https://doi.org/10.1016/j.resconrec.2020.104855

Boafo, F., Kim, J.-H., & Kim, J.-T. (2016). Performance of Modular Prefabricated Architecture: Case Study-Based Review and Future Pathways. Sustainability, 8(6), 558. https://doi.org/10.3390/su8060558

Watson, B., & Prasad, D. (2017). Performance and Perception in Prefab Housing: An Exploratory Industry Survey on Sustainability and Affordability. Procedia Engineering, 180, 676–686. https://doi.org/10.1016/j.proeng.2017.04.227

Olivares, P., & Andres, A. (n.d.). Sustainability in Prefabricated Architecture: A Comparative Life Cycle Analysis of Container Architecture for Residential Structures (Master Thesis). Victoria University of Wellington.

Raworth, K. (2018). Doughnut Economics: Seven Ways to Think Like a 21st-Century Economist (Illustrated). Chelsea Green Publishing.

Mazzucato, M. (2019). The Value of Everything : Making and Taking in the Global Economy: Making and Taking in the Global Economy (1st ed.). Amsterdam, Nederland: Adfo Books.

Minunno, R., O'Grady, T., Morrison, G. M., & Gruner, R. L. (2020). Exploring environmental benefits of reuse and recycle practices: A circular economy case study of a modular building. Resources, Conservation and Recycling, 160, 104855. https://doi.org/10.1016/j.resconrec.2020.104855

Affordability

van der Heijden, H., & Elsinga, M. (2022). Sustainable business model of affordable zero energy houses: Upscaling potentials. Journal of Cleaner Production, 344, 130956. https://doi.org/10.1016/j.jclepro.2022.130956

Urban Land Institute. (2020, February). Promoting housing affordability Best practices to deliver intermediate housing at scale. BPD. Retrieved from https://www.bpd.nl/media/wztpzev5/bpd-onderzoek-promoting-housing-affordability.pdf
Kuenzli, Peter, Arie Lengkeek. operatie wooncoöperatie. Amsterdam: trancity-*valiz, 2022.

Schrenkeisen, M., Dresel, N., & Cook, C. (n.d.). Thinking Inside the Box Affordable Student Container Housing: A Feasibility Study (Report). Western Washington University.

Watson, B., & Prasad, D. (2017). Performance and Perception in Prefab Housing: An Exploratory Industry Survey on Sustainability and Affordability. Procedia Engineering, 180, 676–686. https://doi.org/10.1016/j.proeng.2017.04.227

Raworth, K. (2018). Doughnut Economics: Seven Ways to Think Like a 21st-Century Economist (Illustrated). Chelsea Green Publishing.

Mazzucato, M. (2019). The Value of Everything : Making and Taking in the Global Economy: Making and Taking in the Global Economy (1st ed.). Amsterdam, Nederland: Adfo Books.

Living needs for the target groups

Atkins, L. C. (2022). Palaces for the people: How social infrastructure can help fight inequality, polarization, and the decline of civic life. Community Development, 53(4), 516–517. https://doi.org/10.1080/15575330.2022.2118937

Ahmed, V., & Ijasan, K. (2016). Studentification and the housing needs of international students in Johannesburg: An embedded mixed methods approach. in Ahmed, V., Opoku, A., & Aziz, Z. (2016). Research Methodology in the Built Environment: A Selection of Case Studies. Amsterdam, Nederland: Amsterdam University Press.

Bpd. (2015). Woonwensen van eenpersoonshuishoudens: Samenvatting onderzoeksrapport –december 2015. BPD

BPD. (2016). BPD Mosaic 2016 Doelgroepsegmentatie en woon(milieu) voorkeuren. BPD.nl.

ABF Research, Ministerie van Binnenlandse Zaken en Koninkrijksrelaties, & Kences. (2020, November). LandelijkmMonitor studenthuisvesting. Kences.nl. Retrieved from https://www.kences.nl/publicaties/landelijke-monitor-studentenhuisvesting-2020/

Kruythoff, H. (1994). Starters in the housing market in an urban region: The case of the Randstad Holland, a diversified housing-shortage area. Housing Studies, 9(2), 219–244. https://doi.org/10.1080/02673039408720784

Jürgenhake, Birgit: "Elderly homes – Anthropological research to achieve an architecture for the elderly." Paper presented at the Conference on Architecture Research Care & Health, ARCH 19, Trondheim, 2019. Czischke, Darinka,

Carla J. Huisman: "Integration through collaborative housing? Dutch starters and refugees forming self-managing communities in Amsterdam," Urban Planning vol. 3, no. 4 (2018): 156–65.

Wu, Z., & Sober, R. (2020). Design of Modular Housing Suitable for the Elderly. International Research Journal of Engineering and Technology, 7(12), 1800-1808.

GEWOBA. (2015). Bericht Bremer Punkt. In Gewoba.de. Retrieved February 9, 2023, from https://www.gewoba.de/gewoba/presse/mediencenter/publikationen

GEWOBA & LIN Architects. (2020). Bremer Punkt Work Report. In Gewoba.de. Retrieved February 9, 2023, from https://www.gewoba.de/gewoba/presse/mediencenter/publikationen

GEWOBA. (2021). Bremer Punkt Grundrissfibel. In POLARWERK GmbH, Bremen (Ed.), Gewoba.de. Retrieved February 9, 2023, from https://www.gewoba.de/gewoba/presse/mediencenter/publikationen?keyword=bremer

GEWOBA. (2013). Ungewöhnlich Weiter Wohnen. In Gewoba.de. Retrieved February 9, 2023, from https://www.gewoba.de/gewoba/presse/mediencenter/publikationen

Kockelkorn, A. (2022). Financialized Berlin: The Monetary Transformation of Housing, Architecture and
Polity. Architectural Theory Review, 26(1), 76-104. https://doi.org/10.1080/13264826.2022.2104889

LIN Architects. (2021). Bremer Punkt" = / or Bremen Cube: NEW EUROPEAN BAUHAUS AWARDS : existing completed examples (By European Union). 2021.prizes.new-european-bauhaus.eu. https://2021.prizes.new-european-bauhaus.eu/node/268182

Mietübersicht Bremen 2022 - Gutachterausschuss Bremen. (n.d.). https://www.gutachterausschuss.bremen.de/marktbericht/mietuebersicht-bremen-2022-11593

Mixing production with living

LOVE, T. (2017). A New Model of Hybrid Building as a Catalyst for the Redevelopment of Urban Industrial Districts. Built Environment (1978-), 43(1), 44–57. http://www.jstor.org/stable/44211248

RAPPAPORT, N. (2017). Hybrid Factory | Hybrid City. Built Environment (1978-), 43(1), 72–86. http://www.jstor.org/stable/44211250

Ngo, T., Kashani, A., Imbalzano, G., Nguyen, K., & Hui, D. S. (2018). Additive manufacturing (3D printing): A review of materials, methods, applications and challenges. Composites Part B-engineering, 143, 172–196. https://doi.org/10.1016/j.compositesb.2018.02.012

Attaran, M. (2017). The rise of 3-D printing: The advantages of additive manufacturing over traditional manufacturing. Business Horizons, 60(5), 677–688. https://doi.org/10.1016/j.bushor.2017.05.011

How Much Does a 3D Printer Cost? (z.d.). Formlabs. https://formlabs.com/eu/blog/how-to-calculate-3d-printer-cost/

Figures:

Moreno, L. (n.d.). Figure 11. Retrieved from https://sabukaru.online/articles/the-promised-tokyo

Metalocus. (n.d.). Figure 14. Retrieved from https://www.metalocus.es/en/news/nakagin-capsule-tower-tokyo-1969-72-kisho-kurokawa

Architecture with Ashleu. (2022). Figure 15. Retrieved from https://www.youtube.com/watch?v=ROu43rlGJrA

Harbison, W. (2009). Figure 16. Retrieved from http://harboproject.blogspot.com/2009/08/nakagin-capsule-tower-tokyo-1972.html

Metalocus. (n.d.). Figure 17. Retrieved from https://www.metalocus.es/en/news/nakagin-capsule-tower-tokyo-1969-72-kisho-kurokawa

LIN Architects. (n.d.-a). Figure 18 . Lin-a.com. https://www.lin-a.com/gallery/bremen-competition-lin-project-housing/bremer-punkt

LIN Architects. (n.d.-b). Figure 19 . https://www.lin-a.com/gallery/bremen-competition-lin-project-housing/bremer-punkt

LIN Architects. (n.d.-c). Figure 20. https://www.lin-a.com/gallery/bremen-competition-lin-project-housing/bremer-punkt

LIN Architects. (n.d.-c). Figure 23. https://www.lin-a.com/gallery/bremen-competition-lin-project-housing/bremer-punkt

GEWOBA & LIN Architects. (2020). Figure 33. https://www.gewoba.de/gewoba/presse/mediencenter/publikationen

GEWOBA & LIN Architects. (2020). Figure 34. https://www.gewoba.de/gewoba/presse/mediencenter/publikationen

GEWOBA & LIN Architects. (2020). Figure 35. https://www.gewoba.de/gewoba/presse/mediencenter/publikationen

GEWOBA & LIN Architects. (2020). Figure 36. https://www.gewoba.de/gewoba/presse/mediencenter/publikationen

GEWOBA & LIN Architects. (2020). Figure 37. https://www.gewoba.de/gewoba/presse/mediencenter/publikationen

GEWOBA & LIN Architects. (2020). Figure 38. https://www.gewoba.de/gewoba/presse/mediencenter/publikationen

GEWOBA & LIN Architects. (2020). Figure 39. https://www.gewoba.de/gewoba/presse/mediencenter/publikationen